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NUCLEAR REACTOR SAFETY SYSTEMS AVAILABILITY UPGRADING ANALYSIS

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ABSTRACT The analysis evaluates the consequences of the removal of the autoclosure interlock (ACI) on the Residual Heat Removal System (RHRS) suction/isolation valves at the nuclear power plant.
The deletion of the RHRS ACI is in part based on a probabilistic safety analysis (PSA) which justifies the removal based on a criterion of increased availability and reliability.
Three different areas are to be examined in PSA: the likelihood of an interfacing system LOCA, RHRS unavailability, and low temperature overpressurization control.
The paper emphasises particularly the RHRS unavailability and the likelihood of an interfacing system LOCA evaluation utilising the current control circuitry configuration and then with the proposed modification to the control circuitry.

1. INTRODUCTION

Deterministic Analyses and the Probabilistic Safety Analysis (PSA) have become a very powerful tool to identify possible failure modes, reveal weak points in the design of nuclear power plant and give a "measure" of nuclear safety. The numerous PSAs carried out have clearly shown the importance of the nuclear reactor safety systems in both the success and the failure of operating or accident conditions; they also have identified the shut down state as an important contributor to overall risk due to fact that many systems are not in their normal operating state. However, the use of PSA for improving nuclear power plant operations is still in its infancy. Namely, the problems in using PSA for operations improvement are different from the use of PSA for safety since operation tends to have little redundancy; today there is a very loud "cry" for simplifications in operation as well as in design and maintenance. The purpose of this paper is to illustrate the possibility for simplification in design and operation of a safety system and to demonstrate that such a simplification may enhance the safety system availability. The paper analyses the acceptability of removing the nuclear power plant "Krško" AutoClosure Interlock (ACI) on the Residual Heat Removal System (RHRS) suction/isolation valves. A rather complex analysis has to be performed. A part of such an analysis addresses these three questions:

1. *would operation without the RHRS ACI involve a significant increase in the probability or consequences of an accident previously evaluated?;*
2. *would operation without the RHRS ACI create the possibility of a new or different kind of accident from any accident previously evaluated?; and*
3. *would operation without the RHRS ACI reduce the margin of safety as defined in the basis for any technical specification?*

In addition, three different areas were examined by the PSA:

- *the likelihood of an interfacing system LOCA;*
- *RHRS unavailability; and*

- *low temperature overpressurization control.*

The paper answers the questions and emphasises particularly the RHRS's unavailability and the likelihood of an interfacing system LOCA evaluation utilising the current control circuitry configuration and then with the proposed modification to the control circuitry. At the end the sensitivity analysis has been performed to make sure whether or not is the proposed simplification an improvement in safety operation of a nuclear power plant.

2. BACKGROUND INFORMATION

An interest has been expressed in the acceptability of removing the ACI on the RHRS suction/isolation valves [1]. This interest is in response to growing concerns about the loss of residual heat removal capability during cold shutdown and refuelling operations due to inadvertent isolation of the RHRS caused by failure of the ACI circuitry. Namely, two motor operated gate valves are provided in each RHRS inlet line from the Reactor Coolant System (RCS). These valves are normally closed except when the RHRS is in operation during plant cooldown. Each of these valves is interlocked with the RCS pressure transmitter. This interlock prevents inadvertent opening of the valve when the RCS pressure is above definite fixed setpoint value and also closes the valve automatically when the RCS pressure becomes higher than the setpoint value. In other words that means that if the RCS has been depressurized and the valves are open, they will close automatically if a pressure excursion causes the RCS pressure to rise above the particular setpoint value. Inadvertent isolation of the RHRS while operating will result in a loss of decay heat removal capability and it is also a potential [1] contributor to overpressurization of the RCS.

The RHRS operation analysis has recognised that corrective actions are necessary to minimise the risk associated with loss of decay heat removal capability caused by the inadvertent actuation of the ACI, but also has highlighted concerns associated with intersystem Loss-of-Coolant-Accident (LOCA) and RHRS relief capacity. Therefore, in order to prevent inadvertent RHRS suction/isolation valve closures (during RHRS operation), it has been recommended to consider either the removal of the ACI to the RHRS suction/isolation valves during RHRS operation (the open permissive interlock will remain intact), or the removal of power to those valves when valve motion is not required. However, removing power from the suction/isolation valve motor operator is a questionable method of avoiding inadvertent valve closure, since such action compromises the ability to quickly isolate RHRS suction from the RCS in the event of an RHRS LOCA. Also, prior to implementing the removal of the ACI, it is necessary to ensure that there is adequate relief capacity to prevent overpressurization of the RHRS and, if the plant that implements the RHRS ACI removal will require procedural changes, to insure that the RHRS valves are closed during start-up.

It was shown in [1] that the RHRS relief valves should have adequate capacity to mitigate pressure transients that occur during RHRS operation because, while it is true that the interlocks provide an automatic closure to the RHRS suction/isolation valves on high RCS pressure, overpressure protection of the RHRS should be provided by the RHRS relief valves since the slow acting suction/isolation valves that isolate the RHRS from the RCS cannot protect it from overpressure. The purpose of the interlocks could be therefore to assure that there is a double barrier (two closed valves) between the RCS and the RHRS when the plant is at normal operating conditions (hot and pressurised) and not in the RHRS cooling mode. Thus, the interlock safety function is to preclude conditions that could lead

to a LOCA outside of containment due to an operator error and not to isolate the RHRS from the RCS when the RHRS is operating in the decay heat mode. The sequence that concerns most, if the RHRS ACI has been deleted, is that case in which the operator closes one of the isolation valves and not the other, since if both valves were left open, the operator would not be able to pressurise the plant. An alarm should be added therefore to each RHRS suction/ isolation valve which will actuate if the valve is open. (The setpoint for the alarm is a plant-specific concern.) In that case there would be several levels of defence which would assure that there is a double barrier between the RCS and RHRS when the plant is at normal operating conditions. The first level would be the plant operating procedures which instruct the operator to isolate the RHRS during plant heatup. The second level would be the installation of an alarm that sounds given a "valve not fully closed" signal in conjunction with a "RCS pressure high" signal. The intent of the alarm would be to alert the operator that either of the RCS-RHRS suction/isolation valves is not fully closed, and that double isolation is not intact. The third level of defence would be revised alarm response guidelines and operator training. (It should be noted that the open permissive interlock is not changed and it would still function to prevent opening of RHRS suction/isolation valves when the RCS pressure is above RHRS design pressure.) However, as a minimum, any proposal to remove the ACI should be substantiated by proof that the change is a net improvement in safety.

3. PSA AND ANSWERS TO THE QUESTIONS

The PSA was performed to justify removal of the RHRS suction/isolation valve ACI. Three different areas were examined: *1) the likelihood of an interfacing systems LOCA; 2) low temperature overpressurization concerns; and 3) RHRS unavailability.* Each of the three areas was analysed utilising the current control circuitry configuration and then with the proposed modification to the control circuitry. The net change in each area was estimated and the overall detriments and benefits were weighed to determine the acceptability of removal of the ACI from a probabilistic standpoint.

The probabilistic analysis performed to determine the change in the frequency of an interfacing systems LOCA due to removal of the ACI shows that the deletion of the ACI and the inclusion of a control room alarm to alert the operator of an improperly positioned the RHRS suction/isolation valve will decrease the frequency of an interfacing systems LOCA, Table 1.

The overpressurization analysis is an extensive analysis which uses event trees to model the mitigating actions (both automatic and manual) following the occurrence of low temperature overpressurization events. The analysis is divided into two parts: *1) determination of the frequency of cold overpressure events and 2) the effect of mitigation on the transients.*

The qualitative results of the overpressurization analysis show that removal of the ACI feature will have no effect on the heat input transients and will result in a slight increase in frequency of occurrence for some categories of the mass input transients with a decrease in others. The net effect of the ACI feature removal can be considered to be a net improvement in plant safety. Such conclusion is logical since the RHRS suction/isolation valve closure time of approximately two minutes, and the ACI setpoint which is above the RHRS design pressure, prevent the ACI from being an effective system for low temperature overpressure mitigation. Low temperature overpressure mitigation capability is therefore provided by the pressurizer PORVs and/or the RHRS relief valves. Removing the

ACI helps ensure that the RHRS relief valves are available to mitigate potential overpressure transients. In addition, removing the ACI reduces the potential for the inadvertent isolation of the RHRS that can cause a low temperature overpressure transient.

The fault trees (FTs) were developed to model the likelihood of interfacing system LOCA and RHRS unavailability. The RHRS suction/isolation valves were modelled down to the control circuitry level to explicitly show the change in unavailability due to removal of the ACI. Parts of the FTs are shown in Figures 1 and 2.

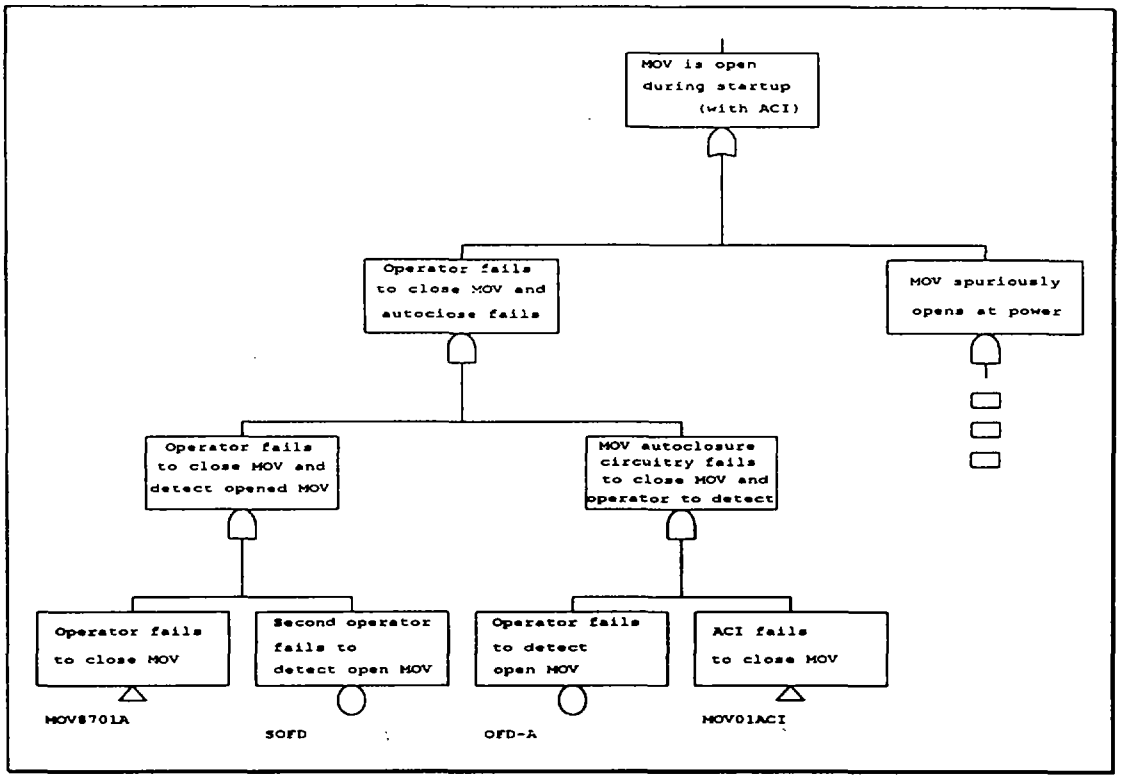

Figure 1 Fault Tree "MOV open (with ACI), (part)

The result of FTs probabilistic analysis enables to conclude that the availability and reliability of the RHRS will increase with the deletion of the ACI because the suction/isolation valves are less likely to spuriously close, Table 1. The unavailability of the RHRS was considered during long term decay heat removal (six weeks- the average refuelling outage time period).

Table 1. Interfacing system LOCA frequencies and RHRS unavailability results

	WITH ACI	WITHOUT ACI	Percent change
LOCA FREQUENCY	1.51E-06/yr	1.16E-06/yr	-23
RHRS UNAVAILABILITY	0.038	0.0096	-74.7

Computer code "PSA-PACK" ver. 4.2 has been used for FTs quantification.
Finally, the answers to the three questions put in 1. are:

1. *the deletion of the RHRS ACI will not pose a significant hazard in the sense that it would involve a significant increase in the probability or consequences of an accident previously evaluated;*
2. *the deletion of the RHRS ACI will not pose a significant hazard in the sense that it would create the possibility of a new or different kind of accident previously evaluated; and*
3. *the answer depends upon the plant's particular technical specifications, however, the conclusion can be made that, since the PSA indicates an increase in RHRS availability and reliability due to the RHRS ACI removal, the margin of safety will actually increase.*

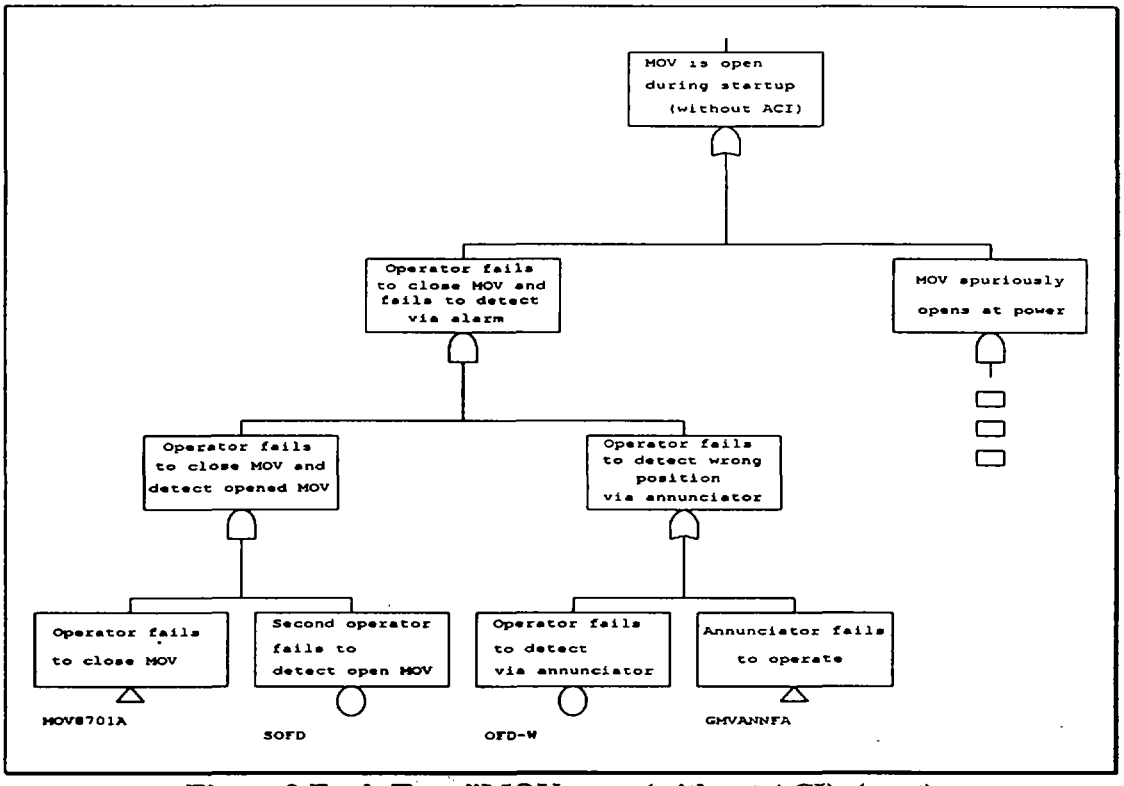

Figure 2 Fault Tree "MOV open (without ACI), (part)

4. SENSITIVITY ANALYSIS

The sensitivity analysis was performed to determine whether or not it would be an improvement in safety operation if the automatic function of closing the RHRS valves was removed and left to operator to close the valves if necessary. It reveals the functional dependence of the probability of the MOV being open on the probability of human errors, as well as the relation between the corresponding probabilities of the valve being open with and without ACI (Figures 3, 4 and 5). The ranges of values over which the human error probabilities were varied were from 9.81E-01 to 9.8E-02 and 2.66E-04 to 2.66E-03. The results of sensitivity analysis performed to evaluate the consequences of the removal of the ACI on the RHRS suction/isolation valve on the probability that this valve is not closed during the startup of the Nuclear Power Plant reveal the strong impact of human (operator) reliability (error) on this probability. However, in the range of examined values the deletion of the ACI will decrease the probability of the top event: "MOV is open during startup of the Nuclear Power Plant".

5. CONCLUSION

The PSA proposes to remove the ACI function from the RHRS suction/isolation valves because the deletion of the ACI function will reduce the number of spurious closures of the RHRS suction/isolation valves, and thus increase the availability and reliability of the RHRS, as well as it is beneficial in reducing the frequency of an interfacing system LOCA. On the other hand the deletion of the RHRS ACI will not pose any hazard in the sense that it would involve increase in the probability or consequences of an accident previously evaluated or that it would create the possibility of a new or different kind of accident previously evaluated.

The open permissive interlock should remain intact however and the alarm should be added to each valve to alert the operator that either of the RCS-RHRS suction/isolation valves is not fully closed.

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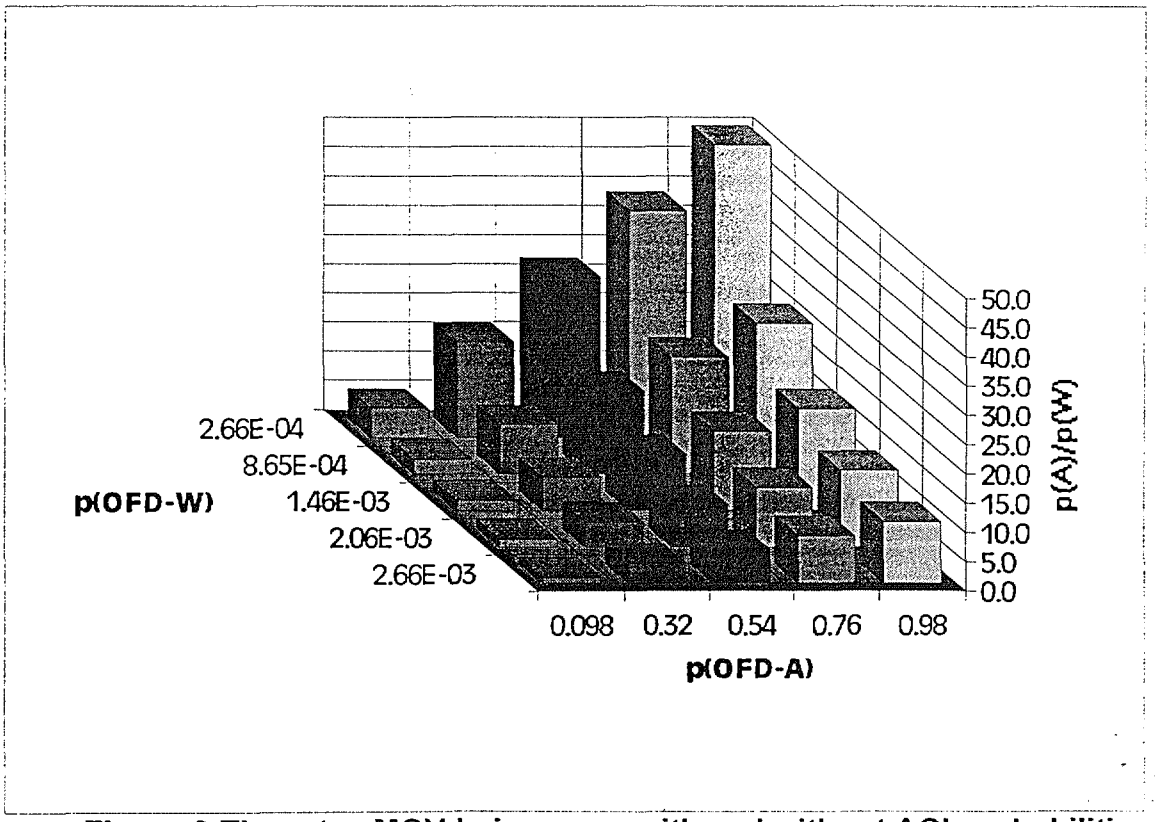

Figure 3 The rates MOV being open with and without ACI probabilities

Figure 4 Sensitivity analysis of the TOP EVENT: "MOV is open (with ACI)"

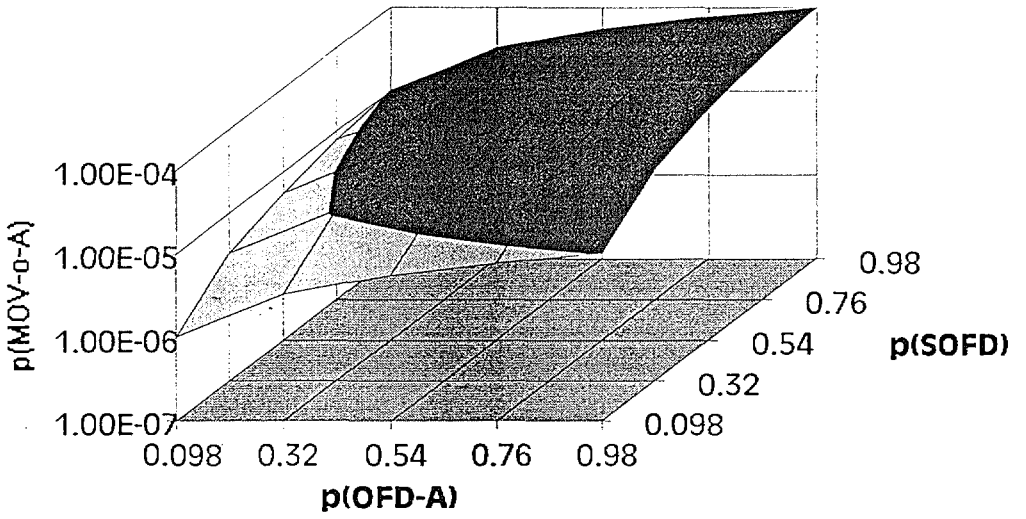

Figure 5 Sensitivity analysis of the TOP EVENT: "MOV is open (without ACI)"