Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

A Preliminary Safety Classification of a Hybrid Low Power Research Reactor

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1. Introduction

Within a Research Reactor Development Project by KAERI, a Hybrid Low Power Research Reactor (H-LPRR) is being under consideration targeted on national education and training for nuclear start-up countries.

A nuclear reactor which is Ultimately Safe, Simple, and Cheap (USSC) must be on the top of the Top-Tier Requirements (TTR) for the H-LPRR.

Safety Classification, part of a systematic safety assessment, is the starting point for reactor design. This paper presents a preliminary safety classification of H-LPRR as well as the design information based on a preliminary deterministic safety analysis.

2. Regulatory position on Safety Classification

In this section some regulatory positions on safety classification of nuclear facilities are described to give a general overview about classification performed over the world.

2.1 Korean Nuclear Safety Law and US 10 CFR 50

Safety-related Structures, Systems, and Components (SSCs) are defined as classified design features of significance to the nuclear safety in accordance with the notice by the Nuclear Safety and Security Commission (NSSC) in the nuclear safety law [1~11].

The maximum allowable exposure radiation dose is defined as the limit in the nuclear safety decree.

Safety-related SSCs shall be designed, manufactured, installed, tested, and inspected to the extent of the safety significance by the nuclear safety regulation.

SSCs in pressurized light water reactors (PWR) are classified as one of safety class 1, safety class 2, safety class 3, and non-nuclear safety (NNS) in accordance with the notice by the Nuclear Safety and Security Commission (NSSC). In this notice, safety functions are defined as 1) to maintain the pressure-retaining components integrity, 2) to shutdown reactor and maintain it in a safe shutdown state, and 3) to prevent or mitigate off-site exposure within the limit as given in 10 CFR 100.11 [1~11].

Codes and standards for each classification shall be in accordance with the KEPIC codes and standards by the notice, which includes quality assurance requirements, construction requirements, seismic requirements, qualification requirements, Control and Instrumentation requirements, and electric requirements, and so on[4,11].

2.2 IAEA standards for Research Reactors

International standards provided a systematic and comprehensive approach to classify SSCs according to the significance to the nuclear safety in a technology-neutral way including graded approaches for application into research reactors [12~21].

An essential set of tasks includes the safety fundamentals on the top, general safety requirements for safety assessment of the general safety requirements, safety of research reactors of specific safety requirements, and classification and graded approach from safety guides as given in the following figure.

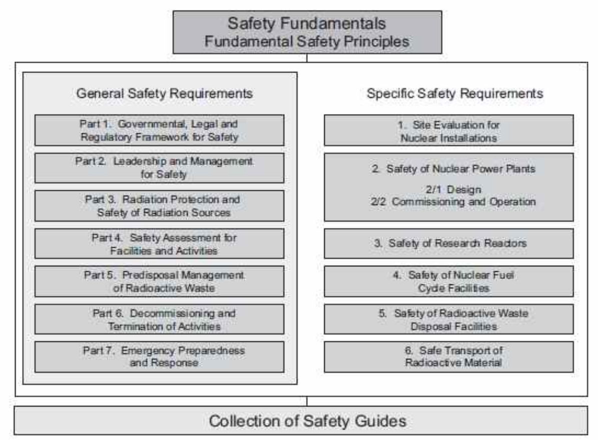


FIG. 1. The long term structure of the IAEA Safety Standards Series.

The nuclear safety should be based on the concept of defense in depth, safety margin, and multiple barriers, which must be assessed mainly for radiation protection, safety functions, and engineering aspects, and verified by the safety analysis of a specific design as in the following figure by IAEA standard [15].

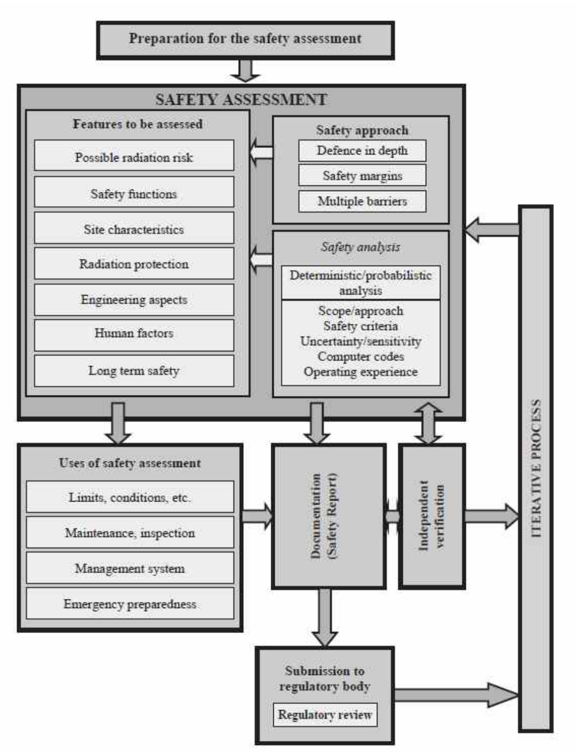


FIG. 1. Overview of the safety assessment process.

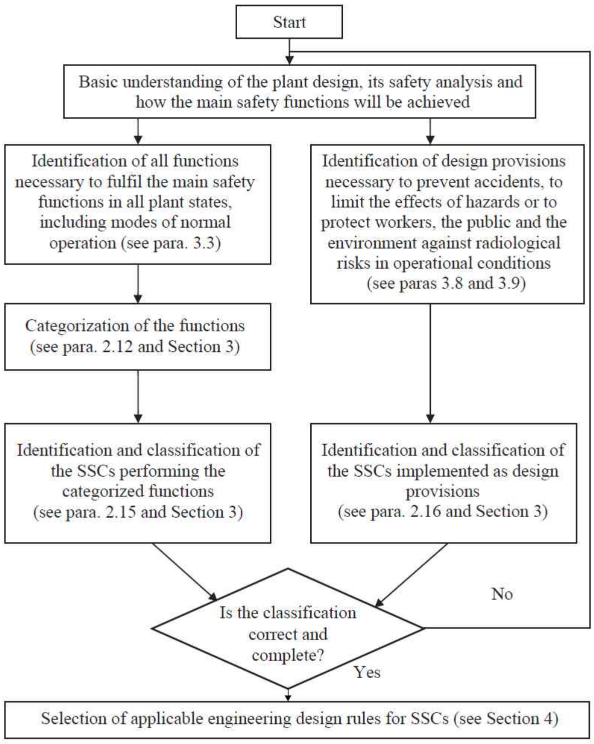


FIG. 1. Flow chart indicating the classification process.

Of the engineering aspects considering overall safety of nuclear facilities, safety classification is major process to reach a design goal of nuclear facilities. The classification process starts from basic understanding of a plant design followed by identification of all safety functions and design provisions. The last activity is to select applicable engineering design rules for SSCs as in the following figure by IAEA standard [20]. But the IAEA standards do not force to follow any specific rules but are open to select .

2.3 Others

The office of nuclear regulation (ONR) provides its inspectors with a guidance for categorization and classification, which is very explanatory [22].

The roles and scheme of safety function categorization and classification, the initial safety function categorization, and off/on site frequency/ consequences regions were given as an acceptance criteria for further classification as in the following figures by the ONR.

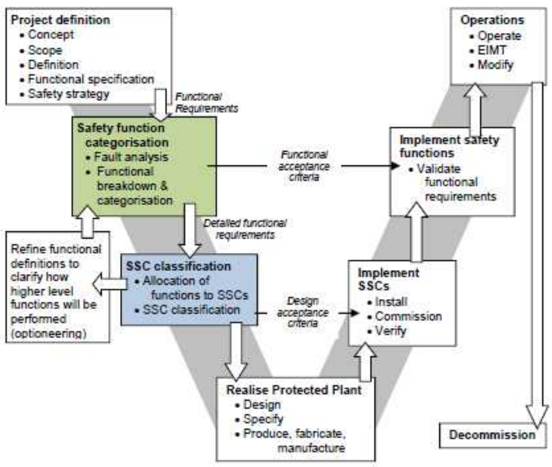


Figure 1 – Role of safety function categorisation (green box) and SSC classification (blue box) within the lifecycle model ("V-diagram")

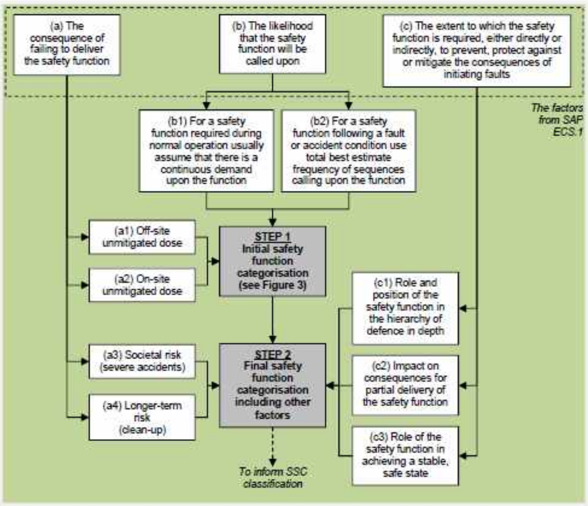


Figure 2 – safety function categorisation scheme

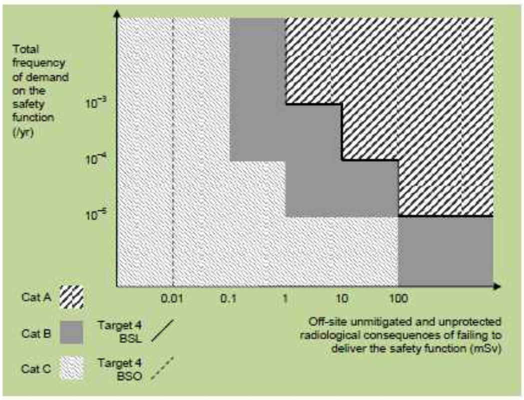


Figure 3a – Off-site frequency/consequence regions for initial safety function categorisation (see Section 5.5.2)

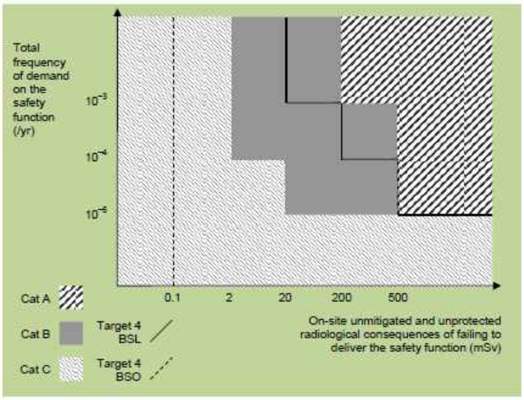


Figure 3b – On-site frequency/consequence regions for initial safety function categorisation (see Section 5.5.2)

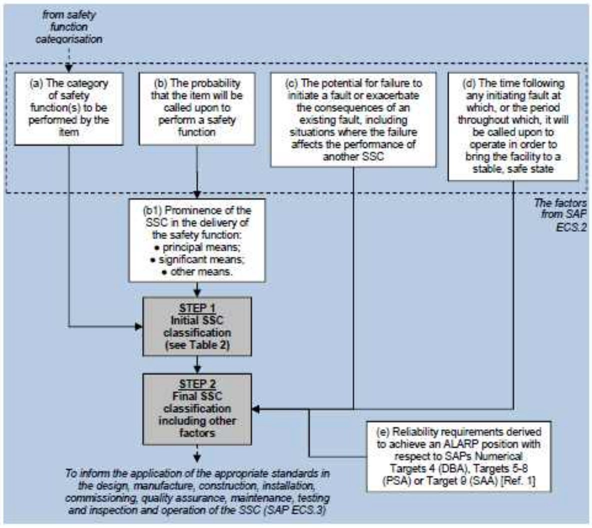


Figure 4 – SSC classification scheme

The guideline by the KINS [23] follows the regulatory guide by the USNRC [24] for research reactor application, which gives different criteria [25] for radiation exposure.

A practical reference about the Category III reactor, of which the first subgroup (< 1 MW) includes the pool type reactors that generally do not require active-systems for reactor heat removal, which is adequately removed by natural convection during normal operations, proposes a realistic approach and an example to determine the classification of the SSCs depending on the significance to the nuclear safety.

3. Preliminary Safety Classification

In this section a preliminary classification process is described for the H-LPRR following the contents in the IAEA standards [12~21]. A typical process includes understanding design with acceptance criteria, defense in depth, categorization (initial classification), classification, and verification.

2.1 Understanding Design

A succinct overview of the conceptual design, the H-LPR is as given in the following table.

Reactor		Open pool in tank
Core	Thermal Power	~ 50 kW_{th}
	Neutron flux	~4.0×10^{12} (n/cm^2-sec)
	Size	53.7cm×53.7cm×53cm
	Fuel dimension	27cm×27cm×39.6cm
Fuel	Shape	Rod type

	Type	UO_2
	Enrichment	4.65 wt%
	Cladding	Zr-4
Coolant	Material	Light water
	Cooling method	Natural circulation
Moderator	Material	Light water
Reflector	Material	Beryllium, Carbon
Control Rods	Material	B_4C
	Function	Power control
Reactor Structure	Material	Zr-4

Ultimately Safe, Simple, and Cheap (USSC) on the top of the TTR for the H-LPRR should be realized within the ALARA (As Low As Reasonably Achievable) as well as the stringent acceptance criteria for exposure dose of radiation without any active systems or components.

2.2 Defense-in-Depth

Following tables present the defense-in-depth for the safety functions such as reactivity control, core cooling, and water inventory control

There is not any safety function but design provisions that must be assured by the deterministic safety analysis for the conceptual design.

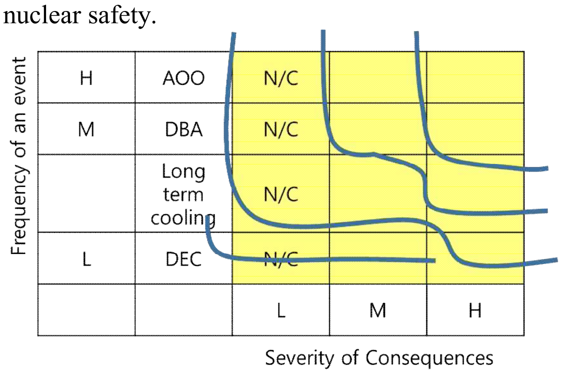
Level	Functions and Design Provisions	To be Assured
1	Conservative selection of fuel properties Conservative selection of fuel oxidation Conservative design of core (inherent safety features) Conservative design/manufacturing/construction/installation/inspection of Fuel, Core, Core Structures Quality assurance of fuel, core, core structures Qualification Fuel/Core management	
2	Power Control System	
3	No protection, shutdown Emergency Operating Procedures	No fuel failure

Level	Functions and Design Provisions	To be Assured
1	Quality assurance of core flow by commissioning Conservative selection of flow	
2	Cooling by pool water during LOEP Abnormal Operating Procedures	Necessity of Make-up Operational exposure Confinement integrity
3	No protection, shutdown Emergency Operating Procedures	No fuel failure

Level	Functions and Design Provisions	To be Assured
1	Conservative selection of fuel properties Conservative selection of fuel oxidation Conservative design of core (inherent safety features) Conservative design/manufacturing/construction/installation/inspection of Fuel, Core, Core Structures, pool liner Quality assurance of fuel, core, core structures, pool liner Qualification Fuel/Core management	
2	Normal Make-up Abnormal Operating Procedures	Necessity of Make-up Operational exposure Confinement integrity
3	No protection, shutdown Emergency Operating Procedures	No fuel failure

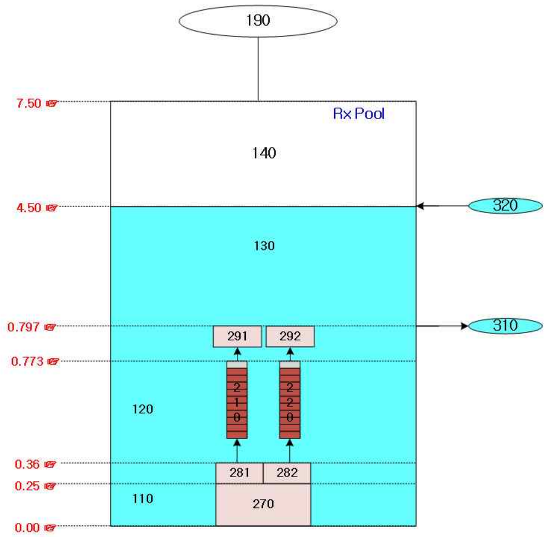
2.3 Categorization and Classification

An initial categorization for reactivity control looks like the following figure: all SSCs are categorized as "non-categorized" since, with no SSCs except for the design provision, there will be no hazards from ionizing radiation hazards to the workers and public by using the H-LPRR, which shall be verified by a deterministic safety analysis. The classification will be followed by the initial categorization according to the significance to the nuclear safety.

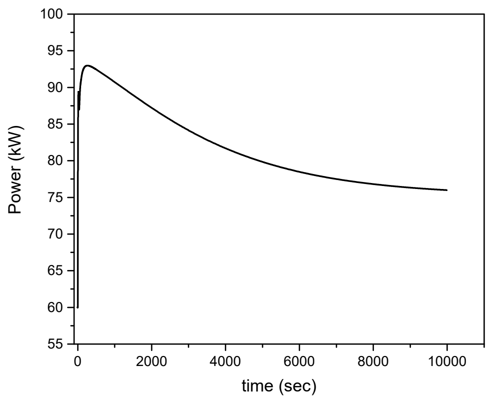


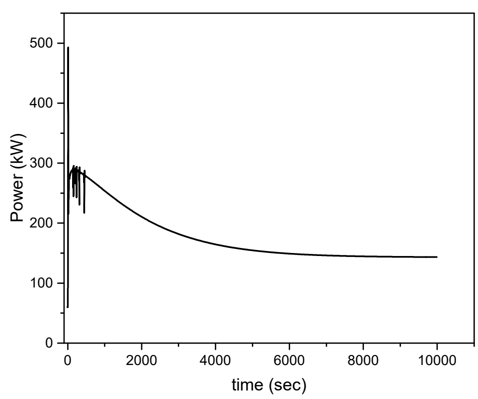
2.5 Verification

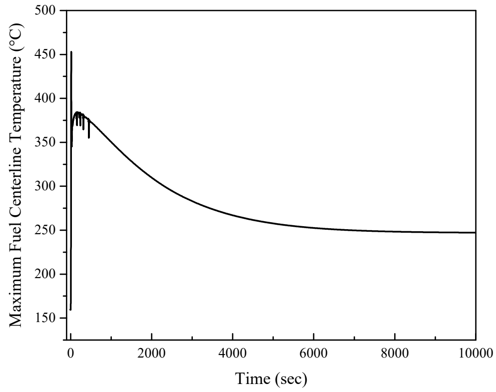
An initial classification is assured by the deterministic safety analysis with modeling of the H-LPRR as given in the figure below.



The transient was given as for the power because of both ramp and step reactivity insertion: because of both the limitation of excess reactivity and the ultimately inherent safety feature of temperature coefficients there is no tragedy. In addition, the temperature rise will be only limited to the extent of only 300 degree in Celsius.







Only tenth order of the criteria as given in the figure was assured by the analysis about the fuel failure mechanism, PCMI [27, 28] during pre-DNB as given in the figure.

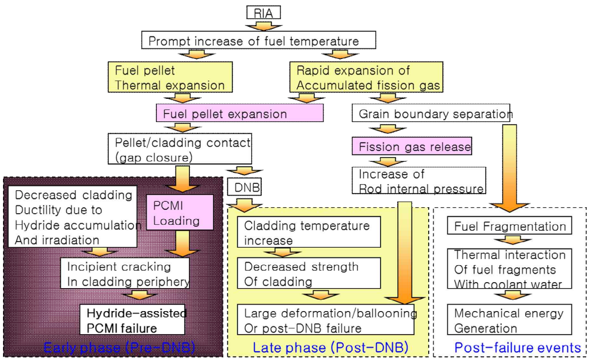
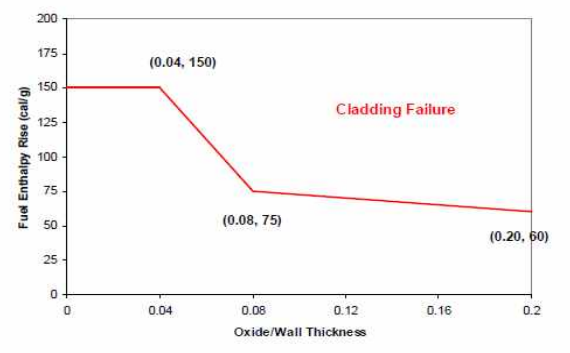


FIGURE B-1: PWR PCMI Fuel Cladding Failure Criteria



2.6 Design rules

The initial classification, "Non-Categorized", was verified to be applicable by the analysis. Then the design rules for reactivity control can be selected as the normal industrial standards with appropriate quality assurance, seismic requirements, if there are no specific legal requirements.

2.7 Future works

A set of design bases should be firmly established for more realistic engineering works. Based on the bases iterative assessments should be performed following this preliminary classification complemented by probabilistic safety analysis.

3. Conclusions

A preliminary safety classification was prepared for the H-LPRR targeted on countries starting nuclear engineering based on the IAEA standards. The classification was supported by a deterministic safety analysis for the conceptual design evaluation.

The classification should be refined by the future works such as justification of design bases, detailed design, comprehensive deterministic safety analysis with probabilistic safety analysis, and design verification.

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