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"Object-Oriented Modeling and simulation of a TRIGA reactor plant with Dymola"

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Abstract

This work presents the modeling and simulation of a TRIGA-Mark II pool-type reactor with Zirchonium-Hydryde and Uranium fuel immersed in light water, with Modelica object-oriented language, in Dymola simulation environment. The model encompasses the integrated plant system including the reactor pool and cooling circuits.
The reactor pool plays a fundamental role in the system dynamics, through a thermal feedback effect on the reactor core neutronics. The pool model is tested against three experimental transients: simulation results are in good accordance with experimental data and provide useful information about the inertial effect of the water inventory on the reactor cooling.

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Keywords: Reactor dynamics; reactor pool; object-oriented simulation; Modelica; TRIGA

1. Introduction

Nowadays, validated and well-recognized tools for numerical simulation of accident transient behavior in reactor plants are available. On the other hand, control-oriented simulation models have to feature, at the same time, a good level of accuracy and the capability to represent a wide range of operating conditions and transients, at a viable computational effort. In other words, they have to be flexible and robust to a wide change in the input conditions and provide reliable prediction of system dynamics, in reasonable computational time. The Modelica language [1,2] offers an object-oriented approach that makes the modeling of complex systems flexible, modular and re-usable. Components are based on non-linear, first-principles models and are either lumped-parameter models or 1-D

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distributed parameter models. The degree of detail is suited to system studies, while offering acceptable computational time. Modelica language has already been used in the nuclear field [3,4] to simulate the dynamics of an integral-type PWR, in its concept-design phase. This work presents a simplified model of a TRIGA-Mark II (Training Research and Isotope production General Atomics), whose simulation results have been tested against experimental data. A model of the same plant has been presented in [5,6], limitedly to the reactor core, by means of Matlab-Simulink modeling tool, with a causal approach. This model simulated the core dynamics with thermal feedback to the neutronics. The response to reactivity insertion transients was coherent with experimental data on the reactor power dynamics.

In this pool-type reactor plant, the pool thermodynamics is of capital importance in the overall system behavior, since it provides a relevant thermal inertia that influences the core neutronics through the fuel temperature, the coolant temperature and density feedback. For this reason, this work extends the scope of simulation to the full plant including the reactor pool and the hydraulic cooling systems, while adopting the object-oriented modeling approach. This work is a first step in the set-up of a control-oriented simulation strategy [7].

An experimental campaign is currently on-going on the TRIGA plant, to record the temperature measurements of the reactor pool and primary circuit, during different power and cooling transients. The accuracy of the simulation model presented in this work has been validated against these experimental data.

Nomenclature

α_f	reactivity change per fuel temperature change, $pcm{\cdot}K^{-1}$
α_m	reactivity change per coolant temperature change, $pcm{\cdot}K^{-1}$
α_d	reactivity change per coolant density change, $pcm{\cdot}m^3{\cdot}kg^{-1}$
CFD	Computational Fluid Dynamics
PID	Proportional–Integral–Derivative
PWR	Pressurized Water Reactor
RTD	Resistance Temperature Detector
UZrH	Uranium-Zyrconium Hydride

2. The TRIGA plant

The TRIGA-Mark II reactor at the Laboratorio Energia Nucleare Applicata (L.E.N.A.) of the University of Pavia is a research pool-type reactor with nominal power of 250kW, in operations since 1965. The reactor core is placed at 0.6 m from the bottom of an Aluminum-concrete cylindrical pool (6.25 m height; 1.98 m diameter), containing 18.9 m^3 of water. A graphite reflector ring surrounds the core [8].

Neutrons are moderated by the demineralized water contained in the pool and by the fuel itself. The specific composition of the low-enriched (slightly less than 20%) Uranium-Zirconium Hydride (UZrH) fuel, with 8.5% U in weight. has a large prompt negative thermal coefficient of reactivity. This means that, as the temperature of the core increases, the reactivity undergoes a prompt decrease. Due to the particular interaction of thermal neutrons with the Hydrogen in the fuel lattice, an increase in fuel temperature is able to increase the chance for low neutrons to be accelerated instead of being slowed during an elastic scattering. As a result, the prompt temperature coefficient of fuel is due for more than 80% to the behavior of Hydrogen in the UZrH lattice and for 20% to the Doppler effect and the fuel thermal expansion. Two different fuel element types feature the core configuration: Aluminum clad (Al-1100F alloy) and stainless steel clad (304-SS alloy). Ninety slots are placed in the core in six concentric rings, with 83 fuel elements and 3 control rods - named SHIM, Regulating (REG) and Transient (TRANS) (Fig.1).

The hydraulic system of the TRIGA-Mark II at L.E.N.A. is made up of three separate circuits interfaced with each other: the primary (I), the secondary (II) and the tertiary circuits (III) respectively. An active heat removal system draws the water from the top of the reactor pool and sends it to a the primary hydraulic system, where it goes through a shell-and-tube heat exchanger with exchange surface of 30.7 m^2 and is re-injected above the core upper plate. An intermediate closed loop removes the heat through a second, plate-type heat exchanger, with 45 plates and total exchange surface area of 10.3 m^2. This is interfaced with a tertiary open cooling line [9], that draws coolant