COMISSIONING OF THE NEW HEAT EXCHANGER FOR THE RESEARCH NUCLEAR REACTOR IEA-R1

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Abstract. *The Research Reactor IEA-R1 placed at IPEN/CNEN-SP is of the swimming pool type, light water moderated and with graphite reflectors, and was build and designed by Babcock&Wilcox Co. Start up operation was in September the 16th, 1957, being the first criticality for South Hemisphere. Although designed to operate at 5 MW, the IEA-R1 was operated until 2001 with 2 MW and was suitable for use in basic and applied research as well as the production of medical radioisotopes, industry and natural sciences applications. Due to a recent demand increase on radioisotopes in Brazil for medical diagnoses and therapies applications, IPEN /CNEN updated the IEA-R1 power to 5 MW and to work at continuous operation regime. Studies on the Ageing Management for the Research Reactor IEA-R1 were conducted according to IAEA procedures. As result of these studies critical components within the Ageing Management Program were identified. Also were made recommendations on the implementation of test scheduling and standardization procedures to organize data and documents. One of the main results was the need of monitoring the two heat exchangers, the two primary circuit pumps and the data acquisition system. During monitoring procedures, issues were observed on the IEA-R1 operation at 5 MW mainly due to the ageing of the Babcox & Wilcox TCA heat exchanger, and excessive vibrations at high flow rates on CBC's TCB heat exchanger. So, from 2005 on, it was decided to work with 3,5 MW and provide a new IESA heat exchanger with 5 MW capacity, to substitute the TCA heat exchanger. This work presents results on the commissioning of the new heat exchanger and compares against the values calculated in the IESA project. The results show that the IEA-R1 Reactor can be operated more safety and continuously at 5 MW with the new IESA heat exchanger .*

Keywords: *Heat exchangers, IEA-R1, Research reactors, Radioisotope production.*

1. INTRODUCTION

The reactor cooling system has two independent flow circuits. In the primary flow circuit the cooling fluid flows inside the tubes of heat exchanger A (TCA) or inside the shell of heat exchanger B (TCB). After the two heat exchangers, the cooling fluid flows to flowmeter and then returns to the bottom of the pool through a diffuser to achieve a better mixture with the pool water. In both the inlet and outlet streams of the pool, there are installed motor driven isolation valves. The schematic diagram of this circuit is presented in Fig. 1. The secondary circuit is composed by two cooling towers, two heat exchangers, two pumps and valves, as presented in Fig. 2.

The oldest heat exchanger (TCA) was design and build by Babcock&Wilcox in 1957 when the reactor was started up. In 1974, TCB was designed and build by CBC (Companhia Brasileira de Caldeiras), installed together with the second cooling system. Both were designed to a 5 MW reactor power operation, but until 2001, there was no need to operate at power higher than 2 MW. From 2001 on, there were a substantial demand increase on medical and therapy diagnoses radioisotopes, so the reactor had to increase its power operation to 5 MW and operate at continuous regime.

IPEN/CNEN updated the IEA-R1 power to 5 MW. Studies on the Ageing Management for the Research Reactor IEA-R1 were conducted according to IAEA procedures described in the technical report 338 (IAEA, 2001) and technical document 792 (IAEA, 1995). As result of these studies critical components within the Ageing Management Program were identified. Also were made recommendations on the implementation of test scheduling and standardization procedures to organize data and documents. One of the main results was the need of monitoring the two heat exchangers, the two primary circuit pumps and the data acquisition system. During monitoring procedures, issues were observed on the IEA-R1 operation at 5 MW mainly due to the ageing of the Babcock&Wilcox TCA heat exchanger, and vibration problems at high flow rates on CBC's TCB heat exchanger. So, from 2005 on, it was decided to work with 3.5 MW and provide a new IESA heat exchanger with 5 MW power capacity, to substitute the TCA heat exchanger.

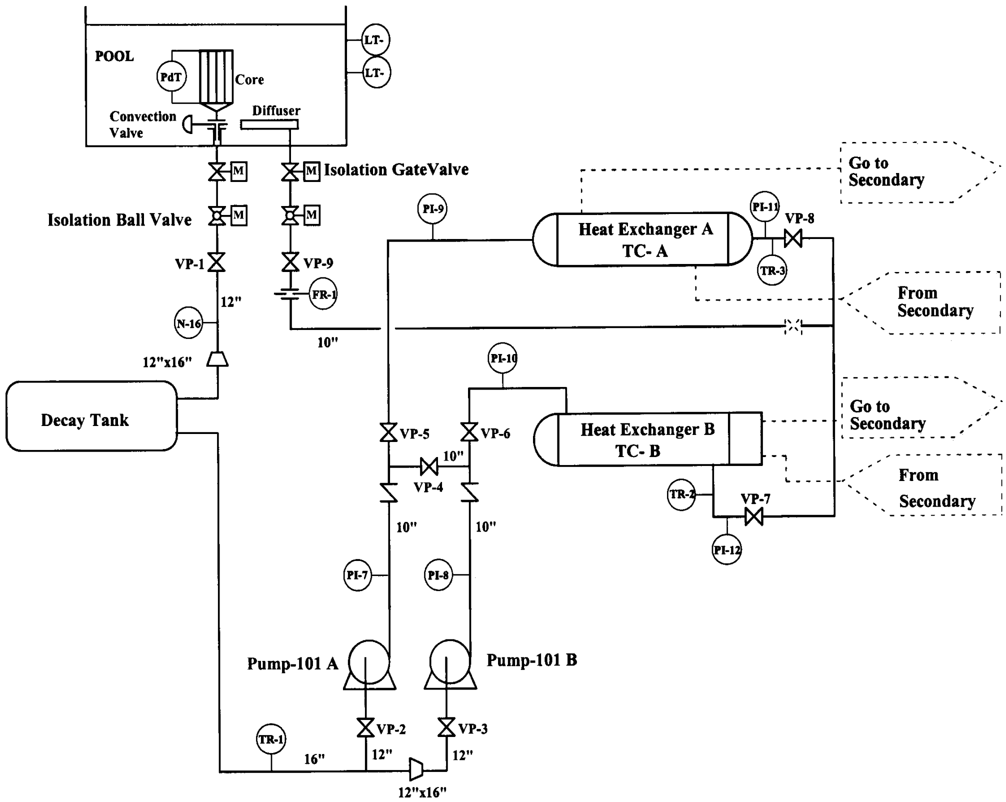

Figure 1. Primary cooling circuit of IEA-R1 reactor

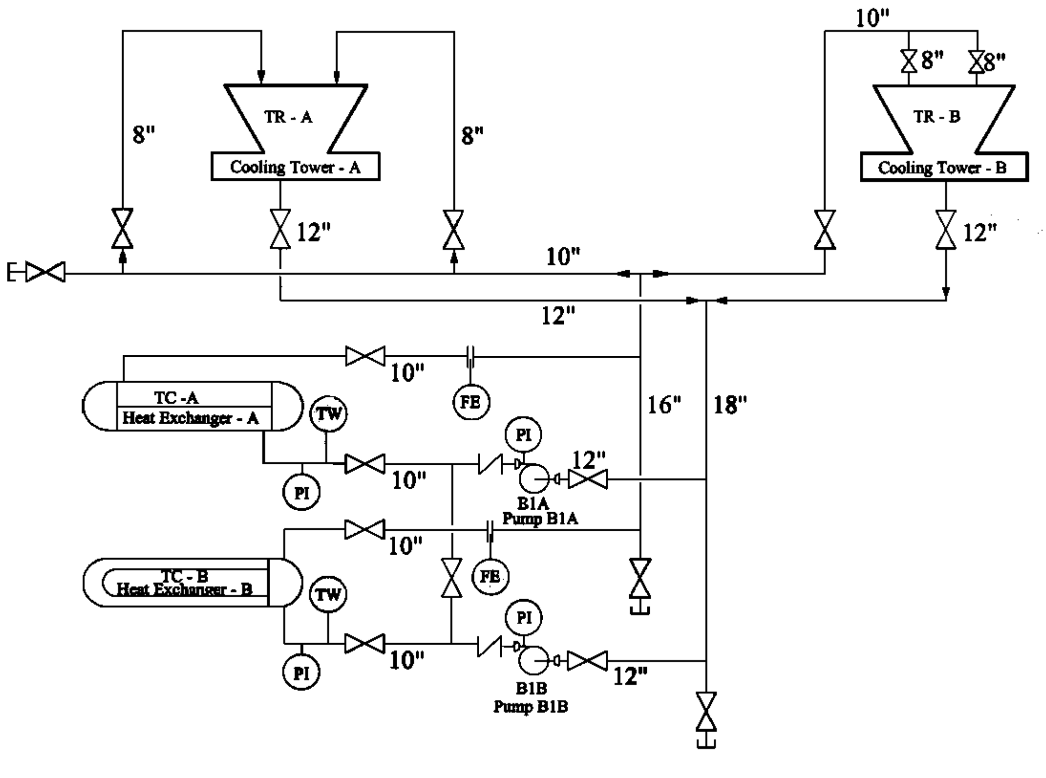

Figure 2. Secondary cooling circuit of IEA-R1 reactor

2. EXPERIMENTAL METHODOLOGY

The commissioning was made in two experimental stages, stage one with the reactor powered off and the stage two with the reactor power varying between 3.5, 4 and 5 MW. The B cooling tower was used in all experiments. The main objectives of experiments were:

1. to obtain pressure loss in IESA heat exchanger at reactor operational flow conditions in the primary cooling circuit (shell side),
2. to obtain pressure loss in IESA heat exchanger at reactor operational flow conditions in the secondary cooling circuit (tube side),
3. to obtain IESA heat exchanger vibrations at reactor operational flow conditions,
4. to obtain the flow coast down at 5 MW and 3500 gpm.

In the experiments, were used two Fischer pressure transmitters for pressure loss measurement, one Bruel & Kjaer accelerometer was used for vibration measurement, two bourdon manometers for pressure measurement, all installed in the IESA heat exchanger, as shown in Fig. 3. Also, a Bruel & Kjaer accelerometer was used for vibration measurement in the pump. The primary flow rate was varied between 2700 to 3830 gpm. The secondary flow rate was varied between 1900 to 2300 gpm. The reactor data acquisition system was used to acquire the values of primary and secondary flow rate, and its temperatures. The signals of the pressure transmitters and the accelerometer were acquired with a portable acquisition system, as shown in Fig. 4. The portable acquisition system uses a program based in the LabVIEW 7.0 Software and DAQ-Hardware, both from National Instruments.

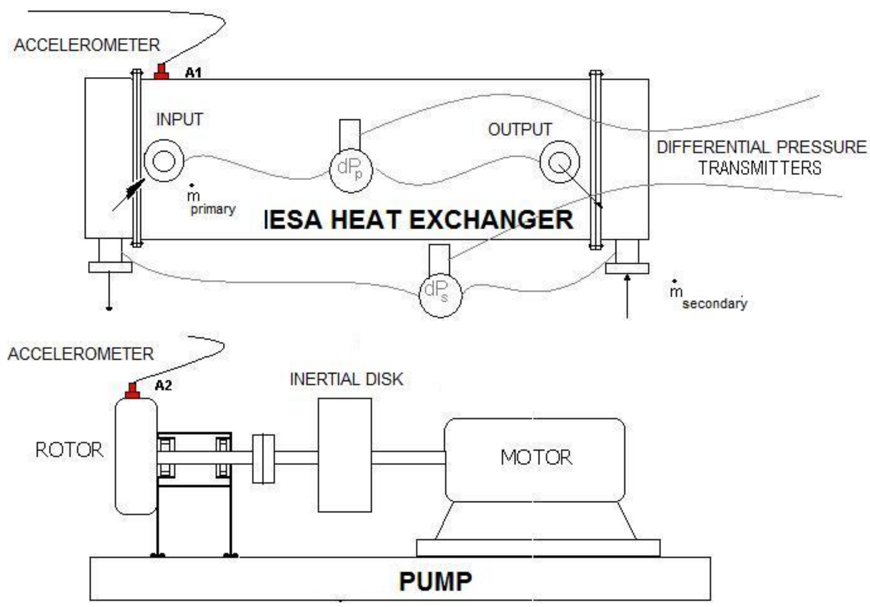

Figure 3. Heat exchanger and pump instrumentation scheduling

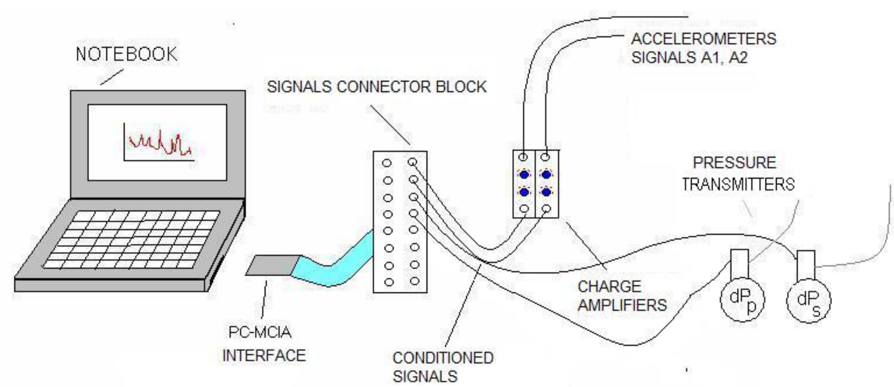

Figure 4. Portable data acquisition system

3. RESULTS

The operational conditions for all experiments are presented in Tab.1. Calculations were made with the thermocouple measured values to evaluate the energy balance in both sides of IESA heat exchanger. The percentual error was obtained from Eq. 1.

$$\varepsilon = \frac{\text{Nominal Reactor Power} - \text{Measurement of Heat exchanged}}{\text{Nominal Reactor Power}} \tag{1}$$

Table 1: Operational conditions for the experiments.

Experiment	Power (MW)	Primary Flow Q_p [gpm]	Secondary Flow Qs [gpm]	Inlet Primary Heat Exchanger Temperature T_{pe} [°C]	Outlet Primary Heat Exchanger Temperature T_{ps} [°C]	Inlet Secondary Heat Exchanger Temperature T_{se} [°C]	Outlet Secondary Heat Exchanger Temperature T_{ss} [°C]	Inlet Cooling Tower Temperature T_{te} [°C]	Outlet Cooling Tower Temperature T_{ts} [°C]
01	0	2700	1910	22.35	18.70	16.49	18.06	18.45	16.49
02	0	2900	1915	22.40	18.70	16.88	18.15	18.35	16.79
03	0	3000	2000	22.40	18.70	17.2	18.20	18.35	17.08
04	0	3100	2000	22.45	18.70	17.28	18.15	18.45	17.18
05	0	3300	2100	22.45	18.74	17.37	18.15	18.54	17.28
06	0	3500	2200	22.45	18.84	17.47	18.25	18.54	17.37
07	0	3700	2300	22.55	18.93	17.47	18.25	18.64	17.37
08	0	3830	2430	22.55	18.93	17.57	18.25	18.64	17.57
09	0	3500	2200	22.55	19.03	18.06	18.35	18.64	17.67
10	3.5	3200	2000	32.50	28.60	24.80	29.40	29.80	24.60
11	4.0	3500	2200	33.90	29.70	25.00	30.10	30.60	24.80
12	5.0	3600	2300	36.00	30.90	25.70	31.50	32.10	25.30

Table 2 presents the energy balance results for the IESA heat exchanger. For the energy balance of the primary side (tube side) of heat exchanger a 3 % error can be observed for the 5 MW operational condition, which is acceptable. For the 3.5 MW operational condition the energy balance error was larger, 6%, but it was acceptable too because for smaller temperature differences small errors in temperature measurements produce larger errors in the energy balance. The thermocouples are calibrated and well installed in the heat exchanger, therefore this error probably is generated by heat loss in the pipeline and decay tank.

Table 2: Energy balance for the IESA heat exchanger.

Nominal Power Reactor [kW]	Primary Flowrate [gpm]	Primary Mass Flow [kg/s]	ΔT_P [°C]	Primary Heat Exchanged [kW]	Error [%]
3500	3200	201.6	3.9	3292	6.0
4000	3500	220.5	4.2	3878	3.0
5000	3600	226.8	5.1	4843	3.0

To analyze the pressure losses and the vibrations for the IESA heat exchanger was used the software Matlab 6.5.3. Statistical values data as rms, maximum and minimum peak, standard deviation, skewness, kurtosis and Power Spectral Densities for the accelerations in the shell and differential pressures primary/secondary side were calculated for the different experimental conditions.

To the experimental conditions 1 to 8, the accelerometer signals were conditioned with a 3000 Hz low-pass filter and 0.2Hz high–pass filter. The accelerometer and pressure transmitter signals were digitalized with a 5000 Hz scanning frequency during 20s. In the experimental condition 9, flow coast down experiment, the signals were digitalized with a 1000 Hz scanning frequency during 180s.

In reactor powered experiments, conditions 10, 11 and 12, the signals were digitalized with a scanning frequency 4000 Hz during 30s.

The Tables 3, 4 and 5 present the results obtained with the Matlab6.5.3 software to the pressure losses in the primary circuit (shell side), pressure losses in the secondary side (tube side) and the shell accelerations of the IESA heat exchanger for different operational reactor flow rates and power.

Table 3: Results for the primary pressure losses (Shell Side) - IESA heat exchanger.

Experiment	Power [MW]	Flow[gpm]	ΔP_{Prms} [bar]	σ_{Psp} [bar]	ΔP_{Pmax} [bar]	ΔP_{Pmin} [bar]	Skewness	Kurtosis
1	--------	2700	0.2825	0.0109	0.3144	0.2506	0.1142	2.6907
2	--------	2900	0.3330	0.0324	0.4301	0.2272	0.0096	2.8775
3	--------	3000	0.3531	0.0317	0.4542	0.2375	0.0298	3.7030
4	--------	3100	0.3721	0.0270	0.4623	0.2964	0.0928	3.3236
5	--------	3300	0.4240	0.0320	0.5344	0.3323	0.0553	3.1057
6	--------	3500	0.4736	0.0293	0.5579	0.3902	0.0167	2.9001
7	--------	3700	0.5324	0.0255	0.5996	0.4553	0.0022	3.0390
8	--------	3830	0.5584	0.0222	0.6308	0.4982	0.0719	2.8104
9	--------	3500	-----	-----	----	----	----	----
10	3.5	3200	0.4160	0.0443	0.4659	0.2486	0.3983	2.0647
11	4.0	3500	0.4850	0.0430	0.4985	0.4407	-0.4261	1.7388
12	5.0	3600	0.5126	0.0382	0.5122	0.3641	-0.7914	2.3028

Table 4: Results for the secondary pressure losses (Tube Side) - IESA heat exchanger.

Experiment	Power [MW]	Flow[gpm]	ΔP_{Prms} [bar]	σ_{Psp} [bar]	ΔP_{Pmax} [bar]	ΔP_{Pmin} [bar]	Skewness	Kurtosis
1	---------	1910	0.0591	5.4×10^{-4}	0.0613	0.0578	0.3050	2.8313
2	---------	1915	0.0592	7.81×10^{-4}	0.0620	0.0572	0.5739	3.1727
3	---------	2000	0.0634	0.0006	0.0655	0.0613	0.0439	2.8618
4	---------	2000	0.0627	0.0007	0.0649	0.0605	0.3413	3.0661
5	---------	2100	0.0672	0.0008	0.0697	0.0649	0.0129	2.8817
6	---------	2200	0.0714	0.0008	0.0743	0.0691	0.1349	2.5596
7	---------	2300	0.0763	0.0010	0.0799	0.0743	1.0892	3.7318
8	---------	2430	0.0789	0.0009	0.0814	0.0757	-0.0042	2.4636
9	---------	2200	-----	------	-----	----	-----	-----
10	3.5	2000	0.0629	00009	0.0632	0.0528	0.1435	3.5345
11	4.0	2200	0.0713	0.0009	0.0749	0.0486	0.1762	4.3811
12	5.0	2300	0.0753	0.0009	0.0732	0.0641	0.2912	3.5108

Table 5: Results for the shell accelerations - IESA heat exchanger.

Experiment	Primary flowrate [gpm]	Secondary flowrate [gpm]	$A1_{avg}$ [m/s2]	$A1_{rms}$ [m/s2]	σ_{sp} [m/s2]	$A1_{max}$ [m/s2]	$A1_{min}$ [m/s2]	Skewness	Kurtosis
1	2700	1910	1.7534×10^{-5}	17.569×10^{-5}	17.569×10^{-5}	78.125×10^{-5}	-78.125×10^{-5}	-0.0056	3.0138
2	2900	1915	-1.8935×10^{-5}	56.932×10^{-5}	56.901×10^{-5}	0.0027	- 0.0026	-0.0054	3.0503
3	3000	2000	-1.8573×10^{-5}	52.531×10^{-5}	52.498×10^{-5}	0.0024	- 0.0024	-0.0210	3.0376
4	3100	2000	0.0000	0.0005	0.0005	0.0022	-0.0022	-0.0002	3.0231
5	3300	2100	0.0000	0.0004	0.0004	0.0019	-0.0023	-0.0050	3.1451
6	3500	2200	0.0000	0.0004	0.0004	0.0029	-0.0024	0.0058	3.1670
7	3700	2300	0.0000	0.0004	0.0004	0.0051	-0.0045	-0.0203	3.7948
8	3830	2430	0.0000	0.0005	0.0005	0.0024	-0.0023	0.0012	3.1303
9	3500	2200	----	----	----	----	----	----	----

To the project conditions for the IESA heat exchanger, primary flow rate Q_P=3600 gpm and secondary flow rate Q_S=2300 gpm with 5.0MW heat transfer capacity, we can observe that the result to the primary side(shell side), ΔP_{Prms} = 0.5126 bar was little higher as the value calculated by IESA($\Delta P_{Pallowed}$=0.45 kgf/cm2 e $\Delta P_{Pcalculated}$=0.408 kgf /cm2). In the secondary side (tube side), the value measured was ΔP_{Srms}=0.0753 bar, similar as calculated by IESA ($\Delta P_{Sallowed}$=0.20 kgf/cm2 e $\Delta P_{Scalculated}$=0.0714 kgf /cm2).The values from IESA can be obtained from Baumann (2006).

The difference between the values calculated by IESA and the measured values at the comissioning in the primary side can be explained due the complex geometry from the bundle of tubes, and the direction changes in the flow in the shell side, cross-flow, stagnation regions, etc.

With relation to the pressure loss measured in the secondary side the result was very satisfactory. The flow regime in the tubes is not complex and can be calculated with very good precision with simple empirical correlations. The measured and calculated values were similar.

From shell accelerometer signals was observed that the rms values are very low compared with allowable values from vibrations norms (Alvim de Castro, 2002). Comparing with the results from CBC Heat Exchanger (TCB) experiments in the same conditions, we can observe that the values were 3000 times lower.

Figures 5 and 6 show the primary and secondary pressure losses versus time for the pump flow coast down experiment.

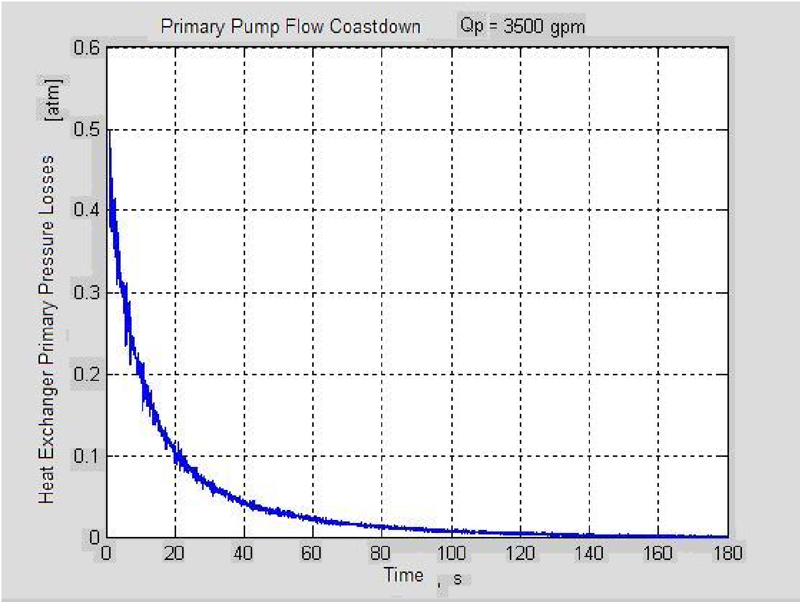

Figure 5. Primary pump flow coast down. Pressure loss x Time.

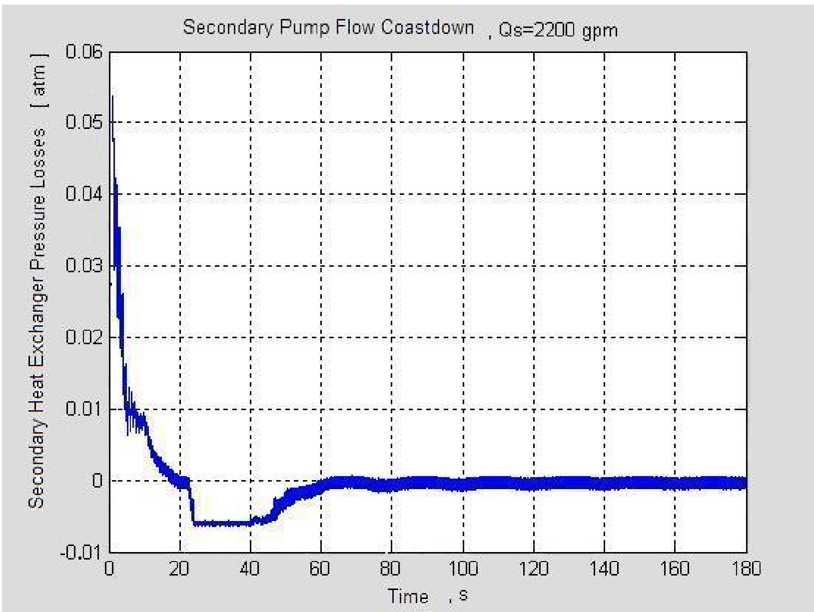

Figure 6. Secondary pump flow coast down. Pressure loss x Time.

Figure 6 shows a reversal flow in the secondary circuit from the IEA-R1. This occurs because there is a water column between the IESA heat exchanger and the B cooling tower. This causes no problem to IEA-R1 reactor installation.

In the Figure 7 we observe the primary flow rate in the flow coast down experiment. This result is very important in relation to the safety operation of the IEA-R1.

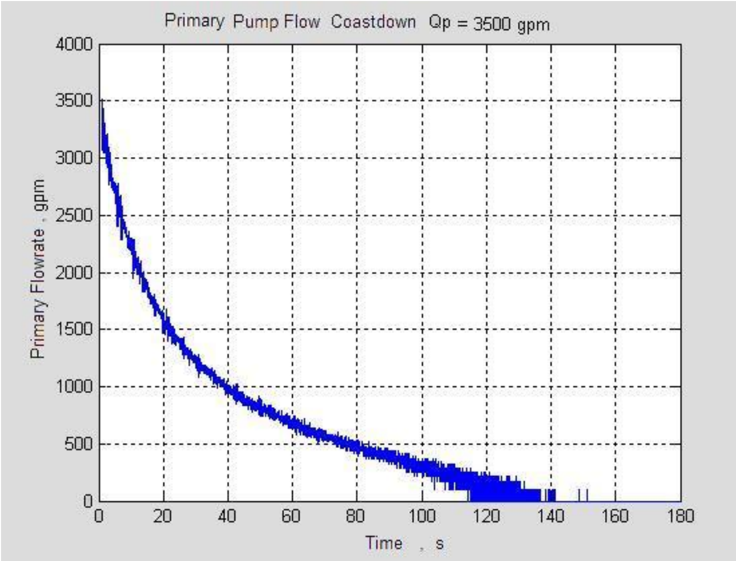

Figure 7. Primary pump flow coast down, Primary flow x Time.

4. CONCLUSIONS

The comissioning experiments show us that the IEA-R1 can be operated at the 5MW operational conditions safety and in continuous regime with the new IESA heat exchanger. In relation to the Fig.7 and to the reactor safety, we observe that the 500 gpm flow rate is obtained after 70s the pump cutoff. The IEA-R1 has a isolation valve that close the primary fluid circuit for flow rate below 500 gpm. So, we can say that in 3500 gpm primary flow rate condition in accidental conditions with pump cutoff, the IEA-R1 installation will have cooling primary flow to remove residual heat from the reactor during 70s.

5.ACKNOWLEDGMENTS

We wish to thank the operational staff from the IEA-R1 for preparing the experiments and Eletronuclear for financial providing the IESA heat exchanger.

6. REFERENCES

IAEA – International Atomic Energy Agency, 1995, “Management of Research Reactor Ageing”, Technical Document 792, IAEA-TECDOC-792, 66 p.

IAEA – International Atomic Energy Agency, 2001, “Methodology for the Management of Ageing of Nuclear Power Plant Components Important to Safety”, Technical Report 338, IAE- TECDOC-1197, 46 p.

Baumann, A. , “Memorial de Cálculo Térmico Trocador de Calor do Reator IEA-R1 5MW”, Technical Report – IESA, 2006, 40 p.

Alvim de Castro, A.J.,” Análise de Vibrações do Trocador de Calor TCB do IEA-R1”, Technical Report PSE.CEND.IEAR1.030.01-RELT.001.00 – IPEN, 2002, 120p.

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