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ONE-DIMENSIONAL TERMOHIDRAULIC MODEL OF THE NUCLEUS AND LOWER AND UPPER POOL REGIONS OF THE REACTOR RMB

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ABSTRACT

The computer codes used in construction of nuclear reactors projects, specifically with regard to the thermo-hydraulics concepts part of your core, whose main goal reproduce actual operating conditions in order to predict quantitatively the limiting conditions of operation so that the safety limit is not exceeded. Computational methods for studies of fluid flow are developed around the world, including Brazil. With the evolution of computers application of numerical methods greatly reduced response time results, and tends to further decrease the extent that the computers and processors develop, making it feasible to use programming accident simulations of heat transfer reactors.

The software developed in this paper presents a method for analyzing the thermo-hydraulic behavior of the Brazilian Multipurpose Reactor (RMB) after its shutdown. The software solves the conservations equations applied to the core and also the lower and upper regions of the RMB. The thermo-hydraulics characteristics studied are: the temperatures of the core, cladding and refrigerant, the mass flow and the heat transfer. The numerical resolution was performed using the Matlab language and the outputs are presented in graphs and tables forms.

1. INTRODUCTION

Some computer codes that make real simulation of a power reactor, are developed and applied also in research reactors, where every year experts develop new skills and safety techniques that will be applied in the field. Among the computer codes used in most simulations of nuclear reactors, include: RELAP5, COBRA-III and IV, TRAC, ATHLET, CATHARE and PARET / ANL [1]. The motivation to study research reactors comes from a detailed analysis of its function may contribute to the safe use and lifetime of power reactors. The Brazilian Multipurpose Reactor (RMB) project under development by the National Commission of Nuclear Energy (CNEN), due to start operating in the municipality of São Paulo Iperó 130 kilometers from São Paulo, with the Center for Experimental Aramar, Navy, where developed the prototype of the Brazilian nuclear submarine. It is a research reactor and radioisotope production of molybdenum-99 (Mo-99), which is a by-product technetium-99m (Tc-99m), radiopharmaceutical in Brazil used extensively in the medical field. Technetium-99m is used in over 80% of nuclear medicine procedures in the country, which corresponds to approximately 3.5 million per year for medical procedures [1]. Besides the production of radioisotopes, the RMB also has basic functions such as conducting irradiation tests of nuclear fuels and structural materials used in power reactors, as well as conducting scientific research with neutron beams, acting as a complement to the National Laboratory Synchrotron Light (LNLS). The venture RMB is being coordinated by the Research and Development CNEN with the participation of its research institutes and has a partnership with other institutions of the Brazilian nuclear sector.

2. METHODOLOGY

The computer codes used in construction projects of nuclear reactors, specifically with regard to the thermo-hydraulic its core, has the main objective to analyze actual operating conditions in order to predict quantitatively the operating conditions so that the limit security is not exceeded. In a nuclear reactor in actual operation, the temperature should not exceed the melting temperature of the material constituting the cladding of the fuel even possible the occurrence of reactions between the fuel material and lining, which would geometric and structural change of the fuel element, causing poor performance.

2.1 The thermo-hydraulic model of the nucleus and the pool of Brazilian Multipurpose Reactor (RMB)

The Thermo-Hydraulic Model code - Brazilian Multipurpose Reactor (MT-RMB.V1) was developed to simulate the natural convection that occurs in a pool type reactor after its shutdown. It was developed to study the parameters of RMB 30 MW [2]. We used a simplified manner (one dimensional) of the equations of motion of the refrigerant, coupled to the energy equations of fluid and heat conduction in the fuel rods. The results were used for a pre-assessment of an auxiliary removal of residual heat. The simulation also allows calculations detailing the transfer of heat by convection and mass flow rate of this reactor.

2.1.1. Heat conduction in the fuel and coolant RMB

To calculate the temperature distribution in the fuel, coolant and a channel average cooling the reactor core uses a model of concentrated parameters. The temperatures of the upper and lower regions of the well of the reactor are calculated using a form (simplified) of the homogeneous equation of energy conservation. A simplified form of the equations of motion are used to calculate the flow rate of natural convection and heat transfer coefficient of the coating liquid fuel. Taking into account the diffusion of heat in the fuel and in jacket via a thermal resistance equivalent written as:

$$C_1 \frac{dT_1}{dt} = q'_1(t) - \frac{T_1 - T_2}{E_1} \quad (1)$$

$$C_2 \frac{dT_2}{dt} = q'_1(t) \left[\frac{A_1}{E_2} - \frac{B_1}{E_1} \right] + \frac{T_1 - T_2}{E_1} - \frac{T_2 - T_3}{E_2} \quad (2)$$

$$C_3 \frac{dT_3}{dt} = \frac{T_2 - T_3}{E_2} - \frac{T_3 - T_5}{E_3} \quad (3)$$

where:

T_1 is the average temperature of the fuel;

T_2 , the temperature of the coating;

T_3 , coolant temperature;

T_5 , the temperature of the lower chamber.

$$C_1 = \pi R_1^2 \rho_1 C_{p1} \quad (4)$$

$$C_2 = \pi (R_2^2 - R_1^2) \rho_2 C_{p2} \quad (5)$$

$$C_3 = (\rho^2 - \pi R_2^2) \rho_3 C_{p3} \quad (6)$$

$$E_1 = (8\pi k_1)^{-1} + (2\pi R_1 h_g)^{-1} \quad (7)$$

$$E_2 = (2\pi R_2 h_f)^{-1} \quad (8)$$

$$E_3 = L(2\dot{m}_3 C_{p3})^{-1} \quad (9)$$

$$A_1 = \left[0,25 - 0,5 R_2^2 (R_3^2 - R_2^2)^{-1} \ln \left(\frac{R_3}{R_2} \right) \right] (\pi k_2)^{-1} \quad (10)$$

$$B_1 = \left[0,5 R_3^2 (R_3^2 - R_2^2)^{-1} \ln \left(\frac{R_3}{R_2} \right) - 0,25 \right] (\pi k_2)^{-1} \quad (11)$$

Temperatures in the upper and lower chambers are calculated using the following energy balance based on the delay models of fluid transport ("transport delay").

$$C_4 \frac{dT_4}{dt} = \frac{T_7 - T_4}{E_4} \quad (12)$$

$$C_5 \frac{dT_5}{dt} = \frac{T_4 - T_5}{E_4} \quad (13)$$

where:

T_4 is the temperature of the upper chamber;
 T_7 , the outlet temperature of the coolant of the reactor core.

$$C_4 = \rho_4 C_{p4} V_4 \quad (14)$$

$$C_5 = \rho_5 C_{p5} V_5 \quad (15)$$

$$E_4 = (\dot{m}_3 C_{p3})^{-1} \quad (16)$$

Assuming a linear distribution of temperature of the fluid in the core, caused by gradual heating along the length of the fuel, one can write:

$$T_3 = 0,5(T_5 + T_7) \quad (17)$$

$$C_4 \frac{dT_4}{dt} = \frac{2T_3 - T_4 - T_5}{E_4} \quad (18)$$

Writing the equations (1), (2), (3), (17) and (18) in matrix form yields:

$$\frac{d\Psi}{dt} = A\Psi + \xi \quad (19)$$

where:

$$\Psi = \text{col}[T_1, T_2, T_3, T_4, T_5] \quad (20)$$

$$\xi = \text{col}\left[\frac{q'_1}{C_1}, \frac{q'_1}{C_2} \left(\frac{A_1}{E_2} - \frac{B_1}{E_1}\right), 0, 0, 0\right] \quad (21)$$

$$A = \begin{bmatrix} \frac{-1}{C_1 E_1} & \frac{1}{C_1 E_1} & 0 & 0 & 0 \\ \frac{1}{C_2 E_1} & -\left[\frac{1}{E_1} + \frac{1}{E_2}\right] & \frac{1}{C_2 E_2} & 0 & 0 \\ 0 & \frac{1}{C_2 E_2} & -\left[\frac{1}{E_2} + \frac{1}{E_3}\right] & 0 & \frac{1}{C_3 E_3} \\ 0 & 0 & \frac{-2}{C_4 E_4} & \frac{-1}{C_4 E_4} & \frac{-1}{C_4 E_4} \\ 0 & 0 & 0 & \frac{1}{C_5 E_4} & \frac{-1}{C_5 E_4} \end{bmatrix} \quad (22)$$

Integrating equation (19) using the Crank-Nicolson, are obtained:

$$\left[I - \frac{h}{2} A^{(1)}\right] \Psi^{(1)} = \left[I + \frac{h}{2} A^{(2)}\right] \Psi^{(0)} + \frac{h}{2} [\xi^{(0)} + \xi^{(1)}] \quad (23)$$

Setting up:

$$A_0 = \frac{h}{2C_1 E_1} \quad (24)$$

$$B_0 = \frac{h}{2C_2 E_1}$$

$$C_0 = \frac{h}{2C_2 E_2}$$

$$D_0 = \frac{h}{2C_3E_2}$$

$$E_0 = \frac{h}{2C_3E_3}$$

$$F_0 = \frac{h}{2C_4E_4}$$

$$G_0 = \frac{h}{2C_5E_4}$$

It is written:

$$B^0 = \left[I + \frac{h}{2} A^{(0)} \right] = \begin{bmatrix} 1 - A_0 & A_0 & 0 & 0 & 0 \\ B_0 & 1 - B_0 - C_0 & C_0 & 0 & 0 \\ 0 & D_0 & 1 - D_0 - E_0 & 0 & E_0 \\ 0 & 0 & 2F_0 & 1 - F_0 & F_0 \\ 0 & 0 & 0 & G_0 & 1 - G_0 \end{bmatrix} \quad (25)$$

$$\left[I - \frac{h}{2} A^{(1)} \right] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ c & 1 & 0 & 0 & 0 \\ 0 & f & 1 & 0 & 0 \\ 0 & 0 & l & 1 & 0 \\ 0 & 0 & 0 & p & 1 \end{bmatrix} * \begin{bmatrix} a & b & 0 & 0 & 0 \\ 0 & d & e & 0 & 0 \\ 0 & 0 & g & 0 & k \\ 0 & 0 & 0 & m & n \\ 0 & 0 & 0 & 0 & q \end{bmatrix} \quad (26)$$

where;

$$a = 1 + A_0$$

$$b = -A_0$$

$$c = -\frac{B_0}{a}$$

$$d = 1 + B_0 + C_0 - b * c \quad (27)$$

$$e = -C_0$$

$$f = -\frac{D_0}{d}$$

$$g = 1 + B_0 + E_0 - e * f$$

$$k = -E_0$$

$$l = -2 \frac{F_0}{g}$$

$$m = 1 + F_0$$

$$n = F_0 - k * l$$

$$p = -\frac{G_0}{m}$$

$$q = 1 + G_0 - n * p$$

being;

$$Z = B^0 \Psi^0 + (\xi^0 + \xi^1) \frac{h}{2} \quad (28)$$

Gets the coefficients;

$$x_1 = z_1$$

$$x_2 = z_2 - cx_1$$

$$x_3 = z_3 - fx_2 \tag{29}$$

$$x_4 = z_4 - lx_3$$

$$x_5 = z_5 - px_4$$

$$T_5 = \frac{x_5}{q}$$

$$T_4 = [x_4 - nT_5]/m$$

$$T_3 = [x_3 - kT_5]/g \tag{30}$$

$$T_2 = [x_2 - eT_3]/d$$

$$T_1 = [x_1 - bT_2]/a$$

2.1.2. The model termoidr ulico core and pool Brazilian Multipurpose Reactor (RMB)

The Brazilian Multipurpose Reactor is a pool type reactor, with its cobblestone-shaped core and fuel elements in the form of plates. When the suction of the cooling pumps stop working, two valves that operate by pressure, release flow by natural circulation. This is what happens when the reactor is shut down and the core begins to be cooled only by natural circulation. In the shutdown state of the reactor, the water heated by the core up through the chimney by natural convection reaching the top of the pool, losing energy and falling thereafter the flow tubes, generating a flow of water that will remove the residual heat present in the core.

The circulation flow rate is directly proportional to the power of this reactor, namely, the higher the power, the greater the flow velocity and hence the removal of heat. Figure 1 shows the schematic of the cooling core of Brazilian Multipurpose Reactor.

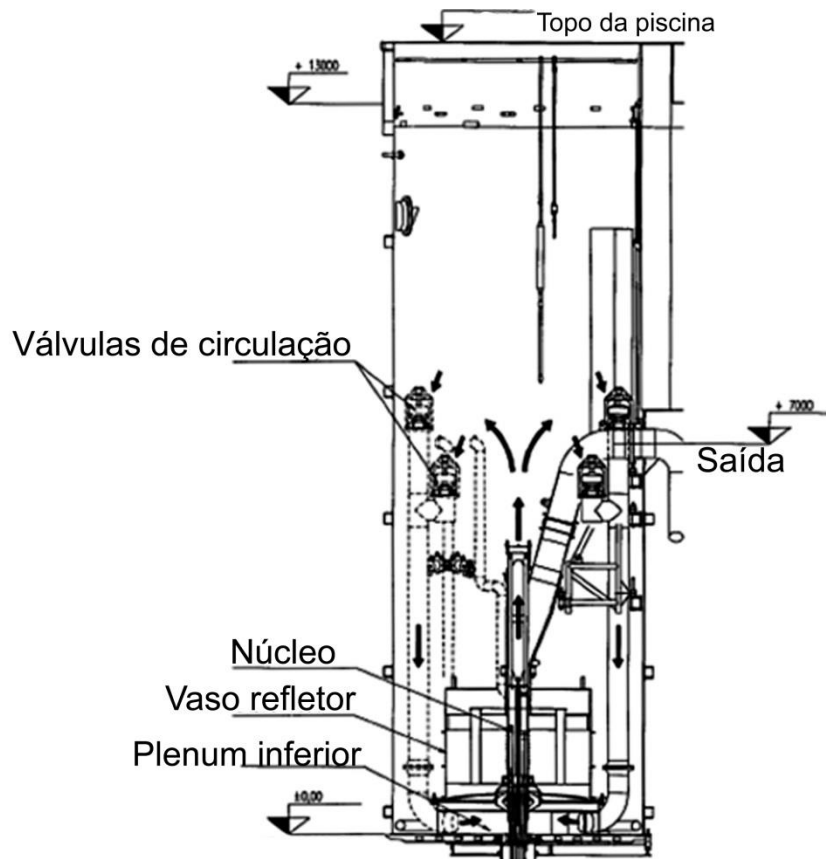


Figure 1: Schematic of the RMB core cooling by natural convection.

Reactor for both Production of Radioisotopes for when the Brazilian Multipurpose Reactor, the motion equation and the approximations calculated remains the same, changing only the physical characteristic of reactors such as volume chambers, size, fuel, thermal conductivity, type fuel, power, operating time, initial temperatures and so on.

3. RESULTS

The validation code MT-RMB.V1 was made by comparing the results with those obtained using Thermo-Hydraulic Model Code Natural Convection in reactors made by researchers from the Institute of Nuclear Engineering (IEN) in 1984. The following Figure 2 show the behavior of the system before the power shutdown highlighting the evolution of fuel temperature and coating.

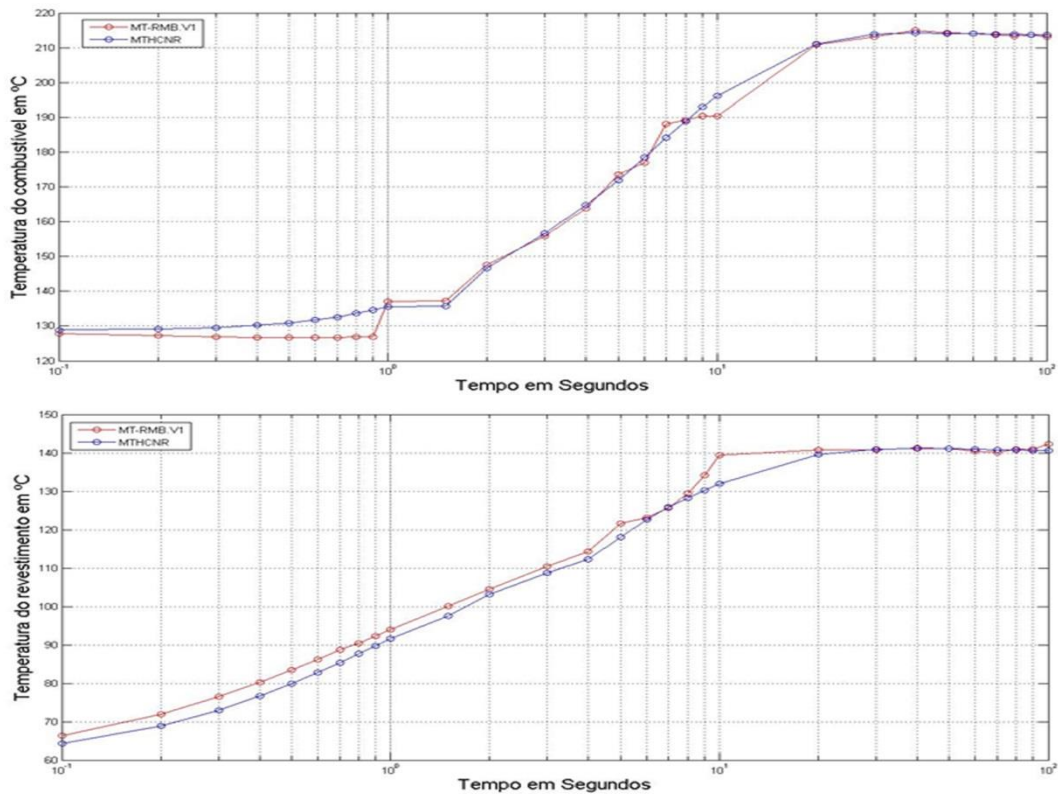


Figure 2: Evolution of the temperature of the fuel and coating with the reactor at full power.

Figure 3 shows the evolution of the core temperature of the RMB after reactor shutdown, simulated by the code-RMB.V1 MT (red). The core temperature falls gently from 45 ° C (core temperature value before shutdown) until it reaches a new level of around 35 ° C, after 3 hours. The average temperature of the pool water with the reactor in normal operation, varies around 35 ° C and 45 ° C for hot water this layer, the upper region of the reactor core [Oliveira, 2012].

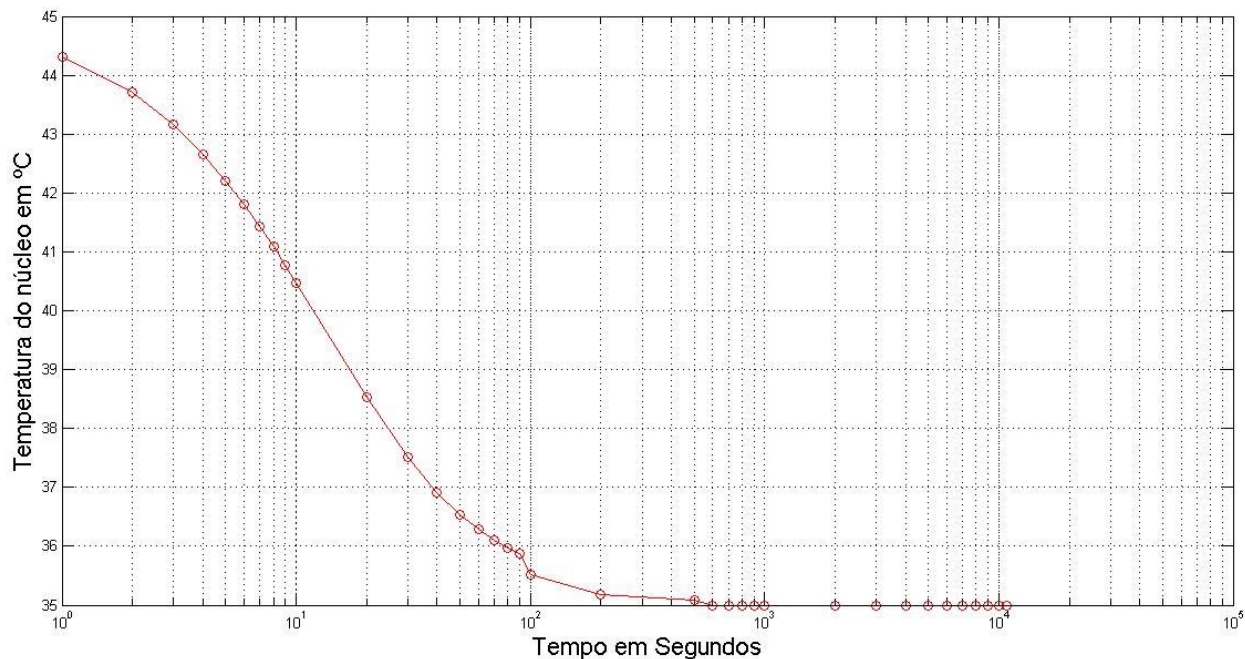


Figure 3: Evolution of the core temperature of the RMB after reactor shutdown.

4. CONCLUSIONS

The MT-RM.V1 code developed in Matlab to solve the simplified model proposed was initially valid through MTHCNR code, developed by researchers at the IEN, simulating the behavior of the reactor core termoidráulico RPR. A Root Mean Square Error maximum of 0.0309% between the values simulated by the codes found in the simulation of the temperature of the coating after reactor shutdown, which demonstrates the good performance of the developed code.

The results obtained with the simplified model developed can be concluded that there will be no problems with high temperatures in the fuel and coat, in the first moments of a casualty loss of forced flow, provided it has been properly shut down the reactor.

The results showed that the design of the reactor core RMB does not exceed safety limits and that the removal of residual heat from the core and the reactor pit, after the shutdown of it, is guaranteed by the natural circulation of the coolant.

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