



Technical Note

Study of the boron homogenizing process employing an experimental low-pressure bench simulating the IRIS reactor pressurizer – Part I

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ABSTRACT

The reactivity control of a nuclear reactor to pressurized water is made by means of controlling bars or by boron dilution in the water from the coolant of a primary circuit. The control with boron dilution has great importance, despite inserting small variations in the reactivity in the reactor, as it does not significantly affect the distribution of the neutron flux. A simplified experimental bench with a test section manufactured in transparent acrylic, was built in reduced scale as to be used in a boron homogenizing process, simulating an IRIS reactor pressurizer (International Reactor Innovative and Secure). The bench was assembled in the Centro Regional de Ciências Nucleares do Nordeste (CRCN-NE), an entity linked to the Comissão Nacional de Energia Nuclear (CNEN), Recife – PE.

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1. Introduction

A nuclear reactor in normal operational conditions has a constant potency level; in such case the neutrons production rate through radioactive fission and decay reactions must be balanced by the neutrons loss via the absorbing and escaping of the system. Any alteration in that condition will result in a temporal dependency of the neutrons population and, naturally, will change the level of the reactor potency.

In the pressurized water reactors, the so-called PWRs, the main function of the Reactor Coolant System (RCS) is to transport the thermal energy generated in the reactor to the steam generators, where this energy is transferred to the secondary system.

The pressurizer is an important component in the functioning of a PWR reactor as it controls the RCS pressure, keeping it subcooled, through electrical heaters and water spray valves. The pressurizer is a bi-phase chamber, where the steam occupies the superior part, and the liquid the inferior one. During the normal operation of a reactor, the system pressure is controlled by the pressurizer through the working of the aspersion valves and the electrical

heaters which keep the temperature of the pressurizer in a reference value.

The IRIS is a III+ generation modular reactor, refrigerated by pressurized light water, with integral configuration. The IRIS reactor project, fruit of a consortium of 20 organizations and nine countries, managed by Westinghouse, aims at meeting the four basic requisites of the reactors of the IV generation, which are: safety increase, resistance to the nuclear proliferation, reduction of costs in the electrical energy production, and nuclear waste reduction (Carrelli, 2003).

As well known, boron (B^{10}) is an excellent absorber of thermal neutrons, and in the form of boric acid diluted in the PWR coolant reactors, it is used in the reactivity control. From the beginning of life (BOL) to the end of life (EOL) of a reactor fuel cycle, the boron concentration in the RCS is reduced as to compensate the fuel burning. The homogenizing question becomes an extremely important factor for the safety in the operation of a reactor, by reason of improper procedures in the boron homogenization. If a great amount of water with low boron concentration, below the RCS concentration, is bombed to the core, it can cause an increase in the reactor power. The opposite happens, if the water has a superior concentration of the RCS.

2. Theory

The accident analysis is crucial in the safety area of the nuclear centrals. From the hypothesis of accidents formulation, the behavior of the central is studied and the criteria, which determine the

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condition for a safe operation, are established. The plants are licensed for operation with the guarantee that accidents and postulated transients do not surpass the safety limits established by technical specifications.

2.1. Pressurized water reactors (PWRs)

The PWR reactor, the most widely used power reactor in the world, uses light water as cooler, moderator and reflector. The main characteristic of a PWR unit is the pressured cooling water (primary circuit), always keeping a liquid phase once the pressure varies from 14 to 17 MPa.

The reactor refrigerator removes the heat generated by the core and, also, works as a moderator, reducing the neutrons energy which will produce the fissions in the fuel elements and generate heat. Besides, it also functions as a neutrons reflector, reducing their escape from the interior of the vase of the reactor and also serving as a solvent means of the boric acid which is used to aid in the control of the generation of the power in the nucleus, once it absorbs neutrons and with this, it can be used as to control the fissions reactions, In the interior of the reactor vase, the combustible elements heat the refrigerator, which remains sub-refrigerated (temperature below the saturation point, for the existing pressure), in the sequence, it is taken to the steam generators where it will transfer heat, through tubes for the feeding water which is in the interior of the GVs.

2.2. Pressurizer of PWR

In a PWR pressurizer, the steam and the saturated liquid coexist balanced, keeping, thus, the RCS subcooled as the temperature of the PZR is higher than the one of the RCS. The maintenance of the balance between the steam and the saturated liquid allows the control of the pressure of the RCS. The pressurizer is a vertical cylindrical vase, with the superior and inferior hemispherical lids made in carbon steel, with coating in austenitic stainless steel in all surfaces in contact with the reactor refrigerator. Electrical immersion heaters are installed in the base of the vase, while the junctions of the spray line, relief valves and safety valves are installed in the superior lid of the vase.

The pressurizer is designed as to accommodate the expansions and contractions caused by load variations. The breakout line, which leaves the base of the pressurizer, links the pressurizer to the hot leg of the primary circuit of the RCS. During volumetric expansions (due to temperature rises), the spray system, whose water comes from the cold legs of the RCS, condenses part of the existing steam in the pressurizer, avoiding that the pressure reaches the actuator value of the relief valves.

During the RCS volumetric contractions, the transformation of water into steam and the consequent steam generation by automatic action of the heaters, keep the pressure above the value in which the shutdown of the reactor, due to low pressure. The heaters are also energized when high levels of water in the pressurizer from the RCS occurs.

2.3. IRIS reactor

The project of an integral reactor contributes to the elimination of accidents, which doesn't happen in PWR type reactors, i.e. The IRIS is a modular pressurized water reactor with an integral configuration, all primary system components (pumps, steam generators, pressurizer and control rod drive mechanisms, are inside the reactor vessel, Fig. 1 (Carelli et al., 2004). The occurrence of Loss of Coolant Accidents – LOCA is practically eliminated, as in these types of reactors, there are no long tube systems. A safety-by-design approach, which aims at eliminating by design the possibility for an accident to occur, rather than dealing with its consequences.

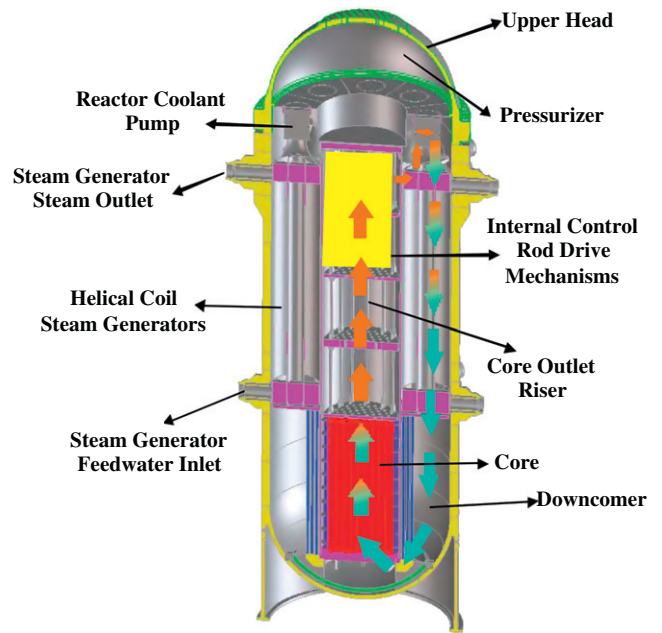


Fig. 1. Transversal cut of the IRIS reactor.

By eliminating some accidents, the corresponding safety system (passive or active) become unnecessary as well. The number and complexity of the remaining passive safety systems and of the required operator's actions are further minimized in IRIS (Barroso et al., 2003; Filho, 2011).

2.4. IRIS pressurizer

The IRIS pressurizer is located in the pressure vessel upper head, above the internal control rod mechanisms. As shown in Fig. 2, the pressurizer saturated water is separated from the reactor circulating, sub-cooled water, by an internal structure with an "inverted hat shape" (Barroso et al., 2003; Botelho et al., 2005). This structure eases the transfer of the heat, keeping the saturated water in the inner part of the pressurizer. Also, in the inferior part of the pressurizer, the heaters and the surges orifices are located through which water passes of the primary system.

2.5. Problems in the boron homogenization

Studies of transients with boron homogenizing deficiency in PWRs have been very highlighted in the last years. One solution

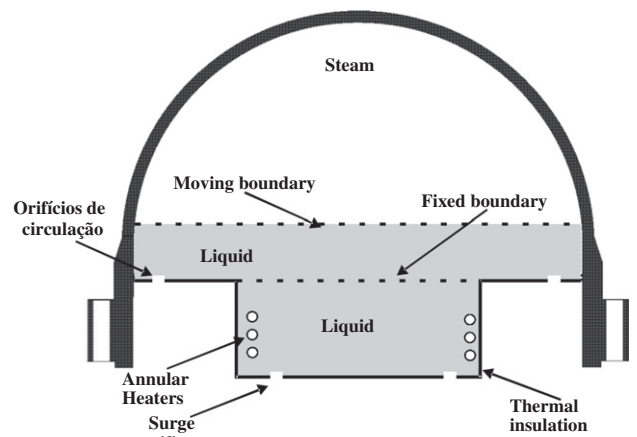


Fig. 2. Transversal cut of the IRIS pressurizer.

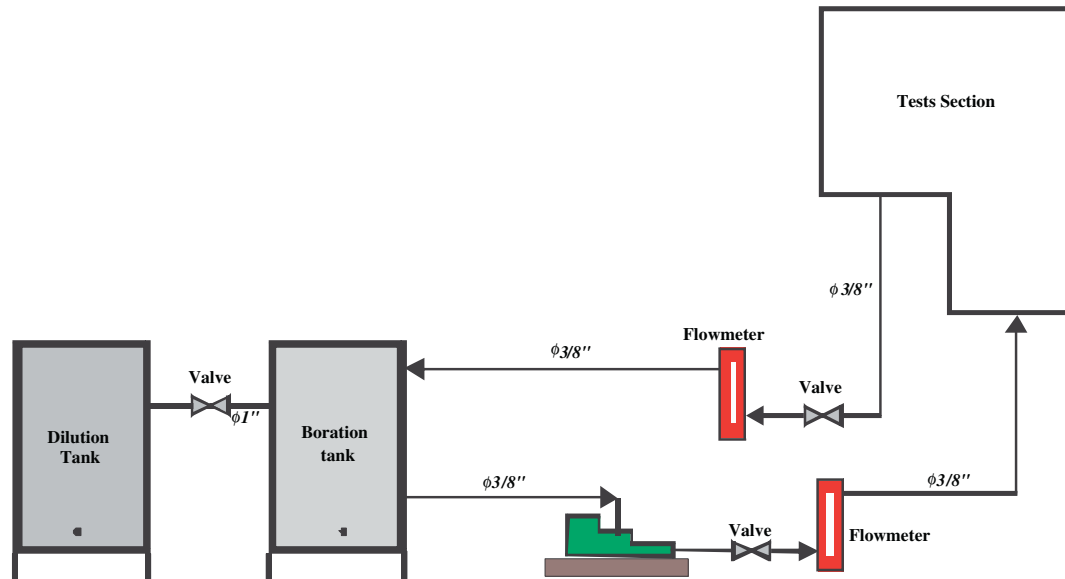


Fig. 3. Bench fluxogram.

of boric acid is normally added to the coolant of the primary circuit, aiding the fission rate control in the reactor's nucleus. Such system, normally is not able to control alone the reactivity as the change in the boron concentration does not act so rapidly as to satisfy the safety requisites, as the control bars do (Silva, 2008).

When a PWR reactor is turned off, the remaining boron in the coolant has the function of maintaining the reactor in a state of sub criticality. If water with low boron concentration is introduced accidentally, it is necessary to make a homogenization, so that the water volumes with low boron quantities do not reach the reactor vase and restart a chain reaction.

3. Methodology

In Fig. 3 there is a fluxogram of the experimental bench used in the study of the boron homogenization process in the IRIS nuclear reactor pressurizer. Its assembly has been based in the study carried out by Silva et al. (2010, 2011) which determined the parameters of a section of tests for the IRIS nuclear reactor pressurizer, using the methodology of similarity called Fractional Scale Analysis FSA (Zuber et al., 2005; Wulff et al., 2005). The simplified bench consists of two 200-liter-volume tanks, where the boration and dilution process happen. A dose pump, frequencimeter, two rotameters for the outflow measurement, stainless accuracy valves, brass sphere vales, connections and tubes with a 3/8" intern diameter in stainless steel. The session of testes, representing 1/4 of the IRIS pressurizer, was built with a 20 mm thick transparent acrylic in the bigger and smaller bases of the cylinders, and the lateral walls with a 10 mm thick transparent acrylic.

Table 1
Data referring to the experiments.

Power (%)	Contraction (ppm)	Tests section (l)	Boration tank (l)	Orifice diameter (mm)	Dye (color)
Experiment – A 100	100	40.5	100	10	Blue
Experiment – B 20	400	40.4	100	10	Blue
Experiment – C 0	1000	17.0	100	10	Blue

The data referring to the experiments are shown in Table 1.

4. Results

The preliminary experimental results were obtained through digital photos and videos of the test session (Canon Mod-G12 camera) during the homogenization process. In the realization of the experiments a dye with similar properties of the boron acid was used as to allow visualization. The pictures were processed with the DIP program (Digital Image Processing) (Vieira and Lima, 2009).

The results from the DIP, have allowed the quantification of the dye concentration value throughout the test session. Fig. 4. shows the plume dye in $t = 2.0$ h. Fig. 5 refers to the same measure after the processing of the image for experiment A.

Table 2 shows a summary of the realized experiment A. The grey tones presented in Table 2 are average values from the superior and inferior region in the test session. Figs. 6–8 show the graphs of the normalized concentrations in function of time, respectively, for the experiments A, B and C. In the three curves, it is noticed that the colorant homogenization time in the system happens in around 3 h.

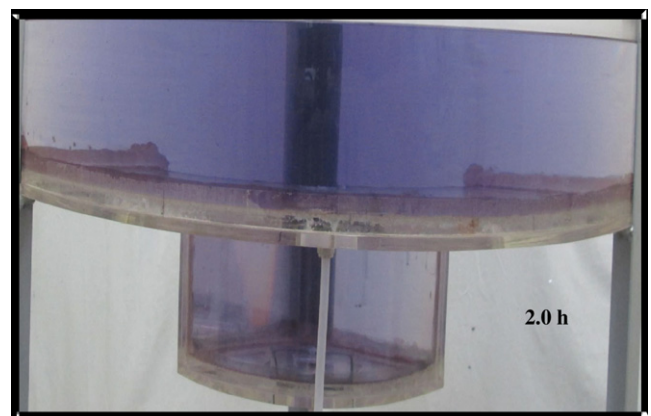


Fig. 4. Plume evolution throughout time ($t = 2.0$ h) – Experiment A.

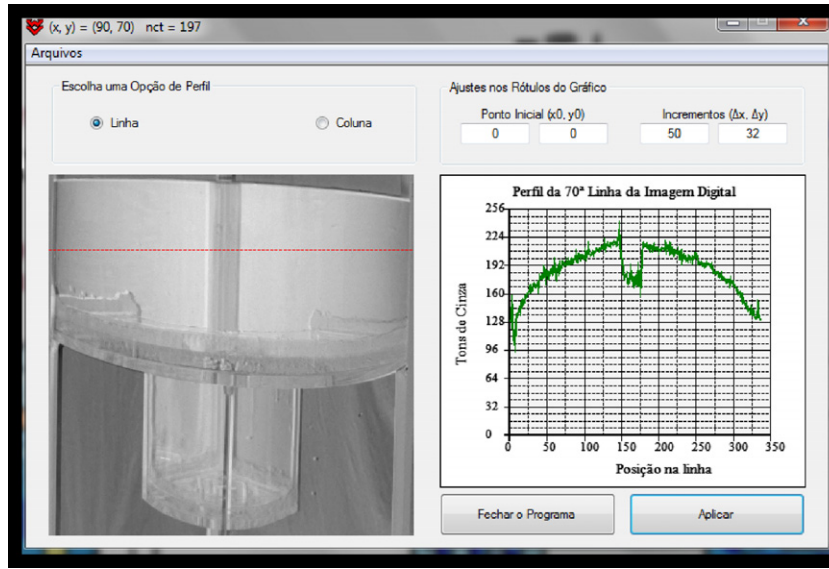


Fig. 5. Processed image of the superior region of the tests session ($t = 2.0$ h).

Table 2
Experiment A data.

Time (h)	Gray shades	Gray shades (N)	Note
Beginning	91.15	0.490	$t = 0.03$ h
0.5	144.20	0.776	
1.0	149.85	0.807	$N = 185.80$
1.5	167.85	0.903	
2.0	182.20	0.981	
2.5	168.30	0.906	
3.0	178.40	0.960	
3.5	178.80	0.962	
4.0	184.25	0.992	
4.5	185.80	1.000	

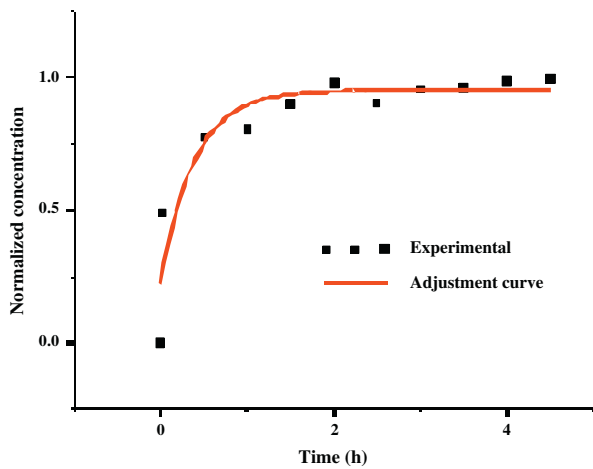


Fig. 6. Normalized concentration \times time – Experiment A.

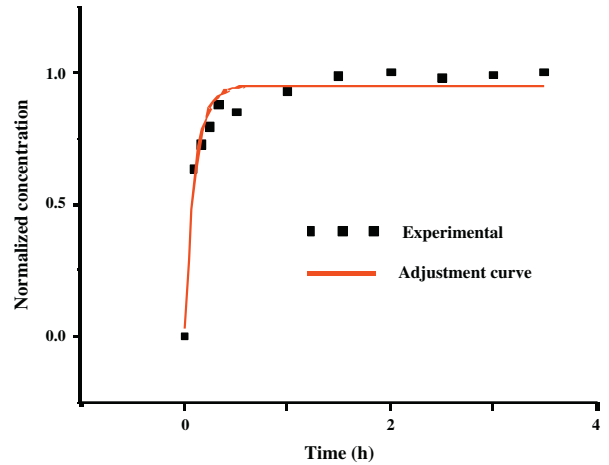


Fig. 7. Normalized concentration \times time – Experiment B.

cess (~ 3 h), which is compliant with what happens during the operation in a nuclear reactor. The exponential behavior of the

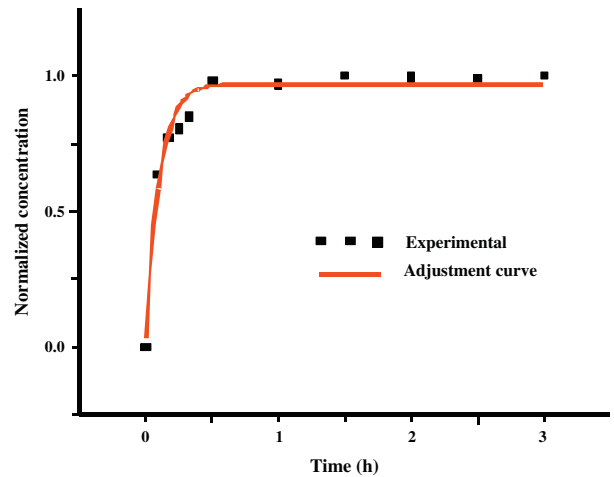


Fig. 8. Normalized concentration \times time – Experiment C.

5. Conclusions

It can be concluded from the results of the measures that the colorant homogenization process in the test session is a slow pro-

experimental curve is also consistent with the boron homogenization in a reactor.

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