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Two group, three dimensional diffusion theory coupled with single heated channel model: A study based on xenon transient simulation of Tehran research reactor

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ABSTRACT

In this work xenon transient analysis of the Tehran research reactor (TRR) core from hot full power without poisoning to xenon saturation is carried out using neutronic and thermal hydraulic coupling. A complete two group, three dimensional neutronic model coupled with one dimensional single phase heat transfer model has been developed and applied to power distribution calculations. We used the WIMS-D5 cell calculation code in order to find a linear relation between important parameters (fuel temperature, moderator temperature and density, and xenon concentration) and group constants of different fuel assemblies. In this way, WIMS running will be bypassed at each time step. We developed and used the ANOMOS code that solves three dimensional diffusion equations using analytic nodal method by transverse leakage approximation in order to find the effective multiplication factor as well as flux and power distributions. Also, we developed and used a SHC code that solves the conservation equations for one dimensional axial homogeneous downward flow through channel using single heated channel model to find the assembly-wise fuel temperature, moderator temperature and density profiles versus generated power. The results have a good agreement with the safety analysis report of the TRR.

1. Introduction

During the course of operation of a nuclear reactor, the fission fragments and their many decay products accumulate. Among these substances there are some, xenon-135, in particular, which have large cross sections for thermal neutron absorption. These nuclei, therefore, act as reactor poisons and affect the multiplication factor, chiefly by decreasing the thermal utilization, as well as flux and power distribution. The concentration of fission product poisons in a reactor is related to the thermal neutron flux (or density). Consequently, when the reactivity is changed, so that there is an accompanying change in the neutron density, the concentration of fission product poisons will be affected and this will, in turn, influence the reactivity, It would appear, therefore, that some allowance for the effect of poisoning should be included in the reactor kinetic equations. However, the rate of change of fission product concentration with time is, in general, small compared to that of the neutron density. Hence, the equations giving the time rate of change of neutron density may be treated quite independently of those for the fission product poisons. The most conventional methods for xenon poisoning calculation usually apply point reactor model that makes possible an analytic treatment of the problem and also allows speeding up computations significantly (Kheradmand et al., 2010). Xenon stability (or more specifically, the degree to which the spatial flux distribution varies for a specific reactor design due to spatial xenon dynamics) has been a topic of interest in reactor control and safety studies (Strydom, 2008). Because of that more studies were done about xenon transient and stability (Onega and Kisner, 1979; Toshinsky et al., 1999; Jeong and Choi, 2000).

In this article, we use the steady state three dimensional neutronic and one dimensional thermal-hydraulic coupling to study slow (large time scale) xenon transients in the Tehran research reactor core. First of all, WIMS code (Askew et al., 1966) is used for generating group constants versus xenon concentration, fuel temperature, and moderator density and temperature as a linear relation. Then, we used the developed ANOMOS and SHC codes for neutronic and thermal-hydraulic calculations, respectively. The most important assumption in this work is the adiabatic approximation in computational process. In other words, this

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Nomenclature

ACMFD	Analytic Coarse Mesh Finite Difference
ANM	Analytic Nodal Method
TRR	Tehran Research Reactor
∇	Nabla operator
∇^2	Laplace operator
$\|\rangle$	Column vector symbol
[]	Matrix symbol
$\overline{\varphi}$	Surface average nodal flux
$\overline{\overline{\varphi}}$	Volumetric average nodal flux
$\overline{\Psi}$	Surface average modal flux
$\overline{\overline{\Psi}}$	Volumetric average modal flux
$\bar{J}$	Surface average nodal current
Exp()	Exponential function
ρ	Water density
P_h	Heated Perimeter
A_z	Flow channel area
p	Pressure
H	Enthalpy
h	Convective heat transfer coefficient
f	Friction Factor
G	Mass flux
T_f	Fuel temperature
T_m	Moderator temperature
D_e	Equivalent Diameter

approximation assumes that at large time scale (one hour) shape function is changing very slowly. Then, the time dependent terms in neutronic and thermal-hydraulic equations are negligible.

2. Main specifications of TRR

Tehran research reactor (TRR) is an open pool type reactor with a maximum thermal power of 5 MWth. The TRR's fuel is U_3O_8–Al with 20% enriched uranium (LEU). There are two types of fuel assemblies, i.e. Standard Duel Element (SFE) and Control Fuel Element (CFE). Table 1 displays the main specifications of the TRR (AEOI, 2009).

First operating core of TRR has 14 SFEs and 5 CFEs (Fig. 1).

3. Xenon poisoning

From the viewpoint of criticality and control, the isotope xenon-135 is the most important of all the fission products. It has a large absorption resonance that peaks at 0.082 eV and results in an absorption cross section of approximately 2.7 million barns at 0.025 eV. Xenon-135 is formed from the decay of iodine-135 (6.7 h half-life) and is itself radioactive (9.2 h half-life). It is part of the fission chain shown in Fig. 2, where all the decay constants λ^j are in 1/sec and the fission fractions γ^{Te} and γ^{Xe} are those appropriate to thermal fission of uranium-235. None of the absorption cross sections in the chain except that of Xe-135 are large enough to be of any significant.

The decay of tellurium-135 is so fast, and that of cesium-135 is so slow (2.6 million year half-life), that we may assume for our purposes that iodine-135 is formed directly from fission with a yield 0.064 and that the chain ends with the destruction, by β decay or neutron absorption, of xenon-135. Then, if I(r,t) and X(r,t) represent the concentrations of iodine-135 and xenon-135 at some location $\vec{r}$ in the reactor, the equations specifying the time dependence of these concentrations may be written,

$$\frac{\partial I(r,t)}{\partial t} = \gamma^I \sum_f (r,t)\varphi(r,t) - \lambda^I I(r,t) \tag{1}$$

$$\frac{\partial X(r,t)}{\partial t} = \gamma^{Xe} \sum_f (r,t)\varphi(r,t) + \lambda^I I(r,t) - \left\{\sigma_a^{Xe}\varphi(r,t) + \lambda^{Xe}\right\} X(r,t) \tag{2}$$

where $\sum_f(r,t)$, $\varphi(r,t)$ and σ_a^{Xe} are macroscopic fission cross section, neutron flux, and microscopic absorption cross section for xenon-135. We shall think of the yields as representing averages over the fissionable isotopes present at location and over the energy spectrum of the neutrons causing fission at that point (Henry 1975). For constant flux the solutions to Eqs. (1) and (2) are (Stacey, 2007):

$$I(r,t_0+\Delta t) = \frac{\gamma^I \sum_f (r,t_0)\varphi(r,t_0)}{\lambda^I}\left\{1 - e^{-\lambda^I \Delta t}\right\} + I(r,t_0)e^{-\lambda^I \Delta t} \tag{3}$$

Table 1
Main specifications of TRR (AEOI, 2009).

Type	Open pool
Power	5 MWth
Fuel	LEU (U_3O_8–Al)
First criticality	December, 1992
Geometry of fuel	Flat plates
Number of fuel plates per SFE	19
Number of fuel plates per CFE	14
Number of SFE in the FOC	14
Number of CFE in the FOC	5
Reflector	Water
Cooling system	Forced flow
Coolant and moderator	Light water
Primary flow	500 m^3/hr
Absorber material	Cd, In, Ag (shim rods)
	Stainless steel (reg. rod)

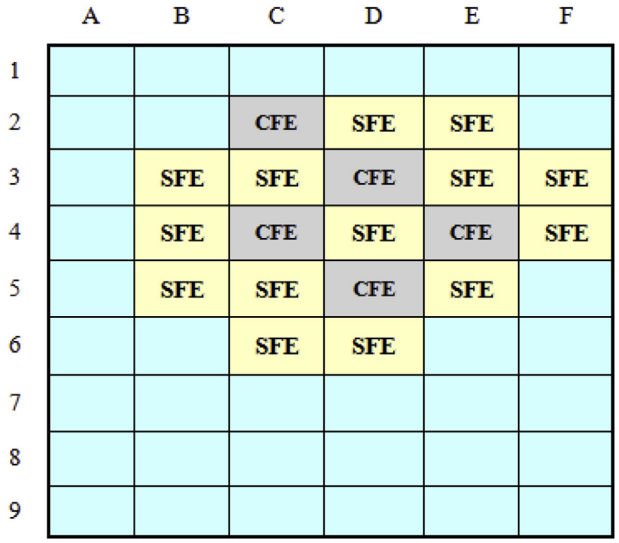

Fig. 1. First operating core configuration of TRR.