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An Analysis on Possible Effects of Instrument Faults on Situation Assessment of Nuclear Power Plant Operators

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1. Introduction

Recently, the effects of instrument faults on the situation assessment of nuclear power plant (NPP) operators have received a lot of attention. In ATHEANA [1], which is a second generation human reliability analysis (HRA) method developed by U. S. Nuclear Regulatory Commission (NRC), many statements emphasizing the importance of instrument faults on the development of wrong situation models can be found in many places. The approach for analyzing errors-of-commissions proposed by Kim et al.[2] also analyze the possibilities of NPP operators being misled to develop wrong situation models due to instrument faults. But, as mentioned in ATHEANA, there has been very little consideration of how instrument faults will affect the ability of the operators to understand the conditions within the plant and act appropriately. In this paper, we provide an analysis results on the possible effects of instrument faults on the situation assessment of NPP operators from the simulation results of Compact Nuclear Simulator (CNS), which is a small simulator for Westinghouse 900MWe Pressurized Water Reactor (PWR) plants.

2. Analysis and Results

The CNS can simulate the effects of 79 different malfunctions. Among them, 36 malfunctions are selected because they can actually change the plant state. Thus, the simulation experiments are performed for 37 different plant states, including the (100% power) normal operation state. For each simulation experiment, the behavior of 31 selected indicators is logged and used to analyze the trends of the indicators. Figure 1 shows the trend of a selected indicator (reactor power) for the 37 different plant states. The analyzed trends of indicators are used to determine the patterns of plant parameters for different plant states.

Beside the patterns of plant parameters for different plant states, we also need NPP operators' expectations on the patterns of plant parameters for different plant states. The best way to get this information is to have interviews with actual NPP operators. But, when the NPP operators are highly experienced, it can be assumed that their expectations on the patterns of plant parameters for different plant states are identical with the actual patterns of plant parameters for different plant states. If this assumption is used, we can analyze the possible effects of instrument faults on the situation assessment of NPP operators by comparing the patterns of plant parameters for the two different plant states

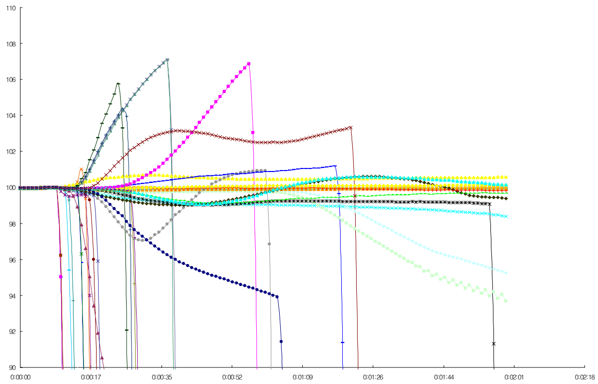

Figure 1. The trend of reactor power for 37 different plant states (Malfunctions are inserted at 10 seconds.) The trends of reactor power are divided into three categories, increase, no change, and decrease. The trends of other plant parameters (indicators) are analyzed in a similar way.

The discrepancies between the patterns determined by NPP simulator simulations and the patterns of NPP operators for various plant states can be the causes of developing wrong situation models in accident or transient situations. In this analysis, because the patterns of NPP operators are assumed to be identical with the patterns determined by NPP simulator simulations, the comparison among the patterns of plant parameter trends for the 37 selected plant states determined by NPP simulator simulations is performed. The comparison is performed by counting the number of different patterns between the patterns of two plant states.

In this analysis, those pairs of plant states whose difference is 1 draws special attention, because the common cause failure (CCF) of one kind of sensors or indicators will possible mislead NPP operators to misunderstand one plant state to the other, which can be interpreted as the development of wrong situation models. In this analysis, 11 pairs of such plant states are identified, which are described in more detail below.

- There are three plant states which have only 1 different pattern of plant parameter trends compared to that of the normal operation state. Because the three plant states are minor transients, the misunderstanding of one plant state to the other plant state does not seem to cause significant safety concerns.
- In case of *rod bank uncontrolled in* and *pressurizer spray valve open*, only the pattern of T_{ref}-T_{avg} *deviation* is different between the two plant states. But, the pressurizer spray flow, which is not included in the selected plant parameters, can provide further information to NPP operators. The confusion between the two plant states will possibly cause reactor trip, but the safety concern associated with it does not seem to be significant.
- In case of *pressurizer pilot-operated relief valve (PORV) stuck open* and *pressurizer safety valve (SV) open* states, the transients are almost identical except the PORV opening alarm among the 31 selected plant parameters. The states of pressuirzer PORV and SV (open or closed), which are not included in the selected plant parameters, can also provide further information to NPP operators. Therefore, the risk due to instrument faults does not seem to be significant. But, the confusion between the two states and corresponding taking wrong actions will possibly cause LOCAs.
- In case of *pressurizer spray valve open* and *pressurizer pressure controller failure – Max* states, the two transients are almost identical except that in the former plant state the proportional heaters and the backup heater are turned on by the pressure controller. In either transient, NPP operators are supposed to switch the pressure control to manual mode and reduce the flow rate of pressurizer spray. After that, they may try to find the root cause of the decrease in presurizer pressure. The instrument faults will possibly confuse NPP operators in finding the root cause, but no significant safety concerns are expected.
- In case of *reactor coolant pump (RCP) seal return flow high* and *RCP seal injection valve closed* states, only the pattern of RCP seal flow is different between the two plant states. The confusion between the two plant states possibly cause reactor trip, but no significant safety concerns are expected.
- In case of *high pressure turbine bypass valve open undemanded* and *main steam line break (MSLB) – isolable* states, the two transients are similar in that the steam is lost from the main steam line. Safety concerns may arise if NPP operators confuse between the two states and take wrong actions.
- In case of *MSLB – isolable* and *MSLB – nonisolable and outside containment* states, the difference of the two transients are the location of the break (upsteam or downstream of main steam isolation valve and steam flow sensors). Safety concerns may arise if NPP operators confuse between the two states and take wrong actions.
- In case of *MSLB – nonisolable and outside containment* and *steam generator safety valve stuck open* states, the latter state is a special case of the former state, and therefore the actions that should be taken are identical. Therefore, the confusion between the two plant states does not seem to cause significant safety concerns.

3. Conclusions

In this paper, we analyzed the possibilities that instrument faults can mislead NPP operators to develop wrong situation models in the operation of Westinghouse 900MWe PWR plants. From the analysis, several pairs of plant states in which NPP operators are possibly confused due to instrument faults are identified. Detailed analysis on the identified pairs of plant states reveals several possibilities and corresponding safety concerns, but the risks associated with those possibilities are qualitatively evaluated to be not significant.

For more accurate analysis, it will be necessary to perform the analysis based on full-scope simulator simulations and interviews with actual NPP operators.

REFERENCES

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