Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, May 17-19, 2016

Preliminary Safety Classification of SSCs for a Pool-Type Research Reactor

Suki Park [a*]
[a] *Korea Atomic Energy Research Institute, Daedeok-daero 989, Yuseong-gu, Daejeon, Korea, 305-353*
[*] *Corresponding author: skpark@kaeri.re.kr*

1. Introduction

A construction project for a pool-type research reactor is in the process of bidding. The technical requirements for the project request that the structures, systems and components (SSCs) fulfilling a safety function be classified according to the IAEA safety standards [1], although it is not cited explicitly.

Guidelines for the safety classification of SSCs of nuclear reactors are introduced and reviewed by Kim [2]. As addressed in the paper, the safety classification of SSCs for nuclear power plants has been well established and accepted by the regulatory body without due consideration. The quality group and safety class of SSCs are described in the regulatory guide and ANSI code of United States of America [3, 4]. However, the safety classification of research reactors has not been established although the minimum safety class guideline for SSCs was developed [5]. It is probably due to the variety of design features and power levels. The SSCs of HANARO, JRTR (Jordan Research and Training Reactor) and KJRR (Ki-Jang Research Reactors) are classified based on ANSI/ANS-51.1 taking into account the non-pressurized cooling system and the non-pressurized confinement building even in postulated initiating events (PIEs).

The project owner requests that all SSCs of reactor be systematically classified into a minimum of four classes (high, medium, low and non-class) according to their safety significance based on deterministic and probabilistic approaches. By the requirements the safety classification of SSCs has been preliminary performed. This paper deals with a brief introduction to the safety classification methodology and the results of safety classification of SSCs. In the safety classification fuel integrity and radiological dose are qualitatively assessed by engineering judgement when the safety functions of a SSC required in an initiating event are failed. And the occurrence frequency of the initiating event is also assumed by the experience on previous reactors.

2. Descriptions of the Proposed Reactor

2.1 Reactor Cooling and Pool-Connected Systems

The proposed reactor is an open-pool and open-tank type and has box type fuel assemblies consisting of flat plate fuels. The coolant and moderator is light water and the reflector is Beryllium. In power operation the flow is upward in the core while it is downward in the reflector region with irradiation holes for Fission Moly (FM) production. The core power of 28 MW is removed by the primary cooling system (PCS) and the secondary cooling system (SCS) to the cannel while the residual heat after reactor shutdown is transferred to the reactor pool by natural circulation via the flap valves. The heat generated from the reflector including FM targets is cooled by the FM cooling system (FMCS) and the SCS. The residual heat in the reflector and FM targets is removed to the pool by natural circulation. The FMCS has also a function of cooling the reactor pool and service pool with spent fuels when the pool water management system (PWMS) is not available, which provides a function of purification and cooling of pool water and primary coolant in normal operation. The reactor has also the hot water layer system (HWLS) to shield persons from the nuclear radiation from the reactor core and the demineralized water supply system (DWSS) to compensate the evaporation of pool water in operational states and accident conditions.

2.2 Reactor Protection and Shutdown Systems

The reactor has two reactor protection systems. The first reactor protection system (FRPS) provides a primary function for actuating the shutdown systems and the engineered safety features such as the isolation valves for pool and containment. The second reactor protection system backs up the FRPS when it is failed.

The reactor has also two shutdown systems. The first shutdown system has four control rods made of Hafnium, which are moved up and down by the reactor regulating system (RRS) to regulate the reactor power in normal operation and dropped to the reactor core by gravity as the electromagnets are de-energized by the actuation signal from the reactor protection systems. The second shutdown system has four cylindrical rods containing B4C powder, which are poised at the full out position by hydraulic force provided by the hydraulic cylinder and pump in power operation and dropped to the reactor core as the hydraulic force is lost by the actuation signal from the reactor protection systems and by failure of pumping.

2.3 Containment Systems

The reactor has a containment building as a physical barrier to prevent radioactive material from releasing to the environment and to protect the SSCs important to reactor safety against the external events including aircraft crash. The containment isolation valves are installed on the containment penetration pipes, which are closed by the actuation signal from the reactor protection systems. The containment air cooling system (CACS) is provided to prevent the containment air temperature and pressure from exceeding the design values for sustaining the integrity of containment. The containment filtered vent system (CFVS) is also applied to protect the integrity of containment when the containment is attacked by undue pressure.

3. Safety Classification Methodology

3.1 Outline of the Safety Classification

According to the IAEA safety standard [1] the safety classification of SSCs begins by the identification of all functions necessary to fulfil the main safety functions in all reactor states and of design provisions necessary to prevent accidents, to limit the effects of hazards or to protect workers, the public and the environment against radiological risks in operational conditions.

The functions to be performed by all SSCs important to safety are categorized on the basis of their safety significance. The safety significance of each function is determined by taking account of three factors:

- Factor 1, severity of consequences due to failure of the function,
- Factor 2, frequency that the function will be called upon, and
- Factor 3, significance of the function in achieving a controlled state or a safe state.

Once the safety categorization of the functions is completed, the SSCs performing these functions are assigned to a safety class consistent with the safety category.

The design provisions are classified directly according to the severity of consequences of their failures. And then the SSCs implemented as design provisions are classified using the same set of classes as those used for the classification of SSCs.

3.2 Identification of Functions to Be Performed

All functions of the SSCs are identified in all operational states and accident conditions. The functions to be performed at all five levels of defence in depth (DID), i.e. prevention, detection, control and mitigation are identified.

The fundamental safety functions of the proposed reactor to be performed are as follows:

- Control of reactivity at all operational states and accident conditions,
- Removal of heat from the reactor and the spent fuel storage, and
- Confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.

In addition to the fundamental safety functions, the following functions are identified:

- Monitoring to provide the reactor staff and the off-site emergency response organization with sufficient and reliable information in the events, owing to the importance of monitoring to safety,
- Either preventing some sequences resulting from additional independent failures from escalating to postulated multiple failure events and core melt accidents, or mitigating the consequences of them, and
- Reducing the actuation frequency of the reactor scram and/or engineered safety features that correct deviations from normal operation, including those designed to maintain the reactor parameters within the normal operational range of the reactor.

3.3 Categorization of Functions

Factor 1 is classified into three levels as follows:

- High severity if the failure of the function could, at worst, lead to a release of radioactive material that exceeds the design criteria (1 mSv per event in off-site), or cause the safety parameters to exceed the acceptance criteria for the level 3a event of DID,
- Medium severity if the failure of function could, at worst, lead to a release of radioactive material that exceeds the design criteria (0.1 mSv per year in off-site), or cause the safety parameters to exceed the acceptance criteria for the level 2 event of DID, and
- Low severity if the failure of function could, at worst, lead to the dose limit to workers (10 mSv/year averaged over 5 years and 15 mSv in any single year).

Factor 2 is determined in accordance with the frequency of occurrence of the respective postulated initiating event. The PIEs of the reactor are classified into the levels of DID such as 2 (anticipated operational occurrence), 3a (single initiating event), 3b (multiple failure event), and 4 (core melt event). The classification of PIEs is performed by engineering judgment based on the experience on research reactors.

Factor 3 is identified to the functions leading the reactor to a controlled state (CS) such as the reactor trip, the removal of decay heat and the isolation of the pool and containment boundary required right after the initiation of an event and to the functions achieving a safe state (SS) of the reactor such as pool cooling and containment air cooling required in a long term phase.

The safety categories of functions to be performed by all SSCs of the reactor are classified according to Table 1.

3.4 Identification of Design Provisions

The safety of reactor is also dependent on the reliability of design features, some of which are designed specifically for use in normal operation. These SSCs are termed ‘design provisions’ in the specific safety guide [1]. Such design provisions should be identified and considered to be subject to the safety classification process. The design provisions include:

- Design features designed to such a quality that their failure could be practically eliminated,
- Design features to reduce the frequency of an accident,
- Passive design features to protect workers and the public from harmful effects of radiation in normal operation,
- Passive design features to protect components important to safety from being damaged by internal or external hazards, and
- Design features to prevent a PIE from developing into a more serious sequence without the occurrences of another independent failure.

3.5 Classification of SSCs

The SSCs performing the functions categorized in Section 3.3 are assigned to Safety Class 1, 2, 3 and non, which are consistent with the safety category 1, 2, 3 and not categorized in Table 1.

The design provisions of the reactor are classified directly according to the severity of consequences of their failures:

- Safety class 1: Any SSC whose failure would lead to consequences of high severity,
- Safety class 2: Any SSC whose failure would lead to consequences of medium severity, and
- Safety class 3: Any SSC whose failure would lead to consequences of low severity.

Any SSC whose failure could challenge the assumption made in the hazard analysis is assigned to safety class 3 at the very least. Where the safety class of connecting or interacting SSCs is not the same, an optical isolator or automatic valve assigned to the higher safety class is implemented.

4. Preliminary Safety Classes of SSCs

The preliminary safety classes of major SSCs are presented in Table 2.

The failure of the confinement function of the containment liner and isolation valves in the level 3a event of DID could lead to the consequences of high severity that the dose at the site boundary exceeds the design criteria. Accordingly, the function of them is safety category 1 and they become SC 1.

The failure of the prevention function of the pool liner, isolation valves and siphon break means from spilling out of pool water in the level 3a event of DID could yield the consequences of high severity that the dose at the site boundary exceeds the design criteria and that the safety parameters exceed the acceptance criteria. Therefore, the function of them is categorized as safety category 1 and they are assigned to SC 1.

Since the failure of fuel assemblies, reactor structure assemblies and pipe downstream of the PCS pumps can lead to directly the consequences of high severity, they are classified into SC 1.

The FRPS is SC 1 because the failure of its function leads to the consequences of high severity in the level 3a events of DID in reaching a controlled state, and the SRPS is SC 2 because its function prevents core melt in an accident with the failure of FRPS. Since the RRS and PICS maintain the reactor parameters within the normal range of operation and their failure could increase the frequency of reactor trip, they are assigned to SC 3. The RMS and CS provide the monitoring needed to reactor staff and the communication means for off-site emergency services, respectively. Accordingly, they are SC 3.

Most fuels are failed if the FSS does not work in in the level 3a events of DID reaching a controlled state, and then the consequences results in the high severity. Thus, the FSS is assigned to SC 1. The SSS is provided according to the requirement that the reactor shall have two redundant, diverse and independent shutdown systems. Hence, the SSS is designed in the same safety class as the FSS.

The primary cooling system is assigned to SC 2 except the pipe downstream of the primary cooling pumps and the pump flywheels designed SC 1 because its failure could leads to the consequences of medium severity. If the FMCS does not work to remove the residual heat of reactor core and spent fuels in a loss of coolant accident classified into the level 3a event of DID, the pool water temperature exceeds the design criteria of 60℃. If the function of FMCS is to maintain a safe state and the event does not become a more severe one due to the failure of FMCS function, the FMCS could be assigned to SC 2. The flap valves of the PCS and FMCS are classified into SC 1 because their failure in the level 2 events of DID results in the consequences of high severity that the dose at the site boundary exceeds the design criteria and that the safety parameters exceed the acceptance criteria.

The PWMS, HWLS and SCS maintain the reactor parameters within the normal range of operation of the reactor. A part of the SCS could be SC 2 because it cools down the pool with the FMCS. The DWSS and pipes associated with pool water supply could be SC 2 because they are required to prevent core melt in the design extension conditions such as a loss of coolant plus the failure of pool cooling function of the FMCS.

The CACS removes the heat generated from the electric equipment and reactor pool to prevent the containment pressure and temperature from exceeding the design values. Since the function of CACS is to maintain a safe state and its failure might lead to the consequences of high severity in such a way that the integrity of containment can be attacked, it could be classified into SC 2. The CFVS protects the integrity of containment in the events of over-pressure and over-vacuum. Thus, it is assigned to SC 1 because its failure might cause the consequences of high severity.

The fire protection system is classified into SC 2 considering the impact on the safety when it does not work properly in a fire although it can be assigned to SC 3 by the IAEA standard [1]. The MCR and HVAC associated with the habitability of operators are assigned to SC 1 considering the importance of safety equipment in the MCR and of operator actions that might be required.

The uninterruptible power supply and the emergency diesel generator provide electricity to the equipment categorized as SC 1. Therefore, they are designed SC 1. Since the failure of class IV power, normal electric power, increases the reactor trip, it can be SC 3.

The owner's requirements request that all SSCs be classified into three quality classes, QC 1, QC2 and QC 3. The quality class should be the same as the safety class or the higher class than the safety class.

Table 1. Functions Credited in the Analysis of PIEs and Safety Categories

Functions credited in the safety assessment	Severity of the consequences if the function is not performed		
	High	Medium	Low
Functions to reach a controlled state after Level 2 of DID	safety cat. 1	safety cat. 2	safety cat. 3
Functions to reach a controlled state after Level 3a of DID	safety cat. 1	safety cat. 2	safety cat. 3
Functions to reach and maintain a safe state	safety cat. 2	safety cat. 3	safety cat. 3
Functions for the mitigation of consequences of design extension conditions	safety cat. 2, 3	not cat.	not cat.

Table 2 Preliminary Safety Classes of SSCs

SSCs	SC	QC
Containment liner and isolation valves	1	1
Containment Air Cooling System	2	2
Containment Filtered Vent System	1	1
Pool liner, isolation valves and siphon break valves	1	1
Reactor Structure Assemblies	1	1
Fuel Assemblies	1	1
First Reactor Protection System	1	1
Second Reactor Protection System	2	2
Radiation Monitoring System (RMS)	3	3
Reactor Regulating System (RRS)	3	3
Process Instrumentation and Control System (PICS)	3	3
Communication System (CS)	3	3
First Shutdown System	1	1
Second Shutdown System	1	1
Primary Cooling System	1, 2	1, 2
Flap valves	1	1
Fission Moly Cooling System	2	2
Pool Water Management System	3	3
Hot Water Layer System	3	3
Secondary Cooling System	2, 3	2, 3
Demi-water storage tank and pipes associated with pool water supply	2	2
Fire protection system	2	2
MCR and HVAC associated with the habitability of operators	1	1
Uninterruptible power supply	1	1
Emergency diesel generator	1	1
Class IV Power	3	3

5. Conclusions

The safety classification of major SSCs of a pool type research reactor in the process of bidding was carried out according to the IAEA safety standard. The classification of PIEs was determined by a qualitative evaluation based on the experience of research reactors without probabilistic assessment. In this preliminary safety classification the severity of failure of SSCs was also assessed by engineering judgment due to a lack of the meteorological data of the site. Thus, the safety classes of the SSCs should be reassessed and verified as the reactor design proceeds further.

Acknowledgement

This work was funded by the Ministry of Science, ICT and Future Planning.

REFERENCES

[1] IAEA Safety Standards, Safety Classification of Structures, Systems and Components in Nuclear Power Plants, Specific Safety Guide, No. SSG-30, 2014.
[2] Tae-Ryong Kim, Safety Classification of Systems, Structures, and Components for Pool-Type Research Reactors, Nuclear Engineering and Technology, pp.1, 2016.
[3] U.S. Nuclear Regulatory Commission, USNRC Regulatory Guide 1.26 (Rev.4): Quality Group Classification and Standards for Water-, Steam-, and Radioactive-Waste Containing Components of Nuclear power Plant, USNRC, Washington, DC., 2007.
[4] America National Standards Institute, America Nuclear Society Standards Committee Working Group ANS-51.1, Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants, ANSI/ANS-51.1-1983.
[5] W. J. Brynda, P. R. Lobner, R. W. Powell, E. A. Straker, BNL50831-III: Design Guide for Category-III Reactors, Pool Type Reactor, Brookhaven National Laboratory Associated Universities Inc, Upton, New York, USA, 1978.