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SENSITIVITY STUDIES FOR THE PWR ROD EJECTION ACCIDENT[1]

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The objective of this study was to understand the uncertainty in fuel enthalpy calculated for the rod ejection accident (REA) in a pressurized water reactor (PWR). This is to help the U.S. Nuclear Regulatory Commission in making judgements about acceptance criteria for the REA when high burnup fuel is used and for assessing the validity of licensee methods for calculating the REA. The approach is twofold. Sensitivity studies were first done to determine the effect on calculated fuel enthalpy of uncertainties in the important parameters which determine the outcome of the REA. The second step, which will be carried out at a later date, is to use the sensitivity to estimate the random error in the fuel enthalpy due to random errors in these key parameters once the variance of these parameters is determined.

The sensitivity is the relative change in energy deposition (equivalent to fuel enthalpy assuming an adiabatic event) per relative change in key reactor parameter. The parameters are related to the reactivity insertion above the prompt critical condition and the negative reactivity feedback from the energy deposition: the reactivity worth of the ejected control rod, ρ_0; the delayed neutron fraction, β; the fuel temperature (or Doppler) reactivity coefficient, α; and the specific heat, C_p of the pellet.

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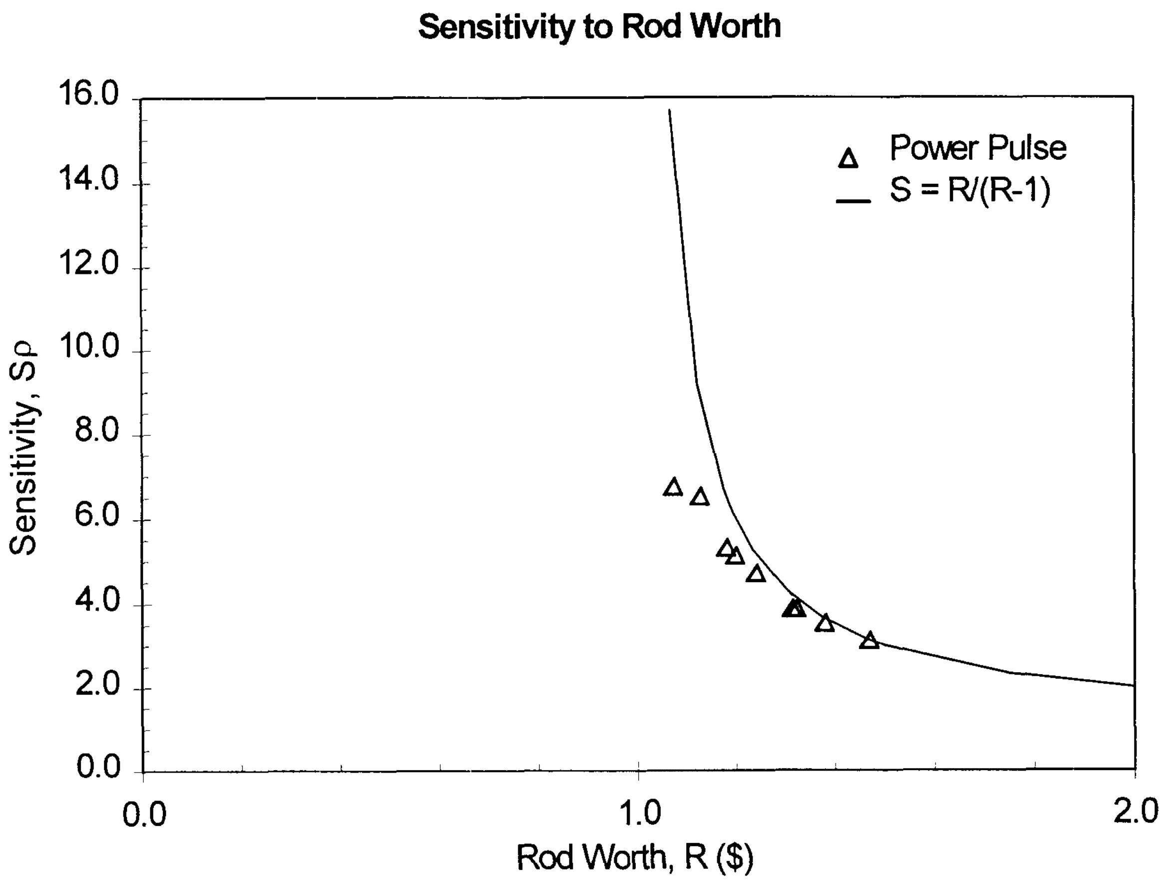
The sensitivity to control rod worth is given in Figure 1 versus control rod worth in units of \$, i.e., $R = \rho_0/\beta$. The data points come from calculations of different reactivity insertion events using the space-time kinetics code PARCS[1]. Only events with rod worths greater than \$1 are of interest. The energy deposition is that deposited during the initial power pulse (i.e. during the adiabatic phase).

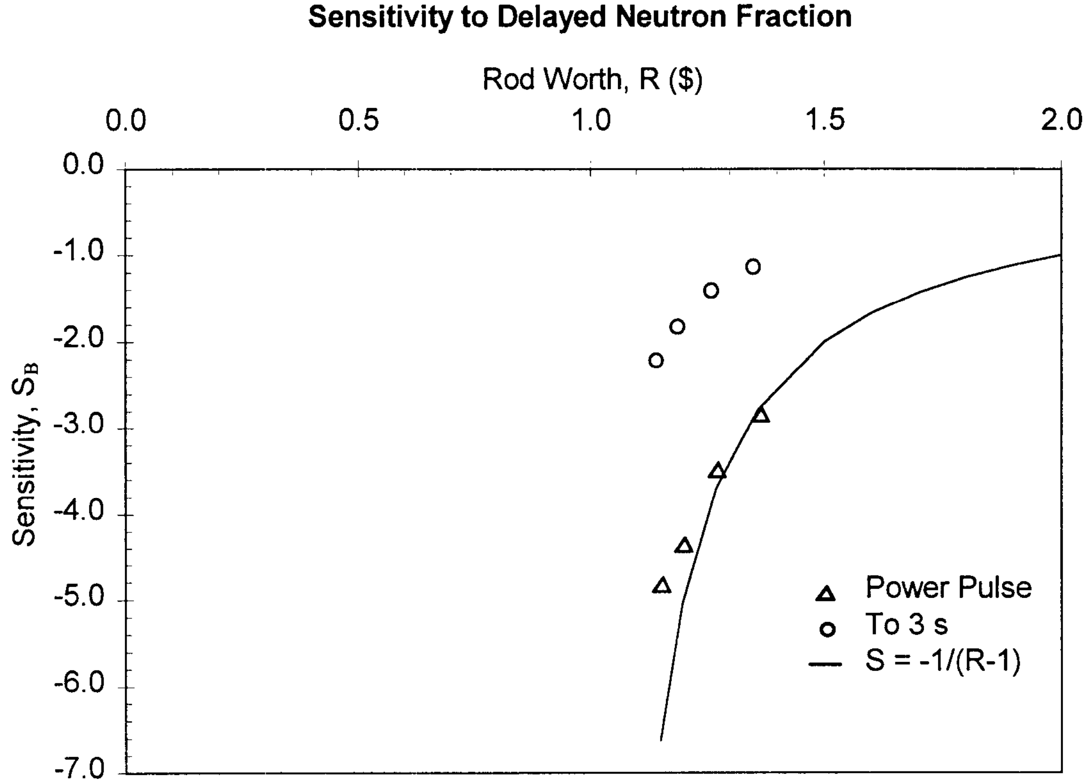
Figure 1 Sensitivity of Energy Deposition to Reactivity Insertion



It is well-known that the power excursion resulting from a reactivity insertion above prompt critical consists of an initial power pulse turned around by feedback followed by a slow decrease in power, due to delayed neutrons, at a level that is still significant as far as energy deposition is concerned. Using the point kinetics model and the Nordheim-Fuchs approximation, a simplified expression for the sensitivity to rod worth can be derived for the time up to the end of the initial power pulse. That expression is $S_\rho = R/(R-1)$ which is plotted on Figure 1. The simplified kinetics model is in good agreement with the PARCS calculations for the range shown. As the rod worth approaches $1 (from above), corresponding to prompt critical, the simplified expression has a singularity and is no longer valid. Nevertheless, the sensitivity does increase as rod worth approaches $1. Although this is true, it is also true that the energy deposition becomes smaller and this sensitivity may become less important.

The sensitivity of energy deposition to delayed neutron fraction is shown in Figure 2 as a function of reactivity insertion. The data points from PARCS are plotted for both the initial power pulse and by accounting for energy deposition out to three seconds. In addition, the graph shows the curve obtained from the simplified model, $S_\beta = -1/(R-1)$. Again it is seen that the results for the initial power pulse are in agreement with the theoretical results for the range shown except that as rod worth approaches $1 from above the agreement begins to fail. The sensitivity to 3 s is less than for the initial power pulse as the energy deposited after the initial power pulse is not dependent on rod worth but only on the delayed neutron decay.

Figure 2   Sensitivity of Energy Deposition to Delayed Neutron Fraction



The sensitivity of energy deposition to fuel heat capacity was also calculated and found to follow the simplified expression ($S_C = 1$) for the initial pulse, and the sensitivity decreased for the result out to 3 s. It is not possible to plot the sensitivity to the Doppler coefficient as that is not a parameter that can easily be extracted from a space-dependent kinetics calculation.

An estimate of the uncertainty in fuel enthalpy can be made from the sensitivity if the uncertainty in the fundamental parameters is known. For example, from Figure 2, the sensitivity to delayed neutron fraction is as high as -6 at the end of the initial power pulse and declines to -3 at 3 s. This is the maximum assuming a rod worth just above prompt critical. If we use the -3 value and assume that the uncertainty at the 1σ level for the delayed neutron fraction is approximately 10% then the uncertainty in energy deposition is ±30% due to this key parameter. This type of analysis would have to be done for all parameters in order to complete the analysis.

In summary sensitivity calculations have been carried out to determine the effect on energy deposition of changes in ejected rod worth, delayed neutron fraction, and fuel specific heat. These can be used to help assess the uncertainty in REA analysis.

REFERENCES

1. H.G. Joo, G. Jiang, D.A. Barber, and T.J. Downar, "NRC-PARCS: V1.00, A Multi-Dimensional Two-Group Reactor Kinetics Code Based on the Nonlinear Analytic Nodal Method, "PU/NE-98-26, Purdue University, September 1998.