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*Operator Decision Aid for Breached Fuel Operation in Liquid Metal Cooled Nuclear Reactors**

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Operator Decision Aid for Breached Fuel Operation in Liquid-Metal-Cooled Nuclear Reactors*

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SUMMARY

Introduction

All current and future-design liquid-metal-cooled reactors (LMRs) rely on the detection and monitoring of delayed-neutron (DN) emitters for annunciation and surveillance of fuel-cladding defects. Extensive breached-fuel testing at Argonne Laboratory's Experimental Breeder Reactor No. II (EBR-II) has led to the discovery that the "age" associated with a fuel breach is not constant with time. The age is defined as the sum of the transit time (T_{tr}) of the DN emitters from the core to the detector and the isotopic holdup time (T_h) of the DN emitters in the fuel. These parameters, along with the DN detector (DND) count rates, have been incorporated into an algorithm that computes an "Equivalent Recoil Area" (ERA), which is a measure of the surface area of exposed fuel at the breach site. It has been learned from in-core breached-fuel experiments[1] that the age of the signal can change spontaneously and frequently, even when all other reactor variables are at steady state. The complex physical mechanisms acting inside a breach to effect changes in T_h are still not fully understood. But the

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ramifications of a changing isotopic age make the analysis and interpretation of DN signals and ERA values extremely complicated, and make it virtually impossible for a human reactor operator to interpret and assess the safety significance of a changing DN signal.

The purpose of this paper is to report the development of an expert system that provides continuous assessment of the safety significance and technical specification conformance of DN signals during breached fuel operation. The completed expert system has been parallelized on an innovative distributed-memory network-computing system that enables the computationally intensive kernel of the expert system to run in parallel on a group of low-cost Unix workstations.

Expert System for Breached-Fuel Surveillance

An AI based expert system has been developed to be used as an operator decision aid during exposed-fuel operation in LMRs. This expert system is embodied in a device we call a failed fuel surveillance and diagnosis (FFSD) apparatus. This device monitors, processes, and interprets information from the DN system and from other key plant variables and displays to the operator the diagnostic information needed to make proper decisions about technical-specification conformance during breached-fuel operation. This operator decision aid enhances plant availability and economics by minimizing unnecessary reactor trips caused by events having no safety significance. Current practice in all countries that have LMR programs is to set conservative shutdown limits on the magnitude of DN signals from breached fuel. By combining and evaluating information from several plant sensors, the FFSD system makes it possible to significantly relax the conservatism in DN shutdown limits without compromising plant-safety assurance. At the same time, the FFSD apparatus reduces complexity and mitigates confusion in the reactor control room. It minimizes the possibility of human error or oversight by providing automatic annunciation of discrepant signals or the incipience of initiating faults. More importantly, even when the FFSD expert system is in its "passive" surveillance mode, the interactive capability is provided for the operator to manually query the status of any component of the system for operability validation. This symbiosis of automatic and manual systems reduces challenges to plant availability while allowing incorporation of the role of the operator in a manner which most effectively augments the achievement of overall plant operability goals.

The expert system has been validated using archive data from actual breached-fuel tests in EBR-II. A detailed parametric sensitivity analysis has been performed using monte carlo simulation techniques to assess propagation-of-uncertainty characteristics for the system's algorithms as a function of both the DND noise level and the levels of various background components that are present in an LMR. Results from this portion of our investigation, analyzed with standard 3-D response-surface methodology, show that the output uncertainty associated with the computed ERA values is +/- 3% during full-power operation with EBR-II's present fission-chamber DN detectors. Expert system surveillance of the ERA signals and the other diagnostic parameters from the DN monitoring system will enhance plant safety by providing the operator with rapid identification of off-normal operation, thereby enabling him/her to terminate or avoid any events that might challenge safety or radiological performance guidelines.

Parallel-Processing for Enhanced Expert System Performance

The completed expert system has been parallelized on a loosely coupled, distributed-memory, network-computing system that enables the computationally intensive kernel of the expert system to run in parallel on a group of SUN workstations. This goal has been accomplished with the use of a portable distributed parallel-computing system, called the P4 system, which has been developed independently at Argonne. Briefly, the P4 system exploits the message-passing constructs of Unix so that a Fortran code can be decomposed into concurrently operating processes on a variety of machine architectures. For the present project the P4 package was exploited to implement a distributed computational environment on a network of SUN workstations that is suitable for testing and validation of computationally intensive reactor-surveillance expert-system software. Timing studies have shown that the failed-fuel surveillance software parallelizes very well. Speedup factors of 98% (of theoretical maximum) and 97% were obtained on rings of three SUNs and four SUNs, respectively. This approach to distributed-memory parallel processing has proven extremely useful and flexible, and will permit the failed-fuel surveillance expert system to operate on low-cost hardware with a higher input sampling rate (1/s) than would have been possible on EBR-II's current data-acquisition system computer.

Summary

In summary, diagnostic information made available from a DN monitoring system in a LMR will be processed, compared against derived information from independent physical sensors, and presented to the reactor operator with the aid of the newly devised AI-based FFSD expert system presented here. This apparatus, which will be multiplexed to output devices in the reactor control room, will provide the operator with rapid identification (as much as 10 minutes in advance of signals from the cover-gas monitoring system) of conditions that could lead to plant operational degradation, enabling him or her to terminate or avoid events which might challenge radiological safety guidelines or plant availability goals.

REFERENCE

1. Gross K. C. and Strain R. V., "Technique for Monitoring the Age of DN Precursors During Breached-Fuel Operation in an LMR," Trans. Am. Nucl. Soc., (57), 317 (1988).