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IMPROVING ROBUSTNESS AND RESILIENCE OF NUCLEAR INSTALLATIONS IN RESPONSE TO EXTERNAL EVENTS BEYOND THE DESIGN BASIS

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ABSTRACT

The International Atomic Energy Agency (IAEA) has initiated a project to help Member States better assess, and thus improve, nuclear installation robustness and resilience. This project will collect and analyse data from actual events at nuclear installations. Analysis of this information and sharing of lessons learnt will lead to better assessment of safety margins at both operating and future installations. Sharing the information collected from Member State best practices will also aid in assessing and improving robustness and resilience. This information will be published in a new Safety Report to benefit nuclear installation operators and Member State regulatory authorities.

INTRODUCTION

The fundamental safety objective of the IAEA is to protect people and the environment from harmful effects of ionizing radiation. All participants in the nuclear industry including regulators, designers, owners, technical service organizations, contractors, and operators strive to keep risk of exposure to ionizing radiation as low as reasonably possible. Next generation reactors, including many small modular reactor designs, have improved passive safety systems that should improve inherent plant safety. Nonetheless, we can still strive to achieve even better safety performance by addressing both the robustness and resilience of nuclear installations subject to external events such as natural phenomena hazards and human induced events.

Nuclear installation designers work to understand and mitigate risk from external hazards through identification of hazards, robust facility design, and implementation of safety features. Structures, systems, and components (SSCs) important to safety can be designed with target safety goals, often expressed as an annual frequency of unacceptable performance, based on the severity of consequences resulting from the item's failure. The magnitude and frequency of various hazards are analysed, as well as their potential effects on SSCs. These analyses are used to derive the design basis events and design basis hazard loads for SSCs. The SSCs are designed to ensure they can withstand these loads with a controlled level of margin such that the components meet their intended performance goals. Of course, for natural phenomena hazards such as wind, tsunami, and earthquake the design basis event is not the only event that can occur at an installation. It is possible that very rare events, larger than the design basis event will impact a nuclear installation. This does not, however, suggest that the performance of the nuclear installation has failed – only that the design basis load has been exceeded. This inherent design margin should allow the facility to meet performance expectations for some rare events that exceed the design basis. With regard to these external hazards, a nuclear installation's robustness can be considered its ability to withstand these rare events.

IAEA requirements on this topic are found in General Safety Requirements Part 4 (Rev. 1). Regarding design for external events, paragraph 4.31 states in part,

> "Where applicable, the magnitude of the external events that the facility is required to be able to withstand (sometimes referred to as design basis external events) shall be established for each type of external event on the basis of historical data for the site for natural external events and a survey of the site and the surrounding area for human induced events. Where appropriate, the safety assessment shall demonstrate that the design is adequately conservative so that margins are available to withstand external events more severe than those selected for the design basis.

Paragraph 4.48A goes on to state, "Where practicable, the safety assessment shall confirm that there are adequate margins to avoid cliff edge effects that would have unacceptable consequences."

Resilience is another, but less common consideration in nuclear installation design. Resilience in the context of nuclear power generation is most often associated with the speed at which a facility or electric grid can resume delivery after an outage. It also encompasses the development of flexible solutions that can support the response to emerging, changing, or unknown threats, as well as planning, response, and recovery strategies. With regard to safety, resilience is the ability of a nuclear installation to recover to a safe state after a damaging incident. Robustness and resilience work together. Robustness describes the ability of an installation to withstand the demands of an external event without damage. Resilience describes the ability of the installation to recover to a safe state after being affected somehow, such as loss of offsite power, or a small loss of coolant accident, for example. Resilience is often measured in the time it takes to restore the installation to its original safe, operating, state. In addition to response to individual rare events, an installation may be called upon to respond to unanticipated combinations of external events. Enhanced resilience can minimize the impact of beyond design basis events and can minimize surprises from unanticipated events. Both robustness and resilience can degrade over time due to facility ageing, non-compliances with maintenance requirements, and changes to the external environment. Therefore, organizations should periodically assess and work to understand the potential risk of their operations to people and the environment and work to continually improve the risk posture of their nuclear installations.

PAST IAEA ACTIONS

After the Fukushima accident in 2011, many Member States assessed plant safety margins against seismic and flooding events. The IAEA launched a gap analysis on its own Safety Guide program and improved the content of Safety Requirements and Safety Guides regarding safety margin assessment for beyond design basis external events. In 2017 the Agency published TECDOC-1834, *Assessment of Vulnerabilities of Operating Nuclear Power Plants to Extreme External Events*, providing an updated methodology for assessing the vulnerability of operating facilities to extreme external events. The TECDOC provides a method for identifying the most vulnerable aspects of an existing facility, determining the level of external hazards at which the vulnerable aspects will not fail, and exploring the facility response if a safety function does fail. TECDOC-2043, *Evaluation of Design Robustness of Nuclear Installations Against External Hazards*, published in 2024, discusses lessons learned from existing installations that have experienced severe external events. TECDOC-2043 provides technical bases for defining adequate design margins for existing facilities against external hazards, and it provides guidance for identifying hazard severity corresponding to cliff-edge effects. In addition, it includes procedures for assessing whether protection against external hazards meets IAEA post-Fukushima safety requirements.

CURRENT IAEA ACTIONS

These published TECDOCs provide useful lessons from past major accidents and helpful information for assessing nuclear installation robustness against external events, but they do not address resilience. The IAEA has initiated a project with two primary goals: 1) assemble knowledge from real incidents at nuclear installations to enable a better assessment of safety margins at both operating and future installations; 2) compile Member State best practices in assessing and improving robustness and resilience. The Agency's recently developed External Events Notification System (EENS) can aid in analysing these real events (meteorological, hydrological, seismic, volcanic, wildfire, etc.).

Some external events or combinations of events could affect installations in unexpected ways. Such surprises will have to be managed using flexible response strategies that may not have been planned. Emergency response procedures that anticipate unknowns and have enough flexibility to allow operators to develop innovative solution strategies will enhance resilience. Strong teams that can be creative and improvise during unfamiliar situations are also beneficial. Therefore, the examination of resilience will also consider the response and adaption capacities of organizations. This information will be compiled in a new IAEA Safety Report. The Safety Report will provide Member States with needed tools to better assess resilience of existing facilities, which is the first step toward enhancing resilience.

In addition to learning from the review of real incidents at nuclear installations, the IAEA finds that Member States can benefit from sharing of lessons from external events and conditions. For example, many lessons were learnt following the December 1999 flooding of the Blayais plant in France. These lessons led to both physical and operational improvements. The lessons may have benefitted the Fort Calhoun plant in the United Sates had they been adopted prior to its flooding event in June 2011. The new Safety Report will facilitate sharing of operational information to ensure proper application of existing safety approaches, and it will promulgate new approaches, especially regarding rare external events for which expertise cannot be based solely on established knowledge. The envisioned report will be useful to operators of current nuclear installations, as well as designers and operators of future nuclear installations. It will primarily benefit nuclear power plants but will also apply to other nuclear installations that pose a radiological risk. Member State regulatory bodies may find the Safety Report helpful for modifying their requirements for assessing installation resilience to beyond design basis external events.

SUMMARY

The International Atomic Energy Agency (IAEA) is working to assist Member States in increasing the robustness and resilience of nuclear installations in response to external hazards, including those that may exceed the existing installation design basis. This assistance will come in the form of a new guidance document, a Safety Report that compiles existing information, practical examples, and lessons learnt regarding the assessment and improvement of nuclear installation robustness and resilience in response to external events. The effort to create this Safety Report is just beginning. A team of experts from Member States is being assembled, and they will review worldwide nuclear installation experiences to compile practical examples, lessons learned, and best practices toward enhancing robustness and resilience in response to external events. The target publication date is late 2028.

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