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Adapting Human Reliability Analysis For Small Modular Reactors

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As we move closer to the eventual deployment of the first Small Modular Reactors (SMRs) worldwide, attention has turned towards how these plants will be operated, and whether/how SMR technologies may affect human performance and human reliability. Central to the discussion is the argument for reduced staffing, justified by aspects such as the simplified design, inherent safety characteristics and increased use of automated and passive safety systems (Blackett et al., 2022). SMRs are expected to capitalize on technological advancements that allow for new operational models. Since there are no commercial SMRs in operation today, we do not have the benefit of operational experience to understand the potential effects of SMR design and implementation principles or staffing plans on human performance and human reliability. This uncertainty raises questions about whether the promised technological advancements and/or the new ways of working will introduce new types of human errors or new performance shaping factors (PSFs) that could offset the argument for reduced staffing. This abstract is intended as a call to action for research to address this knowledge gap.

The technological advancements of SMRs create the possibility for new operating models. These include multi-unit operational capability; reduced staffing per reactor unit (in a multi-unit setup); increased use of automation; increased reliance on inherent design features and passive safety systems; scalable and flexible implementation of reactors; and remote operation capability. It should be noted that not all SMR plants will implement all the above operating models. For example, some SMR vendors do not plan to implement multi-unit operation at their sites and are instead opting for the more conventional approach of a single control room per reactor unit.

The above potential operational models are of interest for human reliability analysis (HRA) because they represent a departure from known HRA concepts and analyses for conventional nuclear power plants (NPPs). Aspects such as increased use of automation or multi-unit operations potentially introduce levels of complexity that may not be adequately captured within the PSFs of the HRA methods in use today. Furthermore, aspects of SMR design and operation may introduce new error modes that are not described within existing HRA methods, and research is ongoing to explore this further. For example, Bye (2023) gives an overview of how technological advancements may affect teamwork and human reliability. Park et al. (2018) examines how to approach HRA for multi-unit safety analyses.

One aspect where SMRs are likely to diverge from conventional NPP operation, which is of particular interest for HRA, relates to the requirements for operator actions after an unplanned event has occurred. Most currently operating NPPs are designed with a "grace period" for manual intervention after an event. The grace period is defined as "the period of time during which a safety function is ensured in an event with no necessity for action by personnel" (IAEA, 2016, p. 74). In conventional large NPPs, this period typically ranges from 20 minutes up to 12 hours and is usually around 30 minutes (anecdotally referred to as the "30-minute rule"). This allows operators time to troubleshoot the event and decide on a relevant course of action to handle the event going forwards. Many SMR risk analyses are expected to claim that there is a reduced need for manual operator action after an unplanned event occurs, with indications that grace periods could be extended to 72 hours or beyond (the so-called "72-hour rule"). This will be achieved primarily using passive safety systems, such as gravity-driven water injection and natural water circulation. These systems will ensure that core cooling can be maintained for 72 hours "without any human actions, and in-site or external site intervention, any refilling pool possibility by active means, and of course any external electricity power system connection" (Morin et al., 2020, p. 7).

The 72-hour rule can be misleading, with some describing it as "No need for operator intervention after [an] accident for 72 hours" (ENCO, 2022, p.15) or that the plant "requires no operator action for 72 hours after any design basis event" (NuScale, 2020, p. 3). This can be interpreted as meaning that operators ***do nothing*** after an unplanned event, and that safety will be ensured entirely by the technological systems. Realistically, it is expected that operators will still be required to monitor the passive safety systems to ensure that they have actuated correctly or otherwise to intervene and manually actuate the required systems to shut down and initiate core cooling.

A more accurate way to interpret the 72-hour rule is that the Probabilistic Safety/Risk Assessment (PSA/PRA) for the SMR ***will not include claims on the reliability of operator actions*** after an event has occurred. Instead, the PSA/PRA will center on the reliability of the inherent design properties of the reactor, and the passive design properties of the safety systems to maintain safety after an event. It could be argued that there will still be some operator claims in the PRA/PSA to (i) detect potential initiation failures of passive safety systems, and (ii) correctly perform manual initiation of the safety systems. It is likely that such claims would have a negligible effect on the overall risk model, as the emphasis will predominantly be on establishing the reliability of the technical safety systems in place.

Because there are likely to be less claims (if any) on operator actions after an event, the understanding of how human error could ***contribute to*** or ***cause*** an event becomes even more important. Until now, HRA has tended to concentrate on those operator actions directly contributing to, or immediately following, an event as it is usually directed by the PRA/PSA which focuses on the identification of fault sequences leading to core damage and beyond. As such, questions are now being raised about whether existing HRA methods are suitable for analysis of operator actions beyond the grace period and/or latent actions that may undermine the reliability of the inherent, automated and passive safety systems of new reactors.

Research is needed to understand i) the potential new human error types that may occur as a result of the advanced technology utilized in SMR designs and the increased use of automation, passive safety systems and/or inherent safety systems; ii) how SMRs will be inspected and maintained outside of the control room, and the potential for errors to occur that could undermine automated/passive/inherent safety systems; iii) the potential effects on human situation awareness and process understand of new operating models such as multi-unit operation, remote operation and non-homogenous multi-unit plants. It is vital that current HRA methods are critically evaluated to determine whether they are sufficient to capture new task types and (potentially) new error types, as well as whether data exist to substantiate the human error probabilities for the potential new errors.

Operation of SMRs can be considered a paradigm shift for nuclear operators, and as such the time is right to consider whether/how HRA methodologies may need to be adapted to effectively assess the human contribution to risk in this new operating environment. Until recently, operational aspects of SMR have received very little attention, with global focus almost entirely on technology and hardware developments. Considering that the first commercial SMRs are planned to start operating before the end of this decade, the need for understanding the potential effects of these new operational models on human performance and human reliability is vital and time critical. Ss such the time is right to consider whether/how HRA methodologies may need to be adapted to effectively assess the human contribution to risk in this new operating environment, and further research is needed in this area.

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