Nuclear Engineering and Technology 48 (2016) 1015–1021

Available online at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Safety Classification of Systems, Structures, and Components for Pool-Type Research Reactors

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ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
5 February 2016
Accepted 10 February 2016
Available online 4 March 2016

Keywords:
Pool-Type Research Reactor
Safety Classification
Safety Importance and Significance
Structures, Systems, and Components

ABSTRACT

Structures, systems, and components (SSCs) important to safety of nuclear facilities shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions. Although SSC classification guidelines for nuclear power plants have been well established and applied, those for research reactors have been only recently established by the International Atomic Energy Agency (IAEA). Korea has operated a pool-type research reactor (the High Flux Advanced Neutron Application Reactor) and has recently exported another pool-type reactor (Jordan Research and Training Reactor), which is being built in Jordan. Korea also has a plan to build one more pool-type reactor, the Kijang Research Reactor, in Kijang, Busan. The safety classification of SSCs for pool-type research reactors is proposed in this paper based on the IAEA methodology. The proposal recommends that the SSCs of pool-type research reactors be categorized and classified on basis of their safety functions and safety significance. Because the SSCs in pool-type research reactors are not the pressure-retaining components, codes and standards for design of the SSCs following the safety classification can be selected in a graded approach.

1. Introduction

The most important safety principle in a nuclear reactor facility is the reactor's ability to safely shut down and adequately cool following postulated accidents. To satisfy this principle, structures, systems, and components (SSCs) important to safety should be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to perform. The SSCs are classified according to their safety importance and/or significance using the appropriate classification guideline.

For nuclear power plants (NPPs), SSC classification guidelines have been well-established and applied [1–3]. The conventional SSC classification guideline has been based on the deterministic approach. The recent trend for the classification system is to determine the safety significance of SSCs based on deterministic methods as well as probabilistic methods [4,5] and to classify not only SSCs but also their parts [3]. In

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http://dx.doi.org/10.1016/j.net.2016.02.009

Korea, the SSC classification guideline has been also developed in accordance with American National Standards Institute standards [6].

For a research reactor, however, the minimum safety class guideline for SSCs was developed several decades ago [7] and was left as it is, probably due to the difficulties in establishing a generic guideline covering so many design features and power levels of the reactors. Among them, the most common design is the pool-type research reactor, in which the reactor is immersed in a large pool of water. The main design feature of the pool-type reactor is that the reactor is operating in an open and unpressurized pool. Considering the intrinsic design feature of the pool-type research reactor, the safety classification of SSCs should be differently determined from that used for power reactors. The International Atomic Energy Agency (IAEA) has been recently trying to establish safety standards and guidelines for research reactors [8,9]. Korea has already built a pool-type research reactor, High Flux Advanced Neutron Application Reactor (HANARO; 30 MWth). In addition to this, another pool-type reactor, Kijang Research Reactor (KJRR; approx. 20 MWth), is being built in Kijang, Korea. Therefore, it is time to establish an SSC classification system for pool-type research reactors in Korea.

2. Current status of safety classification for pool-type research reactors

Unlike power reactors, research reactors have various designs, wide range of maximum power levels, different purposes of utilization, etc. According to the BNL 50831-III design guide [7], research reactors can be categorized into several types as shown in Table 1. Among them, open pool-type reactor is a popular reactor because of easy accessibility to the reactor for experimental purposes. The reactor operates in an open and unpressurized pool, with cooling generally achieved by natural convection of light water.

The safety classification of SSCs is based on the facility's safety functions and the significance of the SSCs as in power reactors. The safety functions of a research reactor are as follows:

- Shutting down the reactor and maintaining a safe shutdown condition for all operational states or accident conditions;
- Providing adequate removal of heat from the core after shut down, including in an accident; and
- Containing radioactive material to minimize its release into the environment.

2.1. Department of Energy guideline in the United States

The Department of Energy (DOE) in the United States has already established a design guideline for pool-type research reactors [7]. The fundamental design philosophies for research reactors are similar to those applied to United States Nuclear Regulatory Commission (USNRC)-licensed power reactors. Both require the reactor to be capable of being able to safely shut down and adequately cooled following postulated accidents. In addition, the reactor facility is designed to provide a defense-in-depth against the uncontrolled release of radioactive materials into the environment. Because of the big difference between pool-type reactor and power reactor, however, it is possible to simplify the design of a research reactor while still adequately protecting public and environment. As a result, pool-type research reactors can be adopted to the reactor building (confinement concept), which does not control the release of radioactive material into the environment, unlike a containment generally utilized in power reactors.

The DOE guideline provides recommendations regarding the safety classification of SSCs as follows:

- The minimum safety classes are based on USNRC Regulatory Guideline 1.26 [2], "Quality Group Classifications and Standards for Water, Steam and Radioactive Waste Containing Components of Nuclear Power plants."
- Based on the accident analysis results, the final safety class should be determined. Alternatively, it may be necessary to increase the quality and reliability of the system by designing it to a higher than the minimum safety class.

For the pool-type research reactor, the DOE recommended the safety class of SSCs according to their safety importance as shown in Table 2. Note that there are no SSCs classified as SC-1, because of the characteristics of pool-type reactors (the reactor operates in an open and unpressurized pool).

Although the USNRC Regulatory Guideline 1.26 has been revised [2], the DOE guideline for research reactors has never

Table 1 – Research reactor categories [7].

Category	General reactor characteristics	
	Type	Subtype
I	Critical facilities	Solid fuel system Liquid fuel system Gaseous fuel system
II	Water-cooled reactor with a closed primary coolant system	Tank-type reactors Pressurized water reactors Water-cooled graphite reactors
III	Pool-type reactors	—
IV	Liquid-metal-cooled reactor	—
V	Transient reactors	Fast burst-type reactors Pulse type
VI	Air-cooled graphite reactors	—

Table 2 — General minimum safety class guideline.

Classification	Guideline	SSCs included
Safety Class 1 (Quality Group A)	Pool-type reactors do not require Safety Class 1 SSCs	—
Safety Class 2 (Quality Group B)	• The failure of those systems which may result in the radiological consequences of accidents being in excess of the 10CFR100 guidelines. • The failure of those systems which would prevent the safe shut down and/or cooling.	—
Safety Class 3 (Quality Group C)	Those components, systems, or structures that are not SC-1 or SC-2, but contain or may contain the radioactive material and have the potential for causing offsite doses in excess of 0.5 rem to the whole body or its equivalent to any part of the body, but less than the 10CFR100-dose guidelines.	• Reactor coolant system • Emergency core cooling system • Reactor building • ESF ventilation system • Radiation protection system
Non-nuclear safety (Quality Group D)	Components, system, or structure that contain or may contain the radioactive material but are not SC-1, SC-2, or SC-3, may be designed to non-nuclear safety standards. The maximum offsite doses resulting from the failure of a non-nuclear system should not exceed 0.5 rem to the whole body or the equivalent to any part of the body.	• Nonsafety I&C system • Nonclass 1E electric system • Cooling water system • Fuel handling and storage system • Purification and make-up water system • Fire protection system

ESF, Engineered Safety Feature.

been revised. Since the introduction of the risk concept, the USNRC has adopted the risk-informed regulation by issuing 10CFR50.69 [10] and Regulatory Guideline 1.201 [11]. Accordingly, Regulatory Guideline 1.26 is currently being revised [5] to include the safety significance concept and to harmonize with international standards [4].

As long as the DOE guideline based on Regulatory Guideline 1.26 for research reactors is effective, the minimum safety classification of SSCs for research reactors should also include the safety significance concept.

2.2. *Korean guideline*

The first research reactor in Korea (TRIGA Mark-II) was constructed in 1962 as a turnkey base. It is doubtful whether there was a clear SSC classification at that time. When the next research reactor HANARO was constructed in 1995, Canadian rules and standards [12] were applied because the basic design concept of HANARO came from Maple-X, a research reactor in Canada. In addition, the DOE guideline [7] was also applied for the safety classification of the SSCs of HANARO since there was no clear guideline for research reactors in the Canadian rules. Recently, the Korea Atomic Energy Research Institute has exported a pool-type research reactor, Jordan Research and Training Reactor (JRTR), to Jordan. Because the design concept of JRTR originated from HANARO, the SSC classification is also quite similar to that of HANARO. Table 3 shows the SSC classification of the JRTR [13].

The Nuclear Safety and Security Commission in Korea has also established and applied SSC classification guidelines for power reactors [6]. The Korea Institute of Nuclear Safety has developed a safety review guideline for research and training reactors [14]; however, no separate SSC classification guideline for research reactors has been established. Instead, the rules for power reactors are recommended to apply to research reactors with appropriate modifications [6].

Table 3 — SSC classification of the Jordan Research and Training Reactor.

SSCs	Safety class	Function and characteristics
Reactor building	3	Safety system (protection, mitigation)
• Service building	3	Safety system (protection, mitigation)
• Stack	NNS	Ground release (radiological consequence analysis)
Reactor structure	3	Safety function
Primary cooling system		Safety function
• Pumps	3	
• Heat exchanger	3	
• Flap valve	3	
• Siphon break valve	3	Fail-safe design
• Discharge head	NNS	No safety function
Reactor pool liner	3	Safety function
Secondary cooling system	NNS	No safety function
Emergency water supply system		Safety related
• Inside reactor pool	3	
• After MOV	NNS	

MOV, Motor Operated Valve; NNS, Non Nuclear Safety.

2.3. International Atomic Energy Agency guideline

The IAEA has long developed and revised the nuclear safety requirements and guidelines as the safety standards series. Among them, a specific guideline, SSG-30, has been recently developed for the safety classification of SSCs in NPPs. The SSG-30 guideline provides a methodology for identifying and classifying SSCs important to safety on the basis of their functions and safety significance. The method for classifying the safety significance of items important to safety is based primarily on deterministic methods complemented by probabilistic methods, wherever appropriate. Fig. 1 shows the flowchart indicating the classification process.

It introduces three safety categories for functions and three safety classes for SSCs important to safety. Three safety categories for functions are shown in Table 4 (reproduced from SSG-30). Once the safety categorization of the functions is completed, the SSCs implementing these functions should be assigned to a safety class.

The final safety class of the SSC can be classified directly according to the severity of consequences of their failures as follows:

- *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.
- *Safety Class 3*: Any SSC whose failure would lead to consequences of “low” severity.

The IAEA recommends that the same safety classification guideline be used for research reactors [8]. However, codes and standards used in the design of SSCs should be appropriately selected using a graded approach that takes into account the safety classification of SSCs and the potential radiological hazard associated with the research reactors [9]. Of course, the three basic nuclear safety functions cannot be graded, that is, shutting down the reactor, reactor core cooling, and confining radioactive material.

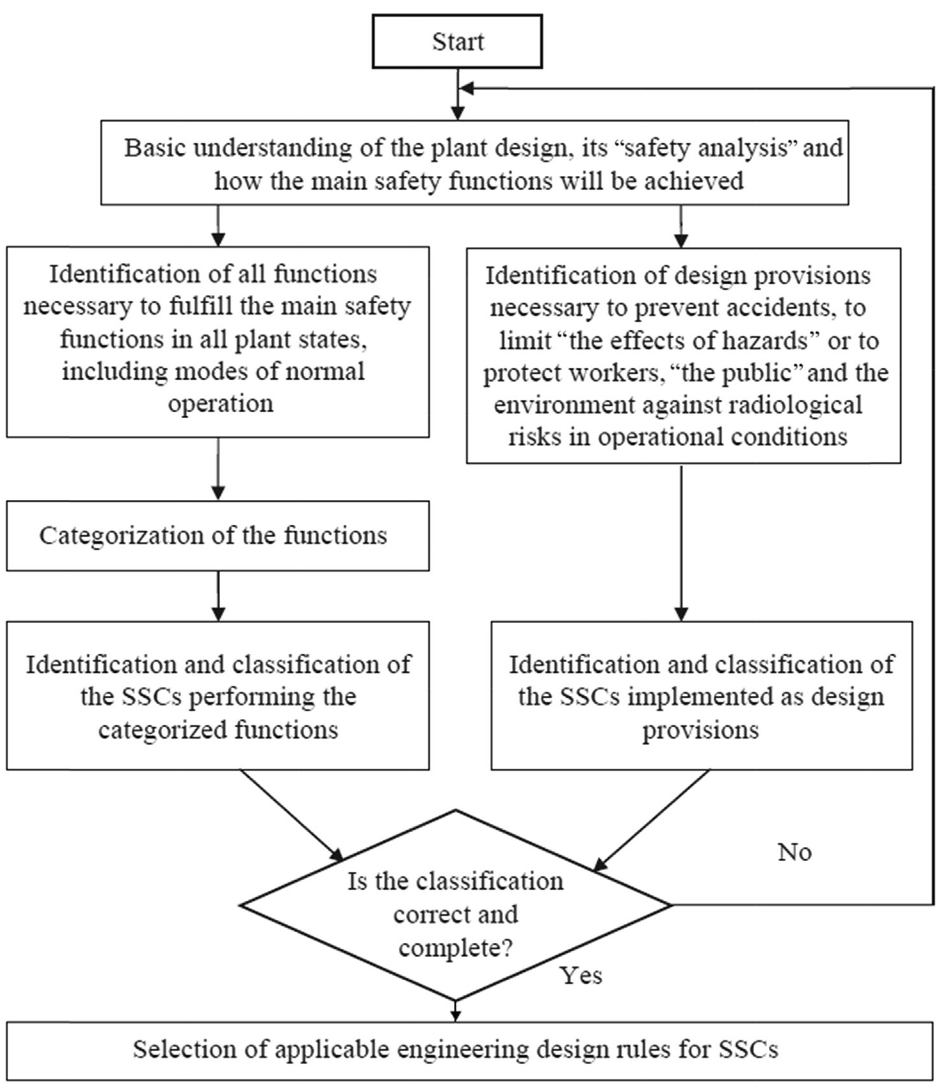

Fig. 1 – Flowchart indicating the classification process. *Note.* Reproduced from “IAEA Safety Standards Series No. SSG-30: Safety Classification of Structures, Systems and Components in Nuclear Power Plants,” by International Atomic Energy Agency (IAEA), 2014, Vienna, Austria. SSC, structures, systems, and components.

Table 4 – Relationship between functions credited in the safety analysis of postulated initiating events 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 anticipated operational occurrences	Safety category 1	Safety category 2	Safety category 3
Functions to reach a controlled state after design basis accidents	Safety category 1	Safety category 2	Safety category 3
Functions to reach and maintain a safe state	Safety category 2	Safety category 3	Safety category 3
Functions for the mitigation of consequences of design extension conditions	Safety category 2 or 3	Not categorized	Not categorized

2.4. *European guideline*

There have been many research reactors in European countries; for example, 10 operating reactors in France, eight in Germany, and three in the UK. Each country must have its own rules and regulations on the nuclear reactors. Although it is very hard to find the safety classification guideline for research reactors, it can be inferred from power reactor guidelines. The Western European Nuclear Regulatory Association (WENRA) had a program for harmonization of reactor safety in 17 WENRA countries. As a result, all countries have tried to harmonize the safety classification guideline for nuclear reactors [15]. Fig. 2 shows the harmonization of safety classification process of SSCs (Issue G). The vertical axis represents the number of country, and the horizontal axis represents the reference levels. The reference level indicates the detailed process as follows [16]:

- G1.1: All SSCs important to safety shall be identified and classified on the basis of their importance for safety.
- G2.1: The classification of SSCs shall be primarily based on deterministic methods, complemented where appropriate by probabilistic methods and engineering judgment.
- G2.2: The classification shall identify for each safety class:
  - The appropriate codes and standards in design, manufacturing, and inspection;
  - Needs for emergency power supply, qualification to environmental conditions;
  - The availability or unavailability status of systems serving the safety functions to be considered in deterministic safety analysis;
  - The applicable quality requirements.
- G3.1: SSCs important to safety shall be designed, constructed, and maintained such that their quality and reliability commensurate with their classification.

As shown in Fig. 2, some countries have their own rules and regulations, but they agreed to implement the rules and regulations in a harmonized manner. As one may expect, the harmonized guidelines were the IAEA safety standards series. Therefore, the safety classification guideline for research reactors in European countries is the IAEA safety standards series.

3. Proposal on safety classification of SSCs for pool-type reactors

In the early days of nuclear history, Korea has traditionally adopted the rules and standards of the country from which the nuclear reactor had originated, that is, USA rules and

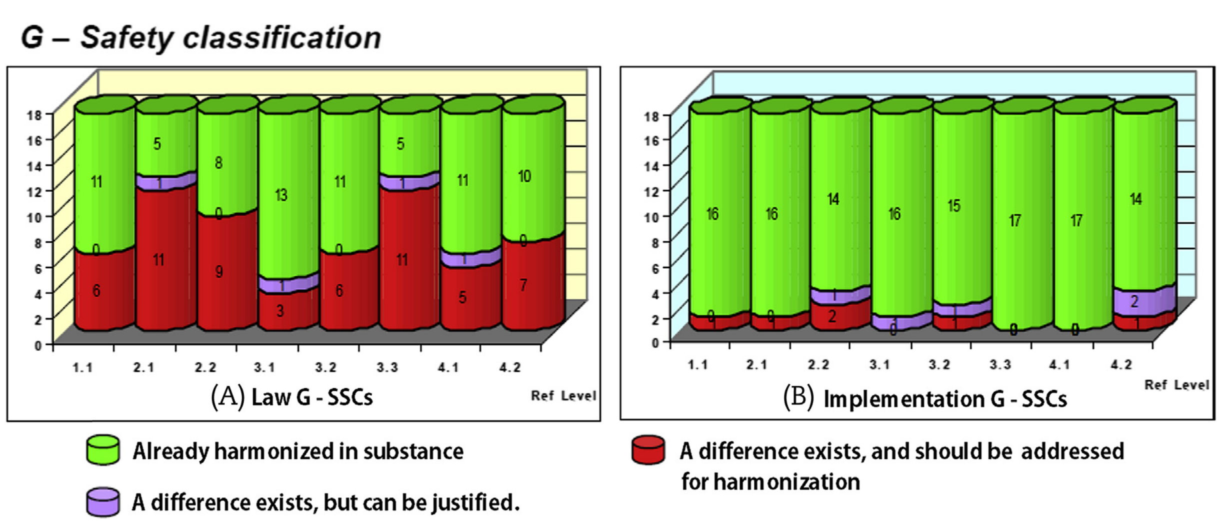

Fig. 2 – Harmonization of safety classification process. *Note.* Reproduced from "Harmonization of Reactor Safety in WENRA Countries (WENRA, 2006.1)," by WENRA Reactor Harmonization Working Group, 2006. SSC, structures, systems, and components.

Table 5 – Safety classification of SSCs for pool-type reactors in Korea.

Functions credited in the safety assessment	Severity of the consequences if the function is not performed		
	High	Medium	Low
Functions defined in Article 5 (SC-1) of The Nuclear Safety and Security Commission (NSSC) Notice 2014–15	N/A	N/A	Safety Class 3
Functions defined in Article 6 (SC-2) of NSSC Notice 2014–15	N/A	Safety Class 3 [a]	Safety Class 3
Functions defined in Article 7 (SC-3) of NSSC Notice 2014–15	N/A	Safety Class 3	Safety Class 3
Functions defined in Article 8 (NNS) of NSSC Notice 2014–15	N/A	NNS	NNS

[a] According to the Article 7 Paragraph 15 of NSSC Notice 2014–15.

standards for Westinghouse plants, French rules for Framatome plants, and Canadian rules for CANDU plants. The same concept was applied to research reactors.

Now, Korea has its own rules and standards for commercial NPPs. It is required that the rules and standards for NPPs be generically applied to research reactors with appropriate modifications. A pool-type reactor, JRTR based on the HANARO design concept, is being built in Jordan. In addition, another pool-type research reactor KJRR (approx. 20 MWth) was decided to be built in Kijang, Korea.

As mentioned earlier, there is no separate guideline on safety classification of SSCs for research reactors in Korea. Because the IAEA has already established safety requirements and guidelines for research reactors, and recommended member states to adopt the IAEA safety standards, it is a good time to establish a separate SSC classification guideline for pool-type research reactors in Korea.

More than 200 research reactors are still operating globally, with a variety of different designs, different power levels, and different purposes. Because of these characteristics, the safety requirements for research reactors may not be required to be applied in the same way. This is why the IAEA has paid attention to the establishment of safety guideline for research reactors [8,9].

It is quite reasonable to propose that the safety significance concept used in the IAEA guideline should be applied to the safety classification of SSCs for pool-type research reactors. Although SSCs in pool-type reactors are not the pressure-retaining components, severity of the consequences following the postulated accidents could be high enough. Fig. 1 and Table 4 can be, therefore, used as the general safety classification of SSCs for pool-type reactors. Of course, the consequences should be confirmed by safety analysis. The specific safety classification of SSCs should be developed according to the specific design features and the nuclear environment where the reactor will be constructed. For example, in Korea, the safety classification can be proposed as shown in Table 5.

Once classified, SSCs important to safety shall be designed, constructed, and maintained such that their quality and reliability commensurate with their classification. Those classifications will be specified in design specifications of equipment or components, and the relevant codes and standards will be also specified. Codes and standards for the engineering design of SSCs of pool-type reactors according to the safety classification can be selected in a graded approach differently from those for the design of SSCs of an NPP. The acceptance criteria for the component design are normally given in the design codes and standards.

SSCs of nuclear facilities important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions. SSC classification guidelines for NPPs have been well established and applied, but those for research reactors have only been recently established by the IAEA.

The safety classification of SSCs for pool-type research reactors is proposed in this paper based on the IAEA methodology. The proposal recommends that the SSCs of pool-type research reactors be categorized and classified on basis of their safety functions and safety significance. Because the SSCs in pool-type research reactors are not the pressure-retaining components, however, codes and standards for design of the SSCs following the safety classification can be selected in a graded approach.

Conflicts of interest

The author declares no conflicts of interest.

Acknowledgments

This study was supported by the internal fund of KEPCO International Nuclear Graduate School.

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