Impacts of Xe-135m on Xenon Reactivity in Thermal Reactors

Jaeha Kim and Yonghee Kim*
Korea Advanced Institute of Science and Technology (KAIST)
291 Daehak-ro, Yuseong-gu, Daejeon, Republic of Korea, 305-701
**Corresponding author: yongheekim@kaist.ac.kr*

1. Introduction

In the standard analysis model of the Xe reactivity, Xe-135m has been neglected since it decays quite quickly to Xe-135 due to its short half-life (15.29 min). To our best knowledge, the effect of the omission of Xe-135m has never been evaluated before.

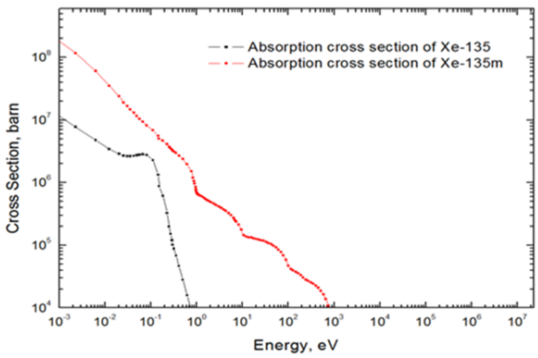

Fig. 1. Neutron absorption cross section data of Xe-135m[1]

Recently, we found that the cross section data of Xe-135m are available from the TENDL-2011 library based on the theoretical evaluations [1]. According to the TENDL data, the neutron absorption cross section of Xe-135m turns out to be much larger than that of Xe-135 in the thermal neutron region, as shown in Fig. 1. In this paper, we evaluated the impacts of Xe-135m on the total steady-state and transient Xe reactivity.

2. Models and Methodologies

To determine the concentration of Xe-135m and Xe-135, the general decay schemes of I-135 in Fig. 2 are considered in this work. The balance equations can be written as follows:

$$\frac{dI}{dt} = \gamma_I \Sigma_f \varphi - \lambda_I I \quad (1)$$

$$\frac{dm}{dt} = (\gamma_m \Sigma_f \varphi + x\lambda_I I) - (\lambda_m m + \sigma_a^m \varphi m) \quad (2)$$

$$\frac{dX}{dt} = (\gamma_X \Sigma_f \varphi + (1-x)\lambda_I I + \lambda_m m) - (\lambda_X X + \sigma_a^X \varphi X) \quad (3)$$

where *m* indicates Xe-135m and *X* denotes Xe-135, and *x* is the branch ratio to Xe-135m and is 16.4%.

All the physics parameters used in this work are provided in Table I. The absorption cross section at 0.0255eV in Fig. 1 is used in this analysis. Assuming a thermal reactor, the initial neutron flux and the fission cross section were determined.

To see the transient behavior of the Xenon worth, we considered a step power drop of -5% from an initial steady state, for which the analytic solution can be obtained.

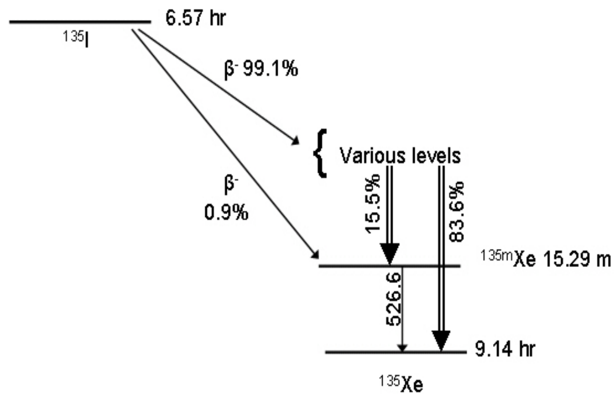

Fig. 2. Decay schemes of I-135[2]

Table I Physics parameters

*Initial flux, $\boldsymbol{\varphi_0}$		1E+14 n/cm^{2}s
Decay constant	I-135, λ_I	2.9255E-5 s^{-1}
	Xe-135m, λ_m	7.554E-4 s^{-1}
	Xe-135, λ_X	2.106E-5 s^{-1}
Fission yield	I-135, γ_I	6.28187 %
	Xe-135m, γ_m	0.178122 %
	Xe-135, γ_X	0.078513 %
*Macroscopic fission cross section, Σ_f		0.1013 cm^{-1}
Branching ratio to Xe-135m, $\boldsymbol{x}$		16.4 %
Microscopic absorption cross section	Xe-135m, σ_a^m	1.901E+7 barns
	Xe-135, σ_a^X	2.9431E+6 barns

*Assumption

When the neutron flux is dropped from φ_0 to φ_1 at t=0, the analytic solutions for Eqs. (1), (2) and (3) are given by

$$I(t) = \frac{\gamma_I \Sigma_f \varphi_0}{\lambda_I}\left[1 - \left(\frac{\varphi_1 - \varphi_0}{\varphi_1}\right) exp[-\lambda_I t]\right] \quad (3)$$

$$m(t) = \frac{\gamma_m \Sigma_f \varphi_1 + x\lambda_I A}{\lambda_m + \sigma_a^m \varphi_1} + \frac{x\lambda_I B}{\lambda_m - \lambda_I + \sigma_a^m \varphi_1} exp[-\lambda_I t] + \left(\frac{x\lambda_I (A+B)}{\lambda_m + \sigma_a^m \varphi_0} - \frac{x\lambda_I B}{\lambda_m + \sigma_a^m \varphi_1} - \frac{x\lambda_I B}{\lambda_m - \lambda_I + \sigma_a^m \varphi_1}\right) \cdot exp[-(\lambda_m + \sigma_a^m \varphi_1)t] \quad (4)$$

where $A = \frac{\gamma_I \Sigma_f \varphi_1}{\lambda_I}$, $B = \frac{\gamma_I \Sigma_f (\varphi_0 - \varphi_1)}{\lambda_I}$

$$X_2(t) = \frac{\gamma_X \Sigma_f \varphi_1 + (1-x)\lambda_I A + \lambda_m P}{\lambda_X + \sigma_a^X \varphi_1} + \frac{(1-x)\lambda_I B + \lambda_m Q}{\lambda_X - \lambda_I + \sigma_a^X \varphi_1} exp[-\lambda_I t] + \frac{\lambda_m R}{\lambda_X - \lambda_m + \sigma_a^X \varphi_1 - \sigma_a^m \varphi_1} exp[-(\lambda_m + \sigma_a^m \varphi_1)t] + (\frac{\gamma_X \Sigma_f \varphi_0 + (1-x)\lambda_I (A+B) + \lambda_m (P+Q+R)}{\lambda_X + \sigma_a^X \varphi_0} - \frac{\gamma_X \Sigma_f \varphi_1 + (1-x)\lambda_I A + \lambda_m P}{\lambda_X + \sigma_a^X \varphi_1} - \frac{(1-x)\lambda_I B + \lambda_m Q}{\lambda_X - \lambda_I + \sigma_a^X \varphi_1} - \frac{\lambda_m R}{\lambda_X - \lambda_m + \sigma_a^X \varphi_1 - \sigma_a^m \varphi_1}) \cdot exp[-(\lambda_X + \sigma_a^X \varphi_1)t] \quad (5)$$

where $P = \frac{\gamma_m \Sigma_f \varphi_1 + x\lambda_I A}{\lambda_m + \sigma_a^m \varphi_1}$, $Q = \frac{x\lambda_I B}{\lambda_m - \lambda_I + \sigma_a^m \varphi_1}$,

$$R = \frac{x\lambda_I (A+B)}{\lambda_m + \sigma_a^m \varphi_0} - \frac{x\lambda_I B}{\lambda_m + \sigma_a^m \varphi_1} - \frac{x\lambda_I B}{\lambda_m - \lambda_I + \sigma_a^m \varphi_1}$$

In the case of no Xe-135m, x=0 and the fission yield of Xe-135m should be added to that of Xe-135.

3. Numerical Results

Assuming that the total Xe reactivity is proportional to the sum of the capture reaction rate of Xe-135m and Xe-135, we have investigated the impacts of the Xe-135m on the total xenon reactivity during the transient. In this preliminary study, the initial total Xe reactivity without Xe-135 is assumed to be 2,800 pcm.

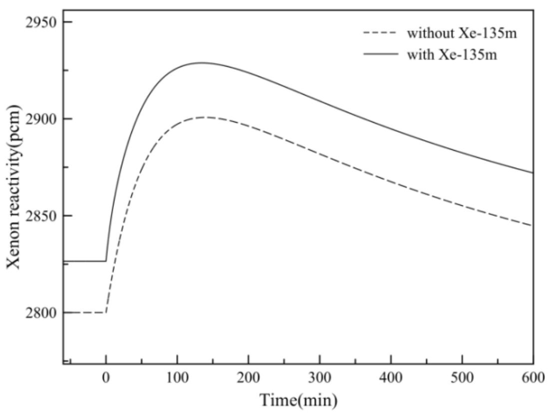

Fig. 3. Xenon reactivity change during transient

Figure 2 shows the change of the total xenon reactivity during the 5% power-drop transient. We analyzed the results in terms of initial reactivity and reactivity change during the transient. First, when Xe-135m is considered, the initial steady state reactivity of xenon is slightly increased to 2826.50pcm from 2800pcm, about 0.94% increase. It means that the negative reactivity due to xenon in thermal reactors has been slightly underestimated.

In the power-drop transient, the total Xe reactivity should increase during the early transient period. Table II compares the total xenon reactivity change from the initial one for the two models during transient as a function of elapsed time from the initial state. From Table II, one can clearly observe that the reactivity increase is noticeably higher with Xe-135m modeling than in the conventional case. It is worthwhile to note that the difference between the two models is quite significant during the early transient period and the difference gradually decreases with time. This is simply because Xe-135m decays rather quickly and it mostly affects the early transient period. It is easily expected that a larger reactivity difference will be observed for a bigger power transient and a smaller difference for a smaller transient.

Table II Reactivity change from the initial value

Time (min)	$\Delta\boldsymbol{\rho}$(pcm)	
	Without Xe-135m	With Xe-135m
0	0	0
10	21.46	28.56
20	38.96	46.52
30	53.21	59.94
60	81.24	85.51
120	99.99	101.90

The small reactivity difference during the power transient may indicate an important role of the Xe-135m in measuring a small reactivity coefficient such as power coefficient of reactivity (PCR). In thermal reactors such as CANDU with a small PCR, the transient Xenon reactivity should be accurately estimated and a small change in the Xenon reactivity may affect the PCR significantly.

4. Conclusions

By taking into account Xe-135m in the I-135 decay, we have found the followings. First, the steady state total xenon reactivity is slightly increased by ~0.94% as compared with the conventional model. Second, the impact of Xe-135m on the transient Xe reactivity is rather significant. In particular, the reactivity change during the early transient period can be noticeably enhanced by accounting for Xe-135. And this indicates that Xe-135m may play an important role in measuring the PCR for which the transient Xenon reactivity should be accurately estimated. Currently, the impacts of Xe-135 on the PCR measurement are under investigation.

REFERENCES

[1] A. J. Koning, D. Rochman, TENDL-2011, Nuclear Research and Consultancy Group(NRG), 2011
[2] J. K. Hartwell, D.M. Scates, J.B. Walter, and M.W. Drigert, Determination of the Quantity of I-135 Released from the AGR-1 Test Fuels at the End of ATR Operating Cycle 138B, Idaho National Laboratory, p.2, 2007.