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A Preliminary Analysis on the Safety Effect of the Downgraded Heavy Water of a Research Reactor

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1. Introduction

Heavy water, which is an effective moderator with low absorption cross section, is used as a reflector in a Research Reactor (RR) rated to 5MW. The reflector is installed around the reactor core submerged in the reactor pool, an ultimate heat sink. Light water is the coolant that is stored in the reactor pool. For both waters, the cooling system for each is absolutely isolated and run independently. The classification is also different: safety system for cooling light water as coolant and non- nuclear safety for cooling heavy water as reflector. There will be, therefore, only negligible effect on the safety from any failures related to the cooling system for heavy water outside the reactor pool.

Failures such as pipe ruptures in the heavy water system inside the reactor pool introduce, however, a different issue concerned with power control.

Here the issues are presented and it will be shown that the safety of the research reactor is to be assured.

2. Short Description of the Reactor and the Sequences

In an automatic power control mode, power of the research reactor is controlled by using the neutron detectors installed around the reflector tank over the reactor core. The neutron detectors are calibrated with thermal power whenever starting a new cycle of fuel management.

When a leakage in the heavy water system inside the reactor pool the heavy water flows out into the reactor pool, and the light water ingress inside the reflector tank, that is, the heavy water storage vessel: the quality of the heavy water is downgraded.

The excessively huge difference in neutron absorption cross section between heavy water and light water will induce loss of neutron flux detected at the neutron measurement system even though the thermal power of the reactor stay unchanged.

The reactor power regulating system will identify this loss of neutron flux as loss of power with unchanged demanded power. The reactor regulating system will immediately respond in order to compensate the power loss by withdrawing the control rods as quickly as allowable in an automatic mode.

The reactor power will start to increase continuously as the quality of heavy water in the storage vessel, the reflector decreases with the postulated initiating event on progress.

Of the trip parameters, high neutron power cannot be used due to the faulty reading of the drastically reduced neutron flux. Instead high gamma power, also installed around the reflector vessel, in the reactor protection system will be used to recognize this power transient.

3. Numerical models and Assumptions

In this section some of the numerical models used to simulate the reactor system transient are described. The reactor system model includes a thermal-hydraulic model, performance of the reflector, and assumptions.

The analysis of the transients due to a pipe rupture in the heavy water system inside the reactor pool is separated into several steps.

First, the amount of light water introduced into the reflector tank following a heavy water piping rupture inside the pool may be calculated as a function of time. But the validation is not so clear and the rated flow rate is selected as the rate of change in quality in a conservative manner.

Second, the neutron flux at the detector location is calculated when light water flows into the heavy water vessel.

Then the reactor power to be followed will be calculated by combining the downgrading of heavy water and reduction of neutron flux. The thermal hydraulic transients are simulated until the reactor comes back to the safe condition after actuating the reactor protection system.

3.1 Ingress of light water

Due to ingress of light water, the quality of the reflector in an isotopic purity of the heavy water can be expressed with respect to time as in Fig. 1 assuming constant ingress of light water into the reflector storage tank.

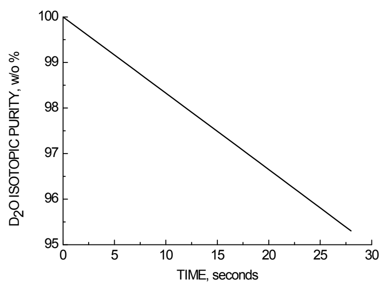

Fig. 1. Heavy water purity transient with respect to time.

3.2 Neutron flux

The effect of light water ingress into the heavy water storage tank on the neutron flux detected by the neutron measurement system is presented with respect to isotopic purity of heavy water in the reflector tank as in Fig. 2. This can be obtained from the simulation of McCard or MCNP.

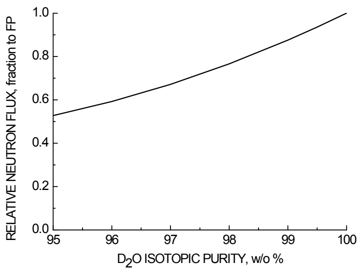

Fig. 2. Detected neutron flux with respect to isotopic purity of heavy water.

3.3 Thermal-hydraulic model

The numerical model for analyzing the effect of the heavy water quality is based on the nodal and the steady state as in the reference [1].

RELAP5/MOD3.3iy (Patch04), generally thought to be typically not design specific, to be applicable to a wide variety of thermal hydraulic system transients, is used for the analysis.

3.4 Assumptions

For this analysis several assumptions are established in order to have conservatism with ease as follows.

1) The rate of ingress is equal to the rated flow rate in the system even though there is no clear evidence.
2) The introduced light water into the reflector tank is assumed to be mixed with heavy water instantaneously and homogeneously.
3) A control rod with the largest worth is not inserted when the reactor is tripped.
4) Initial power, coolant temperature, coolant cooling system flow rate, power distribution, and decay power are selected in a conservative way.

4. Results

From the start to the end the sequence when the downgrading accident occurs is below in Table I: an accident with pipe rupture happens while the reactor power is near the rated power with measuring uncertainty; due to the faulty reading of neutron the power control system will increase the reactor power up to the predetermined setpoint of trip parameter such as gamma power for reactor protection; the reactor protection system actuates the control rods in order to shutdown the reactor with an inevitable time of delay.

Table I: Sequence of the PIE

Time (sec)	Event	Remarks
0	A pipe rupture accident	10x% FP[1)]
10.00	Trip signal initiated	12x% FP
10.00+delay	Trip actuated	Delay
10.00+delay+α	Shutdown	12x% FP

* Full power

The modeled core power transient is as in Fig.3: from the initiation of the accident power increases and goes down to a level of decay power after shutdown.

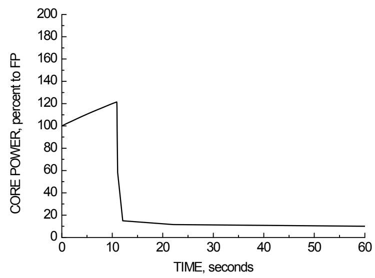

Fig. 3. Core power transient

The coolant and fuel centerline temperature are presented as in Fig.4: fuel centerline temperature responds right after initiation of the event, coolant temperature at reactor outlet is decreased after shutdown. Both parameters are much less than the required design limit even for anticipated occupational occurrence and the limiting condition for safe operation.

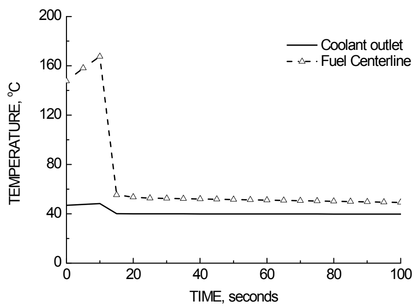

Fig. 4. Temperature of coolant and fuel

Another design limit to assure the reactor safety, minimum critical heat flux ratio (MCHFR) as in Fig. 5 is shown to be promising the reactor safety from the fuel integrity point of view: so far from the required level of MCHFR as same as for the fuel temperature.

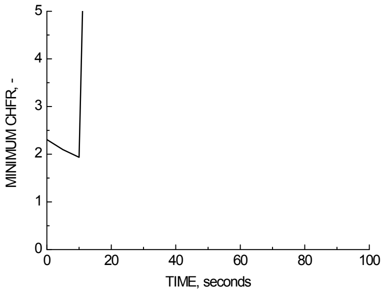

Fig. 5. Minimum critical heat flux ratio

5. Conclusions

A postulated initiating event related to the power control introduced by downgrading of the heavy water, i.e., a reflector was analyzed by simulating the reactor transient with the RELAP code.

The result showed that the fuel integrity is assured using the reactor protection system with acceptable margin.

REFERENCES

[1] RELAP5/MOD3.3 CODE MANUAL VOLUME V: USER'S GUIDELINES, Division of Systems Research, Office of Nuclear Regulatory Research U. S. Nuclear Regulatory Commission, Information Systems Laboratories, Inc. Rockville, Maryland Idaho Falls, Idaho, October 2010