

CALCULATION OF THE TEMPERATURE DISTRIBUTION IN A TRIGA TYPE FUEL ELEMENT FOLLOWING THE PULSE OPERATION

Büke T.

Muğla University, Muğla, Turkey

ABSTRACT

Time dependence of temperature distribution in a TRIGA type fuel element following the pulse operation was calculated by using the computer code TEMPUL for different coolant velocities in the coolant channel.

The effect of the air gap produced between the fuel bulk and the cladding interface by pulsing was considered in the temperature distribution calculations.

The code was developed for the analysis of boiling crisis and DNB conditions in TRIGA core after the pulse operation and provided necessary database consisting of material properties for several types of TRIGA fuel. It solves the diffusion equation for heat transfer in cylindrical geometry using finite difference method.

The form of flow channel is equilateral triangle, bound by three cylindrical fuel elements. The coolant in coolant channel has a constant velocity, which is an input data and that axial power distribution is a cosine function.

The results from the calculation show that the fuel temperature will never be exceeded under any conditions of after the pulse operation.

1. INTRODUCTION

Investigations of transitional processes in the pulsed type reactors are important for the safety and reliability operation. Therefore a lot of theoretical and experimental studies have been performed to check the ability of the reactor to operate at pulsing conditions with sufficient safety margins [1-4].

The temperature distribution in a fuel element during pulsing conditions is completely different from that which occurs during steady state operation. Adiabatic conditions persist over most of the pulse duration and thus the peak fuel temperature during a pulse occurs near the fuel-cladding interface where the thermal flux is a maximum.

In practice, the manner in which the reactivity is reduced may depend in detail on the reactor design and on the rate at which the neutron population increases.

It is important to know time dependence of temperature distribution in fuel element after the pulse since large power excursions are of interest in a variety of situations, both real and hypothetical in TRIGA type reactors.

In this study, time dependence of temperature distribution in the fuel element of the TRIGA Mark-II reactor at the Istanbul Technical University (ITU) following the pulse operation was calculated by using the computer code TEMPUL [5] for different coolant velocities in the coolant channel. The effect of the air gap produced between the fuel bulk and the cladding interface by pulsing was considered in the temperature distribution calculations.

2. DESCRIPTION OF THE COMPUTER CODE TEMPUL

Time dependence of temperature distribution in a TRIGA type fuel element following the pulse operation was calculated by using the computer code TEMPUL. The code was developed for the analysis of boiling crisis and DNB conditions in TRIGA core after the pulse operation and provided with necessary database consisting of material properties for several types of TRIGA fuel elements.

It solves the diffusion equation for heat transfer in one-dimensional cylindrical geometry using finite difference method. All coefficients used in the diffusion equation are functions of

temperature and also of the material. They are given in a form of tables in the code. The temperature distribution immediately after the pulse is calculated by the code from known heat generation in a pulse and with the assumption that temperature distribution in a fuel rod before the pulse was uniform.

In TEMPUL code very similar boiling curve is used as it is used by “General Atomics”. It is divided into four heat transfer regimes. Each regime is characterized by different heat transfer mechanism. The correlations for the heat flux are incorporated into the code in all four regimes. They are derived with the assumption, that the coolant in coolant channel has a constant velocity, which is an input data, and that axial power distribution is a cosine function. It is also taken into account that at given flow velocity the coolant temperature is a function of core height and time. Two different types of coolant channels can be used; first one is characterized by equilateral triangular arrangement, while second one has fuel arranged in a square pitch. It is assumed that all coolant channels in the reactor core are the same. All the thermal properties of coolant in the coolant channel are bulk temperature dependent.

The gap between the fuel bulk and the cladding is treated as a perturbation, where the temperature distribution has a discontinuity. The gap thickness is a function of average fuel bulk and cladding temperature and gap conductivity is tabulated in dependence of temperature for two gases: for air and helium. Gap thickness at room temperature is input data. The temperature dependence of gap thickness is calculated by using the thermal expansion coefficients for fuel bulk and cladding.

Two test cases are presented in this study. In both the conditions after the pulse, where maximal fuel temperature achieved at 468 °C, are treated. This is the maximum fuel temperature in the ITU TRIGA Mark-II reactor core after the pulse. It is calculated by the code PULSTRI [3] that calculates maximum fuel temperature in a pulse using adiabatic Fuchs-Hansen approximation. Before pulsing the reactor was shut down, so that the room temperature was established all over the reactor tank. The form of coolant channel is equilateral triangle and three standard TRIGA fuel elements with 8.5 w/o of uranium and 20% enrichment surround it, flow velocity is 9 cm/s.

In first test case fuel bulk is in contact with the cladding, while in second case constant gap resistance is assumed and it is filled with air.

Fuel element is divided into 100 mesh points in the calculations and there are 3 homogeneous unit cells namely zirconium rod, fuel bulk and stainless-steel cladding beginning from the center of the fuel element. Bulk coolant temperature is calculated at core height since the highest value is achieved at the top of the core. The main input data are listed in Table 1 [6,7].

Calculated outer clad temperatures as functions of time after the pulse for different coolant velocities are shown in Fig.1.

To considering the effect of the air gap between the fuel bulk and the cladding interface, fuel-cladding interface and outer clad temperatures as functions of time after the pulse are shown in Fig.2 and Fig.3 respectively.

Table 1. Main input data used in the calculations

Explanation	Value
Maximum fuel temperature at the point of peak power	468 [°C]
Initial coolant temperature	33 [°C]
Radius of zirconium	0.3175 [cm]
Radius of fuel bulk	1.8161 [cm]
Radius of fuel element	1.8669 [cm]
Core height	38.1 [cm]
Core height for bulk coolant temperature calculation	38.1 [cm]

Fuel element gap thickness (gap is filled with air)	0.00381 [cm]
Fuel array pitch	4.3564 [cm]
Flow velocity	9 [cm/s]
Pressure at the bottom of the core	1.6019 [bar]
Number of radial mesh points	100
Radial mesh interval	0.0200 [cm]

3. RESULTS AND CONCLUSIONS

Time dependence of temperature distribution in the fuel element of the ITU TRIGA Mark-II reactor following the pulse operation has been investigated by the code TEMPUL. Results of calculation are shown in Fig.1 to Fig.3. As seen in Fig.1 at the beginning, the outer clad temperature is increasing with increasing time for all coolant velocities in the coolant channel since the adiabatic conditions are exist. And then, coolant velocity effect on the outer clad temperature is seen when the adiabatic effect is lost.

The air gap between the fuel bulk and the cladding interface are produced by pulsing. This gap causes the measured steady-state temperature increased significantly. On the other hand after several pulses of the maximum reactivity insertion, the size of the air gap essentially stabilizes [8].

Very small constant gap thickness is assumed in the calculations since the fuel elements in the ITU TRIGA Mark-II reactor core are not used very much both steady-state and pulse operation. To considering the effect of the air gap, fuel-cladding interface and outer clad temperatures as functions of time after the pulse are shown in Fig.2 and Fig.3 respectively. The gap resistance effect on both fuel-cladding interface and outer clad temperatures can be seen from the Fig.2 and Fig.3 respectively at the time heat transfer is started.

The results from the calculation shows that TEMPUL computer code with a simple analytical model can be easily applied to calculate time dependence of temperature distribution in a TRIGA type fuel element following the pulse operation.

REFERENCES

1. Erradi, L.; Essadki, H.: Analysis of safety limits of the Moroccan TRIGA Mark-II research reactor. Radiation Physics and Chemistry, 61 (2001) 777-779
2. Popov, A. K.; Pepelyshev, Yu. N.; Bondarchenko, E. A.: The model of the IBR-2 pulsed reactor of periodic operation for investigations of transitional processes. Annals of Nuclear Energy, 27 (2000) 563-574
3. Ravník, M.; Mele, I.; Dimic, V.: PULSTRI-1 A computer program for mixed core pulse calculation. Twelfth European Triga Users Conference, Pitesti, Romania, (September-28, October-1, 1992) 6-49, 6-60
4. Mele, I.; Ravník, M.; Trkov, A.: TRIGA Mark II benchmark experiment, Part II. pulse operation. Nuclear Technology, 105 (1993) 52-58
5. Mele, I.; Slavic, S.; Ravník, M.: TEMPUL A computer program for temperature distribution calculations in fuel element after the pulse. IAEA 1338/01, (October-1992)
6. Safety Analysis Report for the ITU TRIGA Mark-II Reactor. August 1978
7. Büke, T.; Yavuz, H.: Experimental and analytical investigation of ITU TRIGA Mark-II reactor core. Kerntechnik, 68, 5-6 (2003) 228-234
8. Levine, S. H.; Geisler, G. C.; Totenbier, R. E.: Temperature behavior of 12 wt % U Triga fuel. Third TRIGA Owner's Conference, (February-1974) 4-13, 4-28

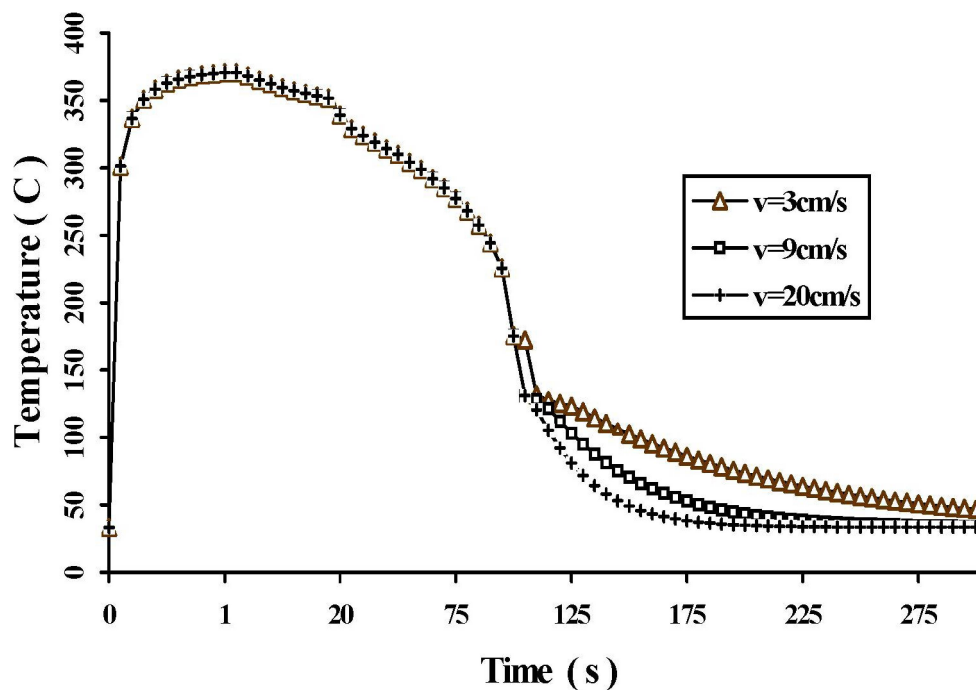


Fig. 1: Outer clad temperatures as functions of time after the pulse for different coolant velocities

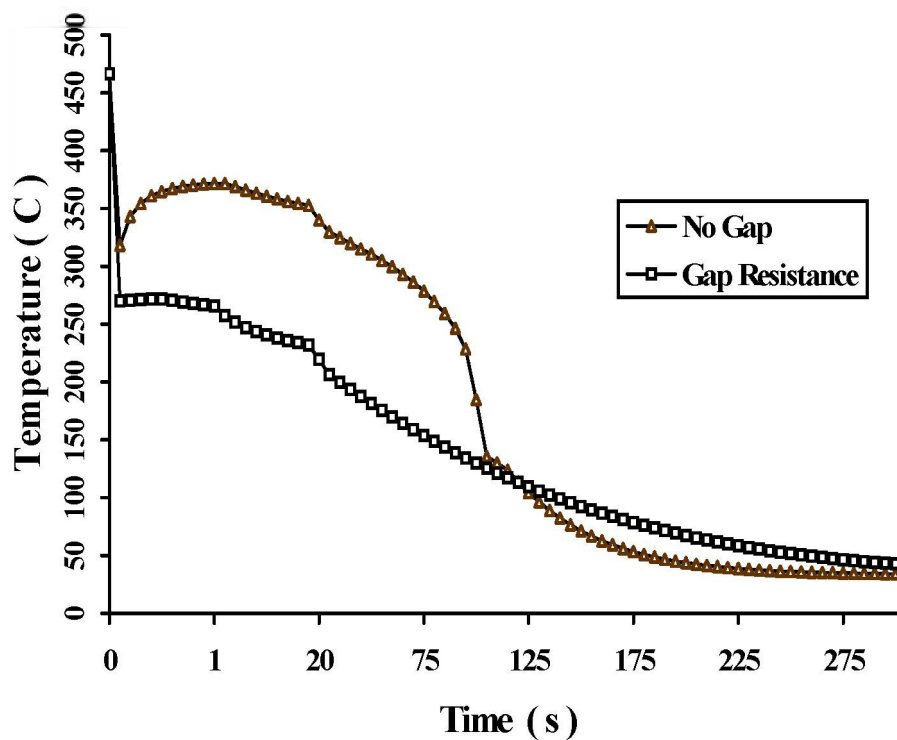


Fig. 2: Fuel-cladding interface temperatures as functions of time after the pulse ($v=9$ cm/s)

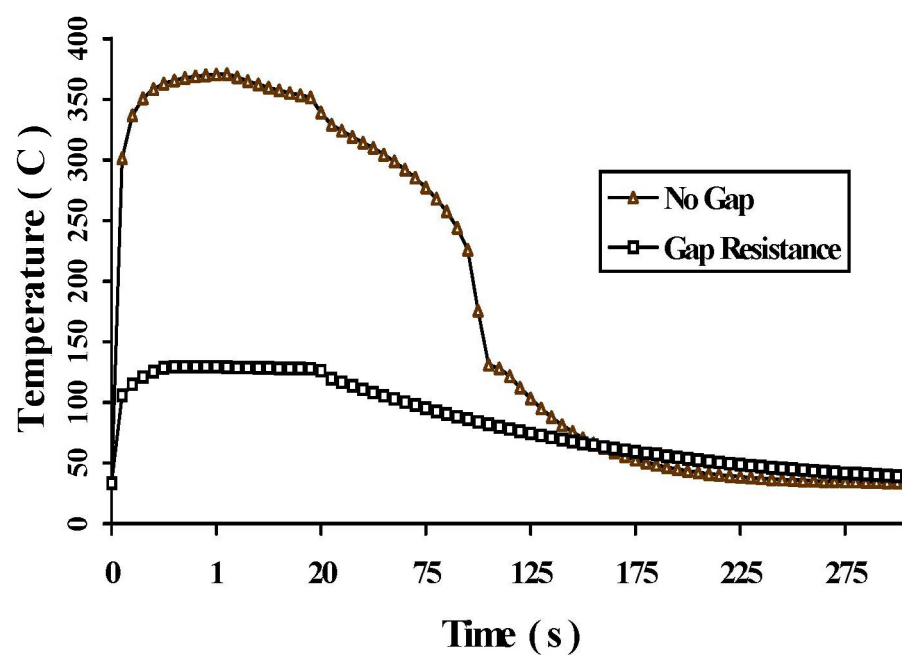


Fig. 3: Outer clad temperatures as functions of time after the pulse ($v=9$ cm/s)