THERMAL-HYDRAULIC ANALYSIS OF URANIUM SILICIDE FUEL ELEMENTS TO BE IRRADIATED AT RA-3 REACTOR WITHIN THE QUALIFICATION PROGRAM

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ABSTRACT

A qualification program of technology and installations to manufacture MTR fuel elements based on uranium silicide disperse in aluminum (U_3Si_2–Al) is being carried out in CNEA. As a part of this program it is necessary to irradiate fuel elements to know its behavior. In this way two MTR prototypes, named P-06 y P-07, are being irradiated at RA-3 reactor.

There are some differences between P-06 or P-07 and normal fuel elements (ECBE) used at RA-3 reactor: geometric differences, fuel plates number (P-07 has 20 fuel plates, that is one more than ECBE) and a greater mass of U^{235} (20 % in the case of P-06 y 50 % for P-07).

Although the presence of P-06 and P-07 in core does not affect its hydraulic characteristics (because the core is mostly composed of ECBEs) the differences in geometry will change coolant velocity between the plates.

Additionally, the quantity of U^{235} in P-06 and P-07 changes the cooling requirements. Thus, it was necessary to make a thermal/hydraulic analysis to determine the feasibility of irradiating them with the adequate cooling condition in RA-3 reactor. This work presents the performed analysis. The calculations were performed with TERMIC code.

The analyzed fuel elements can be irradiated if the relation between its maximum heat flux and average heat flux in the core is lower or equal to: 3.5 for the P-06 case and 3.3 for the P-07 case.

INTRODUCTION

A qualification program of technology and installations to manufacture MTR fuel elements based on uranium silicide disperse in aluminum (U_3Si_2-Al) is being carried out in CNEA. As a part of this program it is necessary to irradiate fuel elements to know its behavior. In this way two prototypes named P-06 y P-07 are being irradiated at RA-3 reactor.

RA-3 typical reactor core is composed by 25 MTR fuel elements (ECBE): 20 of them are ordinary type and 5 are control fuel elements. Due to the differences between P-06 or P-07 and ECBE it was necessary to carry out a thermal/hydraulic analysis.

The calculations of allowable maximum heat fluxes on P-06 and P-07 fuel elements to be irradiated at RA-3 for different operation modes are presented.

ANALYSIS

The analysis goal was to calculate the maximum allowable heat flux on P-06 and P-07 fuel elements in order to select the core location where they are being irradiated.

To calculate the maximum allowable heat fluxes, it is necessary to know the coolant velocity in between fuel plates, it depends of reactor operating mode.

For each reactor operating power there is a minimum coolant flow necessary to assure the fuel elements cooling. RA-3 reactor primary circuit has 3 heat-exchangers (HHXX) and 3 pumps (PP). The number of equipment used to obtain a certain coolant flow is called operating mode.

Operating modes, and the correspondent reactor power, are [1]:

Operating Mode	**Equipment**	**Operating Power**
III	2 HHXX - 2 PP	8 MW
IV	3 HHXX - 2 PP	9 MW
V	3 HHXX - 3 PP	10 MW

Data

The principal characteristics of ECBE, P-06 and P-07 are:

	ECBE	**P-06**	**P-07**
Fuel meat	U_3O_8 - Al	$U_3\,Si_2$ – Al	$U_3\,Si_2$ – Al
Mass of U^{235} per plate [g]	14.98	17.98	21.37
U^{235} / U^{235} ECBE	1	1.2	1.5
Enrichment	20	20	20
Plates per fuel element	19	19	20
Meat length [mm]	615	619	615
Meat width [mm]	60	60	60
Meat thickness [mm]	0.7	0.51	0.61
Fuel plate thickness [mm]	1.5	1.5	1.35
Cladding thickness [mm]	0.4	0.495	0.37
Channel thickness [mm]	2.7	2.7	2.6

Hypothesis

For the calculation there were assumed the following hypothesis:

- Core configuration: 23 ECBE, 1 P-06 and 1 P-07 (Figure 1)
- The presence of P-06 or P-07 does not change core hydraulic characteristic, that is the relationship between coolant flow and pressure drop through the core.
- Cosinus distribution of neutron flux
- Maximum coolant inlet temperature = 45°C

Limiting Conditions

There were assumed:

- Three options for maximum cladding temperature
  - 105 °C without considering uncertainties coefficient
  - 110 °C without considering uncertainties
  - Boiling temperature considering uncertainties coefficient
- It was assumed a margin to critical phenomena (flow instability) ≥ 2

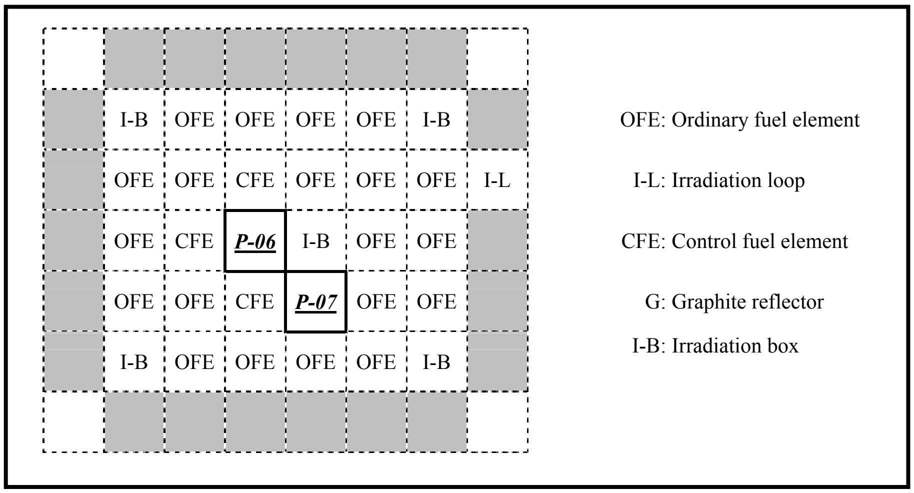

Figure 1: Core Configuration

Coolant velocity

Due to the fact that fuel elements channels are arranged in parallel form the pressure drop (ΔP) across the core is the same for all of them.

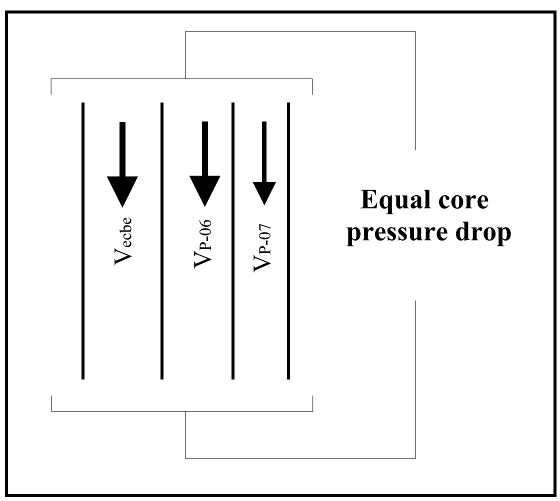

Figure 2: Coolant velocity calculation condition

Thus, P-06 and P-07 channels velocity is obtained from the condition:

$$\boxed{\Delta P_{06} = \Delta P_{07} = \Delta P_{ECBE}}$$

Coolant velocities for different operating modes are:

Operating Mode	Primary Coolant Flow [m3/h]	ΔP_{core} [m H_2.O]	Velocity [m/s]		
			ECBE	P-06	P-07
III	1000	1.80	2.60	2.60	2.50
IV	1100	2.30	2.94	2.94	2.82
V	1300	2.75	3.20	3.20	3.07

Calculation tool

After the coolant velocity is known, it is necessary to calculate the maximum allowable heat flux on the fuel plates of P-06 and P-07 prototype. It was performed with "TERMIC" code [2] that calculates, for certain coolant velocity and the fixed design limits, the allowable maximum heat flux in a fuel channel.

This code uses a calculation methodology developed in Grenoble Nuclear Centre (France) for the thermal/hydraulics analysis of research reactors with coolant at low-pressure [3].

Cladding temperatures obtain with the correlation and test results show good agreement when the calculation was performed without taking into account uncertainties coefficient [4].

RESULTS

The values of allowable heat fluxes, for each prototype and operating mode (coolant velocity) are shown in the following tables and in Figure 3:

- **P-06 fuel element:**

	Maximum allowable heat flux [W/cm^2]		
Operating Mode	T_C= 105 °C	T_C= 110 °C	T_C= Boiling temp.
2 HHXX - 2 PP	86.4	94.6	108.8
3 HHXX - 2 PP	96.0	105.2	121.2
3 HHXX - 3 PP	99.0	113.0	130.6

- **P-07 fuel element:**

	Maximum allowable heat flux on P-07 [W/cm^2]		
Operating Mode	T_C= 105 °C	T_C= 110 °C	T_C = Boiling temp.
2 HHXX - 2 PP	83.2	91.2	104.8
3 HHXX - 2 PP	92.2	101.0	116.6
3 HHXX - 3 PPs	99.0	108.5	125.6

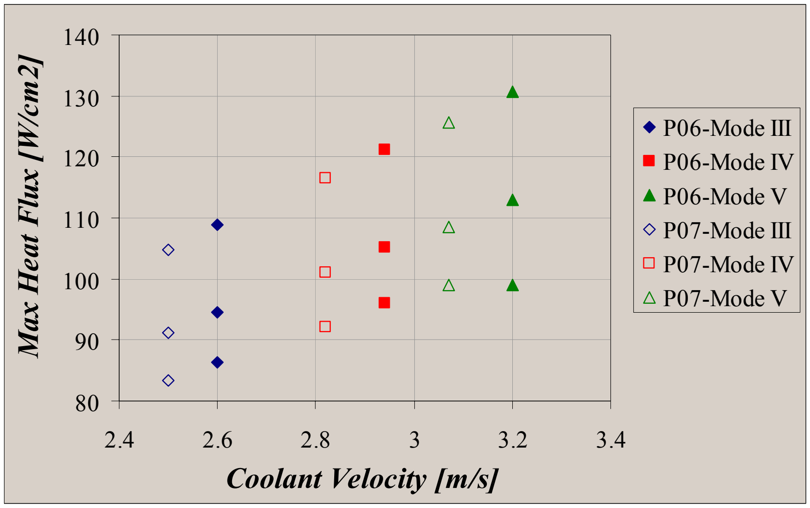

Figure 3: Max. heat fluxes for each prototype and operating mode

CONCLUSIONS

Maximum and average heat fluxes for ECBE fuel elements with cladding temperature of 105ºC as limiting condition, a core configuration of 25 ECBE and a power picking factor of 3.5 are shown in the following table

- **ECBE fuel element:**

Operating Mode	Operating Power [MW]	Primary Coolant Flow [m^3/h]	Average heat flux [W/cm^2]	Maximum allowable heat flux [W/cm^2]
2 HHXX - 2 PP	8	1000	24.3	85.0
3 HHXX - 2 PP	9	1100	27.4	95.0
3 HHXX - 3 PP	10	1300	30.0	105.0

In order to minimise the corrosion process, the results were analysed assuring that cladding temperature is maintained under 105ºC

Thus, comparing the tables for ECBE and P-06 or P-07 it is possible to determine the allowable power picking factor for the new fuel elements as the relation between the maximum heat flux allowable for P-06 or P-07 and medium heat flux in RA-3 core.

The following table shows where the prototypes fuel elements had to be located in RA-3 core:

Prototype	Power picking factor
P-06	<= 3.5
P-07	<= 3.3

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