External Hazard Analysis Based on Operational Performance Information for NPPs

Gibae Kim*, Youngsun Choun, Soohyuk Chang
CENITS Corporation Inc., 233, Gasan digital 1-ro, Geumcheon-gu, Seoul, South Korea
**Corresponding author: kibae2@naver.com*

1. Introduction

Operational performance information system for nuclear power plant (OPIS) provides the accident and failure events during the operation of the nuclear power plant (NPP) were operated to the present [3]. It can be difficult to objectively evaluate the events disclosed by OPIS due to various factors. In this paper, the status of NPP events was reviewed, focusing on natural hazards, which are external effects provided by OPIS. We provided objective information to ensure the safety of NPPs through the analysis of the cause of external effect of events occurring at NPPs.

2. Classification of operational events

Currently, 25 NPPs are in operation except for the 2 permanently suspended NPPs, and a total of 782 events have occurred from the start of operation of the NPP to the present (February 2023). The causes of the events, in the order of frequency, include instrumentation (217 events), mechanical (202 events), electrical (147 events), human (137 events), external effect (71 events) and etc. (8 events). The distribution of causes for an event can be seen in figure 1. Instrumentation refers to causes by instruments related to control systems, measuring instruments, and transmitters. Mechanical is caused by components such as pumps, valves, and pipes. Electrical is generated in relation to electrical equipment such as generators, motors, circuit breakers, and power boxes. Human is the events that occurs due to mistakes made by operators and maintenance personnel during activities such as operating and maintaining component. External effects are caused by environmental factors such as typhoons, high winds, extreme rains, earthquakes, forest fire and etc. Here, the frequency of events caused by instrumentation, mechanical, and electronical is very high, and accounts for 72% of all events. The 3 dominant causes are shown for each event in table I.

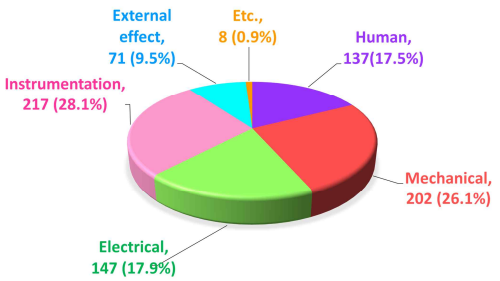

Fig. 1. Events current status by cause

Table I: Cases of events by dominant cause

Facilities (Date)	Description
Shin-kori unit 5 (17/07/04)	Cause: Instrumentation Summary: During the 80% load drop test, the steam bypass control system (SBCS), which is required to operate, did not operate properly, and as a result, the reactor pressure increased and exceeded the reactor protection signal trip stop, so the reactor was stopped.
Hanul unit 4 (18/08/31)	Cause: Mechanical Summary: The main feed water pump outlet check valve 02 was detached from the bonnet and the fixing pin that caused the cage to fail. As a result, when the booster pump was operated, the cage rotated due to the flow inside the valve and the outlet flow path was blocked.
Kori unit 1 (13/04/04)	Cause: Electrical Summary: The ratio differential protection relay (587MT) operates due to a wiring error of the instrument current transformer in the integrated switch yard that supplies the current input signal to the ratio differential protection relay for main voltage protection, and the integrated switch yard circuit breaker (7B00, 7B72) opens. Turbine-generator and reactor automatically shut down.

3. Analysis of external events

3.1 Cause of external events

In this paper, the external effects were reviewed and analyzed with a focus on natural hazards. As a result of reviewing 782events of OPIS, the number of external events caused by external effects is found to have increased from 71 events to 74 events. The causes of external events were organic material (21 events, 28.4%), typhoon (20 events, 27.0%), earthquake (11 events, 14.9%), lightning (9 events, 12.2%), extreme rain (4 events, 5.4%), high wind (3 events, 4.1%), and etc. as shown in figure 2. Here, the distribution of events caused by organic materials, typhoons, and earthquakes is high, and occupies 70% of external events. The 3 dominant causes are exemplified in table II. However, it is judged that the events caused by organic material will not cause a serious NPP events because the actions to these events can be immediately taken

and time is also sufficient. The external effect that occupies the second highest distribution is typhoons. In particular, summer typhoons such as Thelma in 1987 (5 events), Maemi in 2003 (5 events), and Maysak in 2020 (6 events) caused many events. Next, earthquake-related events account for a high proportion due to the Gyeongju earthquake in 2016. These natural hazards are expected to increase in intensity due to climate change [1, 2]. In addition, as shown in figure 3, as a result of confirming the distribution of external events by 10-year-period increases, the frequency of external events gradually increased. This tends to increase the frequency of natural hazards due to climate change.

Next, as a result of analyzing external events based on recovery time, 13 cases were stopped for more than 72 hours (table III). External effects were caused by various effects such as typhoons, earthquakes, forest fires, lightning, extreme rain and etc. Among them, 10 events occurred within the last 10 years, and this is judged to be due to an increase in the intensity and frequency of natural hazards.

Figure 4 shows the distribution of systems affected by external events. Events related to power system (34 events) and water intake structures (22 events) are dominant, accounting for 76% of external events. Table IV shows an example of the dominant 2 events. In the power system, 13 events occurred on-site area, and the most frequent events were related to transformers. In addition, 21 cases occurred in off-site areas, and it was dominant that the transmission system affected the on-site power system. Etc. refer to events related to the Shutdown system No.1 and are limited to the CANDU type in Wolsong NPP.

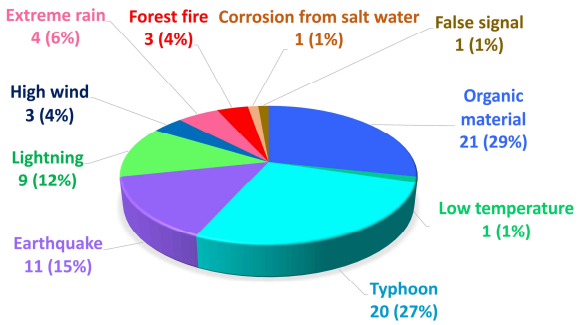

Fig. 2. Distribution of external sources

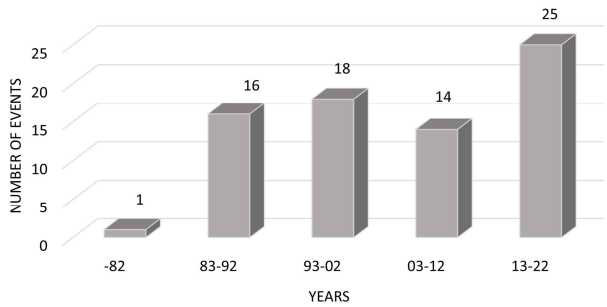

Fig. 3. Number of external events (10-year-period increases)

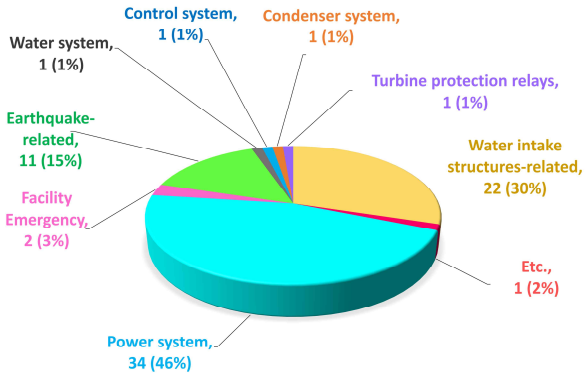

Fig. 4. Systems affected by external effects

Table II: Event cases by dominant external effect

Facilities (Date)	Description
Hanul unit 5 (21/04/06)	Cause: Organic materials Summary: A large amount of marine organisms have entered the water intake, and as the pressure of the intake drum screen rapidly increased, each circulating water pump (2 units) was automatically stopped.
Kori unit 1 (03/09/13)	Cause: Typhoons Summary: Due to the effect of the typhoon, Shin-Kori #1 transmission line was cut off due to a breakdown, and Kori Units 1 and 2 stopped generating power. As the salt deposited on the suspension insulator destroyed the insulation of the insulator under the effects of the typhoon, an arc was generated due to the leakage current, resulting in a ground fault.
Wolsong unit 1 (17/11/15)	Cause: Earthquakes Summary: A seismic event warning occurs when the motion recorder and warning device operate.

Table III: Events with a recovery time of more than 72 hours

Facilities	Date	Recovery time (d:h:m)	Cause
Kori unit 4	86/08/28	6:13:40	Typhoons
Hanul unit2	97/02/01	3:8:56	Organic materials
Hanul unit2	00/04/11	31:3:22	Forest fire
Kori unit 1	08/08/08	3:7:08	Lightning
Kori unit 2	14/08/25	29:22:53	Extreme rains
Hanbit unit 2	15/06/03	8:6:14	False signals
Wolsong unit 4	16/09/12	24:14:16	Earthquakes
Wolsong unit 3	16/09/12	23:19:46	Earthquakes
Wolsong unit 2	16/09/12	23:19:51	Earthquakes
Wolsong unit 1	16/09/12	25:11:16	Earthquakes
Shin-kori unit 2	20/09/03	27:3:48	Typhoons
Kori unit 4	20/09/03	3:6:59	Typhoons
Hanul unit 2	21/03/22	8:10:54	Organic materials

Table IV: Cases of dominant system affected by external effects

Facilities (Date)	Description
Wolsong unit 2 (03/09/12)	Cause: Power system Summary: A ground fault occurred due to the collision of the flying product from the turbine building with the c-phase bushing of the main transformer.
Hanul unit 2 (21/04/06)	Cause: Water intake structures-related Summary: As the intake drum screen self-pressure increased rapidly, all the expiratory circulation water pumps were automatically stopped.

3.2 Dominant external events in NPP sites

The external events that occurred at the NPP site are shown in figure 5. Kori/Shin-kori, Wolsong/Shin-wolsong, and Hanul NPPs located on the east coast have been confirmed to have an effect on typhoons, high winds, and extreme rain. In particular, the Kori and Shin-Kori NPPs located on the southeast coast had a number of events due to the effects of typhoons. Wolsong/Shin-wolsong NPP, located in Gyeongju, is located close to the fault, resulting in a number of earthquakes. The Hanul NPP, located in Uljin on the east coast, was dominated by organic materials. On the other hand, Hanbit NPP located on the west coast is confirmed to have less damage than other NPPs located on the east coast.

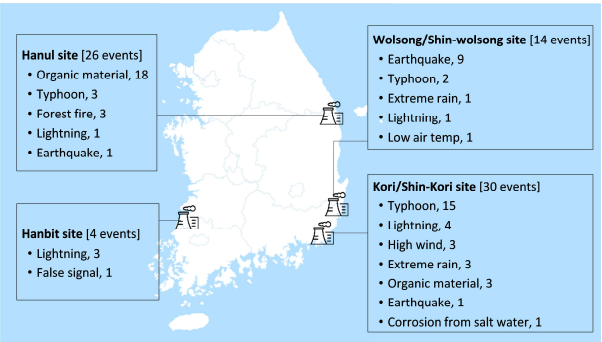

Fig. 5. External events for dominant

4. Conclusion

In this paper, external events were analyzed based on the information provided by OPIS, and the analysis contents are as follows:

(1) As for the cause of the all events, the events caused by instrumentation, mechanical, and electrical are dominant with more than 72%;
(2) The effects of external events are dominated by organic materials, typhoons, and earthquakes with more than 70%;
(3) The frequency of natural hazards tends to increase according to climate change;
(4) Based on recovery time of 72 hours or more, more than 76% of events occurred within the last 10 years;
(5) As for systems affected by external effects, causes related to power system and water intake structures dominate with more than 76%;
and
(6) Kori and Shin-kori NPP site is dominated by typhoons, Wolsong and Shin-wolsong NPP site by earthquakes, and Hanul NPP site by organic materials.

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