Kartini Reactor is a nuclear research reactor (non power) type Triga Mark II. Maximum power Kartini Reactor 250 kW, operating power 100 kW. The history of nuclear reactors in Indonesia starts from the construction of research reactor type TRIGA Mark II (Training Research and Isotope Production by General Atomic), in the 1960s in Bandung. The reactor was built by General Atomic Co., San Diego, CA, USA, designed and built with a power of 250 kW, reached its first critical date on October 10, 1964.[1]

In 1974, based on the Decree of the Director General of BATAN No. No. 119 / DJ / 13 / XI / 1974 dated November 13, 1974, formed a group named the Reactor Development Team of the Atomic Gamma Research Center, tasked with planning and executing the construction of a nuclear reactor at the Atom Gama Research Center (Puslit) Yogyakarta. The Reactor Development Team designed the reactor by utilizing the reactor core of 250 kW of former TRIGA Mark-II Bandung reactor and reactor tank of IRT-2000 Serpong reactor. Physical construction was completed by the end of 1978, the first criticality test was conducted on Thursday, January 25, 1979 at 17:40 WIB. Furthermore, the use of the reactor was launched by President Soeharto on March 1, 1979, and was given the name "Kartini Reactor" as well as operating at power level for the first time at 50 kW nominal power level.

At the age of 37 years in September 2016 Reactor Kartini still able to perform operations for 100 hours non-stop. This achievement received deserves appreciation considering the age of nearly 40 years. In order to improve the performance and safety of the Kartini in 2017 reactor has done some replacement of new components due to aging such as, cooling tower and secondary cooling system pipe.

Kartini reactor is equipped with two cooling system of primary and secondary cooling system. The primary cooling system is categorized as unforced cooling system. Primary coolant pumps are mounted but these pups just circulate the coolant through two heat exchangers without forcing the coolant flow through the core. Besides, the primary coolant is also pumped through demineralizer to keep clean the coolant. The pump is also used for keeping the water level of the reactor through a makeup tank. The secondary cooling system circulates the secondary coolant from the heat exchangers to the cooling tower. The heat is released to open air by natural heat transfer. The schematic diagram of Kartini reactor cooling system shown in Fig.1[2], [3][4]

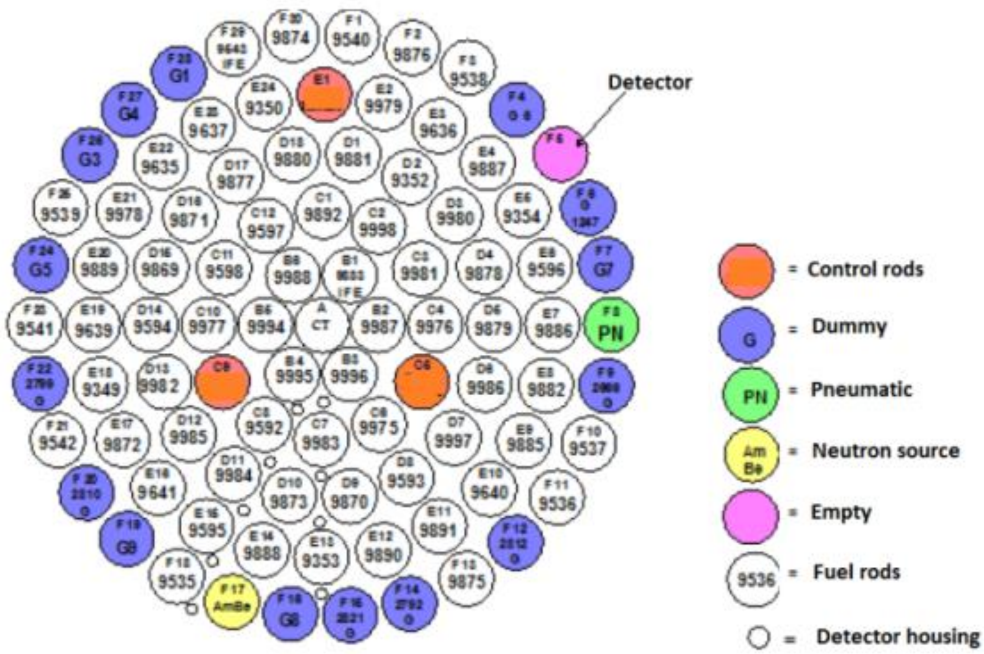

Figure 1. Core structure of the Kartini reactor

The Kartini reactor is used for reactor operation training and experiments reactor physics, sample irradiation for element measurement with analytical methods, neuron activation, reactor instrumental and control, Research and Development Internet Reactor Laboratory (IRL) and the use of neutrons from several beam ports.

Table characteristic of Kartini reactor Shown as

Table 1. Core Characteristics of the Kartini Reactor

Parameter	Value
Thermal power (kWth)	100
Operating pressure (atm)	1
Total height of core (cm)	76.2
Active core height (cm)	38
Numbers of fuel rods	69
Outer diameter of fuel rod (mm)	35.6
Gap of fuel (mm)	0.2
Outer diameter of cladding (mm)	37
Wall thickness of cladding (mm)	0.5

a. Kinematic Reactor Equation

Neutron behavior in the nuclear reactor is shown by the reactor kinetics equation. This equation is driven from the equilibrium of the neutron population in the core with assumption that a single, thermal, homogenous reactor is independent from space variable. Reactor kinetics is calculated using followed equation[5][6]

$$\frac{dn(t)}{dt}=\frac{\rho(t)-\beta}{\Lambda}n(t)+\sum_{i=1}^{6}\lambda_i C_i+S(t) \qquad (1)$$

And

$$\frac{dC_i}{dt}=\frac{\beta_i}{\Lambda}n(t)-\lambda_i C_i t \qquad (2)$$

Where $n(t)$ is neutron density at time t ($neutron/cm^3$), $C_i(t)$ concentration of neutron precursors in i index, $\rho(t)$ teras total reactivity at time t, β_i neutron fraction kasip at index i, β effective group neutron fraction kasip, λ_i decay constant of the i-th group casip neutron precursor (second-1), Λ neutron generation lifetime (second), *S* external neutron source $\left(neutron/cm^3.\mathrm{s}\right)$

.

b. Control Rod Position Change Conversion

In reactor simulation calculations, it is necessary to consider the formula for converting changes in control rod position into reactivity so that it can be calculated using the reactor kinetics equation which is written in equation (1). The equation is written as follows[5][6]

$$\Delta\rho(x)=\Delta\rho(H)\left(\frac{x}{H}-\frac{1}{2\pi}\sin\left(\frac{2\pi x}{H}\right)\right) \qquad (3)$$

Where ρ is reactivity control rod (dollar), $\Delta\rho(x)$ is reactivity change (dollar), *H* is total heigh of reactor teras, $\Delta\rho(H)$ change in reactivity due to full insertion of the control rod.

c. Power Conversion

The calculation of reactor kinetics using equations (1) and (2) provide neutron densitythat will be converted into power using equation as follows:

$$P=\frac{\sum f\phi V_r}{3.125\times10^{10}} \qquad (4)$$

Where P is reactor power (watt), $\sum f$ macroscopic cross section (cm^{-1}), ϕ neutron flux (neutron/cm^2.second), V_r core volume (cm^3), 3.125 x 10^{10} is core fission coefficient. Macroscopic cross section can be calculated using following equation

	$\sum f = N \times \sigma_f$	(5)
	$N \frac{N_A m}{VBA}$	(6)

Where N is the density of the material can be split (core/cm^3), σ_f microscopic cross-section (1 barn = 10^{-24} cm^2), N_A Avogadro number, m fuel mass (kg), V teras volume (cm3), BA uranium atom mass (235).

Kartini Internet Reactor Laboratory (IRL)

Internet reactor laboratory (IRL) is a means of learning about nuclear physics in this case by utilizing Kartini reactor as a tool and material of education and training. The topic of learning is about understanding theoretical physics of nuclear physics especially the reactor physics and practice of such understanding trough interactive Website tools so that the distance problem between Kartini reactor user and reactor owner/operator can be shortened for efficiency and effectiveness of education and training implementation. The IRL is designed for users at higher education levels.[7], [8]

The reactor physics experiment is carried out by the laboratory operators located at the reactor operating site in Kartini room control. Experimental results are presented in graphical form or in the form of physics and reactor operating parameters. IRL development increases Kartini's reactor capability in serving education and training. Trough the use of IRL, it is expected that geographical problems are not an obstacle in order to understand the operation and kinetics of nuclear reactor to students in universities located far from the Kartini reactor site. The concept of IRL is illustrated in Fig.2

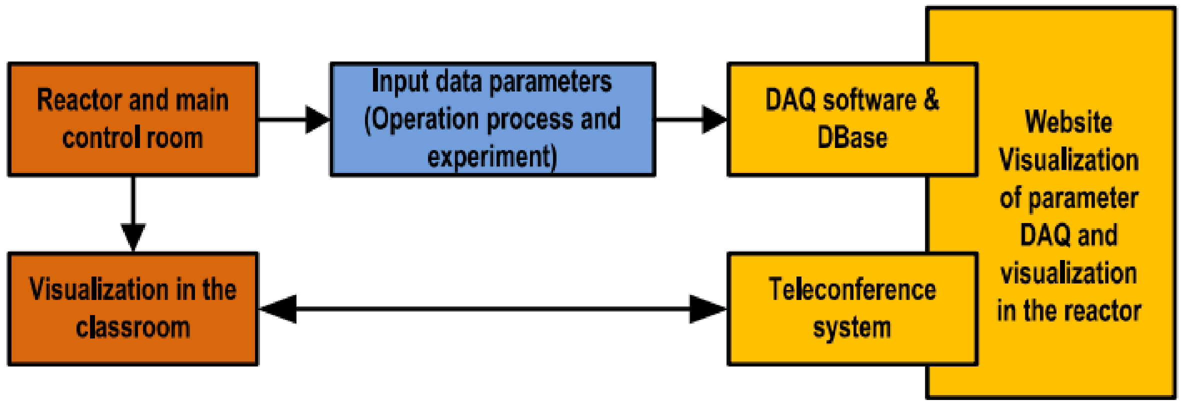

Figure 2. Illustration of IRL concept.

The concept of IRL by utilizing Kartini reactor is done through a concept similar to IRL in PULSAR from North Caroline State university. Fig 3 shows the implemented concept of IRL by utilizing Kartini reactor. Based on the acquisition data received by the computer process of data reception by software at Nuclear Training Center (NTC) and collected on the computer data base server. Principles of operating and/or experimental data parameters from NTC and data base sent are made through a switching hub connected to the router and together audio/visual information from the camera IP can be sent to the client PC through router as an IRL service over internet.[7], [9]

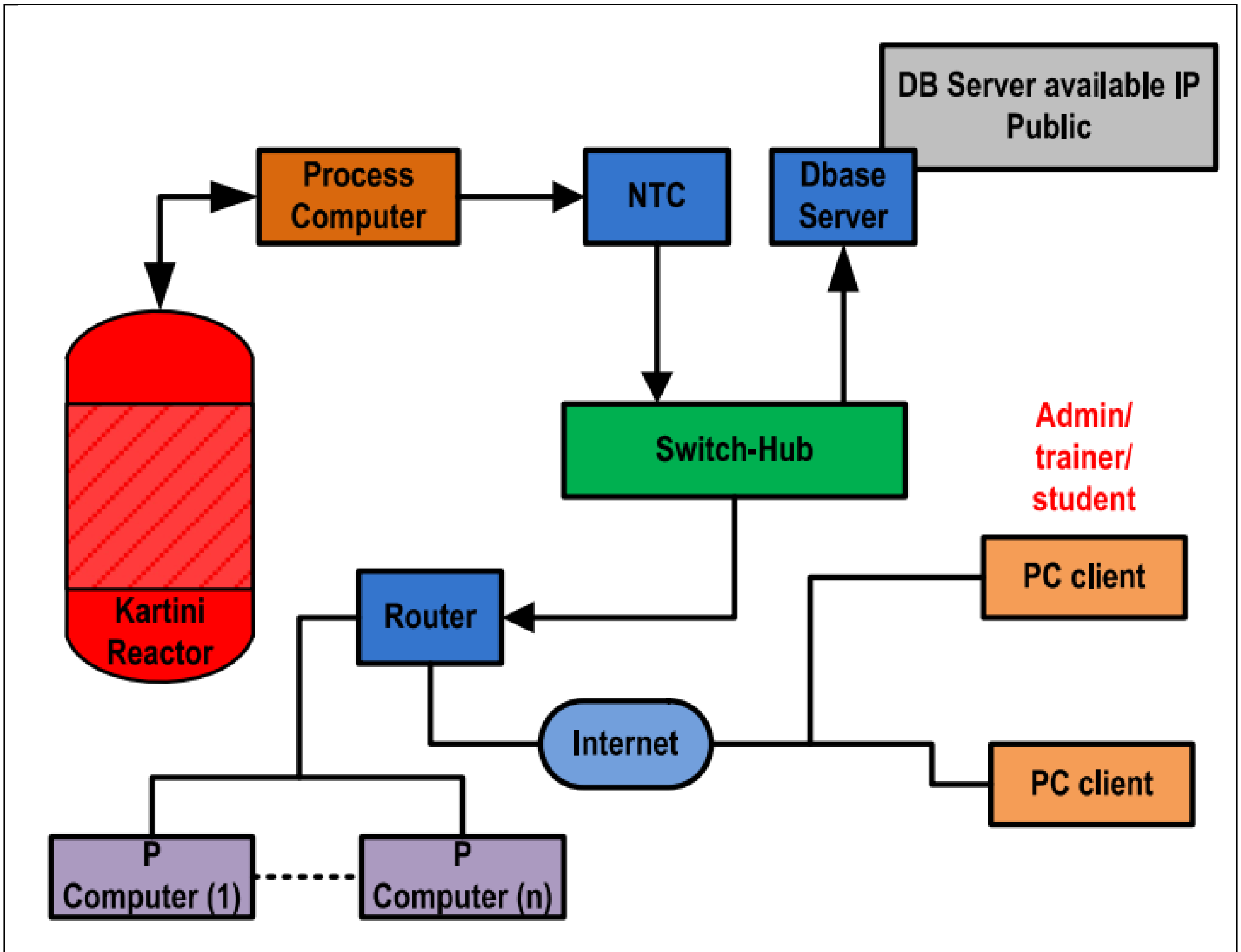

Figure 3. Implementation of IRL concept using Kartini Reactor

- Kartini Reactor Process Parameter Data

Kartini reactor process parameter data in the form of reactor operation data, namely linear power from NP-1000, logarithmic power from NLW-2, period, position of control rods, safety and compensation, time and reactor trip parameters. This data is sent from the process computer via RS-232 communication with a baud rate of 115200.[4]

a. Linear Power N-1000

The NP-1000 linear power channel uses a compensated ionization chamber (CIC) type detector to measure neutron flux at power levels. The CIC detector works on the principle of voltage compensation from a gas chamber coated with boron. The output from the detector is in the form of a current that is proportional to the neutron flux so that the reading of the CIC detector output is carried out using a current by the NP-1000 from General Atomic Corp.

The calculation formula from voltage to power of the NP-1000 is according to the following equation

	$NP-1000=V\times k$	(7)

Where $NP-1000$ is linear Power (KW), *V* NP-1000 power line output voltage (V), and *k* is conversion constant ($24\,KW/V$).

b. Logarithmic power NLW-2

The NLW-2 logarithmic power uses a fission chamber (FC) detector to measure the neutron flux from source level to reactor power level and period. The Neutron FC detector is a gas filled detector coated with a fissionable material, namely U-235. When a neutron hits the detector, a fission reaction occurs. The radiation resulting from the fission will be read by the gas-filled chamber. The FC detector is read using the pulse counting method for low power and high pulse for high power.

The calculation formula from voltage to power of the NLW-2 is according to the following equation

	$NLW-2=k\times e^{\left(2.30\times\left(2\times\left(V+0.08\right)\right)\right)}$	(8)

Where NLW-2 Logarithmic power NLW-2(KW), *V* NLW-2 power line output voltage (V), and *k* is conversion constant ($1\times10^{-8}\,KW/V$).

c. Period for NLW-2

The reactor period is the time needed for the reactor to change power e times. The Kartini reactor period was measured using NLW-2. The period of NLW-2 is obtained from differentiating the results of connecting the log count rate and Champbell series using a differentiator series to obtain the value of decades per minute. The period is converted into an output voltage in the form of a voltage of 0-5 V which will be read by the process computer via the ADC from the PCL-812PG sent via serial RS-232.

Formula for reactor period is

	$\alpha=\dfrac{26.06}{1.38\times V}=\dfrac{k}{V}$	(9)

Where is reactor period (second), V is NLW-2 power line output voltage (V) and k is is conversion constant (18.84 second.volt).

d. Control Rod Position

Formula calculation of the tension to the position of each control rod in accordance with

	$BK=V\times k$	(7.10)

Where *BK* is position of control rod (%), *V* is Control rod potentiometer output voltage (V), and *k* is conversion constant (20 %/V).

e. Kartini Reactor Trip Parameters

The basic principle of a reactor trip is to provide a signal to break the current of the control rod holder's electromagnet. The limits of each parameter have been determined as safety limits for actuating the current break. The trip limits are:

1. Manual Trip, namely when the control rod Scram button is pressed.
2. Trip Watchdog, namely the signal given by the acquisition computer safety if program execution stops.
3. CIC detector high voltage power supply trips, that is, if a high voltage failure occurs on the CIC detector.
4. NP-1000 maximum power trip, namely when the power on the NP-1000 reaches 110%.
5. Trip the high voltage power supply of the FC detector, that is, if a high voltage failure occurs on the FC detector.
6. Trip period NLW-2, namely when the period at NLW-2 is less than 7 seconds.
7. Source level trip from NLW-2, namely when the neutron source is not in place or the pulses from NLW-2 are less than 4 pulses per second.
8. Trip level above NLW-2, namely the power from NLW-2 reaches 110%.

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