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Transient analyses to support the definition of trade experiment start-up procedures

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Abstract

The TRADE experiment, where a TRIGA reactor in subcritical configuration is coupled with a proton accelerator (cyclotron) through a spallation target interface, is conceived to demonstrate the feasibility of the coupling of the different components of an ADS (accelerator, target and subcritical core) at a thermal power level able to trigger the reactivity thermal feedbacks. Among the main purposes of the TRADE experiments there is the investigation of the start-up and shutdown procedures, to be defined as much as possible according to the TRIGA-RC1 safety approach. In this paper a preliminary analysis of TRIGA transients induced by accidental jumps of the cyclotron proton beam current impinging on the target assuming different subcriticality levels of the core has been carried out by means of TIESTE-MINOSSE and PARCS/RELAP5 codes, both able to treat coupled neutron kinetic and thermal-hydraulics.

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Keywords: Accelerator-driven systems; Safety; Accidental transients

1. Introduction

In accelerator, target and subcritical core (ADS) [1], sudden risings of the proton beam intensity (called beam jumps) cannot be completely excluded as accidental events [2], in particular during start-up. The present work aims at contributing in the definition of TRADE experiment [3] start-up procedures by preliminarily investigating these transients, induced by accidental jumps of the cyclotron beam current intensity. Beam jumps have been assumed to start from low values of the beam intensity, typical of start-up procedures, and to be unprotected, i.e. any rod insertion or beam switch-off command consequent to too high power or power variation signals have been pessimistically assumed to fail.

Different TRADE configurations at different subcriticality levels have been considered with the worst assumption on the beam jump: from a minimum cyclotron current, provided for each transient, to the maximum cyclotron current of about 300 μA.

A first analysis has been performed by means of the fast-running TIESTE-MINOSSE (T/M) code [4] in order to analyse the accidental sequence in a wide range of scenarios and a confirmatory analysis in the most critical cases has been carried out using a more detailed model by means of the best-estimate PARCS/RELAP5 (P/R5) code [5].

Similar approach can be followed for the safety analyses required in a licensing procedure and applied to other coupling experiments in TRIGA reactors such as the US RACE experiment.

2. Investigated trade configurations

The configurations taken into account in the T/M code are a "low K" (−8\$, $k_{\mathrm{eff}}\sim 0.947$ at 200 kW), a "high K" (−1.74\$, $k_{\mathrm{eff}}\sim 0.988$ at 200 kW) and "very high K" (−0.72\$, $k_{\mathrm{eff}}\sim 0.995$ at 200 kW). Concerning the last configuration, where the system would become critical for lower power levels (about 30 kW) if control rods should not

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be inserted to compensate the lower feedback effects, T/M results have been compared to the investigations performed by means of the P/R5 code.

For each configuration, two cases of accidental beam jumps have been considered occurring from low level of beam intensity (1.75 μA), moreover the larger beam jump has been also simulated from complete beam interruption to evaluate the impact of the initial level assumption:

- "jump 1" to the beam intensity corresponding to the 200 kW nominal reference power level;
- "jump 2" to the maximum current intensity of the cyclotron (about 300 μA);
- "jump 2" from zero current to the maximum current intensity of the cyclotron (about 300 μA).

2.1. T/M analysis of "low K" and "high K" cases

TIESTE-MINOSSE is a fast-running code developed at the ENEA to carry out analyses of ADS core dynamics by coupling thermal hydraulics (TH) and point neutron kinetics (NK) models. MINOSSE solves the point NK equation by the "spectral method" when variable reactivity and/or external source are given. TIESTE can represent a single reactor channel, with fuel, clad and coolant zones.

The code takes into account the feedback on the reactivity due to the Doppler or any other fuel temperature effect, coolant density transient, clad dilatation.

For the present TRADE analysis only the fuel feedback effects have been considered. Based on experimental data, two different linear dependences of the fuel feedback coefficient on the fuel temperature have been assumed and completely defined by three couples of values: (293 K, −0.5 ¢/K), (427 K, −2.1 ¢/K), (526 K, −1.4 ¢/K) [6].

Results relevant to the "low K" and "high K" configurations, shown in Figs. 1 and 2, respectively, show that the maximum power level reached in the −8$ TRADE configuration is about 215 kW in the "jump 1" case and about 360 kW in the "jump 2", while in −1.74$ configuration the maximum power level reached is about 255 kW in the "jump 1" and about 1550 kW in the "jump 2".

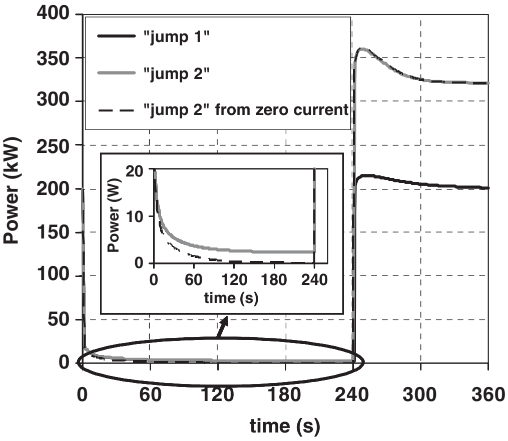

Fig. 1. Power transients in the −8$ TRADE configuration.

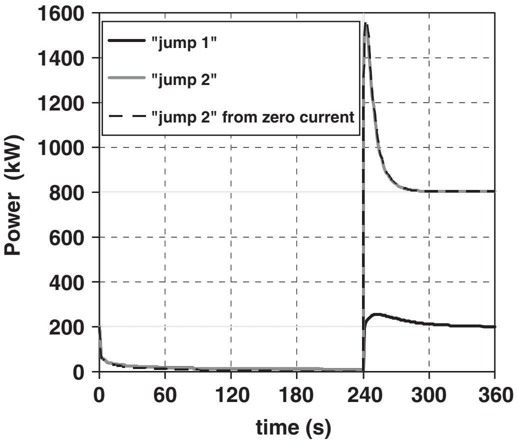

Fig. 2. Power transients in the −1.74$ TRADE configuration.

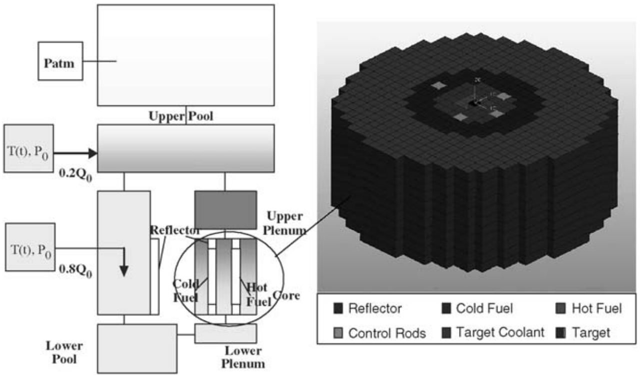

Fig. 3. PARCS/RELAP5 Nodalization of TRIGA RC-1 in Subcritical configuration.

Fuel temperature and heat flux results confirm that the beam jump induced transients are higher on configurations closer to criticality.

2.2. T/M and P/R5 analysis of "very-high k" case

Thermal-hydraulic code RELAP5 and neutronic 3D code PARCS were originally coupled for the transient analysis of water-cooled critical systems using the parallel virtual machine technique. Within the frame of Italian ADS research programs (TRASCO) the application field was extended to subcritical systems [5]. The code is able to model the coupled behaviour of the whole reactor systems for a wide range of accidents and operational transients.

The reactor TRIGA model combines a 1D description of the reactor pool T/H with a 3D core neutronics (Fig. 3) that provide the spatial distribution of neutronic source and fuel feedback reactivity coefficients [7].

The reference P/R5 code has been used to simulate this worst case and the results compared to the T/M ones.