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Xenon Changes Under Power-Burst Conditions

D. J. Diamond
Brookhaven National Laboratory
Department of Nuclear Energy
Upton, New York 11973

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Under ordinary operating conditions the xenon concentration in a reactor core can change significantly in times on the order of hours. Core transients of safety significance are much more rapid and hence calculations are done with the xenon concentration held constant. However, in certain transients (such as reactivity initiated accidents) there is a very large power surge and the question arises as to whether under these circumstances the xenon concentration could change. This would be particularly important if the xenon were reduced thereby tending to make the accident autocatalytic. The objective of the present study is to quantify this effect to see if it could be important.

The equations for the time dependent ^{135}I and ^{135}Xe concentrations can be written

$$\dot{I} = \gamma_I F - \lambda_I I \qquad (1)$$

$$\dot{X} = \gamma_X F + \lambda_I I - (F/N + \lambda_X) X \qquad (2)$$

where the notation is standard except for the use of $F=\Sigma_{f1}\phi_1 + \Sigma_{f2}\phi_2$ and where the assumption is made that $\sigma_{x2}\phi_2 = F/N$. The parameter N has units of number density (cm^{-3}) and will be approximated below.

Equations (1) and (2) were solved analytically for two problems. In the first problem it was assumed that the initial flux level was insignificant (i.e. $F_0=0$) but that there were initial concentrations of xenon and iodine (X_0 and I_0, respectively). The power burst was represented as

$$F = \Delta E \delta(t) \tag{3}$$

where ΔE is the number of fissions (per unit volume) during the power burst and $\delta(t)$ is the Dirac delta function. The resulting xenon concentration was

$$X = X_0 e^{-\Delta E/N} e^{-\lambda_X t} + \gamma_X \Delta E e^{-\lambda_X t} + (I_0 + \gamma_I \Delta E) \frac{\lambda_I}{\lambda_X - \lambda_I} \left[e^{-\lambda_I t} - e^{-\lambda_X t} \right] \tag{4}$$

The first term in Eq. 4 is the exponential decay in time of the initial concentration of xenon which has been modified by neutron transmutation due to the burst. The second term is the decay of xenon which was produced as a direct fission product in the burst. The third term is the standard radioactive-series expression for daughter atoms from an initial concentration of parent atoms. In this case xenon is the daughter and iodine is the parent. The initial concentration of iodine has been modified by that amount produced as a direct fission product in the burst.

In the second problem we consider the flux to be at some non-negligible level initially and then to return to that level after the power burst, i.e.

$$F = F_0 + \Delta E \delta(t) \tag{5}$$

The resulting xenon concentration is

$$X = X_0 \left[1 + (e^{-\Delta E/N} - 1)\, e^{-F_0/N} e^{-\lambda_X t} \right] + \left[\gamma_X \Delta E - \frac{\gamma_I \lambda_I \Delta E}{F_0/N - \lambda_X - \lambda_I} \right] e^{-F_0/N} e^{-\lambda_X t}$$

$$+ \frac{\gamma_I \lambda_I \Delta E}{F_0/N + \lambda_X - \lambda_I} e^{-\lambda_I t} \tag{6}$$

and the equilibrium xenon concentration (before and after the burst) is

$$X_o = (\gamma_X+\gamma_I)\ F_o/(F_o/N+\lambda_X) \tag{7}$$

The interpretation of these terms is similar to that done for the first problem.

Numerical results were obtained for a rod drop accident (RDA) in a boiling water reactor (BWR). The xenon concentration is assumed to correspond to full power conditions in order to try to maximize the effect of a decrease in concentration. For a typical BWR the average power density at power is 51 W/cm^3 corresponding to $F_o = 1.75 \times 10^{12}\ cm^{-3}\text{-}s^{-1}$. The parameter N is approximated as Σ_{f2}/σ_{x2} which for a typical BWR is approximately $2.12 \times 10^{16}\ cm^{-3}$.

In order to maximize the effect of the burst we assume that it yields 1GW-s. This is larger than in any case considered in a recent RDA study (1) at low power initial conditions. At full power the amount of energy released is lower. This assumption gives $E = 0.53 \times 10^{12}\ cm^{-3}$ on a core-wide basis. We next assume that the region of interest (where the rod is removed) has a peaking factor of 100 in order to further maximize the effect.

Using either Eq. 4 or 6 the resulting concentration at the point of peak power is essentially unchanged. If we assume a further increase of a factor of ten in ΔE then $X/X_o \approx 0.98$ for $t < 10^3$ s. Hence, it is concluded that under all RDA situations of interest the xenon concentration will not change significantly. Furthermore, since the energy release for a rod ejection accident (REA) in a pressurized water reactor is of the same order of magnitude as for an RDA in a BWR, it can also be concluded that the effect of transient xenon is unimportant during an REA.

Reference

1. H.S. Cheng and D.J. Diamond, "Analyzing the Rod Drop Accident in a Boiling Water Reactor," Nucl. Tech., 56, 40 (1982).

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