Analysis of a Total Flow Blockage of a Fuel Assembly in a Typical MTR Research Reactor by RELAP5/MOD3.3

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ABSTRACT

The lack of full understanding of complex mechanisms connected with the interaction between thermal-hydraulics and neutronics still challenge the design and the operation of nuclear reactors by the adoption of conservative safety limits. The recent availability of powerful computer and computational techniques together with the continuing increase in operational experience imposes the revisiting of those areas and eventually the identification of design/safety requirements that can be relaxed [1]. Currently, the enlarged commercial exploitation of nuclear Research Reactors (RR) has increased the consideration to their corresponding safety issues.

Almost all of the safety analyses have so far been performed using conservative computational tools [2]. Nowadays, the application of Best-Estimate (BE) methods constitutes a real necessity in order to increase their commercial productivity. In this framework, an attempt is made to apply the BE technique to perform a safety evaluation under research reactors operational conditions. In fact, this technique has been largely verified and validated for power reactors using coupled system thermal-hydraulic and three-dimensional neutron kinetics [1].

For this purpose, as typical representative of research reactors, the IAEA 10 MW MTR Research Reactors problem [3] is considered. The system thermal-hydraulic RELAP5 [4] code was developed to simulate transient scenarios in Power reactors such PWR, BWR, VVER, etc. However, only limited work was performed to access the applicability of the code to Research Reactors operating conditions (low pressure, mass flow rates, power, etc) [5]. Previous works performed in this field are reported in [5], [6] and [7]. In this framework, total and partial blockage of a single Fuel Assembly cooling channel are investigated. As a first attempt the calculations are performed by applying the BE thermal-hydraulic system code RELAP5 alone using its point kinetic model to derive the instantaneous core power.
1 INTRODUCTION

1.1 Description of the reactor

The IAEA Research Reactor as defined in reference [3] is a pool 10 MW MTR type. The core is cooled and moderated by downward forced circulation of light water.

The reactor core consists of 5 x 6 grid core (Fig. 1) containing 21 Standard MTR Fuel Elements SFE (Fig. 2) and 4 Control Fuel Elements CFE (Fig. 3). The core is reflected by graphite on two opposite faces and surrounded by water. The SFE contain 23 standard plates containing 280g U-235 whereas the CFE contain 17 standard plates with a special region to receive the 4 fork type absorber blades. No information was made available for the coolant loop in the benchmark specification volumes [3].
1.2 Coolant loop nodalization

In the current framework and in order to perform a numerical simulation of the problems using the RELAP5 code [6], a standard nodalisation of a typical MTR research reactor was performed (see Fig.4 and 5). This nodalisation, includes the main reactor components such as the core zone, the reactor pool, the holdup tank, the main coolant pump, the heat exchanger, and a valve component to represent the obstruction of the SFE.

The reactor pool above the core zone was modelled in a way that allows adequate simulation of the natural convection process (Fig. 5). Each fuel assembly is simulated in the current nodalisation in order to perform a BE approach of the physical phenomenology involved during such a transient. The SFE channel number 60 (see Fig. 4) was chosen to carry out the total and partial flow blockage simulations.

2 RESULTS ANALYSIS

The analysed cases are divided in two categories. The first one is a partial blockage of an SFE channel in which we have 95% of nominal flow area obstruction. The second one is an extreme scenario where a total blockage of the cooling channel of the same FA (Channel number 60) is considered. All the transients start after 50 s of steady state calculations. The transient simulation begins when the channel obstruction is initiated.
2.1 Case 1: Partial blockage

Results obtained from RELAP5/MOD3.3 calculations for 95% of nominal flow area obstruction are described in this section. Relevant output data are sketched in Figs. 6 to 10.

When the transient starts, there is a redistribution of the mass flow in each channel (Fig. 6). The fuel temperature in the obstructed channel experiences a sharp increase (Fig. 7), leading to a strong negative reactivity insertion caused by Doppler effect. Furthermore, the loss of flow in the obstructed channel causes an increase of the coolant temperature (Fig. 8) with consequent void production (Fig. 9). Consequently, the reactor power, as shown in Fig. 10, exhibits a self-shutdown behavior. However, after 200 s the reactor power is enough low, the mass flow rate in the obstructed channel is sufficient to cool down the FA temperatures, and consequently void production is stopped. After this, the reactor power continues to reduce with dumped oscillation caused by the moderator feedback coefficient until end of calculations at 1000s.
Figure 8: Coolant temperature in the obstructed channel at different axial levels

Figure 9: Void fraction in the obstructed channel

Figure 10: Reactor Power.
2.2 Case 2: Total blockage

Results obtained for this case from RELAP5/MOD3.3 calculations are described in this section. Relevant output data are sketched in Figs. 11 to 15.

In this extreme case, the loss of flow occurring in the obstructed channel leads to sharp two phase flow conditions with rapid increase of fuel and coolant temperatures (Fig. 12 and Fig. 13). In these conditions as can be seen in Fig. 14 a large vapour production occurs leading to local dryout of the fuel plates. In this case, even though large feedback is involved the reactor power as calculated by the point kinetic model (see Fig. 15) remains high enough to make the cladding temperature reaching the fusion threshold. As can be seen in Fig. 12, the calculations are stopped when the cladding temperature reaches its melting point, after only 8 s of the transient start. This result seems to be unrealistic and too conservative. In fact, the point kinetic model used by RELAP5 code did not consider separately the individual kinetic behavior of each FA. On one hand, the power of the obstructed channel should exhibit a self-shutdown behavior varying axially according to the void distribution. On the other hand, in the intact FA channels the power should increase due to the decrease of the coolant and fuel temperatures as a consequence of the relative rise of the individual coolant mass flow rates (see Fig. 11). This constitutes the limit of the point kinetic approach since the whole reactor core is seen as 0D (zero dimension). Therefore, a BE simulation of such kind of transients requires the use of 3D kinetic calculations. This could be done using the current Coupled Codes computational tool technique.

![Figure 11: Mass flow in different channel](image-url)
Figure 12: Fuel temperature in the obstructed channel

Figure 13: Coolant temperature in the obstructed channel
Figure 14: Void fraction in the obstructed channel.

Figure 15: Reactor power
3 CONCLUSIONS

Increased consideration to safety issues for research reactors has emerged as a consequence of their enlarged commercial exploitation. So far, conservative computational tools are used to perform safety analyses for design and exploitation of such reactors. Nowadays it becomes necessary to review the limiting safety margins by using Best-Estimate calculation methods. The current work constitutes a first attempt to apply this technique to Research Reactors operating conditions. The transients herein considered are partial and total obstruction of a cooling channel of a single Fuel Assembly of a 10 MW MTR core. The considered cases constitute a severe accident for this type of reactor since it may lead to local dryout and fuel integrity damage. For this purpose, each channel of the core was simulated individually. However, as a first approach the point kinetic is used to derive the core power behavior during the transient. According to the calculation results the following conclusions can be drawn:

- For flow blockages under 95% only an increase of the coolant and clad temperature are observed without any consequences for the integrity of the fuel assemblies. The cooling mass flow rate remains sufficient to maintain adequate clad temperature.
- In the case of a total obstruction, it has been observed that the transient is really a severe accident for this type of reactor because rapid dry-out conditions are reached in a short time (after 8s) and melting of the cladding may occur.

The use of the point kinetics approach leads to conservative results that are away from what could be happen in the reality. A Best Estimate simulation requires the use of 3D kinetic calculations. This could be done using the current Coupled Codes computational tool technique.

REFERENCES


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