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ScienceDirect

Nuclear Energy and Technology 2 (2016) 60–63

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The research of feasible temperature modes in the ampoule channel with natural circulation

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Available online 6 May 2016

Abstract

The paper presents the results of a computational analysis into the thin-wall sample cooling during in-pile irradiation in a two-body ampoule channel with heat transfer by natural convection. A two-body design of the channel makes it possible to change the channel wall heat resistance with the channel heat leak regulation by varying the gas composition and pressure inside the gap between the bodies. The purpose of the study is to determine the feasible sample cooling conditions in the considered channel. The computational analysis was based on a thermal-hydraulic code, RELAP5/MOD3.2. For the calculations, helium and nitrogen were assumed to be the filling gas for the gap between the bodies. Major regularities in the variation of irradiation temperatures have been shown depending on the power density in the channel and irradiation device structural materials, the circulation circuit height, and the channel wall heat resistance. By varying the circulation circuit height and the power density in the structural materials, it is possible to provide inside the ampoule channel the sample cooling temperatures in a range from the circumambient primary coolant temperature to the boiling temperature at a given pressure (50–331 °C). With no coolant boiling on samples and with the maximum (8 m) circulation circuit height, not more than 55 kW (14 W/g on samples) is removed when helium is used as the gap filling gas and not more than 15 kW (3.7 W/g on samples) is removed when nitrogen is used, while, with the minimum (1 m) circulation circuit height, the respective values are not more than 10 kW (2.5 W/g on samples) and 5 kW (1.2 W/g on samples).

Keywords: SM research reactor; Natural-circulation ampoule channel; Investigation results; Irradiation temperatures; Power density.

Introduction

The evolution of nuclear power requires more extensive and in-depth studies in the field of reactor material science. The use of loop facilities is the simplest way to ensure the required irradiation conditions for the experiment. However, due to heavy loading of the existing loop facilities, there is an acute need for a tool to be developed to provide the required environment for irradiation of materials inside the reactor [1]. An ampoule channel design based on natural coolant circulation has been proposed as part of the efforts to build such tool. The purpose of the study is to identify the potential modes for the sample cooling via natural convection in the ampoule channel.

This study aims to investigate the major regularities of the thin-wall sample cooling during irradiation in a two-body channel with a gas gap installed in the SM-3 reactor facility reflector cells [2].

Input for the calculation

A diagram of the natural-circulation channel is shown in Fig. 1 [3].

The channel consists of two pressurized bodies 1, 2 separated by a gas gap with a thickness of 1.35 mm. At the level

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Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).

Russian text published: Izvestia Visshikh Uchebnikh Zavedeniy. Yadernaya Energetika (ISSN 0204-3327), 2015, n.4, pp. 72-78.

http://dx.doi.org/10.1016/j.nucet.2016.03.012

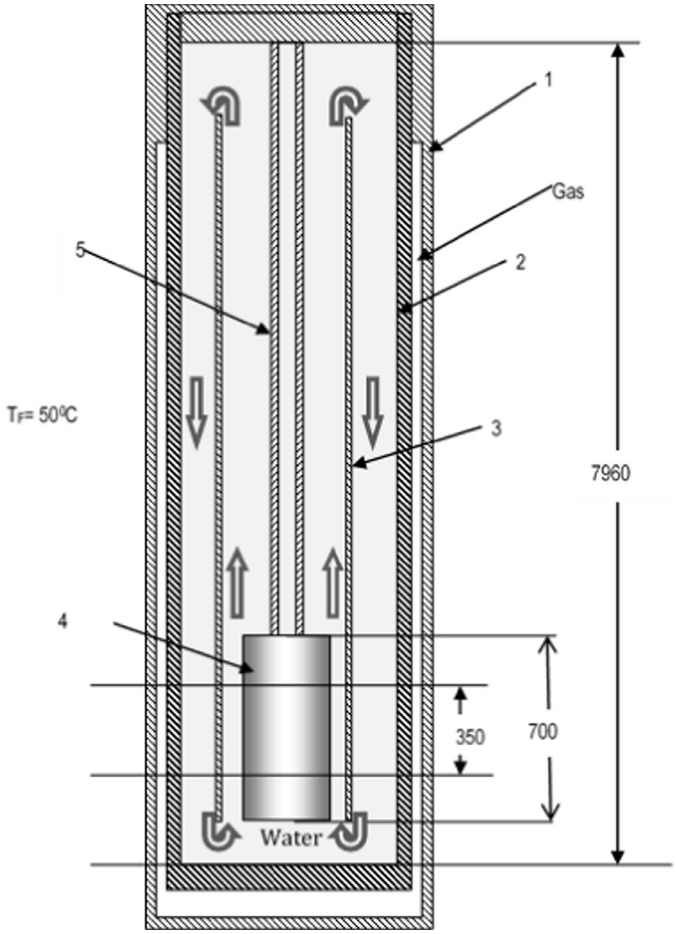

Fig. 1. A diagram of the natural-circulation channel: 1 – outer body; 2 – inner body; 3 – divider; 4 – holder simulator with samples; 5 – rod. 1 – T_F; 2 – Water; 3 – Gas.

of the sample holder, the outer body is a tube of 62 × 3 mm, and the inner body is a tube of 53.3 × 2.65 mm. There is a flow divider 3 in the form of a tube of 38 × 1 mm inside the channel.

The irradiation device (ID) is installed inside the flow divider 4, 5. Samples have the form of thin-wall plates with a developed heat removal surface.

The irradiation temperature inside the natural-circulation ampoule channel is regulated by varying the channel body heat resistance through the selection of the gas parameters [4,5], as well as the circulation circuit height (by plugging the flow path and the overflow holes in the divider). The circulation circuit height is counted off from the channel bottom and may vary in a range of 1 to 8 m.

The computational analysis of the temperature conditions achievable in the natural-circulation ampoule channel was conducted depending on the following parameters:

– Total power density (in the channel structural materials, in the ID with samples);
– Circulation circuit height;
– Channel body heat resistance.

Table 1
Power density distribution in the ampoule channel and ID structural elements.

Structural element	Fraction of power density, rel. units
Divider	0.07
ID	0.35
Body	0.58

The effects of these parameters on the sample cooling conditions were investigated using the RELAP5/MOD3.2 thermal-hydraulic code [6].

Input for the calculation:

– Channel and ID geometry;
– Divider, channel body and ID materials –12Kh18N10T steel;
– Coolant pressure inside the channel –13 MPa;
– Gas in the space between the bodies –helium or nitrogen of 0.1 MPa;
– Conditions of heat removal from the ampoule channel:
– Primary coolant temperature –50 °C;
– Primary coolant pressure –5 MPa;
Downward flow rate in the reactor's central shell – 1400 m^3/h;
– Upward flow circulation rate in the annulus with a 1 mm wide gap at the core level –1.5 m/s.

See Table 1 for the power density distribution in the channel and ID structural materials.

Calculation results

The potential temperatures of the sample cooling in the natural-circulation ampoule channel across the circulation circuit height range (from one to eight meters) are presented in Fig. 2. Helium with a pressure of 0.1 MPa is assumed to be the annulus filling gas [7].

The average coolant temperatures at the sample level are given on the abscissa axis, and the total power density inside the ampoule channel, the divider and the ID is given on the ordinate axis. One kilowatt generated in the ID corresponds to a specific power density of 0.7 W/g.

By varying the circulation circuit height and the power density in the ampoule channel, it is possible to regulate the sample cooling conditions in a range from the circumambient primary coolant temperature to the boiling temperature [8] at a given pressure (50–331 °C).

An increase in the circulation circuit height leads to a temperature decrease on samples due to a larger surface of the heat exchange with the primary coolant.

With the greatest possible circulation circuit height, the lower boundary of the total power at which boiling is achieved on samples is ~55 kW, which corresponds to ~20 kW (14 W/g) generated in the ID with samples. With the minimum circulation circuit height, a total of not more than 120 kW (3.5 kW (2.5 W/g) on samples) can be removed with no coolant boiling.