Technical Challenges in Multi-Unit Fire PSA

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Abstract

In recent years, as a number of U.S. plants have started to risk-inform their fire protection programs per the voluntary option provided in the U.S. Nuclear Regulatory Commission's (NRC) fire protection rule 10 CFR 50.48 (which endorses National Fire Protection Association Standard 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001 Edition"), the maturity and realism of fire PSA methods, models, tools, and data have become subjects of considerable controversy. Largely because of the single-unit focus of current risk-informed regulations and guidance, this controversy has not yet extended to the treatment of fire-induced multi-unit scenarios.

Setting aside the important question of how the results of a multi-unit fire PSA should be used in regulatory applications, it is of interest to see what challenges arise from multi-unit analysis. In particular, does the multi-unit aspect "simply" add resource challenges to the performance of a fire PSA, or are there additional methodological issues that need to be addressed? Conversely, do the intrinsic challenges of a fire analysis add raise fundamental issues for multi-unit PSA?

Table 1 summarizes six fire events involving multiple safety system losses and serious challenges to core cooling that have been identified and analysed in NUREG/CR-6738. Note that the latest event occurred in 1993. Although there have been a number of fires with notable characteristics since 1993 (e.g., the Onagawa switchgear fire in 2011), we are unaware of any post-Narora fires that have posed severe challenges to nuclear safety.

Regarding our question as to whether the needs of multi-unit analysis raise methodological challenges for fire PSA, Table 1 shows that three events (Browns Ferry, Armenia, and Narora) involved fire damage and/or smoke propagation affecting both units, three (Browns Ferry, Greifswald, and Armenia) involved reactor trips of both units, and one (Armenia) involved non-proceduralized recovery actions using a cable cross-tie with the less-affected unit. None of the event descriptions in NUREG/CR-6738 appear to indicate interactions associated with resource constraints (e.g., limited number of personnel).[1] Current PSA (and therefore fire PSA) technology can address interactions associated with system consequences and resource constraints. The treatments of non-proceduralized recovery actions and of large-scale phenomenological impacts are more problematic. Regarding the latter, the events in Table 1 involve large-scale cable fires, large turbine building oil fires and explosions, secondary fires and explosions, and collapsing structures. Although these phenomena are

[1] Narora's use of diesel-driven fire pumps to provide steam generator makeup may be an exception.

not unique to multi-unit scenarios, a multi-unit analysis is likely to have a greater need for methods (including screening methods), detailed models, and tools to implement these detailed models that are both efficient (to enable treatment of additional scenarios) and sufficiently realistic (to ensure the appropriate identification and characterization of important risk contributors). The development of such methods, models, and tools suitable for practical application appears to be a significant technical challenge.

Regarding the fire-unique challenges for multi-unit PSA, we note that a multi-unit PSA (or, more generally, a multi-source PSA) needs to address single source initiators (for scenarios originating in one source which may or may not affect other sources) and common cause initiators (which simultaneously affect multiple sources). The dependencies affecting the likelihood and extent of propagation across sources can be classified as involving shared systems, spatial interactions, common cause failures, or operator actions (where the term "operator" broadly refers to relevant personnel). The events in Table 1 include examples of all of these dependency classes but do not appear to introduce any new classes of dependencies. The principal challenge appears to be, as indicated above, the development of practical methods, models, and tools to treat the fire- and human-related phenomena giving rise to these dependencies.

It is important to recognize that all of the events listed in Table 1 occurred over 20 years ago and much has changed since then. The NRC will further investigate the risk of multi-unit fires as part of its ongoing Level 3 PSA project discussed elsewhere in this workshop. The NRC is also conducting a review of U.S. multi-unit operational experience as part of a research project investigating the current status of advanced knowledge engineering tools. We expect that the results of both of these projects will be reported at future conferences.

Table 1. Nuclear Power Plant Fires Involving Severe Challenges to Core Cooling

Plant	Type	Date	Summary Description (Including Multi-Unit Effects)
Browns Ferry 1 & 2	BWR	3/22/75	Cable fire affecting Unit 1/2 Cable Spreading Room, Unit 1 Reactor Building. Both units manually tripped. Unit 1 most seriously affected: loss of multiple systems; spurious indications and operations; non-proceduralized action to provide high-pressure makeup. Unit 2 effects include: loss of some power and indications; depressurization due to stuck-open relief valve.
Greifswald 1	VVER-440	12/7/75	Cable fire in or near a Unit 1 6kV switchgear. Units 1 and 2 tripped. Unit 1 suffers effective station blackout (SBO), loss of all normal core cooling for 5 hours, loss of coolant through pressurizer safety (failed to reclose); non-proceduralized recovery through low pressure pumps. Unit 2 shut down with apparently few complications.
Beloyarsk 2	LWGR-1000	12/31/78	Lube oil fire in turbine building (shared with Unit 1) collapsed portion of turbine building roof. Fire propagated into several elevations of control building and damaged main control room (MCR) panels. Damage to multiple safety systems and instrumentation, reactor control was "extremely difficult." Fire effects appear limited to Unit 2.
Armenia 1 & 2	VVER-440	10/15/82	Cable fire affecting multiple areas in Unit 1, subsequent secondary explosion and fires. Smoke spread to several areas including Unit 1 MCR. Both units tripped. Unit 1 most seriously affected: SBO, loss of instrumentation ("flying blind") and control power. Unit 2 effects include loss of power, MCR lighting. Power for Unit 1 MCR provided from Unit 2 sources (non-proceduralized action).
Chernobyl 2	RBMK-1000	10/11/91	Lube oil and hydrogen fire in turbine building (shared with Unit 1) collapsed portion of turbine building roof. Eventual loss of all Unit 2 feedwater (debris or de-energization). Fire effects appear limited to Unit 2.
Narora 1	PHWR	3/31/93	Explosion and fire in turbine building (shared with Unit 2). Unit 1 at power, Unit 2 in cold shutdown. Fire propagated along cable trays, smoke forced abandonment of MCR (shared between units). Loss of power to Unit 1 panels in emergency control room (but not Unit 2 panels). Unit 1 effects include: SBO, loss of indications ("flying blind"). Diesel-driven fire pumps used to feed steam generators.