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FUEL-ASSEMBLY VIBRATION-INDUCED NEUTRON NOISE IN PWRs[1]

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Space-dependent reactor kinetics calculations were performed to interpret observed increases in the amplitude of pressurized water reactor (PWR), ex-core neutron detector noise with increasing fuel burnup and correspondingly decreasing soluble boron concentration.[1,2] These noise amplitude increases have occurred at both low frequencies (<1.0 Hz) and in the 2.0- to 4.0-Hz frequency range. It has been postulated that the low frequency noise increases may be the result of the increased reactivity effect of fuel assembly vibrations[3,4] or moderator density (temperature) fluctuations[5] with decreasing soluble boron concentration, while the 2.0- to 4.0-Hz noise increases have been attributed to increased fuel assembly vibrational amplitudes resulting from grid spacer spring relaxation with burnup.[2,6] The noise amplitude increases in the 2.0- to 4.0-Hz frequency range have usually been accompanied by a decrease in the fundamental mode fuel assembly resonant frequency from 3.5 to 2.5 Hz over a fuel cycle, which has also been attributed to grid spacer spring relaxation.

At Sequoyah-1, a Westinghouse 1150-MWe PWR, the normalized root mean square (NRMS) of the ex-core neutron detector noise in the 2.0- to 4.0-Hz range has also increased (by ~60%) over the first fuel cycle and is presented in Fig. 1 as a function of soluble boron concentration. Unlike previous observations, the fuel assembly resonant frequency has decreased by less than 0.5 Hz indicating that significant grid spacer spring relaxation has not occurred during the first fuel cycle.

In order to explain the observed neutron noise increase at Sequoyah-1, two-dimensional x-y geometry calculations[7] of the ex-core detector spatial weighting function (detector adjoint or source-to-detector transfer function) at 3 Hz using three neutron-energy and six delayed-neutron groups were performed with the JPRKINETICS computer code.[8] The ex-core detector noise due to fuel assembly vibrations was determined using a first order perturbation approximation

$$\delta R = \int \phi^{\dagger}(r\omega)\ \delta S(r\omega)\ dr \qquad (1)$$

where $\phi^{\dagger}$ is the complex, frequency-dependent detector adjoint obtained from the kinetics calculation, and δS is a fluctuating external neutron source (Langevin source) due to fuel assembly vibrations as described in refs. 8 and 9. Fuel isotopic concentration changes due to burnup and soluble boron concentration adjustments over a fuel cycle were calculated with the BURNER and VENTNEUT modules of VENTURE[10] respectively. Broad-group, weighted cross-sections both with and without burnable poison rods were generated as described in ref. 7.

Calculation of the total ex-core detector response to vibrations as a function of burnup assumed that all of the fuel assemblies vibrate at the same amplitude, and the results shown in Table 1 were normalized to the mean (steady-state) detector response and the vibrational amplitude. These results show that the calculated ex-core detector noise due to fuel assembly vibrations in a core containing burnable poison rods (as in the first cycle of Sequoyah-1) will increase ~58% as the result of fuel burnup and soluble boron reduction over the first fuel cycle, even though the vibrational amplitudes remain constant. Without burnable poison rods, the calculated noise would have increased ~77%.

The ex-core detector response to moderator density fluctuations at 3.0 Hz was also calculated as a function of burnup using Eq. (1). The results, which are summarized in Table 1, indicate that the ex-core detector neutron noise will increase only 18% and 33% with and without burnable poison rods respectively over the first fuel cycle.

Based on these calculated results, we concluded that the ex-core neutron noise increase observed in the 2.0- to 4.0-Hz frequency range results from the larger detector response to fuel assembly vibrations caused by increased fuel burnup and decreased soluble boron concentration. When the ex-core detector response is corrected for these changes, no increases in the fuel assembly vibrational amplitudes were found over the first fuel cycle. Moderator density fluctuations do not account for the observed noise increases, since the calculated changes due to burnup are much smaller than for fuel assembly vibrations.

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TABLES

Table 1. Calculated ex-core detector response to fuel assembly vibrations and moderator density fluctuations for Sequoyah-1 PWR

FIGURES

Fig. 1. Measured normalized root mean square (NRMS) of ex-core neutron detector noise over 2.0 to 4.0 Hz at Sequoyah-1 vs soluble boron concentration for the first fuel cycle.

Table 1. Calculated ex-core detector response to fuel assembly vibrations and moderator density fluctuations for Sequoyah-1 PWR

		Beginning of Cycle	End of Cycle	% Increase
Burnable poison rods	vibration*	6.0	9.5	58
	moderator**	106.5	126.0	18
No burnable poison	vibration	5.1	9.0	76
	moderator	89.8	119.6	33

*Responses are normalized root mean square (NRMS) per cm of fuel assembly vibrational amplitude. Results assume all fuel assemblies vibrate with the same amplitude and are normalized to the mean detector response.

**Responses are normalized root mean square (NRMS) per fractional density change assuming that coolant in all fuel assemblies undergo a density perturbation. Results are normalized to the mean detector response.

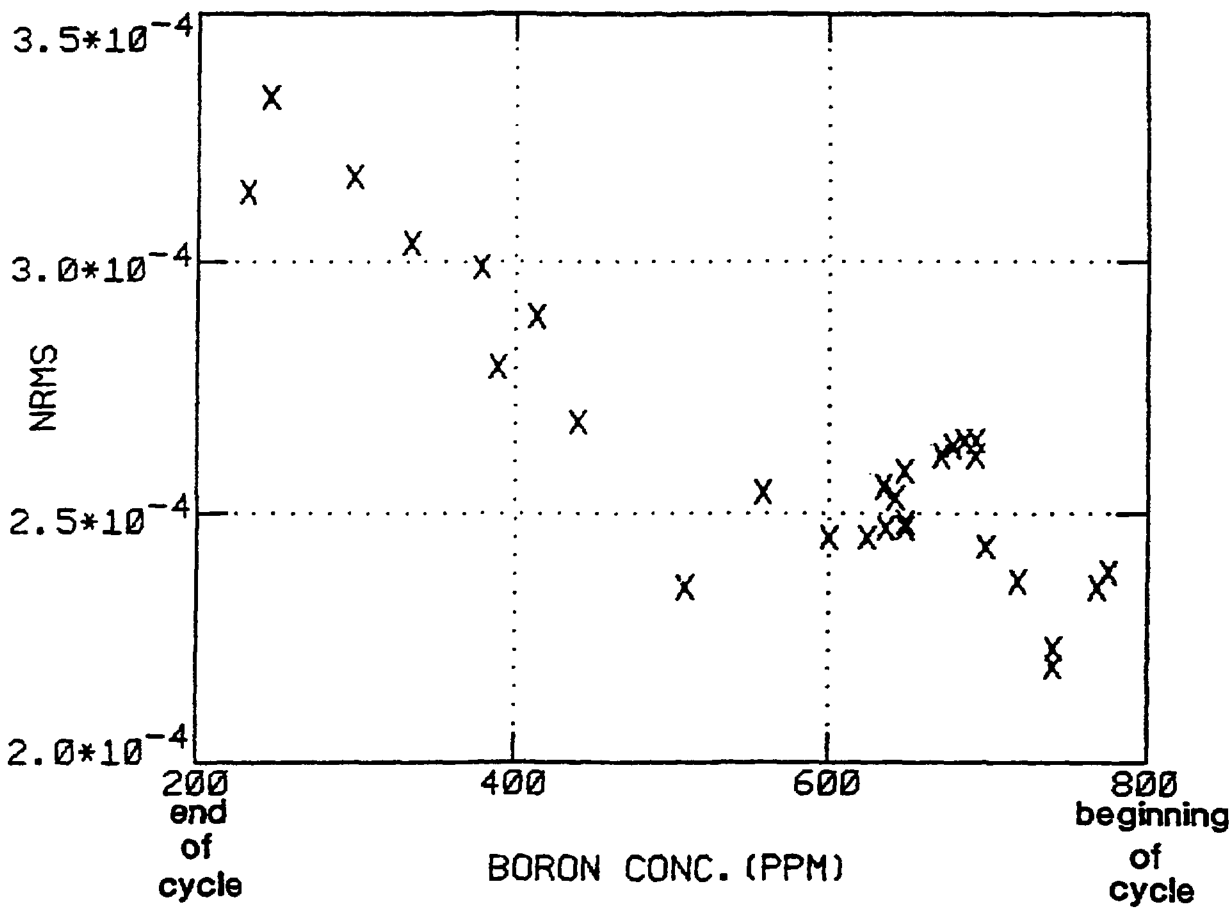

Fig. 1. Measured normalized root mean square (NRMS) of ex-core neutron detector noise over 2.0 to 4.0 Hz at Sequoyah-1 vs soluble boron concentration for the first fuel cycle.