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# THE ANALYSIS OF A FICTITIOUS ACCIDENT DUE TO LOSS OF CONTROL ON THE SHIM RODS IN MITR - II

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# THE ANALYSIS OF A FICTITIOUS ACCIDENT DUE TO LOSS OF CONTROL ON THE SHIM RODS IN MITR-II


## ABSTRACT

The analysis of an accident concerning the withdrawal of the shim rods in MITR-II is considered. Thus the two-dimensional,time dependent,three group diffusion equations for the proposed designed core of the MIT Reactor are written with an extra source term accounting for the photoneutrons generated in the $D_2O$ reflector. An analytical expression is developed for this term. Then an approximate flux composed of two spatial shapes chosen beforehand,each having an unknown time coefficient is inserted into the time dependent multigroup equations and the weighted residual criteria is applied. This yields multimode kinetics equations with generalized definitions for the conventional matrix parameters: generation time,reactivity,delayed neutron(and photoneutron) fractions matrices. The results obtained through OZAN, the code written to perform computations required by the present work, has suggested that a space dependent analysis is required to analyze the accident postulated.


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# MITR-II KONTROL ÇUBUKLARI ÜZERİNDEKİ DENETİMİN KAYBOLMASINDAN DOĞAN HAYALİ BİR KAZANIN İNCELENMESİ


## ÖZET

MITR-II kontrol çubukları üzerindeki denetimin kaybolmasından doğan hayali bir kaza incelenmek isteniyor. Bunun için iki boyutlu,zamana bağlı,üç gruplu difüzyon denklemleri MIT Reaktörünün önerilen kalbi için,$D_2O$ reflektörde oluşan fotonötronları hesaba katacak ek bir kaynak terimi ile birlikte yazılıyor. Bu terim için bir analitik ifade geliştiriliyor. Sonra,herbiri bilinmeyen bir zaman fonksiyonuyla çarpılan,önceden seçilmiş iki adet yere bağlı fonksiyondan oluşan bir yaklaşık akı ifadesi zamana bağlı çok gruplu denklemlerde kullanılıyor ve ağırlaştırılmış kalıntılar yöntemi uygulanıyor.Bunun sonucu olarak genelleştirilen alışılagelmiş matris parametreleri, yani nötron nesil zamanı,uyarım(reaktivite),gecikmiş nötron(ve fotonötron) kesirleri matrislerini içeren çok modlu kinetik denklemleri bulunuyor. Söz konusu parametreler için hesap yöntemleri sunuluyor. Karşılaşılan hesapları gerçeklemek üzere yazılan bilgisayar kodu OZAN 'dan elde edilen sonuçlar, incelenmek istenen kazanın yere bağlı bir yaklaşma yoluyla ele alınması gereğini önermekte.

# THE ANALYSIS OF A FICTITIOUS ACCIDENT DUE TO LOSS OF CONTROL ON THE SHIM RODS IN MITR-II*

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MITR-II stands for the redesign of the MIT research reactor. This reactor is cooled by light water and reflected by heavy water. Photoneutrons are generated in the heavy water region due to the interaction of radiation produced within the reactor by the deuterium nuclei.

Among the requirements for liscensing MITR-II the USA AEC safety experts raised the following problem: during a start up MITR-II all the shim rods continue to move away from their shutdown position with a constant velocity. The power level goes up to 6 MW at which level an order to scram is initiated. It is assumed there is a delay of 0.1 sec. due to the instrumentation. The question is then; how far beyond 6MW level will the power climb during these 0.1 sec. ?

We have considered this problem within the context of "The Reactivity and Transient Analysis of MITR-II"(1). So first a description of the method investigated for the transient analysis of MITR-II will be briefly given. Then the application of this method to the problem in question will be presented. Finally a conclusion will be drawn.

1-The Proposed Transient Analysis Method for MITR-II

As a starting approximation we consider the time dependent multigroup diffusion equations. This is a standard procedure. However the presence of the photoneutrons will require more elaboration. For this purpose an extra photoneutron source term is added so that they became:

$$v^{-1}\frac{\partial \phi(\underline{r},t)}{\partial t} = [\nabla . D(\underline{r},t)\nabla - A(\underline{r},t) + (1-\beta)\nu\chi_p \Sigma_F^T(\underline{r},t)]\phi(\underline{r},t) + \sum_{j=1}^{J}\lambda_j \chi_j \eta_j(\underline{r},t) + S(\underline{r},t) \quad , \quad (1)$$

$$\frac{\partial \eta_j(\underline{r},t)}{\partial t} = \beta_j \nu \Sigma_F^T(\underline{r},t)\phi(\underline{r},t) - \lambda_j \eta_j(\underline{r},t) \quad , j=1,\ldots,J \quad , \quad (2)$$

where $S(\underline{r},t)$ represents the photoneutron source term and the familiar notation is used.

The Photoneutron Source Term $S(\underline{r},t)$

Because an exact calculation of $S(\underline{r},t)$ is very difficult and the importance of the photoneutrons during a transient is uncertain, we need approximations to estimate this term. It was assumed that the radiation that causes photoneutrons comes from an equivalent point source embedded in pure $D_2O$. Moreover the uncollided photons were considered only. Thus $S(\underline{r},t)$ was computed through a shielding type of procedure that involves the photon attenuation and photoneutron reaction cross sections in $D_2O$.

Method of Solution: Time Synthesis[2]

A finite difference type of approach to the System of Equations (1) and (2) seems to be impractical for our purpose; and among a number of approximate

*This work was performed as part of the Ph.D. thesis work, "The Reactivity and Transient Analysis of MITR-II" in the Nuclear Engineering Department of Massachusetts Institute of Technology(1).

ways of solving these equations we choose the simplest one that takes care of the space dependency of the time and space dependent flux over a transient. This method called time synthesis assumes that the time and space dependent flux can be expressed as

$$\phi(\underline{r},t) = \psi_1(\underline{r})N_1(t) + \psi_2(\underline{r})N_2(t) \quad , \qquad (3)$$

where $\psi(\underline{r})$ and $\psi(\underline{r})$ are two trial shapes(or modes) picked beforehand and $N_1(t)$ and $N_2(t)$ are the unknown time coefficients.

Application of the Weighted Residual Method

Since the Expansion(3) is not an exact solution, inserting it into Equations (1) and (2) will give rise to residuals that are space and time dependent. By appropriate weighting and integrations over convenient domains we can get rid of the space dependency and obtain equations for the unknown time coefficients.

Multimode Kinetics Equations

When there are no photoneutrons involved, one obtains through th weighted residual method the so-called multimode kinetics equations. Despite the complications presented by the presence of $S(\underline{r},t)$ in Eq.(1) we were still able to obtain equations for the unknown time coefficients, having the form of the multimode kinetics equations with, however, different definitions for the conventional generation time, reactivity and delayed neutron(and photoneutron) fraction matrices. Thus the equations to be solved for the column vector N(t) are:

$$\Lambda \frac{dN(t)}{dt} = [\rho_{new}(t) - \bar{\beta}_{new}(t)]N(t) + \sum_{j=1}^{H} \lambda_j C_j(t) \quad , \qquad (4)$$

$$\frac{dC_j(t)}{dt} = \bar{\beta}_{jnew}(t)N(t) - \lambda_j C_j(t) \, , \quad j=1,\ldots,H \quad , \qquad (5)$$

where $\rho_{new}(t)$ and $\bar{\beta}_{new}(t)$ refer to new definitions of the reactivity and delayed neutron fraction matrices; H is the total number of delayed neutron (and photoneutron) groups; a matrix notation is used and $\Lambda$, $\rho_{new}(t)$ and $\bar{\beta}_{jnew}(t)$'s are (2X2) matrices; and finally N(t) is

$$N(t) = \text{col}(N_1(t)\ N_2(t))$$

The Computation of the Parameters $\Lambda$, $\rho_{new}(t)$ and $\bar{\beta}_{jnew}(t)$'s

In order to get a solution to Equations (4) and (5), first the complicated integral expressions for the parameters $\Lambda$, $\rho_{new}(t)$ and $\bar{\beta}_{jnew}(t)$'s must be evaluated. This turned out to be a difficult problem, primarily because the spatial shapes or their weighting functions which were generated by the code EXTERMINATOR-II were not well converged. A converged solution for the weighting modes (adjoint fluxes) was found hard to obtain in a reasonable computation time. A second difficulty encountered in the course of the integrations reqired to obtain the parameters for the multimode kinetics equations was that special computation techniques had to be constructed to deal with the leakage terms. Finally it was difficult to work with the analytical expression for the photoneutron distribution in two dimensions.

Model of Computations

A 40 X 48 mesh scheme (already established for MITR-II) in (r-z) cylindrical geometry was adopted and three-groups of neutrons were used.

The Solution of The Multimode Kinetics Equations

To solve Equations (4) and (5) for N(t) we adopted a code employing the method of undetermined parameters, subdomain weighting (2) and inserted it into OZAN, the computer code written to perform computations required by the present work.

2-The Accident Analysis attacked with OZAN

The fictitious accident of interest was analyzed with OZAN.

Some Further Difficulties

Several special difficulties were involved in analyzing the situation in question. Most of them were due to the fact that at the start of the transient the reactor was subcritical. Further theoretical preparations were required to get around these difficulties. An other difficulty consisted of finding the position of the rods when they receive the order to scram(the second trial shape was generated with the rods in that position). In effect we needed to know the answer to the problem before even we started. This difficulty was solved by making use of a point kinetics code and a previously determined rod-worth curve. We were then able to estimate approximately the position of the rods when they receive the order to scram.

The Trial Shapes

The first trial shape was taken to be the critical steady state shape of the reactor. On the other hand a poison search(increasing the absorption cross sections by $\omega v^{-1}$, $v^{-1}$ being the inverse of the diagonal group velocities matrix,and searching for $\omega$ leading to an eigenvalue $k_2=1/(1-\beta)$, $\beta$ being the total delayed neutron fraction) determined the second trial shape.

Results

Two calculations were made. The first one with the first trial shape used alone(thus a point kinetics type of approach,designated by OZAN, NMODES=1); and the second one,using the two shapes (then designated by OZAN, NMODES=2). The results of interest (how far beyond the 6MW level does the power climb during the additional 0.1 sec.) was found to be with OZAN, NMODES=1 : $\sim$ 60 MW: and with OZAN,NMODES=2 : $\sim$ 90 MW. The transient is thus predicted to be more severe by OZAN,NMODES=2,and the comparison has shown the necessity of a space dependent analysis. It is worthwhile to emphasize that this is a fictitious transient. The inherent safety feedback features of the reactor have not been considered in obtaining the results.

Equivalent Reavtivity

One set of useful parameters derived were quantities called equivalent generation time,reactivity and delayed neutron fractions. We have shown that with these new parameters calculated through the appropriate matrix elements of Equations (4) and (5),and $N_1(t)$ and $N_2(t)$,solution of the multimode kinetics equations,one can describe the prediction of OZAN,NMODES=2, through a point kinetics equations. Thus solving

$$\Lambda_{eq}\frac{dN_{eq}(t)}{dt}=[\rho_{eq}(t)-\beta_{eq}(t)]N_{eq}(t)+\sum_{j=1}^{M}\lambda_j C_{jeq}(t) \quad , \quad (6)$$

$$\frac{dC_{jeq}(t)}{dt}=\beta_{eqj}(t)N_{eq}(t)-\lambda_j C_{jeq}(t) \quad , \quad j=1,\ldots,M \quad , \quad (7)$$

for $N_{eq}(t)$,with $\Lambda_{eq}$, $\rho_{eq}(t)$ and $\beta_{eq}(t)$ being the equivalent generation time, reactivity and delayed neutron fraction,gives the same prediction as the one obtained through OZAN,NMODES=2.

The Usefulness of the New Definition

The usefulness of Equations (6) and (7) does not lie in the fact that the multimode kinetics equations are reduced to point kinetics equations,since the calculation of the equivalent parameters requires that the solution of the multimode kinetics equations already be known. The introduction of these parameters is nevertheless useful for two reasons. First,the complicated matrix scheme is now collapsed to scalar quantities with which we are more

familiar so that we understand better what is happening. Secondly,comparing the equivalent parameters to the parameters of the one-mode kinetics equations (OZAN,NMODES=1;representing the conventional point kinetics method) we see that the only major difference is between $\rho_{eq}(t)$ and the corresponding reactivity of the one-mode kinetics equations(OZAN,NMODES=1). Thus we recognize the importance of "reactivity" in determining the prediction about the transient. Different definitions (changing the weighting functions, number of trial modes used,etc) of this quantity will lead to different predictions about the same transient.

Weighting

The other property of the multimode method that became apparent throughout the present study involved the importance of the convergence of the fluxes (spatial shapes and the weighting modes) used to determine relevant matrix elements. It became clear through the study of the matrix elements involved in the transient calculation and through a further study undertaken with OZAN,NMODES = 2 where unity was used throughout the entire reactor as the first weighting function) that the choice of the weighting functions is very important. The adjoint modes of the trial shapes are apparently more properly used as weighting functions. It is also important to undertake computations with well converged weighting functions; otherwise erroneous predictions may result.

3-Conclusion

The way of finding a satisfying solution with the proposed method is to guess the right trial shapes and the related weighting functions(which we hope we did). It is conjectured that for the present study a better prediction would be made if we had better converged weighting functions. It is also conjectured that the generation of well converged trial shapes and weighting modes for some cases may be very expensive. Thus since the only way to validate the proposed method is to compare it to the exact solution it may be advisable,when only few cases are involved,to develop the more exact finite difference calculations.

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