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Study on the Safety Classification Criteria of Mechanical Systems and Components for Open Pool-Type Research Reactors

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1. Introduction

Different safety classification criteria for systems, structures, and components (SSCs) of nuclear reactors are used among the countries that export or import nuclear reactor technology, which may make the nuclear technology trade and exchange difficult.

Thus, such various different approaches of safety classification need to be compromised to establish a global standard. This article proposes practicable optimized criteria for safety classification of SSCs for open pool-type research reactors (RRs).

2. General Design and Safety Features of Pool-Type Research Reactors

This paper focuses on the water-moderated pool-type RRs, where the core is covered enough amounts of water for providing sufficient cooling and radiation shielding. RR having a built-in safety feature can reduce its power during design basis accidents (DBAs) before an unacceptable power level or temperature could be reached.

The total thermal energy produced by a RR typically ranges from $0.1\,W_{th}$ to $30\,MW_{th}$, while that by even a small commercial nuclear power plant (NPP) amounts to over 1,500 MW_{th}. Because of this big difference in thermal power between RRs and NPPs, the consequence of an accident at a RR is much lower than that at a NPP. For this reason, forced cooling of the core is not necessarily required for RRs during short periods after shutdown and the emergency planning zones are well within the confinements or containments. The RRs have fail-safe shutdown systems such as the control rods which can be dropped by gravity even when loss of powers occurs and also have redundant diverse shut down systems. In addition, most RRs are operated on a very limited schedule and have a very small amount of radioactive material.

These inherent safe design features require no or minimal engineered safety features (ESFs) to be incorporated.

3. Current Status of the Safety Classification of Nuclear Reactor SSCs in Various Countries.

3.1 Korea

The Korean rules and regulations stipulate that the regulatory requirements and technical standards for NPPs can be applied mutatis mutandis to RRs for which any regulatory requirements and technical standards are not specified separately. This makes the regulation on the safety classification of SSCs for NPPs applicable for RRs. The notice of NSSC 2012-9 [1] specifies the general requirements for the safety classification of SSCs at NPPs.

According to the regulation, the SSCs are graded as either safety class 1, 2, 3, or non-safety class as: (1) Safety class 1 (SC1)shall apply to pressure retaining portions and supports of mechanical equipment that form part of the reactor coolant pressure boundary (RCPB) whose failure could lead to a loss of reactor coolant in excess of the reactor coolant normal makeup capability: (2) SC2 shall apply to pressure retaining portions and supports of primary containment and other mechanical equipment, not included in SC1, that is designed and relied upon to accomplish the nuclear safety functions to provide fission product barrier, emergency heat removal, emergency negative reactivity, and emergency core cooling; (3) SC3 shall apply to equipment, not included in SC1 or SC2, that is designed and relied upon to accomplish other nuclear safety functions. This approach is identical to that in the ANSI No.58.14-2011 [2].

3.2 The United States

The US has its own well-established rules specifying the criteria for safety classification of SSCs for NPPs: the conventional one is based on the deterministic approach and the optional is based on the risk-informed approach. The former is the same as that of Korea. However, no regulatory requirement is subject to safety classification of SSCs in US considering their inherent safe design features.

3.3 Canada

The design authority is required to classify SSCs of nuclear reactors in a consistent and clearly defined classification scheme based both on the deterministic and probabilistic approaches and then to design, construct, and maintain the SSCs such that their quality and reliability is commensurate with this classification [3]. All SSCs shall be identified as either important or not important to safety.

The criteria for determining safety importance are based on: (1) Safety function(s) to be performed; (2) Consequence of failure; (3) Probability that the SSC will be called upon to perform the safety function; and (4) The time following a postulated initiating event (PIE) at which the SSC will be called upon to operate, and the expected duration of that operation.

3.4 France

Both RRs and NPPs are commonly categorized as the Basic Nuclear Installations (BNI) and thus are subject to the same regulations in terms of the technical rules and licensing procedures. For this reason, a single safety classification approach is applied for both RRs and NPPs.

The French approach [4] grades all the SSCs into the three safety classes on the basis of their importance to safety as follows: (1) SC1 SSC that forms a primary means of ensuring nuclear safety; (2) SC2 that makes an important additional contribution to nuclear safety, or any SSC whose failure may challenge another SC-1 or 2 item; (3) SC 3 that is not allocated to SC-1 or 2, or any SSC whose failure may challenge another SC-3 item.

According to this approach, low power RRs do not have any safety class SSCs when the decay heat removal is not necessarily required, except the SSCs for accomplishing a safe reactor shut down that are definitely classified as SC1.

3.5 International Atomic Energy Agency (IAEA)

The IAEA has been trying to establish a harmonized safety classification of SSCs in NPPs. The task is still ongoing due to the difficulty in making convergence of the various positions of the member countries that have different regulatory policies and practices with each other. Although the IAEA No. NS-R-4 [5] mentions the necessity of the safety classification of RR SSCs, any attempt to establish the safety classification criteria has not made yet.

4. Assessment of Each Country's Practice of Safety Classification of SSCs for RRs

Korea, France and Canada have their own regulatory requirements of safety classification of SSCs for RRs which are the same as those for NPPs.

Korean safety classification criteria are clearly specified but are oriented to PWRs while both French and Canadian ones are not explicitly specified but are applicable generally to any type of reactors.

In particular, since Canadian regulation requires the design authority to classify reactor SSCs according to the related Canadian regulatory guidelines, a uniform and consistent safety classification can hardly be expected.

The French classification criteria seem to be general and comprehensive, but those are too vague to equally apply to both high thermal power NPPs and very low thermal power RRs because the level of potential risk or safety of a reactor is highly dependent on the amount of thermal power and reactor type. Thus, it is not practicable to consistently identify a suitable safety class for each SSC of a reactor regardless of its type or thermal power.

The US has no regulatory requirement of safety classification of SSCs for RRs because the potential risk anticipated from their operation is too relatively low comparing to NPPs. Nevertheless, stringent safety review requirements are subjected to RRs at the similar level with the NPPs. This means that the level of safety for each SSC of a RR design is ensured by the regulators at the safety review stage.

The IAEA has been making effort for several years to establish a harmonized method for safety classification SSCs of NPPs, which is independent on the reactor type and thermal power level, but any consensus has not reached yet. Furthermore, no attempt has been made to develop harmonized safety classification criteria for RRs.

5. Proposal of Compromised Criteria for Safety Classification of SSCs for RRs

Based on the comparative assessment on the various countries' regulatory practices, the following inclusive safety classification criteria for open-pool type RRs have been derived.

- The standards of Class 1, 2, and 3 components defined in Section MN, "Technical Standards for Nuclear Facilities," of the KEPIC or Section III, "Nuclear Power Plant Components," of the ASME B&PV Code are applied to specify the requirements for design, fabrication, erection, and testing of the mechanical systems and components for both RRs and NPPs. This is because any other globally-used quality standards are not available at present.
- Safety-related SSCs are defined as in the 10CFR50.2 and the IAEA Safety Glossary 2007 edition, that are relied upon to remain functional during and following DBAs to assure: (1) the integrity of the RCPB. (2) the capability to safely shut down the reactor or to remove the residual heat from the core and maintain it in a safe shutdown condition; or (3) the capability to limit the consequences of the accidents which could result in potential off-site exposures comparable to the applicable regulatory limits, as applicable.
- For RRs operating at atmospheric pressure with low thermal power, that have the capability to sufficiently remove the residual heat from the fuel and to prevent loss-of-fuel integrity after a DBA by natural convective coolant-cooling in the core tank (or vessel) with minimum ESFs such as natural convection valves and/or anti-siphon valves, the components comprising both the primary coolant system (PCS) and the ESFs shall be safety class. While, for the systems that are not required to necessarily operate during and following a DBA, or do not comprise the PCS, or are provided as supplementary ESFs against extremely unlikely beyond-DBAs, their components necessarily need not to be safety class.
- For RRs operating at atmospheric pressure of which the thermal power is too low so that the residual heat from the fuel can be removed sufficiently to prevent loss-of-fuel integrity by natural convective air-cooling (without any ESFs) after a DBA, no safety class systems and components are required.

6. Conclusions

This paper describes a new compromised safety classification approach based on the comparative study of the different practices in safety classification of mechanical systems and components of open pool-type RRs, which have been adopted by several developed countries in the nuclear power area.

It is hoped that the proposed safety classification criteria will be used to develop a harmonized consensus international standard.

REFERENCES

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