Tri Dasa Mega Vol. 23 No. 3 (2021) 105–114

Jurnal Teknologi Reaktor Nuklir

Tri Dasa Mega

Journal homepage: jurnal.batan.go.id/index.php/tridam

Map of Radioisotope Production and BATAN Research Reactor Utilization

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ARTICLE INFO

Article history:

Received: 29 March 2021
Received in revised form: 08 July 2021
Accepted: 08 July 202

Keywords:

Utilization map
Research reactor
Tracing and data collection
Radioisotope
National research program

A B S T R A C T

Currently, Indonesia through BATAN is operating three research reactors, namely the RSG-GAS reactor with the power of 30 MWt at Puspiptek south Tangerang (the first criticality in 1987), the TRIGA 2000 reactor with the power of 2 MW in Bandung which the first criticality in 1965 with the power of 250 kW, was increased to 1 MW in 1971, and further upgraded to 2 MW in 2000. Beside that, there is Kartini reactor with a power of 100 kW located in Yogyakarta (first criticality in 1979). These reactors are quite old, and in accordance with Bapeten regulations, have carried out the first periodic safety review, to obtain a reactor license for the next 10 years of operation. In line with this, one of BATAN's current national research programs is to increase the production of radioisotopes and radiopharmaceuticals, where reactors play a very important role in the production of certain isotopes. In tracing the data obtained from operational reports related to irradiation requests from reactor users, namely PTRR, PSTNT, and PT INUKI for radioisotope production, which has been carried out in the last 5 years, May 2015 until 25 August 2020, show that the irradiation request at RSG-GAS is still not optimal. In term of the utilization of RSG-GAS, it can still be optimized, which in this case needs to be balanced with post-irradiation processing capabilities. Meanwhile, from the results of tracing and data collection, it can be shown that at this time the reactors are still operating. The utilization activities of the reactors complement each other according to their age and facilities.

1. INTRODUCTION

Research reactors are sophisticated equipment used for basic and applied research in the fields of particle and nuclear physics, radiochemistry, neutron activation analysis, materials science, nuclear power, and nuclear medicine. Research reactors also serve as important instruments for the production of high-tech commodities, such as a wide variety of radioactive isotopes, as well as

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DOI: 10.17146/tdm.2021.23.3.6288

radiation modification materials essential for microelectronics, and other fields of advanced technology. The reactor also allows for the testing of various types of nuclear fuel and studies on the radiation resistance of new materials. As a source of a high-intensity flux of neutrons, gamma, neutrinos, and other types of radiation, research reactors play an indispensable role in science, industry, and medicine Many research reactors are based in universities and research institutes in the nuclear field, so it can be stated that research reactors have also provided a considerable legacy in the education and training purpose in the fields of science and technology as well as the preparation of human resources for nuclear power plants. The construction of a nuclear reactor must have determined its intended use as indicated in Regulation of National Nuclear Regulatory Board (BAPETEN) No. 2/2009 concerning the Compilation of Design Information Data, Guideline 5/2012 concerning Safety in the Utilization and Modification of non-powered reactors. IAEA Nuclear Energy Series No. NP-T-5.3 regarding Application of Research Reactor[1]. In general, research reactors are used in purposes of (1) Education and research, which includes: Teaching students of physics and biology, teaching students of radiation protection and radiological engineering, teaching nuclear engineering students, training nuclear power plant operators; (2) Neutron Activation Analysis; (3) Prompt Gamma Neutron Activation Analysis; (4) Production of radioisotope; (5) Geochronology which consists of Argon Geochronology and Fission-track Geochronology; (6) Transmutation Effects), consisting of Silicon transmutation doping, gamma irradiation, gemstone coloration, and actinide transmutation; (7) Neutron Imaging; (8) Structural and dynamic studies, the use of neutron beams for science, neutron scattering are applied to scientific research in the field of materials[2].

The license holder of the research reactor realizes that the reactor facility has not been used fully in accordance to the initial design. This is generally related to a variety of complex reasons, especially, very old reactors, require increased attention and funds for repair and maintenance, or are no longer able to carry out innovative research[3]. Also, the neutron intensity at many facilities are lower than a source of neutron spallation-based, and some methods of analysis that have been rendered obsolete and replaced by alternative technologies or more modern equipment in the research reactor are newly built, for example, the reactor TRIGA2000[4] and RSG-GAS[5]. Other problems faced by the international research reactor community are the reduction of experienced staff without adequate replacement and inadequate financial policies on reactor management and the low cost of reactor facility utilization services. Meanwhile, there is increasing pressure from stakeholders to ensure that the reactor generates some form of financial revenue to offset operational and maintenance costs, despite the fact that prospective research reactor users are less proactive in making use of this facility. Many research reactor owners and operators now recognize that there is a need to develop a strategic plan for long-term sustainability, including the marketing of reactor facilities. An important initial stage in the preparation of such a plan is to evaluate the current capabilities and potential of the reactor's facilities[6].

BATAN as a research reactor operating organization in Indonesia also needs to make a synergistic mapping of the utility of its three research reactors, so that it is easies to obtain data for potential users. The Center for Radioisotope and Radiopharmaceutical Technology (PTRR) has produced a product that can relieve pain suffered by people with cancer, namely Samarium (Sm) 153 ETDMP, a research produces of BATAN that is useful in the world of health, especially as a palliative therapy drug. in cancer patients. PTRR-BATAN conducts research and development activities to increase mastery of nuclear techniques, especially in producing radiopharmaceuticals. In addition to Sm 153 EDTMP, BATAN also develop MIBI radiopharmaceutical kits used to detect heart function, MDP radiopharmaceutical kits that are used to detect primary bone cancer and bone metastases, DTPA radiopharmaceutical kits to determine kidney function, and MIBG marked I-131 for neuroendocrine cancer therapy[7, 8].

This study aims to coordinate and organize the utilization of the research reactor in Indonesia, Kartini reactor in Yogyakarta, TRIGA2000 reactor in Bandung, and RSG-GAS in Serpong. Apart from being used to support the RI and RF availability program, the results of this mapping can make it easier for users to obtain usage information, constraints in isotope production, and opportunities to use research reactors

2. METHODOLOGY

The data collection methodology is carried out by conducting an assessment of various regulations related to research reactor utilization. Tracing and identifying data on the RSG-GAS operation report, and data on the utilization of the Kartini reactor through data collection from competent sources and collaboration between work units, research reactor focus group discussion, and analysis of reactor operation report data.

The research scope starts from reviewing various IAEA safety guides and regulations issued by BAPETEN regulatory agencies as well as reactor operation reports and other sources of information, which are sorted as follows. (1) To conduct study analysis on regulations related to research reactor utilization, from international and national regulatory agencies. (2) Tracing and identifying facilities owned by the three research reactors. (3) Identifying and compiling reactor utilization derived from reactor safety analysis reports, periodic safety assessments, reactor operation reports, and FGDs regarding research reactor utilization. (4) Analyze and compile a map of research reactor utilization and SWOT analysis.From the research conducted, data on the utilization of the three research reactors in Indonesia were obtained which are presented in Table 1.

Table 1. Utilization Map of research reactors in Indonesia

No.	Utilization of the RSG-GAS reactor
1.	RSG-GAS has a nominal power of 30 MW.For efficiency purposes, it is currently operated with a power of 15 MW, neutron flux, 2×10^{14} n./cm^2.S. The reactor was built in 1983, first criticality in July 1987, 1992 reached 30 MW thermal power. Reactor G.A. Siwabessy (RSG-GAS) is a pool-type research reactor using Uranium Silicide (U3Si2-Al) fuel with meat density of 2.96 g/cm3. The RSG-GAS facility is used for research activities in the field of nuclear science and technology, isotope production for industry, health, material testing, scientific experiments, to serve target irradiation activities, and nuclear technology introduction visits. Facilities to support the research are the S1-S6 neutron beam (beam tube). Meanwhile, facilities for target irradiation are central irradiation position (CIP), irradiation position (IP), power ramp test facility (PRTF), neutron radiography facility, silicon doping facility, and rabbit system facility[9].
2.	**Utilization of the TRIGA2000 reactor**
	The TRIGA2000 reactor has been upgraded twice, each reaching its first criticality in: (1) The first criticality in 16 October 1964 with nominal power of 250 kW. (2) The first criticality at 1 MW nominal power in 27 November 1971. (3) The first criticality at nominal power of 2 MW in 13 May 2000. At the present, the nominal power is reduced to 1 MW and operated at 700 KW (2020). Neutron flux in the irradiation position: 3.44×10^{11} to 1.63×10^{13} n/cm^2.s. PSTNT BATAN conducts research and development to master technology in the field of radioisotope production, utilizing the developed neutron activation analysis[10, 11]. PSTNT is also used to perform research air quality throughout Indonesia, particularly in relation to nuclear analysis techniques for the study of air pollution, nutrition, marked compounds for therapy and diagnostics, as well as radiometric purposes. Education for students. Using nuclear technology and its contribution to the development of health care facilities, industry, and environmental management[12].
3.	**Utilization of the Kartini reactor**
	The Kartini reactor is a TRIGA reactor type with nominal power of 250 kW, but is currently operated at a power of 100 kW. It was built in 1974 and reached its first criticality on January 25, 1979. The reactor has average thermal flux of: 1.2×10^{13} n/cm^2.s. and average fast neutron flux of: 2.5×10^{12} n/cm^2.s. The Kartini reactor is used for: - research and development related to thermal and epithermal flux testing, key zero, elemental analysis (AAN), a forum for increasing expertise in the field of nuclear instrumentation and control, GIS testing as well as power calibration and control rod calibration as well as a power reactor simulator based on the Kartini reactor. - irradiation - regional and international education and training, as an internet-based reactor laboratory (internet reactor laboratory, IRL) and nuclear training center (NTC), training in the framework of maintaining structures, systems, and components including aspects of aging using replication technique[13, 14]. - As the center for nuclear technology in Yogyakarta.

Table 2. Facilities and functions in every nuclear reactor

	Facilities	Function
1.	GA Siwabessy Reactor, Serpong	
	Reactor core – central irradiation	- the neutron flux at the CIP and IP positions can be used to produce radioactive isotopes,

	Facilities	Function
	position (CIP) – irradiation position (IP)	which are useful for medical, industrial, agricultural, and exploration purposes. Irradiation targets in form of uranium placed in stainless steel tubes for the generation of Mo-99 fission products, irradiation of TeO_2 targets to produce I-125 and I-131, irradiation of topaz gemstone, production of radioisotopes such as P-32, S-35, Au-198, Ir-192, Zn-64, etc. To insert and remove targets from CIP and IP, special handling tools are used according to their requirements[15].
	Silicone Doping	- The silicon doping facility in the RSG-GAS reactor is an experimental and research facility that can be developed into a production facility to meet industrial needs. This facility serves silicon oxide irradiation activities with the properties of the material as an insulator with neutron doping so that the properties of the material are converted into semiconductor material. This semiconductor from silicon is known to have good properties as an integrated circuit (IC) material. This facility can also be used for topaz irradiation outside the core by using a separate irradiation tube.
	Rabbit System	Rabbit system is a target irradiation facility with short irradiation duration, up to a maximum time of 5 hours. The length of the irradiation time depends on the need to use the irradiation target for material analysis purposes. Rabbit system consists of 4 channels that use a hydraulic system and 1 channel filled with dry air called the pneumatic system. The hydraulic system has a maximum irradiation duration of 5 hours and the pneumatic system with a maximum irradiation duration of 3 minutes. The use of the rabbit system, among others, is used for material analysis activities using target activation with neutrons (NAA), general

	Facilities	Function
		irradiation, and for the production of radioisotopes [16].
	Neutron beam tubes	Six beam tubes, four radial, and two tangential tubes are available to be used for several purposes. The neutron beam tube will channel the neutron radiation exposure from the core to the experimental equipment connected to the ends of the beam tube. The file tubes in RSG-GAS are named S1 through S6. The S2 beam tube is used for radiographic image creation, the S3 beam tube is untapped, the S4 beam tube is used for neutron spectrometer-based experiments, the S5 beam tube is used for neutron diffractometer-based experiments, and the S6 beam tube (tangential beam tube) equipped with a powder diffractometer, used for experiments based on narrow-angle neutron diffractometers.
2.	TRIGA2000 reactor	
	Central thimble	for irradiation purposes or experiments with maximum flux.
	Pneumatic transfer tube	to quickly enter and remove samples from the reactor core.
	Rotary specimen racks	Target irradiation
	Incore irradiation pipe	Target irradiation
	Beamports (3)	Neutron radiography, material analysis, has not been used because it requires supporting equipment.
	Thermal column	for the purposes of irradiation with thermal neutrons, PGNAA, has not been used because it requires supporting equipment.
3.	Kartini Reactor Yogyakarta	
	Neutron beam distributor.	for irradiation of samples with a rather large size (15.2 cm in diameter) and to provide a neutron beam for various experimental purposes.
	Thermal	for irradiation purposes with

Facilities	Function
column	thermal neutrons. This column consists of graphite measuring 1.2 m ×1.2 m and a length of 1.6 m plated with Boral and aluminum.
Central thimble	- for irradiation purposes or experiments with maximum flux. This channel is in the form of a tube with a diameter of 3.84 cm and a length of 6 m that extends from the top to the core support through the center of the reactor core.
Irradiation facilities: F1, F-2 and F-3 above the reflector	For sample irradiation. Lazy Sussan, Pneumatic, Beam Port and thermal columns can be used as irradiation tools for neutron activation analysis (AAN), gamma irradiation for radiation chemistry and neutron radiography as well as basic research related to Boron Neutron Capture Therapy (BNCT).
Bulk shielding facility	for experiments regarding radiation shielding, as well as for temporary storage of spent fuel, in the form of a water bath measuring 265 cm long, 240 cm wide and 380 cm high, which is connected to a thermalization column. The thermalization column is similar to the thermal column, but smaller in size.
Subcritical device	for the purpose of studying the reactor static parameters of the uranium-water configuration system. The subcritical reactor is paired with the Kartini reactor, via radial neutron beam transmitters. The fuel used in this device is natural uranium (U235 content = 0.7%), and water is used as a moderator.
Pneumatic transfer system	to quickly enter and extract samples from the core. The sample is placed in a container (rabbit) with a diameter of ± 2.5 cm, moving inside the pipe. The rabbit movement is based on the difference in pressure in the pipe through the blower. Air from the pneumatic system issued passes through a filter.

3. RESULTS AND DISCUSSION

For utilization at RSG-GAS, there are six beam tubes are, four radial and two tangential, available to be used for several purposes. The radial beam tube No. 1 is equipped with Xe-loop to generate I-125 radioisotope; the tangential beam tube No. 2 is dedicated for neutron radiography; the radial beam-tube No. 3 is still unused, beam tubes No. 4 and 6 are both used. Not all of the RSG-GAS facilities have been used, including the S-1 beam tube for the production of radioiodine. Silicon doping facility has also not been used due to geometry problems. The TRIGA-type research reactor is generally used for research activities in the fields of nuclear science and technology, isotope production for the health industry, scientific experiments, to serve target irradiation activities, and visitations to introduce nuclear technology. The notable development carried out on the Kartini reactor is that it is used for regional and international education and training, as an internet-based reactor laboratory (internet reactor laboratory, IRL) and a nuclear training center (NTC), training in the framework of maintaining structures, systems, and components, according to the age of the reactor which is getting older[17].

Meanwhile, in addition to normal operation, the TRIGA2000 reactor is conducting a fuel conversion design from the TRIGA cylinder-type to the plate-type while maintaining the existing secondary cooling system design. The Bandung TRIGA reactor is dynamic enough to increase and decrease reactor power to meet market needs/customer demand (i.e. irradiation) from 250 kW, upgraded to 1000 kW, then upgraded again to 2000 kW, and lowered again to 1000 kW (2016), in accordance with the conditions of fuel availability. This reduction in power does not change the operating condition limit (BKO) of the Bandung TRIGA2000 reactor[18, 19].

Meanwhile, RSG-GAS can be used for all types of research reactor utilization, as mentioned in IAEA Nuclear Energy Series No. NP-T-5.3 regarding Application of Research Reactors. At this time, the reactor is operated at a power of 15 MW, despite its nominal power is 30 MW. This operating power is adjusted for irradiation requirements and other uses. The Figure 1 shows the utilization of RSG-GAS, in a 100th core configuration.

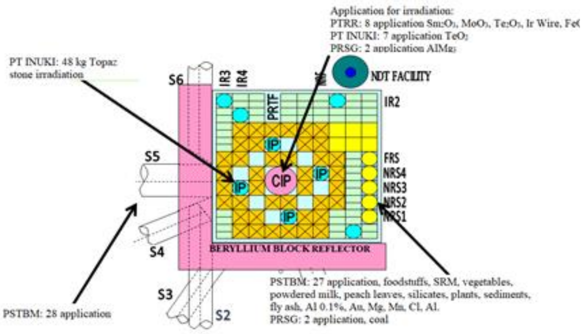

Fig. 1. Utilization of RSG-GAS, in the 100th core configuration

RSG-GAS operation patterns in one cycle of operation are as follows: reactor operates 10 times and each operation lasts for 4 days, which means that during the operational duration, the reactor can be used to irradiate the irradiation target 10 times. An example of the RSG-GAS operation pattern is shown in the Table below.

Table 3. RSG-GAS operation pattern, 100th reactor configuration

Operation stage	reactor operating	reactor shutdown
Fuel element Loading/unloading		
Stage 1	24/10/2019 – 28/10/2019	
Stage 1b.	1/11/2019 – 5/11/2019	
		5/11/2019 – 7/11/2019
Stage 2	08/11/2019 – 12/11/2019	
		12/11/2019 – 14/11/2019
Stage 3	15/11/2019 – 19/11/2019	
		19/11/2019 – 28/11/2019
Phase 4	29/11/2019 – 03/12/2019	
		03/12/2019 – 05/12/2019
Stage 5	06/12/2019 – 10/12/2019	
		10/12/2019 – 02/12/2019
Stage 6	03/01/2020 – 07/01/2020	
		07/01/2020 – 16/01/2020
Stage 7	17/01/2020 – 21/01/2020	
		21/01/2020 – 23/01/2020
Stage 8	24/01/2020 – 28/01/2020	
		28/01/2020 – 06/02/2020
Stage 9	07/02/2020 – 11/02/2020	
		11/02/2020 – 13/02/2020
Stage 10	14/02/2020 – 18/02/2020	
Fuel element Loading/unloading		

RSG-GAS operates with a schedule of 4 days of operation and 3 days of shutdown in a week. The available irradiation positions for isotope irradiation are 4 positions in the center of the reactor core (CIP) and 4 other irradiation positions (IP). The position of the irradiation allows for more irradiation than the requests for isotope production.

In the national research program, to support the healthcare sector, PTRR and PT INUKI utilize RSG-GAS for radioisotope production. PTRR as an R&D institution has developed and produced various types of radioisotopes, according to the demands of the hospital. There are 13 hospitals in Indonesia that require medical treatment using radioisotope (RI) and radiopharmaceuticals (RF). Meanwhile, PT INUKI, in its efforts to meet market demand, is more focused on producing radioisotopes I-131 and Mo-99. For example, Table 3 shows the types of radioisotopes irradiated at the request of the user within a period of 6 months, in the operation of the 100th reactor core configuration. The types of radioisotopes that were irradiated including 6 types, namely Ir-wire, Sm_2O_3, Gd_2O_3, TeO_2, Sulfur, and MoO_3. The types of radioisotopes produced are not always the same. PT INUKI has a role to commercially producing radioisotopes, while PTRR has a role in developing radioisotopes. Table 4 shows the type and number of requests for radioisotope irradiation at the RSG-GAS in a period of 5 years.

Table 4. Utilization of RSG-GAS for isotope production, 100th reactor configuration[20].

No.	Applicant	Target type	Weight (gram)	Date (start)	Date (end)	Position in the core
1.	PTRR	Ir-wire	90.34	28/06/2019	08/11/2019	D-6.
2.	PTRR	Sm_2O_3 Gd_2O_3 TeO_2	10 0.4 50	101/11/2019		E-7
3.	PT INUKI	TeO_2	100	1/11/2019	5/11/2019	D-6
4.	PTRR	Sm_2O_3 Sulfur	10 10	15/11/2019	19/11/2019	D-6

5.	PT INUKI	TeO_2	100	15/11/2019	19/11/2019	E-7
6.	PTRR	Sm_2O_3 MoO_3	10 4	29/11/2019	03/12/2019	E-7
7.	PT INUKI	TeO_2	100	06/12/2019	10/12/2019	E-7
8.	PT INUKI	TeO_2	100	06/12/2019	10/12/2019	D-6
9.	PTRR	Sm_2O_3 MoO_3 TeO_2	10 4 50	03/01/2020	27/01/2020	D-6

Here are the RSG-GAS utilization data in supporting isotopes production for 5 years. There are different types of target irradiated to produce various types of radioisotope. The type of target and the irradiated isotope production yield in the RSG-GAS reactor core in the 2015-2020 period are shown in the following table.

Table 5. Types of targets irradiated at RSG-GAS (2015-2020)

No.	User	Irradiation Target	Production
1.	PTRR	Sm_2O_3	Sm-153
		Lu_2O_3	Lu-177
		MoO_3	Mo-99
		TeO_2	I-131
		G_2O_3	Gd-153
		Yb_2O_3	Yb-169
		Sulfur	P-32
		AuAl foil	Au-198
		Ir wire	Ir-192
		Y_2O_3	Y-90
		Xe	Xe 124
		$YbNO_3$	Yb-176
		Yb oksida	Yb-176
		Zn foil	
2.	PSTNT	Gd_2O_3	Tb-161
		TeO_2	I-131
		TiO_2	Sc-44
		MoO_3	M0-99
		WO_3	W-188
		Sm_2O_3	Sm-153
		Sn metal	Sn-112
			Te-130
3.	INUKI	Te_2O_3	I-131
		U-235	Mo-99
		Gd_2O_3	Tb-161
		Ni-58	Co-58
		Ni-58	Co-58
		Co-59	C0-60

The data presented here is the irradiation request from PTRR, PSTNT, and PT INUKI for radioisotope production, which was carried out in the 87th up to 101st core configuration that was operational in May 2015-25 August 2020. Figure 2 shows the number of radioisotope irradiation target capsules at RSG-GAS. As an R&D institution, PTRR irradiates various types of targets to produce radioisotopes, not only to meet market demand, but also new types for research purposes. PSTNT in 2015-2017 (reactor core configuration no. 87 up to 93) also performed irradiation for isotope production, however at this time PSTNT is concentrating more on irradiating samples for environmental analysis. Meanwhile, PT INUKI is more focused on target irradiation to produce radioisotopes such as I-131, Mo-99, Tb-161, Co-58, and Co-60.

The use of RSG-GAS for various other utilities such as NAA, material irradiation for aging studies, and beam tube utilization were not included in this study.

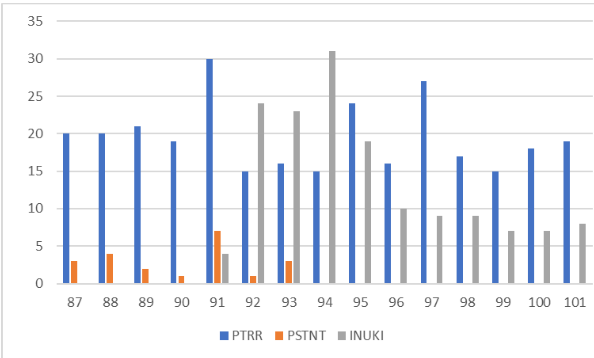

Fig. 2. The number of radioisotope irradiation target capsules at RSG-GAS in the period of May 2015 - 25 August 2020

SWOT Analysis

The analysis was carried out through an evaluation during the 5 years of operation of the RSG-GAS (2015-2020), on the current and potential future stakeholder activities, current reactor operation patterns and utilization, and reactor design capabilities, as well as existing barriers. The evaluation results obtained are as follows:

- The operation pattern of the RSG-GAS reactor for the last 5 years has followed the needs of radioisotope production users so that in one year it only operates 3 to 4 cycles with a power of 50% of the nominal power (15 MW).

- Reactor utilization consists of the type of sample, irradiation facility, and experiment used. Irradiation facilities in the core are widely used for topaz irradiation (4 positions), while other 4 irradiation positions in the reflector area have never been used.

- User development and problems.

Stakeholders in radioisotope production remain only 2, those are PTRR from BATAN and PT. INUKI from the enterprise sector. Until now, no new potential customers have been identified. In other words, the utilization for radioisotope irradiation is not optimal or lower than the available capacity.

For BATAN's Strategic Plan in PRN to provide radioisotope through the irradiation process in PRSG, it is necessary to make improvements in the post-irradiation process, look for potential customers, and the reactor must always be ready to operate where this requires support in handling aging management and how to overcome it. Meanwhile, in the production process, we must always seek innovations in the production of isotopes that are more efficient.

The similarity in the utilization of the reactor facilities in the three reactors is for irradiation, education, and training as well as community visits for education/introduction to nuclear technology. The most obsolete reactor, Kartini Reactor, is used for national and international education and training, as an internet-based reactor laboratory (IRL) and a nuclear training center (NTC). The TRIGA2000 reactor is prioritized for the utilization of neutron activation analysis which is developed to study air quality throughout Indonesia, particularly in relation to nuclear analysis techniques for the study of air pollution, nutrients, marked compounds for therapy, and diagnostics, and radiometry. Meanwhile, RSG-GAS is used for all types of research reactor utilization, as mentioned in IAEA Application of Research Reactor.

5. CONCLUSION

From the results of the data analysis, it can be concluded that at this time (2020) the three reactors in Indonesia are still operating. The utilization activities of the three reactors complement each other according to their age and facilities. The tracing data obtained from the operation report regarding irradiation requests from PTRR, PSTNT, and PT INUKI for radioisotope production, which was carried out in the 87-101 cores, shows that irradiation demand is to produce radioisotopes still not optimal. In terms of the utilization of RSG-GAS, it can still be increased, by increasing with the post-irradiation processing capabilities.

ACKNOWLEDGMENT

The authors would like to thank the Head of the Center for Nuclear Technology and Reactor Safety (PTKRN) for listing this study into DIPA PTKRN in the fiscal year 2019.

AUTHOR CONTRIBUTION

This paper is written with the same contribution between the authors, i.e.: Endiah Puji Hastuti, Iman Kuntoro, Suwoto, Syarip, Prasetyo Basuki, Tukiran, Geni Rina Sunaryo, Sudarmono. All authors read and approved the final version of the paper.

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