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OPERATIONAL PARAMETER BEHAVIOR OF THE IPR-R1 TRIGA MARK 1 REACTOR

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ABSTRACT

In order to study the safety aspects connected with the permanent increase of the maximum steady state power of the IPR-R1 TRIGA Reactor, it was done experimental measures with the reactor working in power steps since "zero" power until 265 kW, with the pool forced cooling system turned off. A number of parameters were measured in real-time such as fuel and water temperatures, radiation levels, reactivity and influence of cooling system. This paper summarizes the behavior of the operational parameters and presents some of the recent results obtained. Information on all aspects of reactor operation is displayed on the Data Acquisition System (DAS) shown the IPR-R1 real-time performance. The DAS was developed to monitor and record all operational parameters. Information displayed on the monitor was recorded on hard disk in a historical database.

1. INTRODUCTION

The natural circulation experiments were conducted to confirm the cooling capability and the flow characteristics of the natural convection in the IPR-R1 (Fig. 1). The natural convection cooling is an ultimate heat removal mechanism as an inherent safety feature. The tests were performed at various power levels in the IPR-R1, a stepped ramp was performed to verify the steady state fuel temperature as function of the power. In the tests the variation of fuel and core hot channel temperatures were measured.

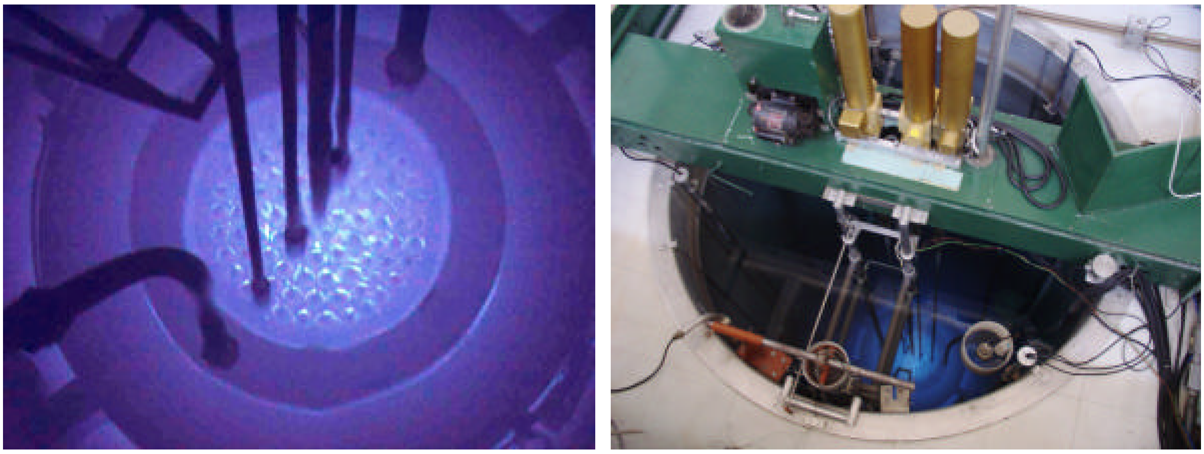

Figure 1. Core upper view and pool of the IPR-R1 TRIGA.

The IPR-R1 Reactor is a standard design, natural-convection-cooled TRIGA reactor. The rector core is located near the bottom of a water filled aluminum tank 1.92 m in diameter and 6.33 m deep. The water provides adequate shielding over the surface of the pool. The reactor can be operated in a steady state mode by either manual or automatic control. The TRIGA fuel is characterized by inherent safety, high fission product retention. The intrinsic safety of the IPR-R1 has been demonstrated by the extensive experience acquired from similar TRIGA systems throughout the world.

2. EXPERIMENTAL METHODOLOGY

Before the experiments the reactor thermal power and the measuring devices were calibrated [1]. The power of the IPR-R1 TRIGA was raised in steps of about 25 kW until 265 kW. The forced cooling system of the reactor pool was turned off during the tests. The increase of the power was allowed only when all the desired quantities had been measured and the given limits were not exceeded. After the reactor power level was reached, the TRIGA was maintained at that power for about 15 min, so the entire steady-state conditions were not reached in the core and coolant. The temperature data was obtained by using an instrumented fuel element (Fig. 2) with thermocouples (type K) embedded in the zirconium centerline pin [2]. The fuel temperature measurements were taken at location B1 of the core (hottest fuel element). The outlet temperature in the hot channel was measured by one thermocouple (type K), inserted near the B1 core position. One platinum resistance thermometer (PT-100) measured the water temperature in the upper part of the reactor tank. Two thermocouples measured the ambient temperatures around the reactor pool.

The gamma doses were measured using the permanently installed Geiger-Müller (GM) detectors in the reactor room. One is located about 30 cm above the tank “Pool”, and the other is 2 m above “Area”. The radiation was also measured in the primary cooling system inlet “Heat Exchanger”. The IPR-R1 Data Acquisition System monitors and records the operational parameters.

The data presented in this article are power, reactor temperatures, control rod insertion positions and radiation levels. The power coefficient of reactivity was determined by calibrated control rods method, and the reactivity loss as function of power is given in another paper [3]. The measured fuel and water temperatures are used to estimate the temperature of the fuel element cladding, the coolant flow rate and other parameters [4].

3. RESULTS

3.1. Reactor Temperatures

The power and fuel temperature versus time is given in Fig. 2. In the experiment the highest fuel temperature was 280 ^{o}C. The maximum permissible fuel center temperature is 550 ^{o}C [5]. The power and the temperatures of the channel outlet, reactor pool, environment around the reactor and in the position 40 of rotary specimen rack are plotted in Fig. 3. The power in the graphics is given by the linear channel (neutron detector). We can see that the power response is faster than the temperature measure. All the reactor temperatures versus power are given in Fig. 4.

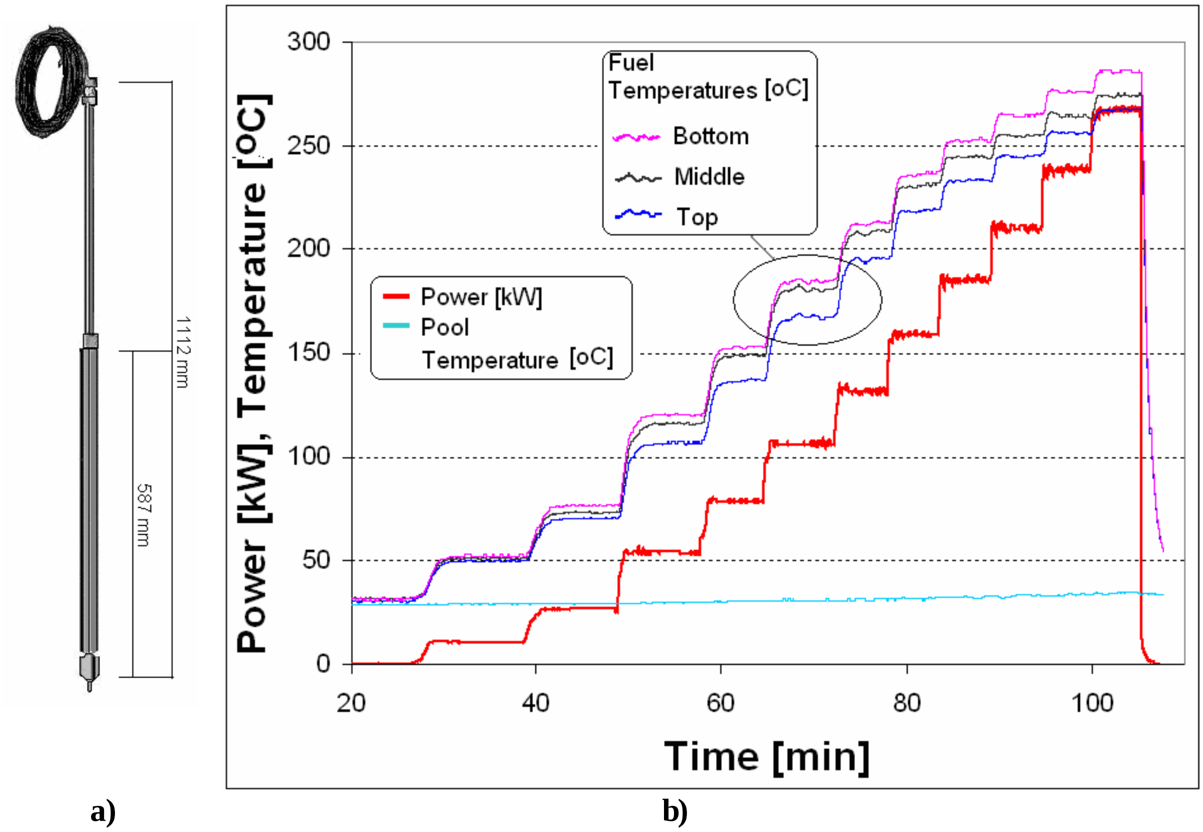

Figure 2. a) Instrumented fuel element; b) Power and fuel temperatures responses of a stepped ramp to 265 kW.

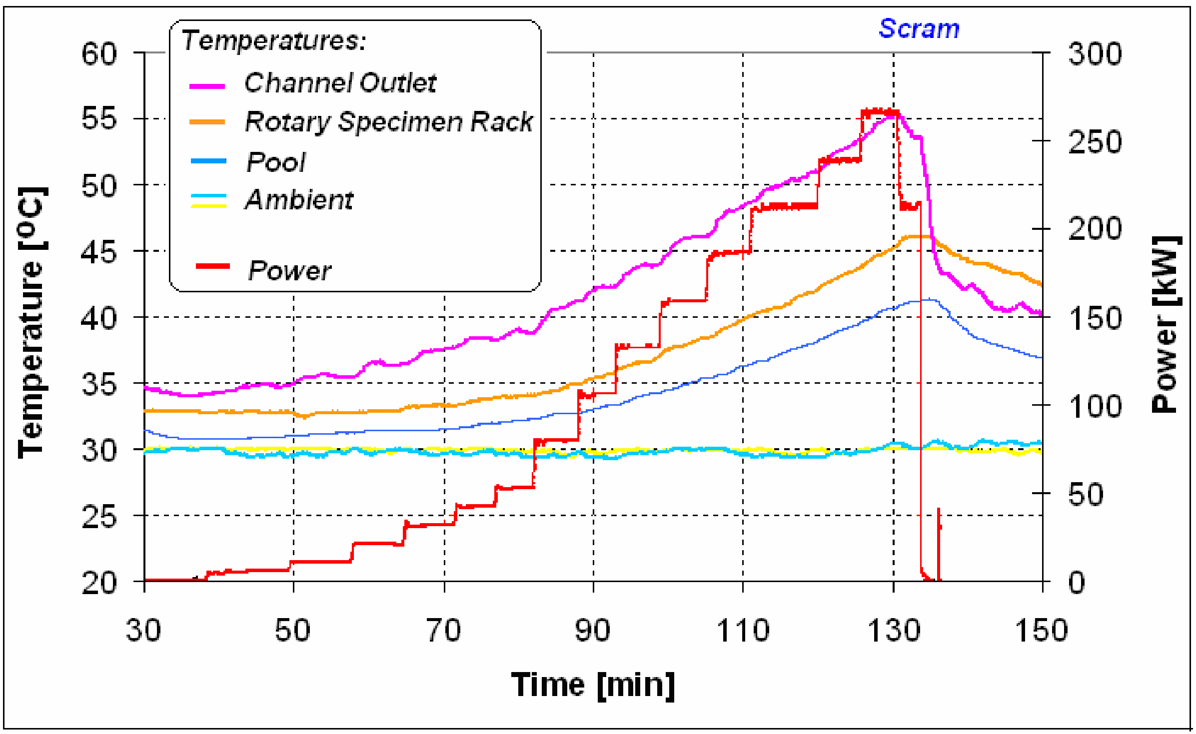

Figure 3. Power and reactor temperatures behavior of a stepped ramp to 265 kW.

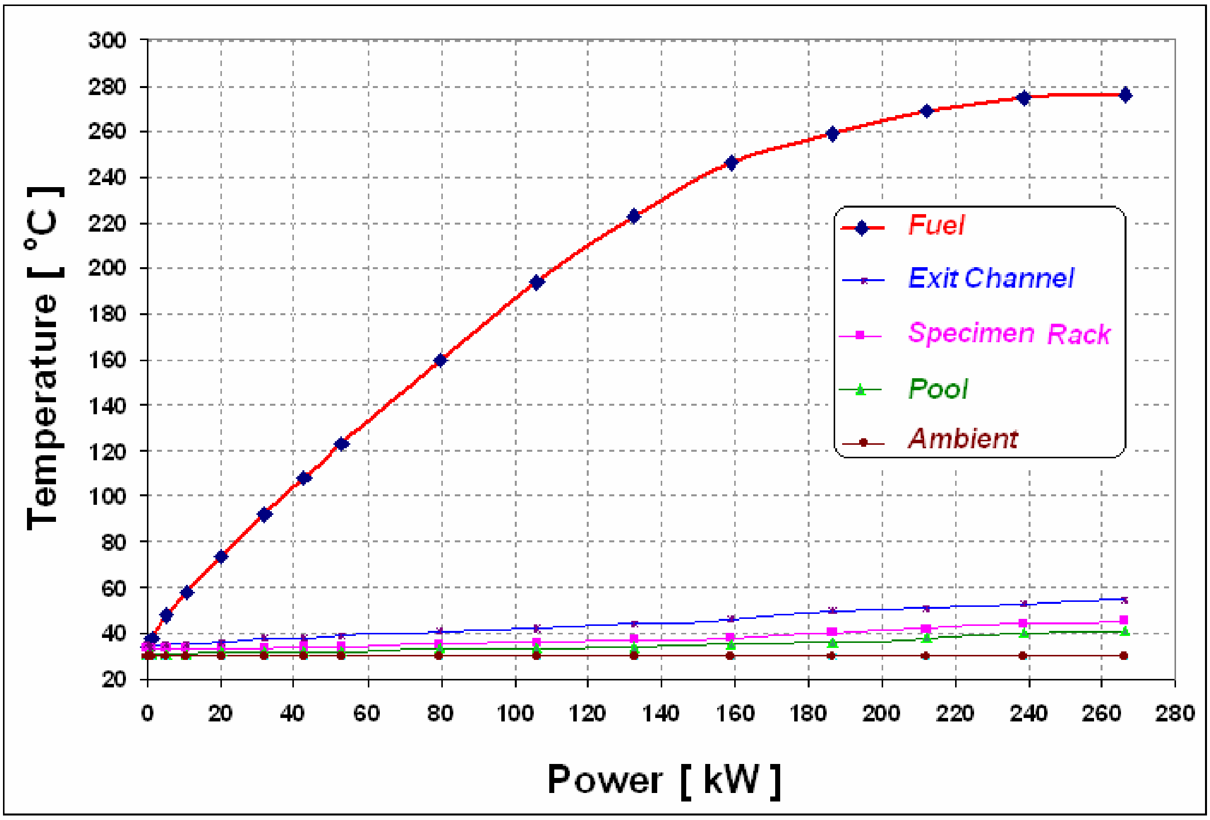

Figure 4. Temperatures versus reactor power.

3.2 Reactor Startup

Figure 5 shows the IPR-R1 reactor startup for a routine operation. Basics operational parameters are given as function of time. The parameters shown are: average fuel temperature, power, reactivity, and control rod positions. In this operation the forced cooling system is turn off. The initial position of the three control rods is about 166 units and the oscillation in the chart is due to noise in the register. The reactor was taken up to power from its shutdown condition by withdrawing the safety rod to their ready position, followed by small stepwise withdrawal of the shim rod and the regulating rod, maintaining approximately same positions for the shim and regulating. The multiplication of the neutrons is followed with the period meter and ionization chamber while the reactor is still subcritical.

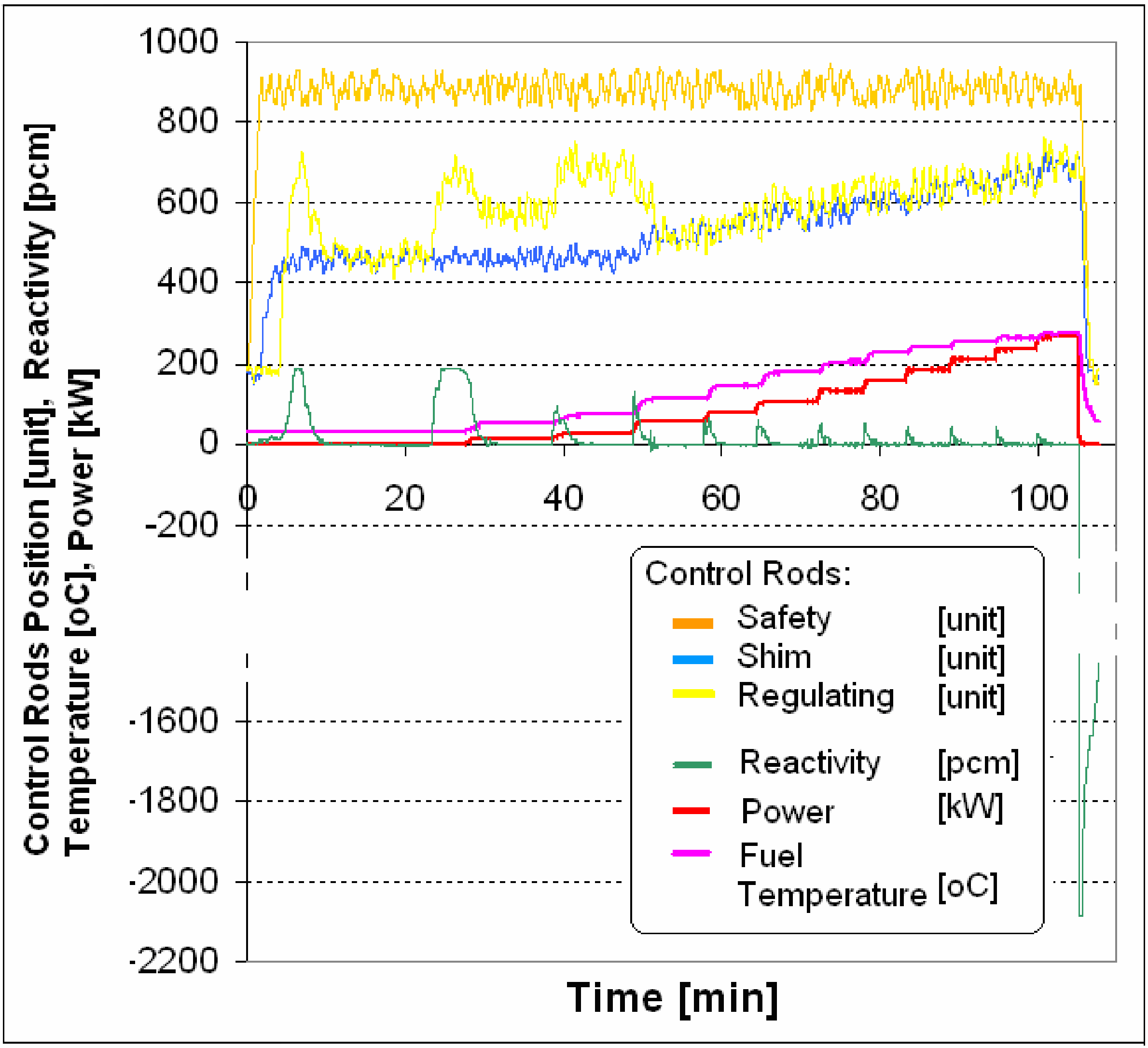

Figure 5. Average fuel temperature, power, reactivity and control rod positions versus time, with the forced cooling system off.

3.3. Gamma Doses

The GM detectors signal depends on the operation of the primary cooling system, and are proportional to the power. The gamma dose rates are mainly due to the ^{16}N activity. The operation of the primary cooling system had a large effect on the gamma dose rates at the upper power level. This influence is illustrated in Fig. 6 and Table 1. Figure 6 and Table 1 compare the gamma dose rate on the Pool, Area and Heat Exchanger inlet; with the forced cooling system turned on and off. Of course, the radiation level in the Heat Exchanger is zero with the cooling system off.

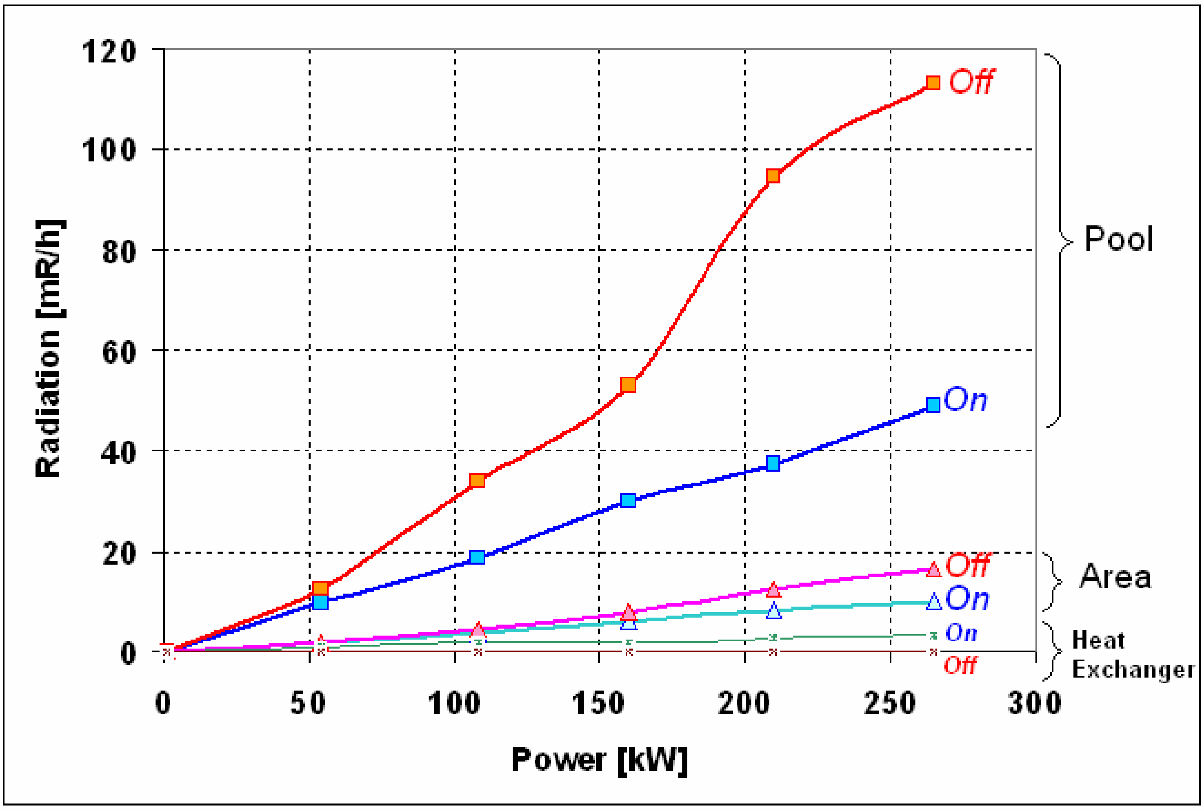

Figure 6. Average radiation levels as function of power with the pool forced cooling system turned on and off.

The radiation level above the pool was higher than 100 mR/h and the radiation device reached the end of the range, according to the graphic shown in Fig. 7. In normal operation, the cooling system is turned on, and the radiation levels above the pool are less than 50 mR/h.

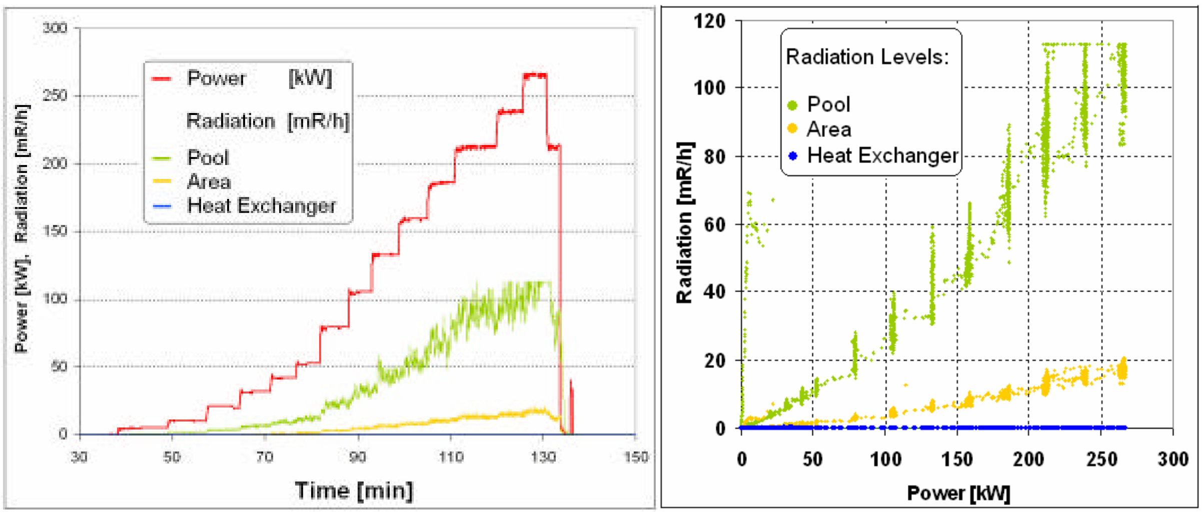

Figure 7. Radiation response of a stepped ramp to 265 kW and radiation as function of reactor power with the forced cooling system off.

Table 1. Radiation levels with the cooling system turned on and off.

Power	Radiation Levels (Average)					
	Pool		Area		Heat Exchanger	
[kW]	[mR/h]		[mR/h]		[mR/h]	
	On	Off	On	Off	On	Off
0,01	0	0	0	0	0	0
54	9.8	12.4	1.7	1.7	0.9	0
108	18.8	34.1	3.8	4.6	1.7	0
160	30.1	53.1	6.1	7.9	1.9	0
210	37.5	94.5	8.3	12.5	2.8	0
265	48.9	113*	10.2	16.6	3,5	0

* end of range

4. CONCLUSIONS

Nuclear reactor operators everywhere need to know the basic reactor behavior in order to understand and safely operate a nuclear reactor. Most of the measured parameters behaved as they were expected to. With no primary cooling, the gamma dose rate above reactor pool at high power levels was rather high. The natural circulation test was performed to confirm the cooling capability of the natural convection in the IPR-R1 TRIGA Reactor. It was confirmed that the IPR-R1 has capability of long term core cooling by natural circulation. The measured maximum fuel temperature of about 280 ^{o}C was lower than the operating limit of 550 ^{o}C [5]. Fuel, channel and pool temperatures depend on reactor power, as well as environment temperature.

In the next experiments, we intend to do visual observations in the core, in order to detect possible boiling in the water. The results of this work and other thermal experiments [1] [4] and [6], are important for the possible upgrade of the IPR-R1 for power higher than 250 kW.

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