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A Development of Technical Specification of a Research Reactor with Plate Fuels Cooled by Upward Flow

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1. Introduction

Technical Specifications (TS) of a nuclear reactor provides an envelope of the parameters which protect the reactor, the personnel, the public and the environment from undue damage, exposure, and contamination.

The contents of the TS are definitions, safety limits, limiting safety system settings, limiting conditions for operation, surveillance requirements, design features, and administrative controls.

TS for Nuclear Power Plants (NPPs) have been developed since many years until now. On the other hands, there are no applicable modernized references of TS for research reactors with many differences from NPPs in purpose and characteristics.

Fuel temperature and Departure from Nuclear Boiling Ratio (DNBR) are being used as references from the thermal-hydraulic analysis point of view for determining whether the design of research reactors satisfies acceptance criteria for the nuclear safety or not. Especially for research reactors using plate-type fuels, fuel temperature and critical heat flux, however, are very difficult to measure during the reactor operation.

In order to establish a TS for a research reactor, measurable variables reflecting characteristics of the reactor need to be applied for safety limits (SLs) and limiting conditions for operation (LCOs).

In this study, SLs and LCOs of a TS are investigated for a research reactor using typical plate-type fuels cooled passively by upward flow in low pressure based on the guides [1-3].

2. Safety Limits

As per 10 CFR 50.36 [1] nuclear reactors shall have safety limits that limit upon important process variables that are found to be necessary to reasonably protect the integrity of certain of the physical barriers that guard against the uncontrolled release of radioactivity.

To comply with the safety limit in the act [1], the reactor core and associated coolant, control, and protection systems need to be designed with appropriate margin to assure that any release of fission product to coolant does not happen during the operational states.

2.1 Safety Limit (SL) for core cooling

For reliable and safe operation, safety margin should be ensured that Minimum Critical Heat Flux Ratio (MCHFR) is satisfied under normal operation mode. MCHFR is defined as the minimum ratio of CHF to actual heat flux at fuel surface. In a research reactor, MCHFR should not be less than 2.0 with a margin during normal operation:

$$q''_{\mathrm{CHF}} \big/ q''_{\mathrm{loc}} > 2.0 \qquad (1)$$

Operation above the boundary of the nucleate boiling regime results in excessive cladding temperature because of the resultant onset of Critical Heat Flux (CHF) and the sharp reduction in heat transfer coefficient.

CHF correlations applicable to plate type research reactors at low P and low T condition are very limited. A set of CHF correlations for narrow vertical rectangular flow channels was proposed by Mishima and Nishihara [4] and Sudo et al. [5]. Kaminaga et al. [6] improved the early CHF correlations with more experimental data in order to implement the inlet subcooling effect for the low mass flux region.

According to CHF correlations by Kaminaga [6], the reactor core critical heat flux is mainly a function of local heat flux (q''_{loc}), coolant flow rate ($\dot{m}$), core outlet temperature of inlet (T_{in}) and outlet (T_{out}), fuel temperature (T_f) and pressure of the reactor (P):

$$CHF = f\left(q''_{\mathrm{loc}}, \dot{m}, \mathrm{T}_{in}, T_{out}, T_f, P\right) \qquad (2)$$

For a research reactor with plate-type fuel, its center temperature and associated heat flux cannot be measured because the plate-type fuel size is too small to measure the variables.

Hence, a combination of independent variables, which are measurable process parameters for the correlations of CHFR, should be introduced as safety limits.

Reactor pressure (P) is negligible for an open pool type research reactor, and fuel temperature (T_f) is also cancelled out because it is difficult to measure for plate-type fuel. Core coolant inlet temperature (T_{in}), a function of outlet temperature (T_{out}), can be considered as one parameter.

Hence, the CHFR can be rewritten with the variables of reactor power (Q), coolant flow rate ($\dot{m}$), and core outlet temperature of outlet (T_{out}) as shown below.

$$CHF = f\left(Q, \dot{m}, T_{out}\right) \quad (3)$$

Therefore, constraints of safety limit for operating region are driven, which can be compared against the region by design limit of MCHFR.

2.3 Safety Limit (SL) for pool level

Reactor core shall be covered with pool water during the operational states and design basis accidents to ensure fuel integrity.

When the reactor is operating at low power in the training mode or is in the state of decay heat cooling after shutdown, its heat needs to be continuously removed by natural convection.

Hence, reactor pool water level shall be higher than a flow path through the flap valves that ensures natural circulation via flap valve(s) to cool down the reactor core.

The SL on the reactor pool water level is determined conservatively so that the natural circulation is ensured at all times.

3. Limiting Conditions for Operations

Limiting Condition for Operations (LCOs) are those established constraints on equipment and operational characteristics that shall be adhered to during the operation of the facility.

LCOs are selected based on 10 CFR 50.36, ANSI/ANS 15.1-1990.

3.1 Criterion

The LCOs for the safe operation are established for each item meeting one or more of the following criteria according to 10 CFR 50.36 “Technical Specifications”.

A. Criterion 1: Installed instrumentation that is used to detect, and indicate in the control room, a significant abnormal degradation of the reactor coolant pressure boundary.

B. Criterion 2: A process variable, design feature, or operating restriction that is an initial condition of a design basis accident or transient analysis that either assumes the failure of or presents a challenge to the integrity of a fission product barrier.

C. Criterion 3: A structure, system, or component that is part of the primary success path and which functions or actuates to mitigate a design basis accident or transient that either assumes the failure of or presents a challenge to the integrity of a fission product barrier.

D. Criterion 4: A structure, system, or component which operating experience or probabilistic risk assessment has shown to be significant to public health and safety.

3.2 Category of LCOs for Research Reactors

In ANSI/ANS 15.1-1990 chapter 3, there are SSCs which are included in LCOs. The main category is as follows. The subsection can be different according to the characteristic of the nuclear reactor.

a) Reactor core parameters
b) Reactor control and safety systems
c) Coolant systems
d) Containment or confinement
e) Ventilation systems
f) Emergency power
g) Radiation monitoring systems (RMS) and effluents
h) Experiments
i) Facility-specific limiting conditions for operations

3.3 Application to a research reactor

LCOs for an open pool research reactor with passive system and plate-type fuel are selected based on the criterion given in 3.1, 3.2. Because of core cooling through passive system, the electric system is not considered as safety system but included for enhancing facilities availability, and the selection of LCOs is focused on both the feasible initial conditions of safety analyses and the possible systems to mitigate accidents.

Table 1: Selection of LCOs

LCOs		Criterion	Remarks
Shutdown margin		2	IC
Reactivity Control system	Control Rod Drive Mechanism	2,3	IC M
	Second Shutdown Drive Mechanism	3,4	M PH/S
	CAR/SSR Position Indications	2,4	IC PH/S
I&C Control system	Reactor Protection System	3	M
	Post-Accident Monitoring System	4	PH/S

	Manual Trip Switch Panel in Supplementary Control Room	3,4	M PH/S
Coolant System	Flow Rate Pool inlet temp. Siphon break V/V Flap Valve	2, 3	IC M
Coolant System	Pool Water Management System	2,4	IC PH/S
Coolant System	Hot Water Layer System	2,4	IC PH/S
Coolant System	Heavy Water System	4	PH/S
Confinmen t System	Confinement Pressure	2,4	IC PH/S
	Confinement Isolation	3,4	M PH/S
Emergency Power	Electrical Power System	4	PH/S
RMS	PCS Neutron Pool Surf. Rad.	2,4	IC PH/S
Experim'nt	Physics Test	2	IC
Specific	Reactivity limit	2	IC

*IC: Initial Condition
PH/S: Public Health and Safety
M: Mitigation

4. Conclusions

This paper described the outline of main contents of a TS for open-pool research reactor with plate-type fuels using core cooling through passive systems, where acceptance criteria for nuclear safety such as CHF and fuel temperature cannot be directly measured, different from circumstances in NPPs. Thus, three independent variables instead of non-measurable acceptance criteria: fuel temperature and CHF are considered as safety limits, i.e., power, flow, and flow temperature. In addition, reactor pool water level is used as safety limit to ensure core cooling through passive system such as flap valves. The LCOs proposed will be useful for safe operation of a specific research reactor.

This development will be used as a reference for developing a TS for research reactors.

REFERENCES

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