Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Analyzing Delay Frequencies and Risk Factors in Nuclear Plant Commissioning: Lessons from BNPP Units 1 and 2

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***Keywords :** Nuclear power plant commissioning, schedule delay, Root-Cause Delay Factors, Delay Analysis*

1. Introduction

Following the successful construction and commissioning of the Barakah Nuclear Power Plant (BNPP), culminating in the commercial operation of Unit 1 (April 2021) and Unit 2 (March 2022), this study aims to leverage these experiences for the successful execution of future international nuclear projects, including the Czech nuclear project, where we have been selected as the preferred bidder.

Given that the commissioning phase exhibits higher variability compared to construction and operational phases, this study analyzes factors contributing to commissioning delays in BNPP Units 1 and 2. By identifying system-specific impacts, we propose preemptive measures to mitigate schedule risks in future nuclear projects.

2. Methods and Results

This study examines 272 cases of commissioning delays in BNPP Units 1 and 2, focusing on specific systems and equipment that caused schedule disruptions [1]. Delay-causing equipment was categorized into two groups: 1) Primary Equipment: Equipment that directly experienced delays and 2) Root Cause Equipment: Equipment whose issues triggered delays in other equipment.

Table 1. Commissioning Delays in BNPP 1&2(Q'ty)

	Mech.	Elec.	I&C	Safety	Non-Safety
NSSS	34	12	22	0	0
TBN	42	33	31	0	0
BOP	19	13	24	0	0
MMIS	0	0	0	21	8
HSE	2	0	2	0	0
Radiation	1	0	1	0	0
Chemistry	3	0	0	0	0
Operation	2	0	2	0	0
Total	103	58	82	21	8

2.1 Reason for Delay in Primary Equipment

Primary equipment delays were categorized based on the type of affected equipment, including valves, pumps, electrical/electronic components, mechanical parts, sensors, instruments, and control/safety devices. Among these, fluid transport and control equipment, such as valves, piping, pumps, and motors, experienced the highest frequency of delays. This is expected, given the strong reliance of nuclear power plants on cooling water systems. Additionally, thermal management devices such as HVAC units and heat exchangers also contributed to commissioning delays.

Table 2. Major Equipment and Associated Components

Equipment	Target Items	Quantity
Fluid Control Devices	Valves, Piping	65
Fluid Transport Devices	Pumps, Motors, Rotating Equipment	62
Thermal Mgmt Devices	Air Conditioners, Heat Exchangers, Heaters	29
Mechanical Equipment	Facilities	29
Electrical & Power Systems	Power Control, Lighting, Batteries	25
Systems & Structures	Systems, Structures	22
Instrumentation & Modules	Modules, Detectors	17
Storage & Tank	Tanks, Water Tank	11
Others	Procedures, Safety	9
Communication Systems	Communication Systems	3
Total	-	272

A significant portion of the delays was associated with fluid-related equipment, accounting for approximately 47% of all delay cases. This highlights the importance of cooling water systems and their interdependence with other plant components. Many of these delays were not isolated incidents but rather chain reactions, where the delay of one component caused further delays in other systems.

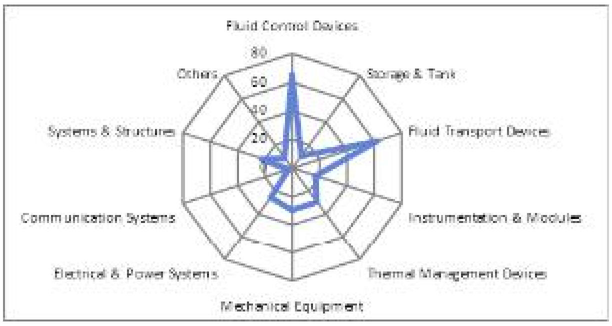

Fig 1. Distribution of Delay Causes by Major Equipment

2.2 Root Causes of Delays

Some delays originated from issues in one system but subsequently affected other systems. These were categorized as root cause delays. Unlike primary equipment delays, root cause delays were more varied and resulted from different sources.

Numerical data has been omitted in Table 3. as it contains detailed information intended for further research and analysis. Instead, a general explanation is provided to highlight key trends and implications without disclosing specific figures.

Table 3. Root Cause Components and Associated Items

Root-Cause Component	Target Items	Quantity
A	Valve stem, Valve positioner, Steam trap, Finger plate, Valve internals, Plug	Q1
B	Piping, Insulation material, Orifice, Exhaust port	Q2
C	Air conditioner, Heater, Thermostat	Q3
	⋮	
Total	-	166

Analysis revealed that electrical and electronic components, along with sensors and instrumentation, were among the most common sources of delays. These components accounted for a significant portion of all root cause delays, highlighting the critical role of control and monitoring systems in nuclear plant commissioning. If sensors and instrumentation are not installed and tested on time, fluid systems cannot be properly controlled, leading to broader commissioning delays.

2.3 Impact of Electrical and Instrumentation Delays

One of the key findings of this study is that electrical and instrumentation system delays had a greater impact on overall project timelines than mechanical equipment delays as shown in Fig.2. Delays in the installation and testing of sensors and instrumentation led to difficulties in controlling fluid systems, which in turn caused delays in commissioning major equipment. Additionally, delays in the supply of electrical and electronic components made it impossible to operate key equipment, further disrupting the project schedule. These findings highlight the importance of early deployment and thorough testing of electrical and instrumentation systems to prevent cascading delays in nuclear power plant projects.

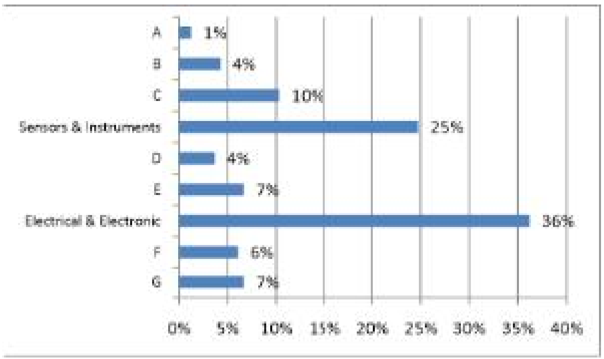

Fig 2. Distribution of Root-cause Components Causing Delays in Main Equipment

2.4 Systems Most Frequently Affected by Delays

This analysis was conducted using the delay frequency and risk assessment framework presented in Table 4. To maintain focus on overall trends while preserving detailed data for further research, specific values have been omitted.

Table 4. Delay Frequency and Risk Analysis Templete

System			Frequency		Frequency of Equipment Delay Causes (Frequency %)				Risk [illegible]	
PBS Description	PBS No.	PBS Description	Delay Quantity	Frequency (%)	Fluid Control	Storage & Tank	…	Others	Test Quantity	Delay(%)
				⋮						
Total			[illegible]	[illegible]	[illegible]	[illegible]	…	[illegible]	[illegible]	Avg %

The condensate and feed water systems were among the most affected by commissioning delays. These systems play a crucial role in managing steam and cooling water, requiring precise control over flow and pressure. Many of the delays in these systems were linked to late installation and testing of sensors and control systems. Without proper real-time monitoring and adjustment capabilities, these systems could not be commissioned effectively.

The emergency diesel generator (EDG) system was also significantly impacted by delays. The EDG system is essential for providing backup power and ensuring plant safety. However, its commissioning was hindered by delays in electrical and electronic components, including protective relays, automatic startup mechanisms, and control systems. The lack of timely testing and validation of these components directly impacted the overall commissioning timeline.

2.5 Systems with the Highest Delay Risk Based on Test Quantity

In addition to delay frequency, the study also analyzed the risk probability based on delays per test item. The Condensate Storage and Transfer system exhibited the highest delay risk, followed by the Main

Steam and Engineered Safety Features-Component Control System (ESF-CCS). The Feedwater system had the next highest risk, followed by the Emergency Diesel Generator (EDG) and Main Turbine and Auxiliary systems. These systems, particularly those related to cooling and power generation, were also among the most frequently delayed, as outlined in Section 2.4.

3. Conclusions

The analysis of commissioning delays in BNPP Units 1 and 2 reveals that systems with higher delay frequencies, such as Condensate Storage and Transfer, Main Steam, and ESF-CCS, also had a higher risk of delays. Despite lower frequencies, cooling and steam-related systems showed significant delay risks. The root cause of these delays was primarily attributed to issues with electrical and instrumentation systems, which had a chain effect on mechanical equipment commissioning.

To mitigate these risks in future projects, several key measures should be considered. First, electrical and instrumentation systems must be deployed early to ensure that critical control functions are operational before major mechanical equipment is commissioned. Second, project schedules should account for the interdependencies between different systems to prevent unexpected delays. Finally, the critical path analysis of nuclear plant commissioning should explicitly include the potential impact of electrical and instrumentation delays.

While this study provides valuable insights into the causes of commissioning delays, it primarily focuses on delay frequency rather than duration of delay-cause disposal. Future research should analyze the recovery times for different delay scenarios to assess their overall impact on project timelines.

Acknowledgement

This research was supported by the 2025 Research Fund of KEPCO International Nuclear Graduate School, the Republic of Korea.

REFERENCES

[1] Y.T.Kown, BNPP Unit 1 Commissioning Experience Report, pp.02-183, 2023.