Journal of Nuclear and Particle Physics 2013, 3(4): 45-54
DOI: 10.5923/j.jnpp.20130304.01

Analysis of Reactivity - Initiated Accident for Control Rods Ejection

H. Mansour[1], Hend M. Saad[2,*], M. Aziz[2]

[1]Physics Department, Faculty of Science, Cairo University, Giza, Egypt
[2]Nuclear and Radiological Regulatory Authority, Ahmed Al Zomor St., Nasr City, Cairo, Egypt

Abstract Understanding of the time-dependent behavior of the neutron population in a nuclear reactor in response to either a planned or unplanned change in the reactor conditions is of great importance to the safe and reliable operation of the reactor. In the present work, the point kinetics equations are solved numerically using the stiffness confinement method (SCM). The solution is applied to the kinetic equation in the presence of different types of reactivities, and is compared with other method. This method is, also used to analyze reactivity induced accidents in two reactors. The first reactor is fueled by uranium and the second is fueled by plutonium. This analysis presents the effect of negative temperature feedback with the addition positive reactivity of the control rods to overcome the occurrence of the control rod ejection accident and damaging of the reactor. Both the power and the temperature pulse following the reactivity- initiated accidents are calculated. The results are compared with previous works and satisfactory agreement is found.

Keywords Reactivity Induced Accident, Stiffness Confinement Method, Point Kinetic Equations, Control Rods Ejection, Reactivity Coefficient, Safety Analysis

1. Introduction

The reactivity- initiated accident is a nuclear reactor accident that involves inadvertent removal of a control element from an operating reactor, thereby causing a rapid power excursion in the nearby fuel elements and temperature. The postulated scenarios for reactivity initiated accidents are therefore focused on a few events, which result in exceptionally large reactivity excursions, and therefore are critical to fuel integrity. In reference[2] model, the reactivity-initiated accident is considered to be due to negative temperature feedback. In the present work, we consider the reactivity accident to be due to negative temperature feedback with the addition positive reactivity of the control rods to prevent such accidents of the control rods ejection and damaging of the reactor. We analyzed accidents in different types of reactors, e.g. modular high temperature gas cooled reactor design like HTR-M, and modular fast reactor design like PRISM, using the stiffness confinement method for solving the kinetics equations. The stiffness confinement method SCM is used to solve the kinetics equations, and overcome the stiffness problem in reactor kinetics[1]. The idea is based on the observation that the stiffness characteristic is present only in the time response of the prompt neutron density, but not in that of the delayed neutron precursors. The method is therefore devised to have the stiffness decoupled from the differential equation for precursors and is confined to the one for prompt neutrons, which can be solved[1]. Numerical examples of applying the method to a variety of problems are given. The method is also used to analyze the reactivity induced accidents in two reactors data, the modular high temperature gas cooled reactor (HTR-M) which is fueled by uranium, and modular fast reactor design (PRISM) which is fueled by plutonium. In the next sections, we discuss the mathematical method; present the results and discussion, and give the conclusion.

* Corresponding author:
hendmohammed_science@yahoo.com (Hend M. Saad)
Published online at http://journal.sapub.org/jnpp

2. Mathematical Method

The stiffness confinement method is used to overcome the stiffness problem in reactor kinetics for solving the point kinetics equations. The idea is based on the observation, that the stiffness characteristic is present only in the response time of the prompt neutron density, but not in that of the delayed neutron precursors. The method is, therefore, devised to have the stiffness decoupled from the differential equations for the precursors and confine it to the one for the prompt neutrons, which can be analytically solved[1]. The point kinetics equations are a system of coupled ordinary differential equations, whose solution give the neutron density and delayed neutrons precursor concentrations in a tightly coupled reactor as a function of time. Typically, these equations are solved using the reactor model with at least six

delayed precursor groups, resulting in a system consisting of seven coupled differential equations. Obtaining accurate results is often problematic, because the equations are stiff with many techniques, where very small time steps are used. These equations take the following form with an arbitrary reactivity function[3, 4]:

$$\frac{dn(t)}{dt}=\frac{\rho(t)-\beta}{\Lambda}n(t)+\sum_{i=1}^{6}\lambda_i C_i(t) \tag{1}$$

$$\frac{dC_i(t)}{dt}=\frac{\beta_i}{\Lambda}n(t)-\lambda_i C_i(t) \tag{2}$$

where: $n(t)$ is the time-dependent neutron density, or (power or neutron flux) all units are (MW) as power unit; $Ci(t)$ is the i^{th} group delayed neutrons precursor concentration or delayed neutrons emitter population or precursor density ("latent-neutron" density or latent power; same units as in the power); i is the number of precursor group; $\rho(t)$ is the time-dependent reactivity; β_i is i^{th} group delayed neutrons fraction, and $\beta = \Sigma_i \cdot \beta_i$, is the total delayed neutrons fraction. In addition, Λ is the neutron generation time (s), and λ_i is decay constant of the i^{th} group delayed neutrons emitters (s^{-1}).

Introducing a set of "Reduced" precursor density functions $\hat{C}i$ (t) and neutron density n (t), through the following equation[1]:

$$C_i(t)=\hat{C}_i(t)\exp[\int_0^t u(t')\,dt'] \tag{3}$$

Defining two auxiliary functions w (t) and u (t), as in Eqs. (4) and (5):

$$w(t)=\frac{d}{dt}\ln n(t) \tag{4}$$

The function w (t) is defined in Eq. (9) below and provides the key mechanism of the SCM. The function u (t), however, has nothing to do with stiffness decoupling and is not really required theoretically. Since an exponential behavior is often characteristic for the first, order differential equations, however, a proper choice of u (t) may make $\hat{C}_i(t)$ vary more slowly in time and thus expedite the numerical calculation. Choose the following u (t)[1]:

$$u(t)=\frac{d}{dt}\ln S(t) \tag{5}$$

Where, S (t) is defined by Eq. (7) as the sum over all $\lambda_i \cdot C_i$ (t). We can rewrite Eqs. (1) and (2) as follows[1]:

$$\frac{d\hat{C}_i(t)}{dt}=\left[\frac{\beta_i}{\Lambda\, w(t)+\beta-\rho(t)}\right]\sum_{i=1}^{6}\lambda_i\hat{C}_i(t) -\left[u(t)+\lambda_i\right]\hat{C}_i(t) \tag{6}$$

$$S(t)=\left[\sum_{i=1}^{6}\lambda_i\hat{C}_i(t)\right]\exp\left[\int_0^t u(t')dt'\right] \tag{7}$$

And,

$$\frac{dn(t)}{dt}=\frac{\rho(t)-\beta}{\Lambda}n(t)+S(t)$$

Suppose that, it is always possible to express:

$$n(t)=\exp[\int_0^t w(t')dt'] \tag{8}$$

and rewrite Eq. (1) as:

$$n(t)=\frac{\sum_{i=1}^{6}\lambda_i C_i(t)}{\left(w(t)+\left[\frac{\beta-\rho(t)}{\Lambda}\right]\right)} \tag{9}$$

Eqs. (6)- (9), form the complete set of kinetics equations for the SCM. The initial conditions are satisfied to be:

$$u(0)=0 \tag{10a}$$

$$w(0)=\frac{\rho(0)}{\Lambda} \tag{10b}$$

$$n(0)=n_0 \tag{10c}$$

and,

$$\hat{C}_i(0)=\frac{n_0\beta_i}{\Lambda\lambda_i} \tag{10d}$$

By using the initial conditions, we can obtain the numerical solution of the equations. We first start by setting w and u in Eq. (6) at their initial values and solve Eq. (6) for $\hat{C}_i$ by discretizing the equation in t. Having obtained $\hat{C}_i$, we calculate S (t) with Eq. (7). Then we use Eq. (4) to re-evaluate $w(t)$, plug it back into Eq. (6) , and repeat the process until w converges (requiring 50 iterations). Calculation for the current time step is finished with an evaluation of the output value of w and u via Eqs.(4) and (5). Afterward, we predict the input values of w and u for the next time step by a linear extrapolation from their output values in the previous and current time steps, and repeat the whole process of calculation for the next time step. It should be emphasized that time step, there is iteration to convergence on w, but no iteration for the function u, because u is not required by the theory of the SCM, and is in principle, an arbitrary independent function chosen only to expedite the computation. A computer program is designed with programming language FORTRAN, and MATLAB code to solve the above equations numerically using Runge - Kutta method for the above differential equations and the output power and temperature are determined under different input reactivities.

It is assumed that, the reactor has a negative temperature coefficient of reactivity α ($\alpha > 0$), when a large step reactivity ρ_0 ($\rho_0 > \beta$) is inserted. Consider the temperature feedback, the real reactor reactivity is:[3, 4]

$$\rho(t)=\rho_0-\alpha\left[T(t)-T_0\right] \tag{11}$$

Then, the derivative of Eq. (11) with respect to time (t) is:

$$\frac{d\rho(t)}{dt} = -\alpha \frac{dT(t)}{dt} \quad (12)$$

Where, T (t) and T_0 are the reactor temperature, and initial temperature of the reactor, respectively. After the large reactivity ρ_0 is inserted into the reactor, the power responds quickly and the adiabatic mode can be used for the calculation of reactor temperature.[3, 4]

Then, the derivative of the temperature w.r.to time can be given as follows:

$$\frac{dT(t)}{dt} = K_c\, n(t) \quad (13)$$

Where, K_c is the reciprocal of thermal capacity of reactor. Substituting Eq. (12) into Eq. (13) results in the following:

$$\frac{d\rho(t)}{dt} = -\alpha\, K_c\, n(t) \quad (14)$$

3. Numerical Solution

The numerical solution of the point kinetics equations is based on SCM .The results are compared against other result, which obtained with other method. The other method is highly accurate, but there are vary widely in there complexity of implementation[1].

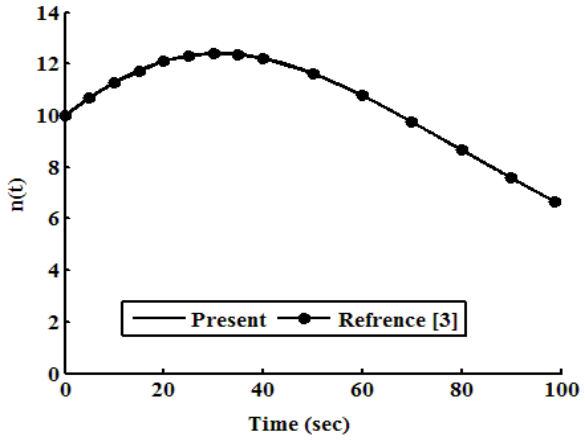

Figure 1. Neutron density as a function of time at ρ_0=0.2β

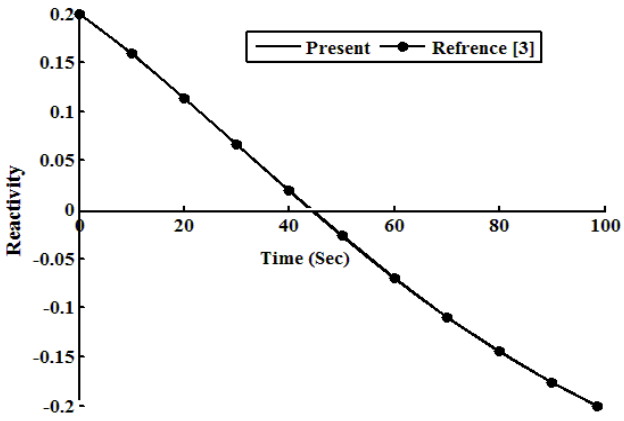

Figure 2. Reactivity as a function of time at ρ_0=0.2β

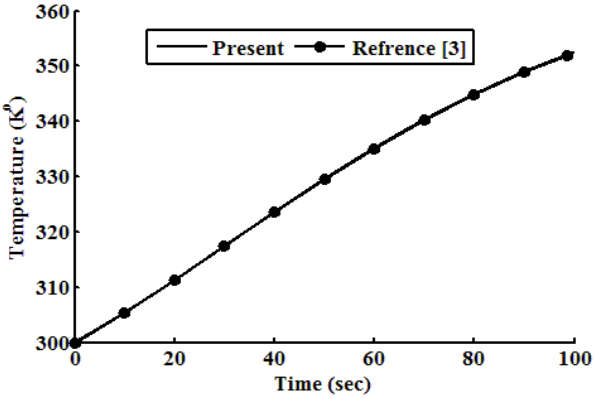

Figure 3. Temperature as a function of time at ρ_0=0.2β

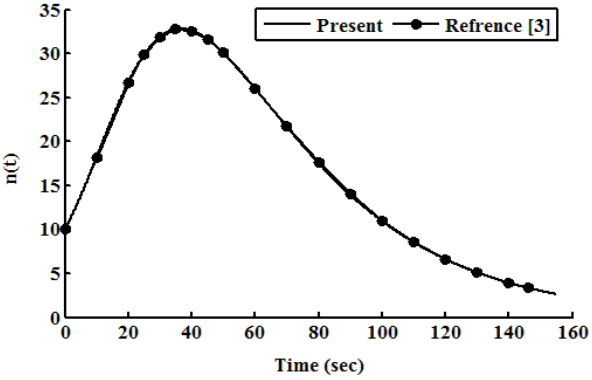

Figure 4. Neutron density as a function of time at ρ_0=0.5β

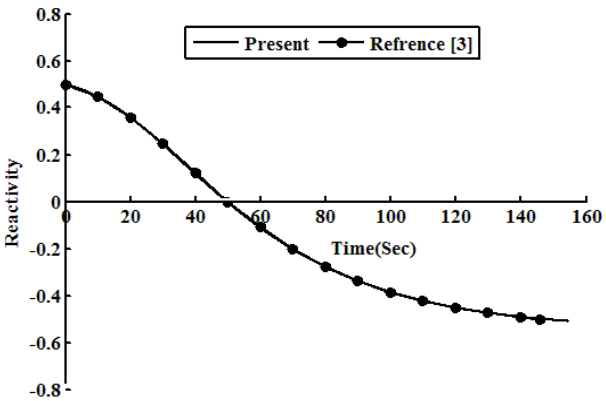

Figure 5. Reactivity as a function of time at ρ_0=0.5β

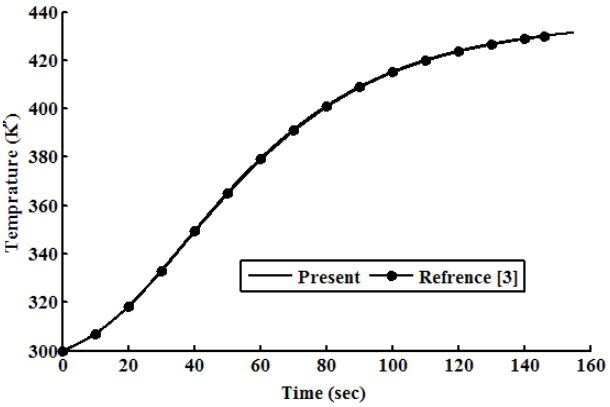

Figure 6. Temperature as a function of time at ρ_0=0.5β

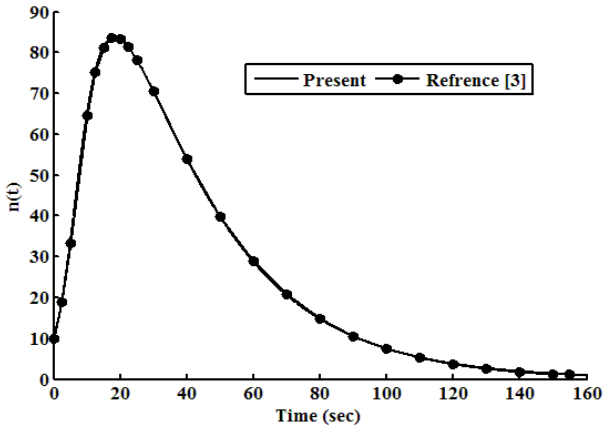

Figure 7. Neutron density as a function of time at ρ_0=0.8β

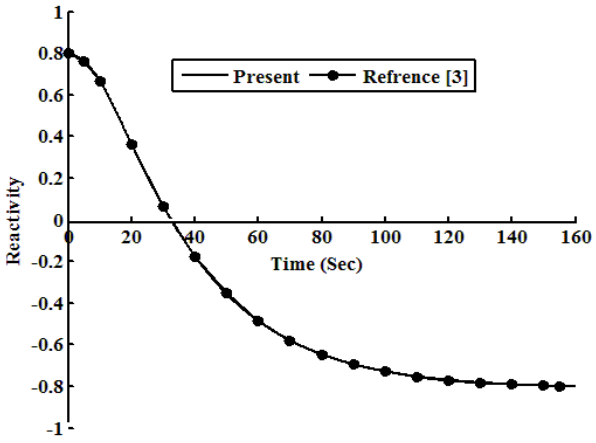

Figure 8. Reactivity as a function of time at ρ_0=0.8β

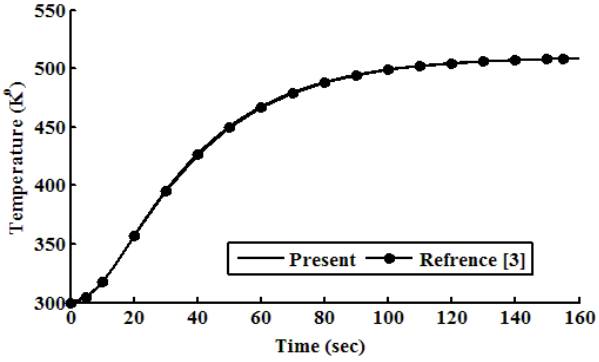

Figure 9. Temperature as a function of time at ρ_0=0.8β

Considering an example ^{235}U as a fissile material under large step reactivity, taking three initial reactivities inserted into the reactor. It is assumed that, the input parameters are: $\lambda_i(s^{-1})$ = (0.0127, 0.0317, 0.155, 0.311, 1.4, 3.87), β_i= (0.000266, 0.001491, 0.001316, 0.002849, 0.000896, 0.000182), Λ=0.0001(s), β_{tot}= 0.0065, K_c= 0.05 K/ (MW s), and $\alpha = 5\times10^{-5}$ (K^{-1}). In this case, ρ_0 =0.2β and 0.5β and 0.8β for t ≥ 0 are used into the reactor, which is operating in critical state with initial power 10 (MW). The relation between time, reactivity, neutron density, and temperature using the numerical solution by the SCM, which are compared with the work of[3], is presented in tables (1, 2, and 3). The results indicate that the present model solutions are in good agreement with other works as shown in following figures (1-8). The iteration in computing is used for repeating the process until *w* and *u* converge (requiring approximately 100 iterations) to get step reactivity insertion with accurate results which are compared with other calculations[1, 3].

Table 1. Neutron Density, Precursor Density, Reactivity and Temperature are functions of time at initial reactivity 0.2β solved with SCM

Time	Reactivity ($)		Neutron Density (MW)		Precursor Density		Temperature (K°)	
(sec)	Present Work	Reference[3]	Present Work	Reference[3]	Present Work	Reference[3]	Present Work	Reference [3]
0.0	0.2	0.2	10.0	10.0	6718	6717.479	300	300
10.0	0.1589	0.158976	11.28	11.270597	7962	7960.6118	305.3	305.333
20.0	0.1139	0.113885	12.11	12.094137	8999	8999.4785	311.2	311.195
30.0	0.06659	0.066610	12.4	12.402006	9720	9720.1787	317.3	317.341
40.0	0.0191	0.019115	12.22	12.220168	10060	10064.441	323.5	323.515
50.0	-0.02687	-0.026878	11.63	11.639050	10030	10034.852	329.5	329.494
60.0	-0.07006	-0.070057	10.78	10.777035	9682	9682.0400	335.1	335.107
70.0	-0.1096	-0.109569	9.751	9.750800	9083	9083.3223	340.2	340.244
80.0	-0.145	-0.144980	8.659	8.658279	8323	8322.8449	344.8	344.847
90.0	-0.01762	-0.176181	7.573	7.572253	7477	7477.1450	348.9	349.04
98.7	-0.2	-0.2	6.673	6.671694	6721	6721.2397	352	352

Table 2. Neutron Density, Precursor Density, Reactivity and Temperature are functions of time at initial reactivity 0.5β

Time	Reactivity ($)		Neutron Density (MW)		Precursor Density		Temperature (K°)	
(sec)	Present Work	Reference [3]	Present Work	Reference [3]	Present Work	Reference [3]	Present Work	Reference [3]
0.0	0.5	0.5	10.0	10.0	4198	4198.4243	300	300
10.0	0.4464	0.446517	18.21	18.195158	8476	8467.9072	307.0	306.953
20.0	0.3594	0.359572	26.75	26.726191	14390	14381.679	318.3	318.258
30.0	0.2453	0.245386	31.89	31.95273	20220	20213.748	333.1	333. 100
40.0	0.1200	0.120072	32.59	32.597210	24080	24083.318	349.4	349.391
50.0	0.00126	0.001244	30.13	30.103104	25300	25304.049	365.2	365.162
60.0	-0.1096	-0.109559	26.08	26.081541	24290	24294.025	379.2	379.243
70.0	-0.2015	-0.201433	21.68	21.698225	21880	21884.133	391.2	391.186
80.0	-0.2768	-0.276824	17.58	17.578548	18840	18841.465	401	400.987
90.0	-0.3373	-0.337342	13.99	13.988706	15710	15704.299	408.9	408.854
100.0	-0.3854	-0.385198	11	10.995258	12790	12785.422	415.1	415.076
110.0	-0.4225	-0.422648	8.578	8.567273	10240	10231.454	419.9	419.944
120.0	-0.4516	-0.451736	6.641	6.633668	8093	8084.229	423.7	423.726
130.0	-0.4743	-0.474206	5.118	5.113089	6335	6327.5962	426.6	426.647
140.0	-0.4916	-0.491496	3.927	3.927845	4923	4917.8364	428.9	428.895
146.1	-0.5	-0.5	3.345	3.339961	2409	4205.6318	430	430

Table 3. Neutron Density, Precursor Density, Reactivity and Temperature are functions of time at initial reactivity 0.8β

Time	Reactivity ($)		Neutron Density (MW)		Precursor Density		Temperature (K°)	
(sec)	Present Work	Reference [3]	Present Work	Reference [3]	Present Work	Reference [3]	Present Work	Reference [3]
0.0	0.8	0.8	10.0	10.0	1679	1679.3699	300	300
10.0	0.6661	0.666886	64.74	64.557487	18210	18124.689	317.4	317.305
20.0	0.3639	0.36352	83.3	83.320236	44500	44500.184	356.7	356.699
30.0	0.06437	0.064528	70.43	70.490250	55350	5534.738	395.6	395.611
40.0	-0.1744	-0.174378	53.9	53.917503	53140	53148.172	426.7	426.699
50.0	-0.3535	-0.353502	39.77	39.60925	45170	45172.699	450	449.95
60.0	-0.4844	-0.484405	28.81	28.824406	35910	35915.492	467	466.973
70.0	-0.5788	-0.78847	20.73	20.703527	27440	27438.424	479.2	479.250
80.0	-0.6465	-0.646493	14.78	14.789428	20440	20440.443	488	488.044
90.0	-0.6947	-0.694731	10.53	10.528523	14980	14977.864	494.3	494.315
100.0	-0.7290	-0.729082	7.484	7.478508	10850	10854.269	498.8	49.774
110.0	-0.7534	-0.753380	5.309	5.304107	7819	7806.8105	501.9	501.939
120.0	-0.7707	-0.770631	-0.770631	3.758143	5595	5585.821	504.2	504.182
130.0	-0.7828	-0.782857	2.665	2.660907	3989	3982.2925	505.8	505.771
140.0	-0.7915	-0.791503	1.886	1.83123	2832	283.9358	506.9	506.895
150.0	-0.7976	-0.797624	1.355	1.332234	2008	2010.3282	507.7	507.691
155.0	-0.8	-0.8	1.122	1.116575	1696	1687.1426	508	508.002

4. Analysis of Reactivity- Initiated –Accident

4.1. Reactivity- Initiated Accident

Reactivity- initiated accident involves an unwanted increase in fission rate and reactor power. The power increase may damage the reactor core, and in very severe cases, even lead to the disruption of the reactor. The immediate consequence of reactivity- initiated accident is a fast rise in fuel power and temperature. The power excursion may lead to failure of the nuclear fuel rods and release of radioactive material into primary reactor coolant. In this study, a new computer program has been developed for simulating the reactor dynamic behavior during reactivity induced transients, and it has been used for the analysis of specified reactivity - initiated accidents in several cases. We introduce the two model reactors with system parameters that are characteristic for modular high temperature gas-cooled reactor design like HTR-M[6], and modular fast reactor design like PRISM[7]. For simplicity, we refer to the input dates of two reactors (HTR-M and PRISM) in tables (4, 5, and 6). For the delayed neutron parameters, it is assumed that, HTR-M is fuelled by ^{235}U and PRISM by ^{239}Pu as fissile nuclides. The dynamic equations (15:21) for the two models

are the conventional point reactor kinetic equations in combination with a linear temperature feedback for the reactivity, an adiabatic heating of the core after loss of cooling[2], where Eq. (17 a) may be modified to add positive control rods reactivity as:

$$\frac{dn(t)}{dt} = \frac{\rho_{net}(t) - \beta}{\Lambda} n(t) + \sum_{i=1}^{6} \lambda_i C_i(t) \quad (15)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} n(t) - \lambda_i C_i(t) \quad (16)$$

$$\rho_{net}(t) = \rho_{feed}(t) + \rho_{ext}(t)$$

$$\rho_{feed} = feedback\ reactivity \quad (17)$$

$$\rho_{feed} = -\alpha(T(t) - T_0) \quad (18a)$$

$$\rho_{ext} = \rho_{CR} = \rho_{cr}1 \quad or\ \rho_{cr2}\ or\ \rho_{cr3}\ or\ \rho_{cr4} \quad (18b)$$

$$\rho_{ext} = external\ reactivity = control\ rods\ reactivity$$

$$\rho_{net}(t) = -\alpha(T(t) - T_0 + \rho_{CR} \quad (19)$$

$$\frac{dT(t)}{dt} = \frac{1}{c} n(t) \quad (20)$$

Where, n (t) = reactor power (MW), ρ_{net} (t) = is the time-dependent reactivity function, ρ_{CR}= Addition positive reactivity of the control rods, β = total delayed neutron fraction, $\beta = \Sigma_i \beta_i$. β_i= Delayed neutrons faction of i^{th} group. Λ = neutron generation time (sec), λi = decay constant of i^{th} group delayed neutrons emitters $(sec)^{-1}$, C_i (t) =delayed neutrons emitter population (in power units), α = temperature coefficient of reactivity (K^{-1}).

In the equation of total reactivity ρ_{net} (*t*), the additional positive reactivity of the control rods ρ_{CR} has four cases to prevent the control rods ejection accident as:

$$\rho cr1 = \rho 1 = 0, \rho cr2 = \rho 2 = (\beta/2),$$
$$\rho cr3 = \rho 3 = (0.8\beta), \rho cr4 = \rho 4 = (\beta) \quad (21)$$

The input parameters of the kinetic equations of two reactors with different fissile materials are shown in tables 4: 6.

Table 4. ^{235}U (Thermal Neutrons)

$\lambda_i(sec^{-1})$	0.0124	0.0305	0.111	0.301	1.14	3.01
β_i	0.000215	0.001424	0.001274	0.002568	0.0007485	0.0002814
β_{tot}=0.0067			Λ=1.00E-4**(sec)**			

Table 5. ^{239}PU (Fast Neutrons)

$\lambda_i(sec^{-1})$	0.0129	0.0311	0.134	0.331	1.26	3.21
β_i	7.6E-005	5.6E-004	4.32E-004	6.56E-004	2.06E-004	7.00E-005
β_{tot}=0.0020			Λ=1.00E-7**(sec)**			

Table 6. Adiabatic Inherent Shutdown Data for Two Model Reactors

Types of Reactors	P_0(MW)	c(MJ/K)	α(K^{-1})
HTR-M	200.00	100.00	2.2E-005
PRISM	470.00	200.00	9.00E-006

4.2. Reactivity Evaluation

The reactivity of one, two and three control rods worth are calculated based on the assumptions of relating the control rod worth by the delayed neutron fraction *β*. We assumed that, the ejection of one, two and three rods could induce positive reactivity as indicated in Table 7 for each type of reactors, in the two models.

Table 7. Additional Positive Reactivity of Control Rods Insertion

No. of control rods	ρ (in $) for U^{235}	ρ (in $) for PU^{239}
1	0.5	0.5
2	0.8	0.8
3	1.00	1.00

5. Results and Discussion

5.1. First Reactor (PRISM Reactor)

PRISM Reactor is assumed to be critical at the zero power condition, and the limited value of time (sec) on x axis is 300 (sec). Reactivity is also added step by step. The control rod insertion increases the thermalization of neutrons, results in a positive reactivity addition. Control rod insertion requires a certain driving force. The driving forces on the control rods in the reactors are the buoyancy from the fuel material and the supporting force from the control system of the reactor. If the control system should lose the support of control rods or control rods should break, control rods would be flown out of the reactor. Thus, in PRISM reactor, accidental insertions can result from the ejection of control rod drive, and/or control rod control system or operator error. Power transients are shown in Figures (10, 11) for one and two, and three control rod ejections, respectively. As can be seen, three rods are ejected; a large power pulse is generated about 83.8085 times of the initial value of power in a very short time. This is because; the accident is reactivity accident. However, the fuel temperature is stabilized at approximately 1435 (K) at the maximum as shown in Figure 12. Even, three control rods are inserted; the maximum temperature is not exceeding 1502 (K) as shown in Figure 12.

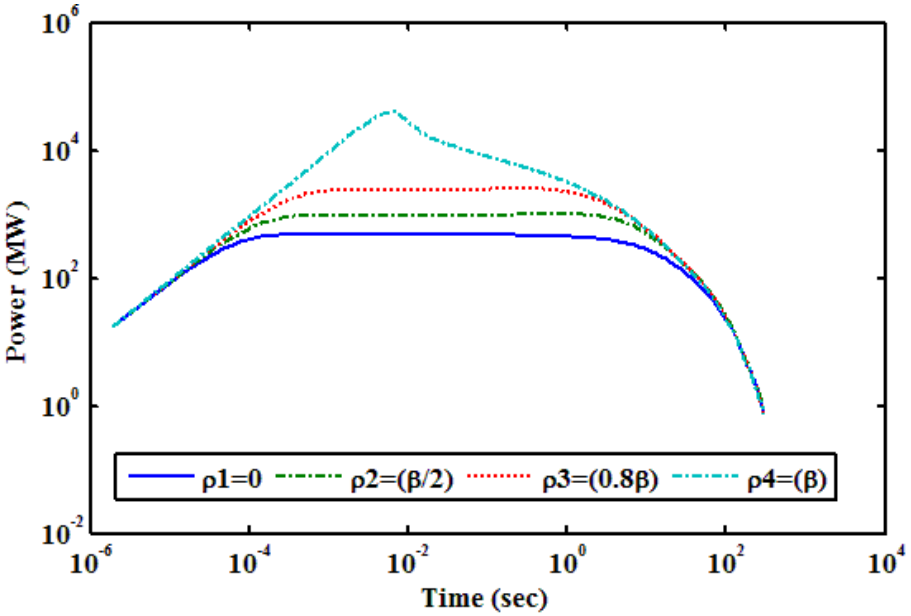

Figure 10. Shows Power (MW) Transient at Zero Power Condition with Different Values of Positive Reactivity of Control Rods Ejection for PRISM Reactor

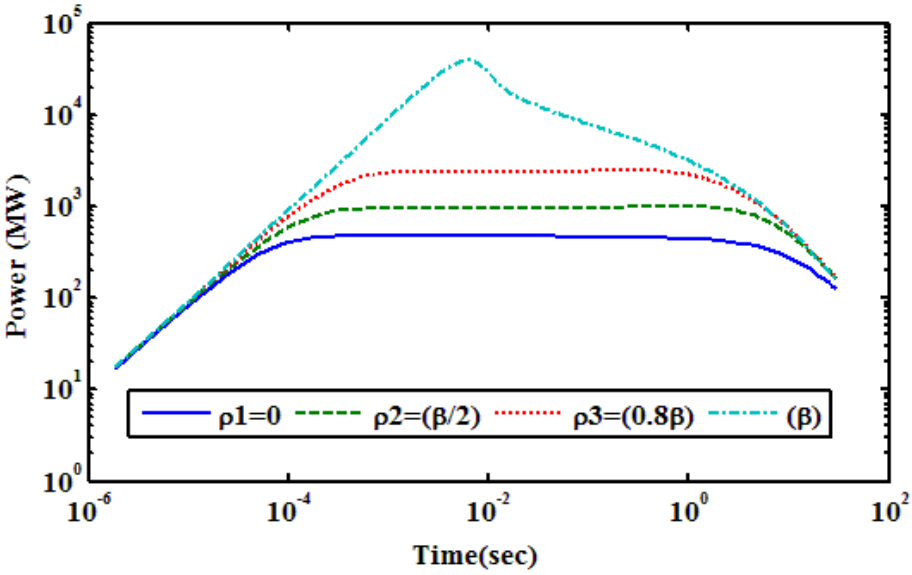

Figure 11. Shows Power (MW) Transient at Full up to 30s with Different Values of Positive Reactivity of Control Rods Ejection for PRISM Reactor

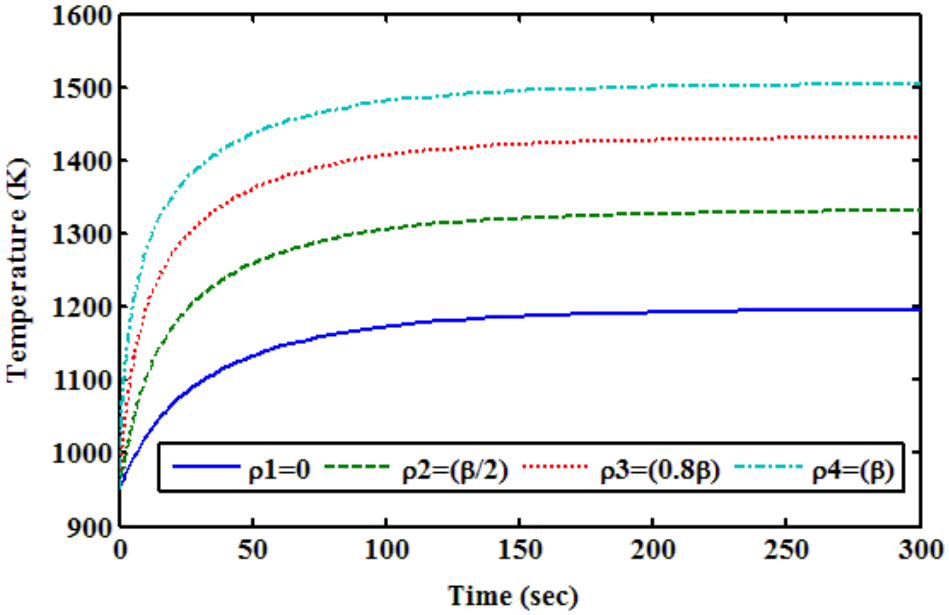

Figure 12. Shows Temperature (K) During the Transients at Zero Power for PRISM Reactor

5.2. Second Reactor (HTR-M Reactor)

HTR-M Reactor is assumed to be critical at the zero power condition, and the limited value of time (sec) on x axis is 300 (sec). Reactivity is also added step by step as explained above in PRISM reactor. The Power transients for one, two, and three control rods ejection are shown in Figures (13, 14), respectively. As can be seen, three rods are ejected; a large power pulse is generated about 53.45 times from the initial value of power in very short time. This is because; the accident is reactivity accident. However, the fuel temperature is stabilized at approximately 916.8 (K) at the maximum as shown in Figure 15. Even, three control rods are inserted; the maximum temperature is not exceeding 983.1 (K) as shown in Figure 15.

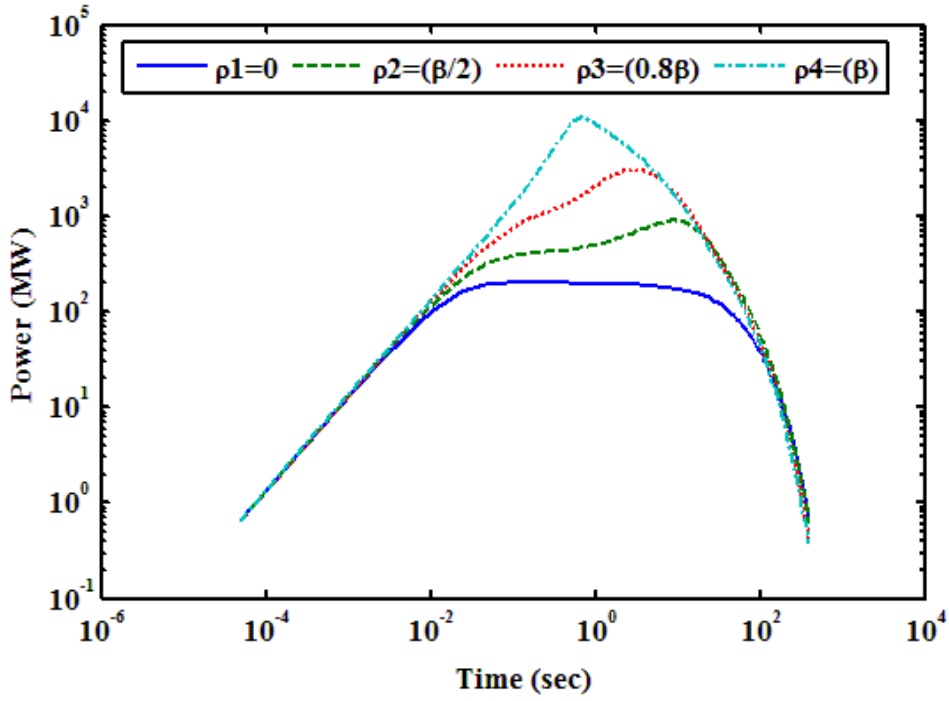

Figure 13. Shows Power (MW) Transient at Zero Power Condition with Different Values of Positive Reactivity of Control Rods Ejection for HTR-M Reactor

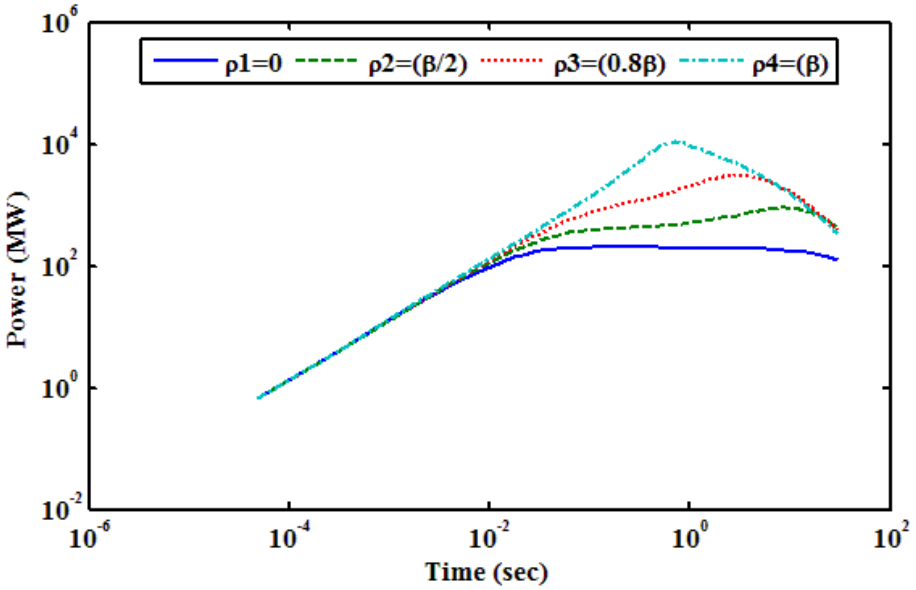

Figure 14. Shows Power (MW) Transient at Zero Power Condition up to 30s with Different Values of Positive Reactivity of Control Rods Ejection for HTR-M Reactor

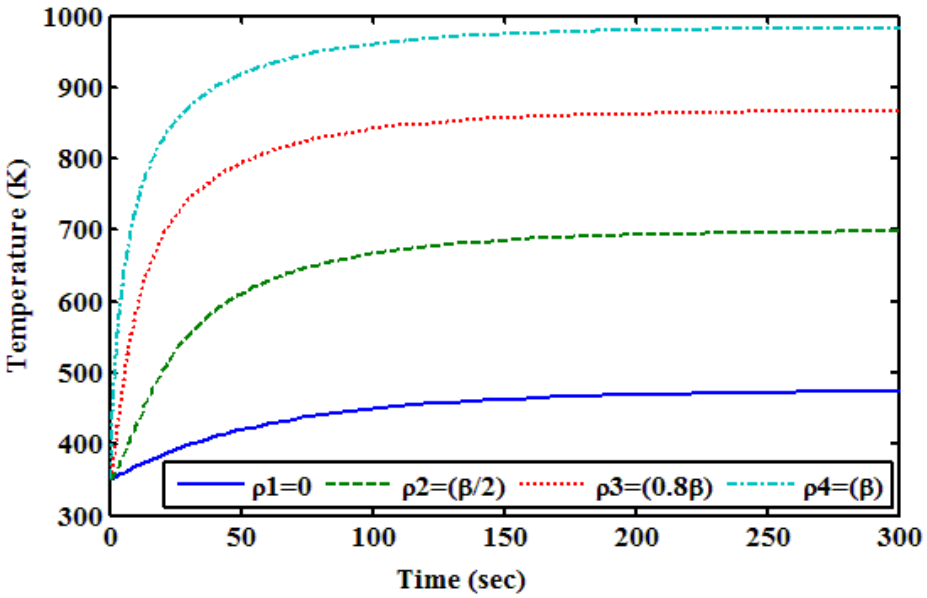

Figure 15. Shows Temperature (K) During the Transients at Zero Power for HTR-M Reactor

6. Conclusions

A computer program is designed to solve the point reactor dynamics equations using the stiffness confinement method (SCM) and different input reactivity. The resultant powers are determined and illustrated. Good accuracy in comparison with reference values is obtained. The model is applied to two types of reactors. There are modular of fast reactor design like PRISM reactor[7], and modular high temperature gas-cooled reactor design like HTR-M reactor[6]. The PRISM reactor is fuelled by 239Pu, the HTR-M reactor is fuelled by ^{235}U as fissile nuclides. In the work of Van Dam[2], (we used it for comparison purpose), the author obtained reactivity accident due to negative temperature feedback after loss of cooling to different reactors with different fissile material. The reactivity- initiated accident is considered to be due to a linear temperature feedback, and an adiabatic heating of the core after loss of cooling. In the present work, we consider reactivity accident due to a linear temperature feedback, an adiabatic heating of the core after loss of cooling with the addition positive reactivity of the control rods. We analyzed accidents in different types of reactors (HTR-M and PRISM), using the stiffness confinement method for solving the kinetic equations. In the present work, one obtains reactivity induced accident due to control rods ejection of (negative temperature feedback, and addition positive reactivity of the control rods) to overcome the occurrence of the control rods ejection accident, and

prevent reactors from damage. The addition positive reactivity of the control rods has four cases: (0, β/2, 0.8β, β), where at the zero case only negative temperature feedback as the case of[2], and the other cases negative temperature feedback with the addition positive reactivity of control rods, this is called reactivity - initiated accident. For ^{239}Pu fueled reactor, when reactivity of the reactor is increased by β, the reactor peak power increases by 83.8085 times of the initial value with saturated temperature of 1,503 (K). For HTR-M reactor, power increases by a factor of 53.5 times the initial value at equilibrium temperature of 1,000 (K) when the reactivity is increased by β.

REFERENCES

[1] Y. Chao, Al. Attard, A resolution to the stiffness problem of reactor kinetics, Nuclear Science and Engineering 90 (1985) 40-46.

[2] H.Vandam, Dynamics of passive reactor shutdown, Prog.Nucl.Energy, 30, (1996), 255.

[3] A. A. Nahla, E. M. E. Zayed,"Solution of the nonlinear point nuclear reactor kinetics equations", Prog. Nucl. Energy, P. (1-4), (2010).

[4] J.J. Duderstadt, L.J, L.J, L.J. Hamilton, Nuclear Reactor Analysis. John Wiley & Sons, 1976, pp. 233-251.

[5] D. McMahon, A. Pierson, A Taylor series solution of the reactor point kinetics equations, arXiv: 1001.4100, V2 (2010) 1-13.

[6] K. Kugeler, R. Schulten, High Temperature Reactor Technology, Springer, Berlin, 1989, pp. 246-260.

[7] G.J. Van Tuyle, G.C. Slovik, R.J. Kennett, B.C. Chan, A.L. Aronson, Analyses of unscramed events postulated for the PRISM design, Nucl. Technol.91 (1990) 165-184.