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EXPERIMENTAL STUDY OF THE IPR-R1 TRIGA REACTOR POWER CHANNELS RESPONSES

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ABSTRACT

The IPR-R1 nuclear reactor installed at Centro de Desenvolvimento da Tecnologia Nuclear CDTN/CNEN, Belo Horizonte, Brazil, is a Mark I TRIGA reactor (Training, Research, Isotopes, General Atomics) and became operational on November of 1960. The reactor has four irradiation devices: a rotary specimen rack with 40 irradiation channels, the central tube, and two pneumatic transfer tubes. The nuclear reactor is operated in a power range between zero and 100 kW. The instrumentation for IPR-R1 operation is mainly composed of four neutronic channels for power measurements. The aim of this work is to investigate the responses of neutronic channels of IPR-R1, Linear, Log N and Percent Power channels, and to check their linearity. Gold foils were activated at low powers (0.125-1.000 kW), and cobalt foils were activated at high powers (10-100kW). For each sample irradiated at rotary specimen rack, another one was irradiated at the same time at the pneumatic transfer tube-2. The obtained results allowed evaluating the linearity of the neutronic channels responses.

1. INTRODUCTION

The IPR-R1 nuclear reactor, installed at Centro de Desenvolvimento da Tecnologia Nuclear, CDTN / CNEN, Belo Horizonte, is a TRIGA reactor type Mark I (Training, Research, Isotopes, General Atomics) and became operational in November 1960.

The IPR-R1 core, installed at the bottom of a 6.5m deep well, uses enriched uranium to 20% as nuclear fuel, zirconium hydride as a neutron moderator and graphite as a neutrons reflector. It is immersed in demineralized light water, which has many functions: natural convection cooling, additional moderator, neutron reflection and biological shield (DALLE, 2005).

Figure 1 shows a view of the submerged core of IPR-R1 nuclear reactor.

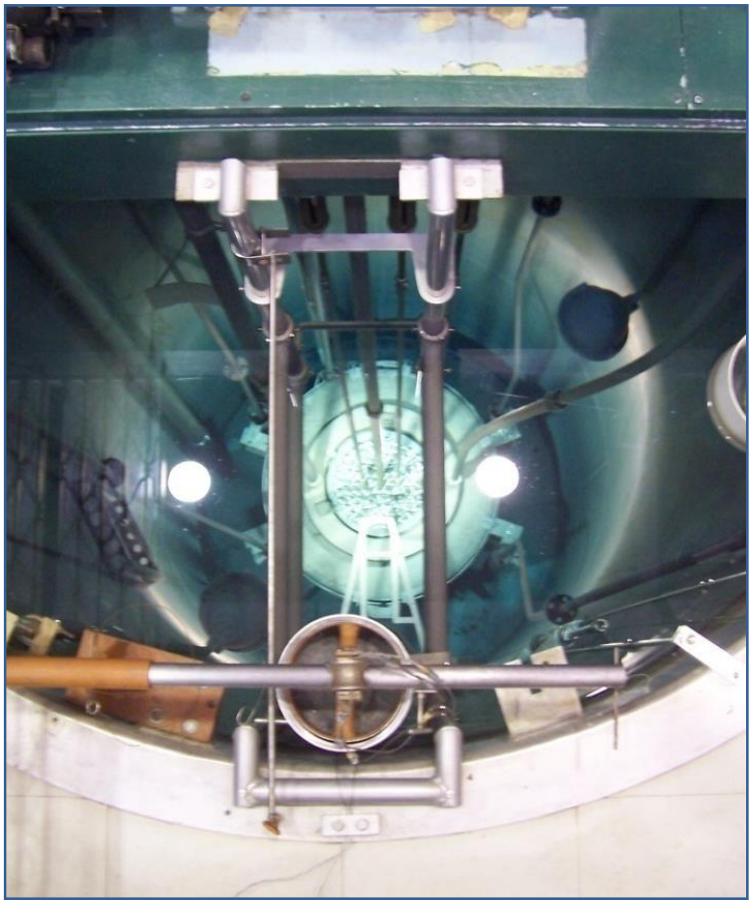

Figure 1: View of the submerged core of the IPR-R1 reactor

IPR-R1 reactor control is performed by operation of three neutrons absorbing bars containing boron carbide. The reactor is operated in a power range between zero and 100 kW. The instrumentation for IPR-R1 operation is mainly composed of four neutronic channels for power measurements – Start Up Channel, Linear Channel, Log N Channel and Percent Power Channel – in addition to others operational variables monitoring channels as temperature, conductivity and radiation levels. The Start Up Channel consists of a fission chamber detector with associated circuits and meters. This channel is used to monitor the neutron flux at the start up power range. Log N Channel consists of a compensated ionization chamber, analog meters of power and period, a digital display of reactivity and a graphic recorder. Power data are presented in logarithmic scale. This channel permits to monitor power levels from the end of the Starting Channel scale up to the maximum power level. The Linear Channel consists of a graphic recorder and analog meter, associated with a compensated ionization chamber and indicates the power level from the source level up to the maximum power level. The Linear Channel presents eight manually interchangeable scales and indicates the power level of the reactor linearly. The Percent Power Channel is composed of a non-compensated ionization chamber, a power meter and voltage sources. This channel consists of a percentage power meter that indicates power level in percentage (0 to 120%) compared to full power (Zangirolami, 2009).

Figure 2 shows the IPR-R1 control console and its power channels.

Figure 2: Top: IPR-R1 control console. Bottom: details of IPR-R1 control console; from left to right, arrows indicate Log N, Linear and Percent Power Channels.

IPR-R1 has four irradiation devices: a rotary specimen rack with 40 irradiation channels for samples irradiation, the central tube, and two pneumatic transfer tubes. The rotary specimen rack is mounted on a swiveling holder and placed in a annular cavity of the graphite reflector. The central tube is made of aluminum and penetrates the central region of the reactor core, allowing samples irradiation under more intense neutron fluxes. The two pneumatic transfer tubes consist of a tube assembly connected to an air suction system, controlled by valves, and allow rapid introduction and removal of samples.

Figure 3 shows the TRIGA IPR-R1 core configuration, where it is possible to see the four power channels and the samples irradiation devices.

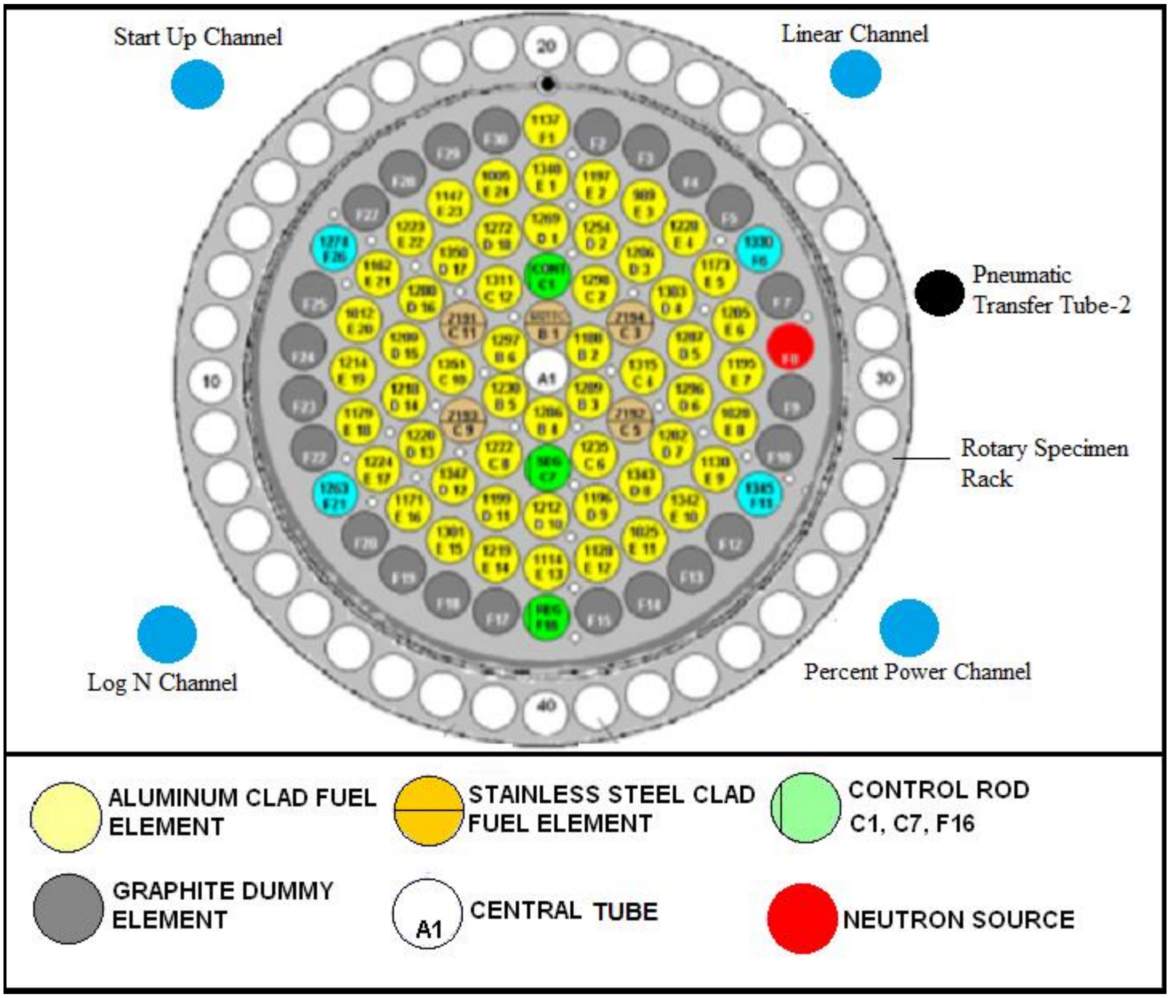

Figure 3: Core configuration of the IPR-R1 reactor

The aim of this work is to investigate the responses of IPR-R1 neutronic channels - Linear, Log N and Percent Power channels - and to check their linearity. Power is one of the main operational variables and must be monitored at all reactor operations. This study was conducted during the scientific initiation scholarship (CNPq-CDTN) between 2014/2015.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Activation Foils

For the evaluation of reactor channels response, two experiments were conducted by using gold and cobalt activation foils sets described in Table 1 and Table 2. These samples were submitted to neutron activation and after analyzed by gamma spectrometry.

Table 1: Sample Sets for Experiment 1

Material	Quantity	Composition	Mass
Gold Foils	10 samples	Au: 99,9976%;	~ 57 mg
Cobalt Foils	20 samples	Co: 99,7392%;	~ 65 mg

Table 2: Sample Sets for Experiment 2

Material	Quantity	Composition	Mass
Gold Foils	12 samples	Au: 99,9976%;	~ 57 mg
Cobalt Foils	16 samples	Co: 99,7392%;	~ 65 mg

2.1.2 Gamma Spectrometer

A gamma spectrometer supplied with a 25% relative efficiency HPGe detector coupled to an 8186 channels multichannel analyzer and to a computer was used to perform acquisition and analysis of gamma spectra of samples after their irradiation at IPR-R1. The main technical characteristics of the spectrometer are:

- Manufacturer:……………………… Canberra®;
- Detector Geometry:..........................*Extended Range Closed-end coaxial;*
- Model:...GX2520;
- Crystal Diameter:.............................62,5mm;
- Crystal Length:................................32,5mm;
- Window Distance:............................5mm;
- Resolution (FWHM) to 1,33 MeV:.....2,0 keV;
- Software:...Genie 2000–*Gamma Acquisition & Analysis by Canberra®.*

2.1 Experimental Methods

2.2.1 Neutron Activation

Neutron activation consists of atomic nuclei irradiation with neutrons to produce radioactive species, usually referred to as radionuclides. The number of produced radionuclides will depend on the number of target nuclei, the neutron fluency rate and on the radiative capture cross section, which defines the probability of activation occurring. The radionuclide activated will decay with a characteristic half-life. Therefore, the growth of activity during irradiation will depend on the half-life of the produced radionuclide (Parry, 2003).

Figure 4 shows a representation of neutron activation process.

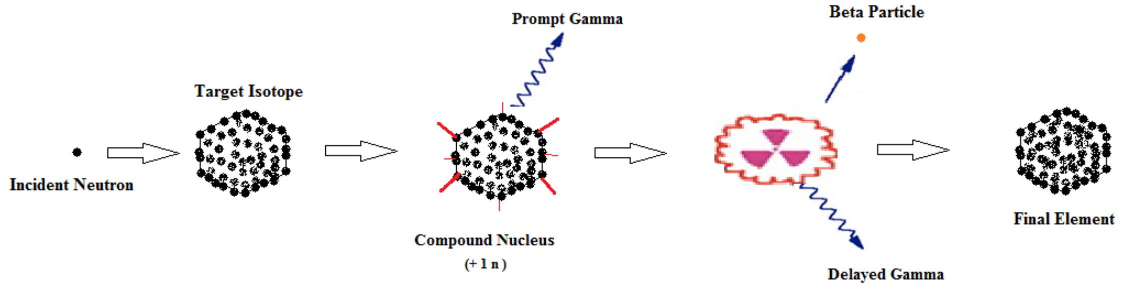

Figure 4: Neutron Activation Process

The induced activity of an irradiated sample can be determined using equation 1 (Zangirolami, 2009):

$$A_0 = N(\phi_{th}\sigma_{th} + \phi_{epi} I_R)(1 - e^{-\lambda t_{irr}}) \quad (1)$$

- N is the number of target nucleus in the sample;
- t_{irr} is the irradiation time;
- λ is the decay constant of the formed nuclide, (s^{-1});
- ($1-e^{-\lambda tirr}$) is the Factor Saturation (S);
- φ_{th} e φ_{epi} are the fluency rates of thermal neutrons and epithermal neutrons respectively, ($n.cm^{-2}.s^{-1}$);
- σ_{th} is the average thermal neutrons radiative capture cross section of target nucleus, (cm^2);
- I_R is the total resonance capture integrals of target nucleus, (cm^2).

2.2.2 Power Channels Responses

Two experiments were performed to check the linearity of the response of the IPR-R1 power channels. Gold and cobalt activation foils were irradiated in two different irradiation devices, simultaneously. At each irradiation, the reactor power was adjusted in different levels. Tables 3 and 4 present details of the two experiments.

Table 3: Details of the Experiment 1, 14/01/2015

Power (kW)	Sample	Irradiation time (s)	Irradiation place *
0,2	Au-1	600	I
	Au-2	600	II
0,4	Au-3	600	I
	Au-4	600	II
0,6	Au-5	600	I
	Au-6	600	II
0,8	Au-7	600	I
	Au-8	600	II
1,0	Au-9	600	I
	Au-10	600	II
10	Co-1	600	I
	Co-2	600	II
20	Co-3	600	I
	Co-4	600	II
30	Co-5	600	I
	Co-6	600	II
40	Co-7	600	I
	Co-8	600	II
50	Co-9	600	I
	Co-10	600	II
60	Co-11	600	I
	Co-12	600	II
70	Co-13	600	I
	Co-14	600	II
80	Co-15	600	I
	Co-16	600	II
90	Co-17	600	I
	Co-18	600	II
100	Co-19	600	I
	Co-20	600	II

* I**:** rotary specimen rack position 6; II: pneumatic transfer tube 2

Table 4: Details of the Experiment 2, 18/05/2015

Power (kW)	Sample	Irradiation time (s)	Irradiation place *
0,125	Au-1	600	I
	Au-2	600	II
0,25	Au-3	600	I
	Au-4	600	II
0,5	Au-5	600	I
	Au-6	600	II
0,625	Au-7	600	I
	Au-8	600	II
0,75	Au-9	600	I
	Au-10	600	II
1,0	Au-11	600	I
	Au-12	600	II
12,5	Co-1	600	I
	Co-2	600	II
25	Co-3	600	I
	Co-4	600	II
37,5	Co-5	600	I
	Co-6	600	II
50	Co-7	600	I
	Co-8	600	II
62,5	Co-9	600	I
	Co-10	600	II
75	Co-11	600	I
	Co-12	600	II
87,5	Co-13	600	I
	Co-14	600	II
100	Co-15	600	I
	Co-16	600	II

* I**:** rotary specimen rack position 6; II: pneumatic transfer tube 2

At each experiment, the Linear Channel was used as reference (nominal power) for the power setup and the power indication of the other channels, Log N Channel and Percent Channel, were registered for comparison.

3. RESULTS

3.1 Results at Low Powers (0 to 1 kW)

Figure 5 shows the obtained results for both experiments at low power, from zero to 1 kW. Power value indicated at IPR-R1 control console by Linear Channel was assumed to correspond to the nominal power. In this power range, the Percent Power Channel did not respond to IPR-R1 power variations.

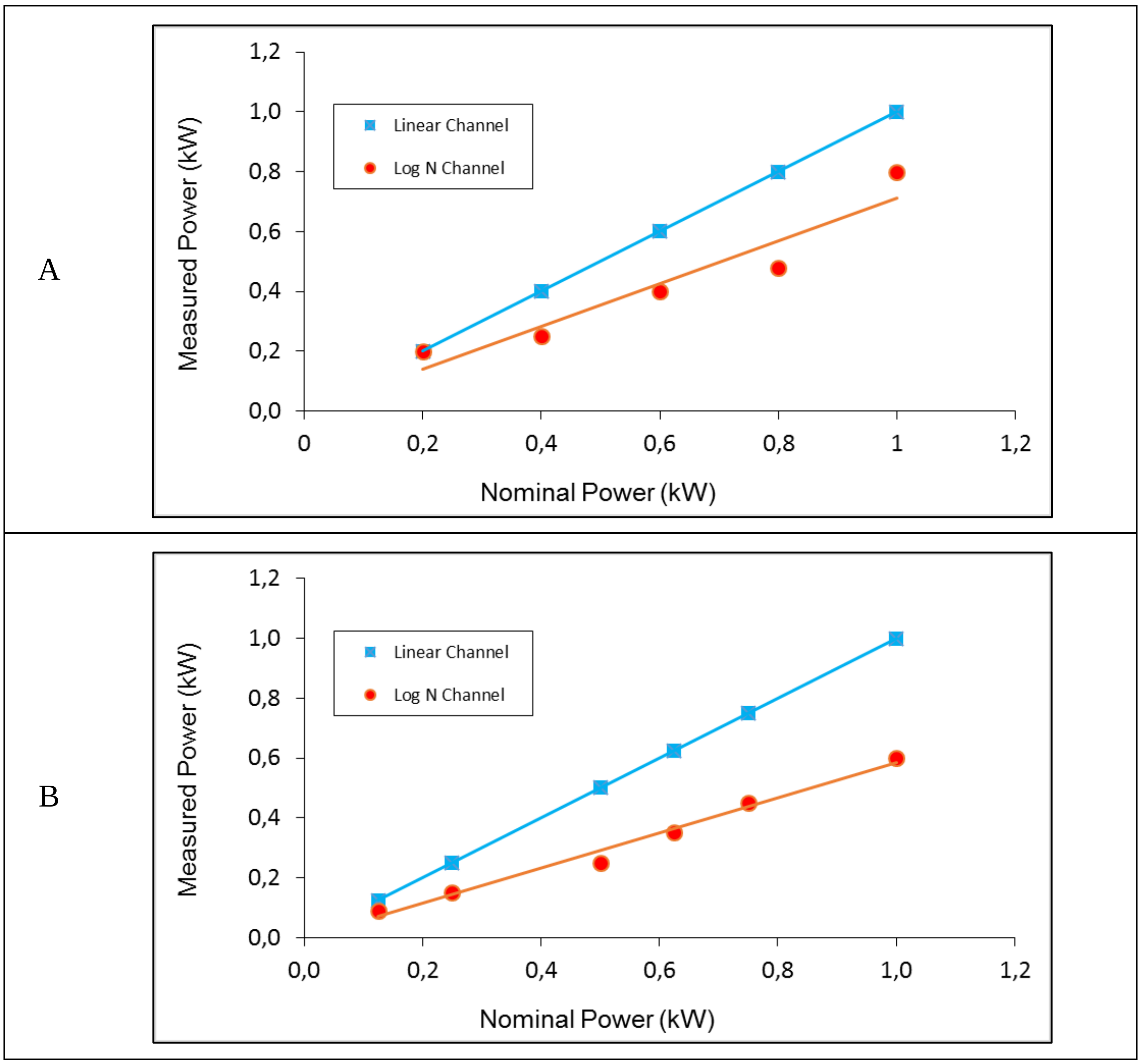

Figure 5: Power Values Indicated at IPR-R1 Control Console
A: Experiment 1, 14/01/2015; B: Experiment 2, 18/05/2015

The results reveal that Logarithmic Channel provides lower power values compared to those indicated by Linear Channel. Despite the lower values, Log N Channel follows linearly the Linear Channel.

Figure 6 shows the relationship between specific induced activity of gold samples and the power value indicated by the Linear Channel (nominal power).

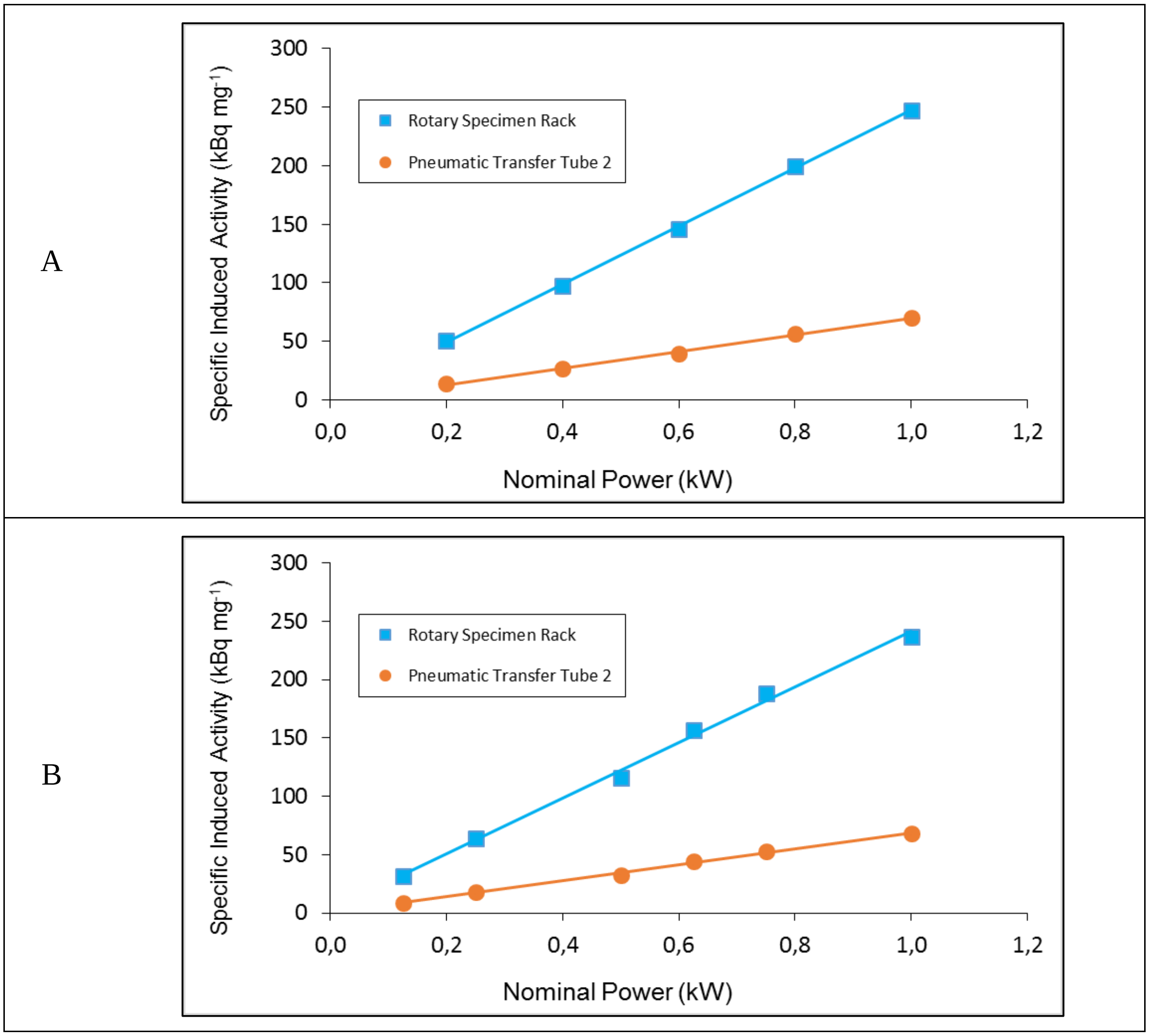

Figure 6: Specific Induced Activity of Gold Samples
A: Experiment 1, 14/01/2015; B: Experiment 2, 18/05/2015

The specific induced activity of the gold samples irradiated at the pneumatic transfer tube-2 is about 4 times smaller than the ones irradiated at the rotary specimen rack, as expected (Zangirolami, 2009). For both experiments, the specific induced activity presents a linear growth with Nominal Power. These results indicate that Linear Channel has a linear response at the power range from zero to 1 kW, since specific induced activity is proportional to the neutron flux, which is proportional to the reactor power.

3.1 Experiments at High Powers (10 to 100 kW)

Figure 7 shows the obtained results for both experiments at higher power, from 10 to 100 kW. As assumed at previous experiments, the power value indicated at IPR-R1 control console by Linear Channel was assumed to correspond to the nominal power.

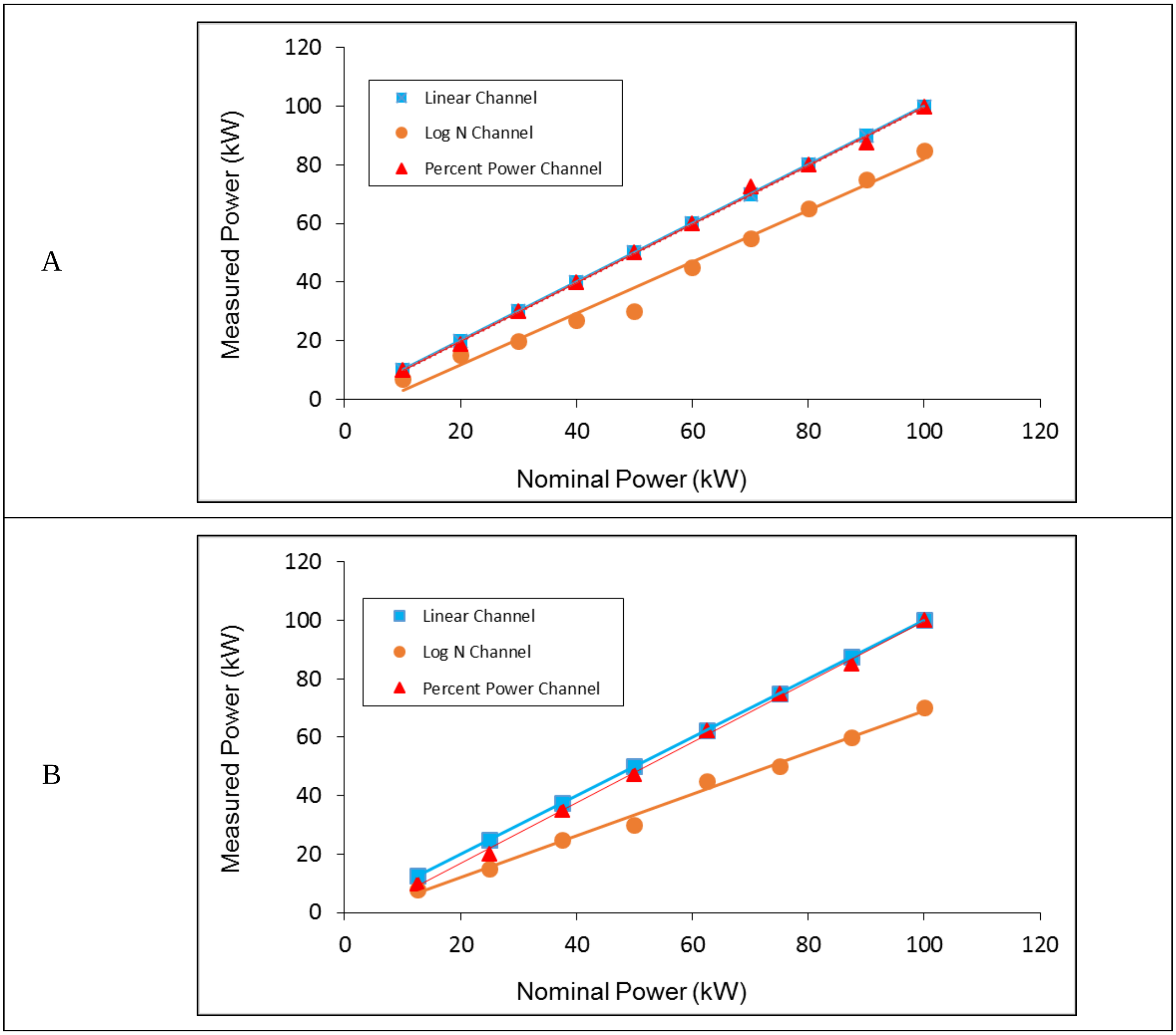

Figure 7: Power Values Indicated at IPR-R1 Control Console
A: Experiment 1, 14/01/2015; B: Experiment 2, 18/05/2015

In this power range, Linear Channel and Log N Channel present similar responses while the Percent Power Channel response is about 70% of them. Both Log N Channel and Percent Power Channel follow linearly the Linear Channel.

Figure 8 shows the relationship between specific induced activity of cobalt samples and the power value indicated by the Linear Channel (nominal power).

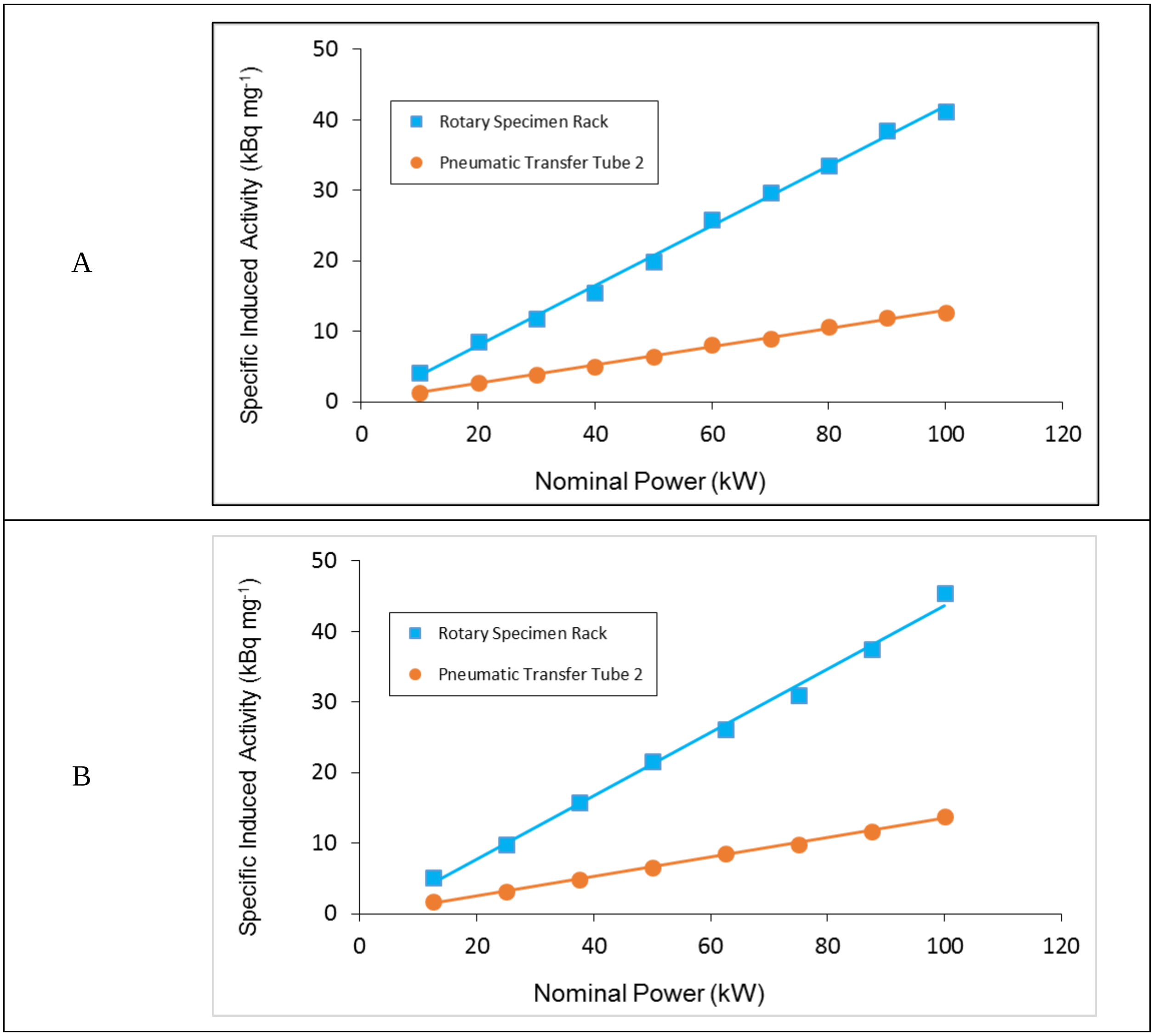

Figure8: Specific Induced Activity of Cobalt Samples
A: Experiment 1, 14/01/2015; B: Experiment 2, 18/05/2015

The specific induced activity of the cobalt samples irradiated at the pneumatic transfer tube 2 is about 4 times smaller than the ones irradiated at the rotary specimen rack. These results are similar to that obtained at lower power (zero to 1 kW). For both experiments, the specific induced activity presents a linear growth with Nominal Power. These results indicate that Linear Channel has a linear response at the power range from 10 to 100 kW, since specific induced activity is proportional to the neutron flux, which is proportional to the reactor power.

4. CONCLUSIONS

The performed experiments shows that the Percent Power Channel did not responds to reactor power variations at the range between zero and 1 kW. At this range, both Linear Channel and Log N Channel present linear responses. However, power values indicated by Log N Channels are about 70% of those indicated by Liner Channel. At higher power, from 10 to 100 kW, Linear Channel, Log N Channel and Percent Power Channel present linear responses. The power values indicated in both Linear Channel and Percent Power Channel are very similar, while values indicated by Log N Channel are about 30% smaller.

ACKNOWLEDGMENTS

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