THE USES OF THE DILATION METHOD IN THE DETECTION OF THE CRITICAL HEAT FLUX IN NUCLEAR SIMULATED FUEL ELEMENTS

Amir Zacarias Mesquita
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN/CNEN, Caixa Postal 941, 30.161-970 – Belo Horizonte, MG, Brasil,
e-mail: amir@cdtn.br

Fausto Maretti Júnior
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN/CNEN, Caixa Postal 941, 30.161-970 – Belo Horizonte, MG, Brasil,
e-mail: fmj@cdtn.br

Elias Basile Tambourgi
Faculdade de Engenharia Química - FEQ/UNICAMP, Caixa Postal 6066, 13083-970 – Campinas, SP – Brasil,
e-mail: elias@desq.feq.unicamp.br

Abstract. *In the thermal hydraulic experiments to determinate parameters of heat transfer, where simulators of fuel elements are heated using electric current, the preservation of the simulators are essential when the heat flux goes to the critical point. One of the most important limits in the project of cooling water reactors is the condition in which the heat transfer coefficient by boiling in the core deteriorates itself. The heat flux just before deterioration is denominated Critical Heat Flux, (CHF). At this time the small increase in the heat flux or in the inlet temperature of the cooler in the core, or the small decrease in the inlet flux of cooling, results in changes in the heat transfer mechanism. This causes increases in the surface temperature of the fuel elements causing failures at the fuel (burnout). It goes the accomplished experiment it was concluded that the uses of the displacement transducer is the most efficient technique at now to detection of the critical flux in fuel elements simulators using direct heating in open vases.*

Keywords. *transducer, flux detection, critical heat flux, temperature measurements, fuel elements temperature.*

1. Introduction

One of the most important limits in the project of the water-refrigerated reactors is the condition in which the heat transfer coefficient for boiling in the core deteriorates. The flux of small heat before this heat flux deterioration is denominated Critical Heat Flux (CHF). Reddy et al (1982) shows that at this time a small increase of the heat flux or in the inlet temperature of the core coolant, or a small decrease in the inlet flux of the coolant results in change in the heat mechanism transfer, causing an abrupt increase of the temperature in the surface of the fuel rods, causing the cladding burn-out.

The boiling crisis that causes the critical flux is usually classified, (Arone, 1978), in two types:

The dry out that happens when the thickness of the layer of water drops to zero, what usually happened in areas of high steam quality and low heat flux.

The departure from nucleate boiling (DNB) happens in the area of low steam quality when there is nucleus formation of bubbles. A steam film sticks the wall of the channel, standing back of the normal process of boiling that is the detachment of the bubbles. In the "DNB" the heat flux are so high.

One of the rules used in the reactor projects, specifies that the heat flux, in continuous operation, should not surpass a determined fraction of the critical flux. This value is specified to maintain the temperature of the fuel elements cladding in safety levels.

Therefore, experiments and studies for the development of more precise correlation on heat critical flux in rod elements assemblies gives economy and safety in the construction and operation of the nuclear reactors.

To qualify the mathematical models of calculation of the phenomenon that happen in the core, the thermal hydraulic tests are accomplished, where tries to reproduce at the maximum the existent conditions in the core. From all these tests, the Critical Heat Flux determination is maybe the most important, because it determines the operation limit of the fuel rods and another components.

2. Detection of the critical flux

In the thermal-hydraulic experiments of heat transfer, where rods electrically heated are used for simulation of the nuclear fuels (Mesquita, 1992), the fast shutdown of the power supply is essential to the preservation of the simulators, when the critical heat flux is reached. Mainly in the tests whose purpose is the determination of this parameter, the detection through a fast and safe way facilitates plenty the tests, because the same rod, or a set of rods can be used several times.

When the critical flux is reached, there is an abrupt increase of the wall temperature. This temperature increase is used directly for the detection of this phenomenon, or then, indirectly using the effects caused by temperature increase in the physical properties of the tube being used (Strupchevsky, A. et al, 1978). To this proceedings there are given four methods that can be used in the detection.

2.1. Temperature measures

Several thermocouples are welded along the wall of the tube and they make the monitoring of the temperature. When happens one abrupt increase of the temperature in some thermocouple the power supply is turned off.

This method has several inconveniences:

- the speed of the detection depends of the thermocouple proximity of the point where happens the “burn-out”;
- the own thermocouple, depending of its diameter and positioning, can serves as a thermal dissipater, contributing to the “burn-out” happens distant of it;
- the thermocouple, mainly that of small diameter, are subject to noises originating from of the electrical power supply, needing use of filters;
- difficulties in the thermocouples placement in the wall of the tube;
- inertia in the thermocouples answer.

2.2. Electric resistance measures

In the place where happens the burnout there is also an abrupt increase of the electrical resistance. Three copper wires are welded along the rod, doing with two of these segments the arms of a Whetstone bridge.
The bridge is balanced and occurring the burnout, the resistance increases in the part where it happens, unbalancing the bridge and causing the turn off of the power supply.

The departure from nuclear boiling was attained by smooth increase of the heated pipe power at the constant coolant flow rate and was recorded by a special detector operating on the principle of a balanced bridge (Bounakov, 1998).

This method is quite efficient and independent of the place where happens the critical flux. There are some disadvantages:

- it is subject to the noises caused by the magnetic field of the electric current in the rod;
- The sensibility is small when the rod is short (less than 600 mm);
- When turn on the power supply, this method is not very practical, with the accomplishment of the unbalance of the bridge.

2.3. Visual observation

In the place where happens the critical flux, the tube becomes red, being able to the observer turn off the power supply. This detection method is only possible when visual access of the fluxing channel is possible, being also not very reliable.

2.4. Measure of the dilation

The increase of the temperature causes the dilation of the rod. Decreton (1982) shows that when occurs the critical flux, the abrupt increase of the temperature also causes an abrupt dilation. By the use of a sensor displacement coupled in the rod, its possible turns off the power supply quickly, avoiding its destruction. This detection method is presented in this paper.

3. Experimental assembly

3.1. Device of test

To check the efficiency of the dilation detection system a device test was set up as schematically shown at the Figure 1. The device consists of an opened vase in stainless steel with external diameter of 60.33 mm, wall of 2.77 mm and length of 790 mm. The simulator rod is positioned and fixed in the down extremity of the vase and electrically isolated of this.

The rod has its superior extremity free and could expand freely. In this extremity is fixed the nucleus of the coil of the displacement transducer, being the coil fixed in the vase. The transducer used at the experiment and shown at the Figure 2, is one of the magnetic types, and its operation will be described in the following item.

There were built three rods constituted of simulators stainless steel tubes, with external diameter of 10.75 mm and internal diameter of 9.75 mm. The lengths were respectively: 600 mm (Rod 1), 560 mm (Rod 2) and 490 mm (Rod 3). Along the wall of the rods were welded several thermocouples type K, being some with stainless steel shielding of 1.5 mm and some without shielding (nude with diameter of 0.2 mm). The Figure 3 shows the disposition of the thermocouples in the three used rods and the approximate place where had rupture of the rod during the tests. The rods just differed in the amount and length of thermocouples used.

The heating of the rod was made by Joule effect using the own wall of the tube as a resistor. A rectifier with continuous adjustment of the power supplied the electrical current.

The vase was filled with non-ionized water, being in contact with the atmosphere. After each test the water level was completed to compensate the evaporation caused by the heating.

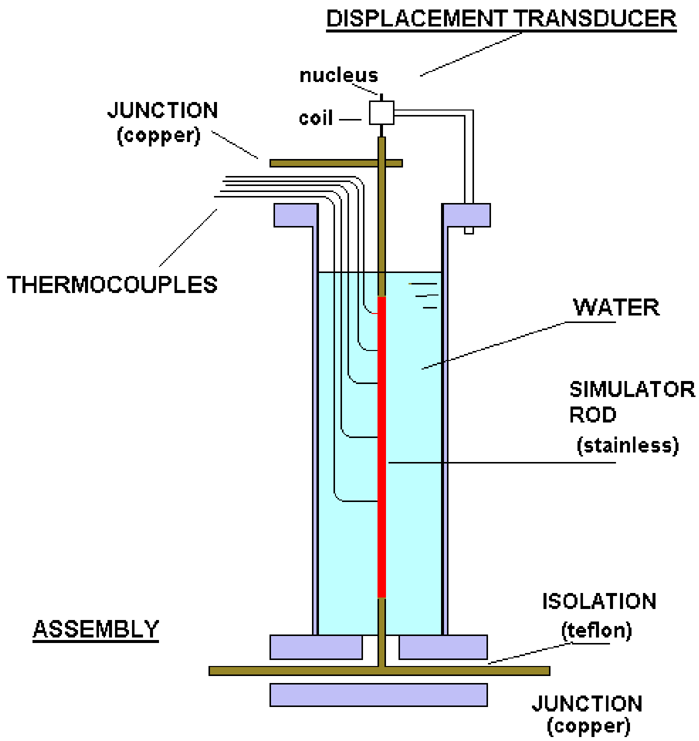

Figure 1. Experimental Assembly.

3.2. Displacement transducer

The sensor of the used displacement consists of a transformer and a nucleus that, when moved lineally along the axis of the coiling causes a voltage change at the exit that is proportional to the movement.

The used displacement transducer, model 24 DCDT-050, was manufactured by Hewlett Packard (1968). Continuous current feeds this sensor. A solid-state oscillator converts the continuous sign in alternate, exciting the primary coil. The secondary has two coils, being each one tied up to a circuit contends a complete rectification bridge and RC filters.

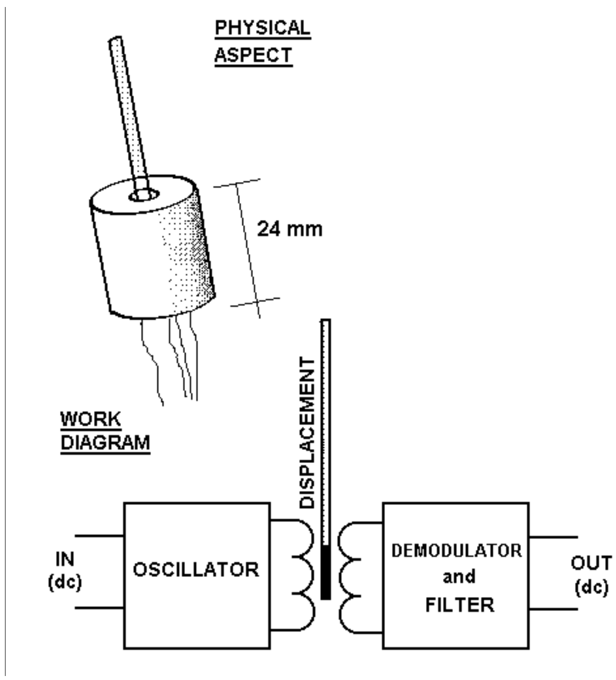

Figure 2. Transducer Displacement.

The axial position of the nucleus determines the value of the voltage induced in the secondary coil. The secondary circuits are connected by differential way, resulting in these a direct voltage output that is proportional to the displacement of the nucleus in relation to central position, where the output is zero. The polarity of the output signal is function of the location of the nucleus in relation to the center of the coil.

The capacity of transducer resolution is theoretically infinite, but practically is limited by the connected measurement instrument at the output. The output electric/displacement relationship is 4.17 V/mm.

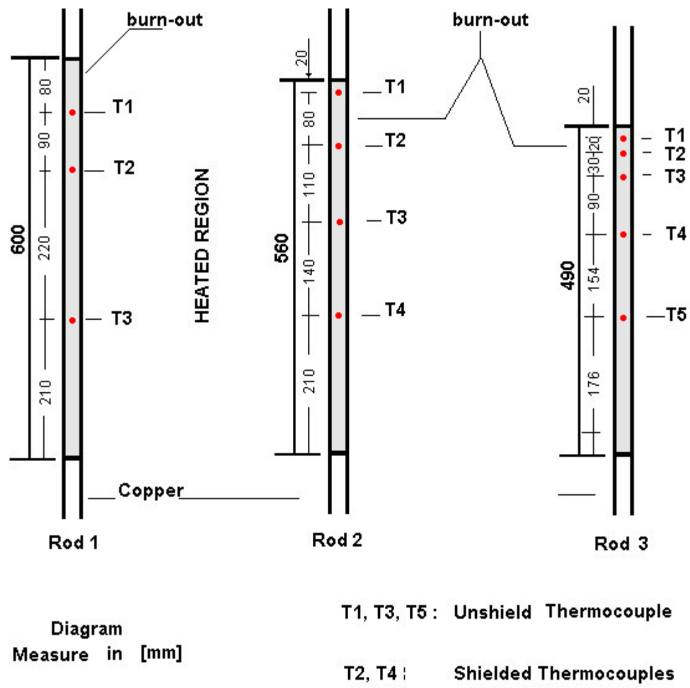

Figure 3 – Simulators rods.

4.Experimental results

4.1. Heating for Joule effect

The purpose of the accomplished tests was comparing the answer of the displacement transducer with the answer of the thermocouples, when it happened the critical flux. For this was adjusted the dissipated power level in the simulator rod with certain value and the registrations were observed supplied by the thermocouples and the displacement transducer for a determined period. Not happening the abrupt increase of these registrations that characterized the beginning of the critical flux, the power level was increased.

When happens the critical flux, with a sudden increase of some registration, the power supply was turned off. In some tests purposely didn't turn off the power until the occurrence of the rupture of the rod, just to observe the behavior of the registrations.

The Table 1 shows a sampling of the collected data of some accomplished tests. The temperature indicated in the table refers to the temperature supplied by the thermocouple T1. The different values of the maximum temperature are due, probably, to the delay of detection of the critical flux for the thermocouple.

In the first test, accomplished with Rod 1, just the transducer detected the Critical Flux. It stayed the power stable just to observes if the thermocouple would detect this flux, what didn't happen and there was rupture of the rod.

When the rod changing, it was observed that the rupture happened about 20 mm of the superior extremity, and the closest thermocouple was about 40 mm of this local. It was concluded that due to the distance, the thermocouple didn't detect the burnout.

In Rod 2 the thermocouples were concentrated on the superior part where have large probability of occurrence of the critical flux. In all tests the transducer detected the appearance of the critical flux, facilitating the turn off of the power supply. The Test 2 was one of the few tests that the thermocouple detected the burnout , having detected it 11 s after the detection coming from the transducer. The Figure 4 shows the evolution of the wall temperature and the output signal of the transducer during the Test 2.

In the Test 4 after the detection of the critical flux by the transducer, purposely didn't turn off the power leaving the rod to fail. Again the thermocouple detected the occurrence of the burnout. When the rod was changed there is observed one rupture that happened approximately about 15 mm of the superior extremity and the 17 mm of the closest thermocouple.

In Rod 3, another thermocouple was increased concentrating them on the superior part. It took place ten tests with this rod, and in just only one of them (Test 14), one of the thermocouples detected the critical flux.

The Figure 5 shows the Test 14. The delay time in the thermocouple detection relational with the transducer was of 22 s, occurring in this test the rupture of the rod.

Table 1. Experimental results.

TEST NUMBER	ROD NUMBER	POWER LEVELS [W]	HEAT FLUX [W/cm^2]	TIME [s]	MAXIMUM TEMPERATURE [^{o}C]	DILATION ROD [mm]	THERMO-COUPLE DELAY [s]
2	2	0	0.0	0	52	0.05	
		966	5.1	86	76	0.06	
		3093	16.4	131	92	0.07	
		4656	24.6	167	103	0.07	
		8286	43.8	215	103	0.08	
		10101	53.0*	242	103	0.70	
		0	0	253	250	0.20	11
3	2	0	0.0	0	65		
		1019	5.4	178	100		
		4042	21.4	214	100		
		6180	32.7	228	100		
		7713	40.8	233	100		
		9049	47.8	239	100		
		10626	56.2*	257	100		
		0	0.0	310	100		54
4	2	0.0	0	0	74		
		9.0	36	36	76		
		23.0	90	90	102		
		33.2	122	122	102		
		48.2	142	142	102		
		57.0*	150	150	102		
		0.0	-	-	102		No detected
13	3	0	0.0	0	53		
		1717	10.4	45	59		
		3647	22.0	138	96		
		6397	38.7	159	99		
		9270	56.0	169	99		
		13869	83.8*	184	100		
		0	0.0	-	100		No detected
14	3	0	0.0	0	20	0.4	
		4558	27.5	135	96	1.0	
		5622	34.0	173	107	0.8	
		12050	72.8	205	110	0.7	
		14440	87.3*	211	210	1.3	
		0	0.0	232	185	0.2	22

4.2. Heating with beak of flame

It was so important to have one idea of the precision in the detection throughout the transducer and also the delay value of the detection throughout the thermocouple due the consideration of the distance of the place of burnout occurrence and them. It was realized an experience where the abrupt increase of the temperature was provoked an equipment of weld oxy-acetylene beak flame.

Rod 3 was removed of the test vase and fixed on the down side in the vertical position, that its up extremity could dilates freely and make the displacement transducer works.

With the beak of flame adjusted in the most possible punctual way, the rod and was warmed and observed, through the use of one graphic register set, that shows the signs supplied by the transducer and the thermocouple.

When the place became red, the flame was put out and can be observed that the transducer immediately signaled this situation. It was verified that these indications were simultaneous. considering the means used to the observation (visual and graphics registration). On the other hand, the answer of the thermocouple varied according the heating place; showing that for distances larger than 50 mm the thermocouple practically didn' t detect the temperature increase.

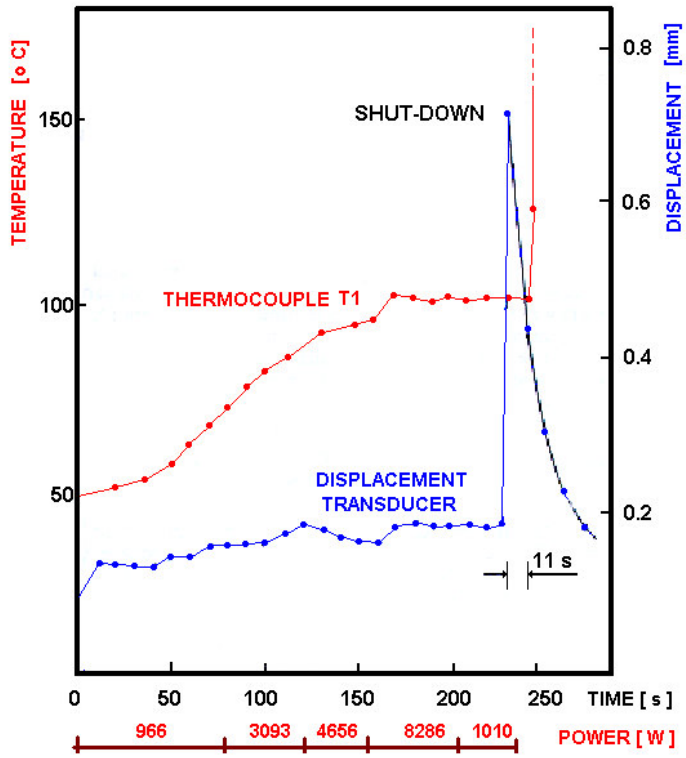

Figure 4 - Evolution of the temperature and of the sign of the transducer during the Test 2.

The Figure 6 shows the graphics that indicates the delay time in the thermocouple indication and its relationship with the answer of the transducer, in function of the distance of the red coloring produced by the flame.

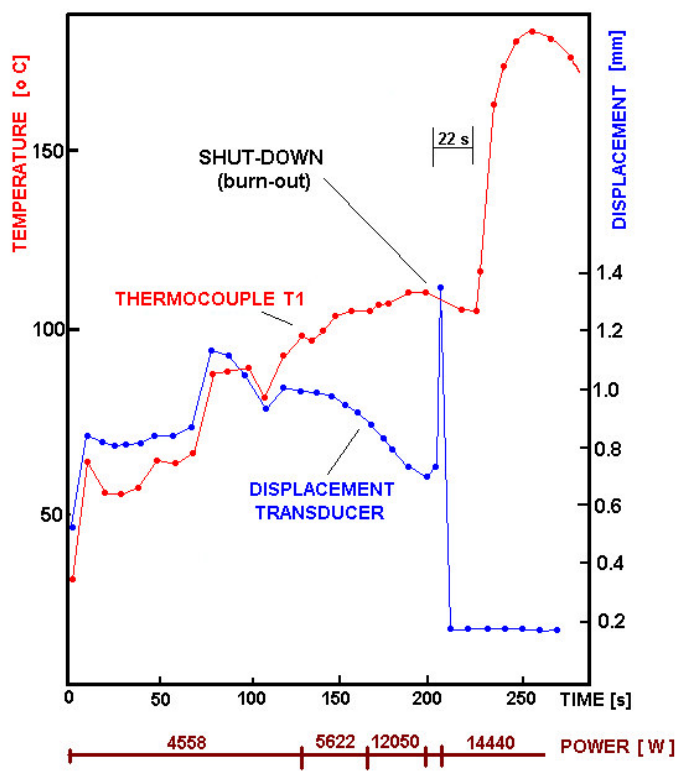

Figure 5 - Evolution of the temperature and of the sign of the transducer during the Test 14.

The thermocouple was used without shielding, where the inertia is smaller. The graphic shows that there was a great dispersion in the time of answer of the thermocouple.

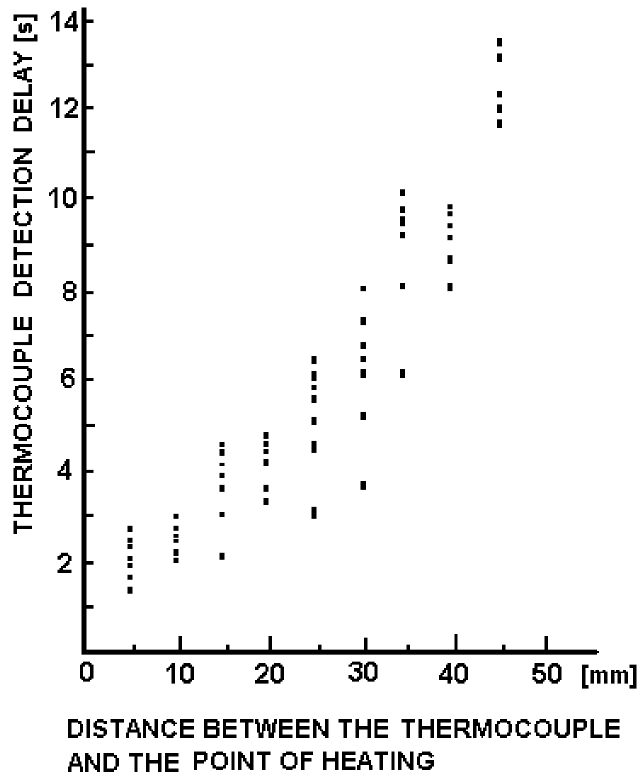

Figure 6. –Delay of the time of answer of the thermocouple with relationship with one of the transducers.

5. Conclusion

In out-reactor heat transfer experiments, electrically heated rods often simulate fuel elements. In order to prevent the heating rod from being damaged by burnout, when the critical heat flux occurs, a safety system is provided witch checks the axial thermal expansion of the rod. In case of sudden temperature increase, the corresponding elongation causes a fast interruption of the electrical power supply.

It goes the accomplished experiences it was concluded that the use of the displacement transducer until the moment is the most efficient technique to detection of the critical flux in simulators rods with direct heating in open vase. The experiments presented here show that this method is more effective than the one that uses thermocouples. This process, unlike the thermocouples uses, the detection don't depends of the place where happens the critical flux. In spite of it have not compared it with the method of Whetstone Bridge (change of the electric resistance), it can be affirmed that it is a least practical, because doesn' t need previous adjustments (balance). The next experience will be the measurement of the critical heat flux and do one comparison with the theoretical calculated values.

6. References

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