COST BENEFIT ANALYSIS OF G. A. SIWABESSY MULTI-PURPOSE REACTOR'S PERFORMANCE FOR RADIO-ISOTOPE PRODUCTION

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Abstract *The G. A. Siwabessy Multi-purpose Reactor (RSG-GAS) is a 30 MW research reactor that requires revitalization after 36 years of operation to enhance its performance. This paper assesses the financial opportunity of radioisotope production post-revitalization by analyzing the project's NPV and IRR using cost-benefit analysis principles. Two scenarios considered: the counterfactual (business-as-usual) and the radioisotope (post-revitalization) scenario. The results indicate that the estimated total annual revenue in the counterfactual scenario is IDR 5,029,577,940.00. Conversely, the radioisotope scenario amounts to IDR 93,245,000,000.00. In the counterfactual scenario, the project is deemed infeasible, as evidenced by the negative NPV of IDR 114,320,284,197 and the absence of IRR. In contrast, the radioisotope scenario is considered feasible, with a positive NPV of IDR 115,364,829,741.00 and a positive IRR of 6.8%, surpassing the discount rate of 3.25%, referring to the long-term government bond interest rate and based on literature review. This results in an incremental NPV of IDR 229,685,113,938.00 and an incremental IRR of 12.4% from the radioisotope scenario to the counterfactual scenario, indicating that the investment made for revitalization is justified. This informs policymakers on the importance of reactor modernization, tariff adjustments for radioisotopes and strategic investments to align with national economic and technological goals.*

INTRODUCTION

Research reactors generally achieve significantly lower operational capacities and possess smaller radioactive inventories compared to nuclear power plants. (1). The G. A. Siwabessy Multi-purpose Reactor (RSG-GAS) is an open pool, water-cooled, and water-moderated reactor with a power capacity of 30 MW, which reached its first criticality in July 1987 (2). Located in the B.J. Habibie Science and Technology Area, Serpong Banten, this reactor, costing USD 50 million, was built by the government of the Republic of Indonesia (cq. The National Nuclear Energy Agency - BATAN) and inaugurated in 1987 by President Soeharto.

The RSG-GAS's core uses plate-type U_3O_8–Al fuel, which is later converted to U_3Si_2–Al fuel with the same uranium density of 2.96 g/cc and enriched at 19.75%. For a better neutron economy, beryllium is used as a reflector. The RSG-GAS typical working core configuration (TWC) consists of 40 fuel elements (FE), 8 control elements (CE), and 30 beryllium reflector elements. The TWC core was achieved through 5 transition cores with different amounts of fuel loading. The average thermal neutron flux is 2.0 × 1014 n/cm^{2}s, and its maximum neutron flux is at the center irradiation position (CIP), up to 5.38 × 1014 n/cm^{2}s. The RSG-GAS is equipped with several test facilities such as a CIP, 4 small irradiation positions (IP) in the reactor core, beam tubes for radioisotope production and basic science experiments, and power reactors fuel development such as power ramp test, fuel irradiation facilities, and others. (2)

IP test facilities in the reactor core of RSG-GAS can produce several radioisotopes by fission method or by activation method. Radioisotopes are isotopes of radioactive substances that are capable of emitting radiation. (3). Radioisotopes are widely applied in various fields, they are radioisotopes for medical purposes (Tc-99m, I-125, Sm-153, I-131, etc.), industrial purposes (Ir-192, Br-82), and research purposes (P-32). Specifically, I-125 is produced through the activation of Xe-124 with neutrons inside the S1 tube (positioned within the core reactor configuration chamber), while other radioisotopes are produced through irradiation inside the core reactor. (4).

Sm-153 is a radioisotope utilized in the field of nuclear medicine. This radioisotope serves as a raw material for the production of the radiotherapeutic agent Sm-153 EDTMP, used in Bone Pain Palliative therapy to reduce pain in cancer patients who have metastasized to the bones (5). I-131 is a radioisotope with applications in Nuclear Medicine, for instance, it can be utilized in the production of oral I-131 radiopharmaceuticals and I-131 MIBG. Oral I-131 can be used for the diagnosis and therapy of thyroid cancer. I-131 MIBG is used for the diagnosis and therapy of neuroendocrine cancers such as pheochromocytoma, paraganglioma, and neuroblastoma (6,7). Mo-99, another radioisotope, finds extensive use in the field of nuclear medicine as well. P-32 is a radioisotope widely applied in agriculture and healthcare. One of the uses of P-32 radioisotope is to determine the distribution patterns and effectiveness of fertilizers in agriculture (8,9).

Demand for medical radioisotopes is experiencing rapid growth due to the annual performance of tens of millions of nuclear medicine procedures. (10). In the context of medical applications, radiopharmaceuticals play a crucial role in clinical diagnosis and/or therapy. The distinction between radiopharmaceuticals and ordinary medicines lies in the incorporation of radioisotopes. (11). In this context, radiopharmaceuticals do not differ from conventional parenteral drugs in terms of purity, safety, and benefits. Quality and purity standards must be established, and these products must undergo testing to ensure compliance with these standards. (12). The radioisotopes essential for these radiopharmaceuticals are commonly sourced from nuclear reactors, constituting an integral component of the radiopharmaceutical supply chain. (13).

Furthermore, based on the 2018 Basic Health Research data, there was an escalation in the prevalence rate of individuals afflicted by cancer in 2018 compared to the 2013 data. In 2013, the recorded prevalence rate of cancer sufferers stood at 1.4 per 1000 population. Contrastingly, in 2018, the prevalence rate escalated to 1.8 per 1000 population. This signifies an average annual growth of approximately 6.6% in the number of cancer sufferers, transitioning from approximately 354,620 in 2013 to 471,060 in 2018 (14). The surge in these prevalence figures inherently points to an expanding market potential for radiopharmaceuticals in Indonesia.

According to the DPFK-BRIN expert team, there is a significant demand for radiography services for the industrial sector in Non-Destructive testing (NDT), particularly in the construction of high-pressure pipelines or shipbuilding, which is one of the sectors with the most demand. One widely radioisotope used for this sector is Ir-192. The current substantial demand is not met by domestic production, leading to a situation where all Ir-192 radioisotope sources are entirely imported. Import destinations include countries like South Korea, Africa, Poland, and others. According to 2021 data, total imports of Ir-192 are approximately 484 units per year, with activity per unit ranging from 99 to 102 Ci, with an import value reaching around IDR 22.3 billion. (15).

Although Indonesia possesses a significant market for radioisotopes, it heavily relies on imports to meet its supply demands. It is realized that RSG-GAS is a vital installation for the state to participate in providing public health and industrial needs through the provision of radioisotopes, which will be difficult for the private sector to fulfill considering the large investment in research reactors. Nevertheless, with 36 years of operation, RSG-GAS is susceptible to degradation due to aging, making revitalization an inevitable choice to enhance its performance.

On the other hand, operating a research reactor may be perceived as a financial burden on the state budget. Consequently, for the revitalized RSG-GAS to achieve financial sustainability independently, it must demonstrate profitability throughout its operational lifetime. Additionally, to justify the investment in revitalization, it must be established that the financial benefits of the revitalized RSG-GAS surpass those of its pre-revitalization state.

The objective of this paper is to determine the viability of the revitalization investment in RSG-GAS and its supporting facility for radioisotope production by conducting a cost-benefit analysis (CBA). The research paper highlights the need to bridge the research gap by conducting a detailed financial CBA to assess the economic viability and profitability of radioisotope production post-revitalization at RSG-GAS, providing insights into the financial implications and benefits of the project. Overall, financial CBA is a valuable tool used throughout the project lifecycle to assess financial viability, support decision-making, manage risks, and ensure that investments generate positive returns.

The choice of using financial CBA as a method in research is influenced by various factors. Factors such as risk aversion towards environmental outcomes, bureaucrats' environmental attitudes, the cost of implementing financial CBA, and the presence of a binding governmental budget constraint play significant roles in determining the probability of utilizing financial CBA information (16). Additionally, the ability of financial CBA to enable the justification of investments, redirect capital to projects, and carefully select alternatives that best meet objectives within relevant constraints also contributes to its selection as a financial analysis method in research. (17). Moreover, the challenges in network security, where a cost-based path characterization technique has been proposed to reduce vulnerabilities in attack graphs, highlight the importance of considering financial CBA. (18). This paper assesses the financial opportunity of a radioisotope production project by analyzing the project's NPV and IRR using cost-benefit analysis principles.

EXPERIMENTAL SECTION

Methods used in the research are following the research methodology with a brief justification. The initial was to define the problem that we need to solve. Next, the literature review and visit the RSG-GAS and its supporting facility. Using insights gained from these preliminary steps, two scenarios were developed to simulate the reactor's performance and economic outcomes. Subsequently, data required for the analysis was collected, ensuring its relevance and accuracy. Input the data needed such as radioisotopes needed, cost of the scenario, and revenue to the scenario. Then apply financial CBA analysis. The results were gathered and discussed, leading to the conclusions.

This study employs a comprehensive method to examine the financial effects of radioisotope production in the RSG-GAS and its supporting facility. The methodology is designed to provide a comprehensive and balanced perspective on the costs and benefits associated with this project. The analysis is conducted based on the requirements of the radioisotope sector and the types of radioisotopes that can be produced. Data is gathered from the RSG-GAS facility and supplemented with relevant literature reviews, also expert adjustments. The collected data was then analyzed using financial CBA procedures to determine the project's profitability. The flowchart research can be seen in **Figure 1.**

2.1. CBA Procedures

CBA is a methodical approach for assessing the potential advantages and associated costs over a specific investment timeframe (19). This method assesses whether the solution provided for the problem being analyzed costs more or is comparable to the benefits obtained. In this process, the costs and benefits of the project are identified and monetized, then compared against the counterfactual scenario and the net present value of each scenario is calculated . As shown in Figure 2, the CBA procedures are analogous to a framework that assists an analyst carrying out his work.

In a Cost-Benefit Analysis (CBA), defining goals and scope (Step 1) is crucial, involving input from experts in reactor technology, radioisotope and radiopharmaceutical technology, nuclear medicine, operations, business processes, and economics. Brainstorming and expert discussions help shape project alternatives (Step 2), with a focus on technical feasibility. Two scenarios, the counterfactual and radioisotope scenarios, are defined for comparison. Identifying and calculating costs and benefits (Steps 3 and 4) involves detailed cost and benefit analysis for each scenario. Next (Step 5), these projections are used to calculate discounted cash flows and project performance criteria, such as Net Present Value (NPV) and Internal Rate of Return (IRR), determining project feasibility. Sensitivity and risk analysis (Step 6) are deemed unnecessary in this study, as NPV and IRR sufficiently assess financial acceptability. The final step (Step 7) provides recommendations based on a comprehensive understanding of the project's financial viability.

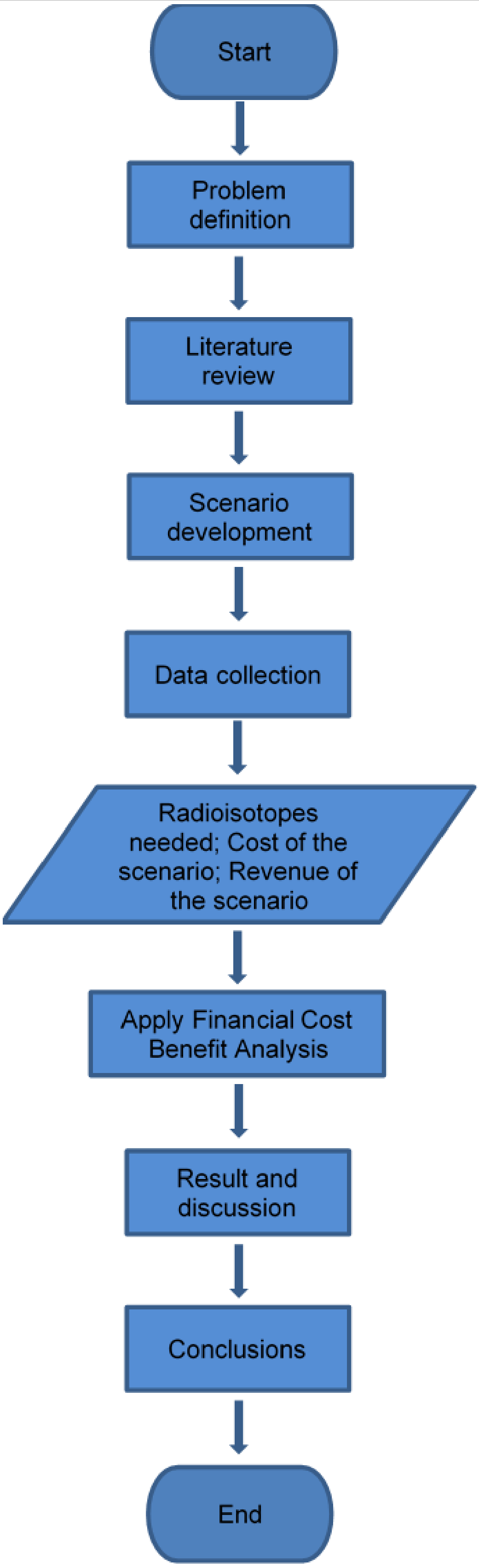

Figure 1. Research Flowchart

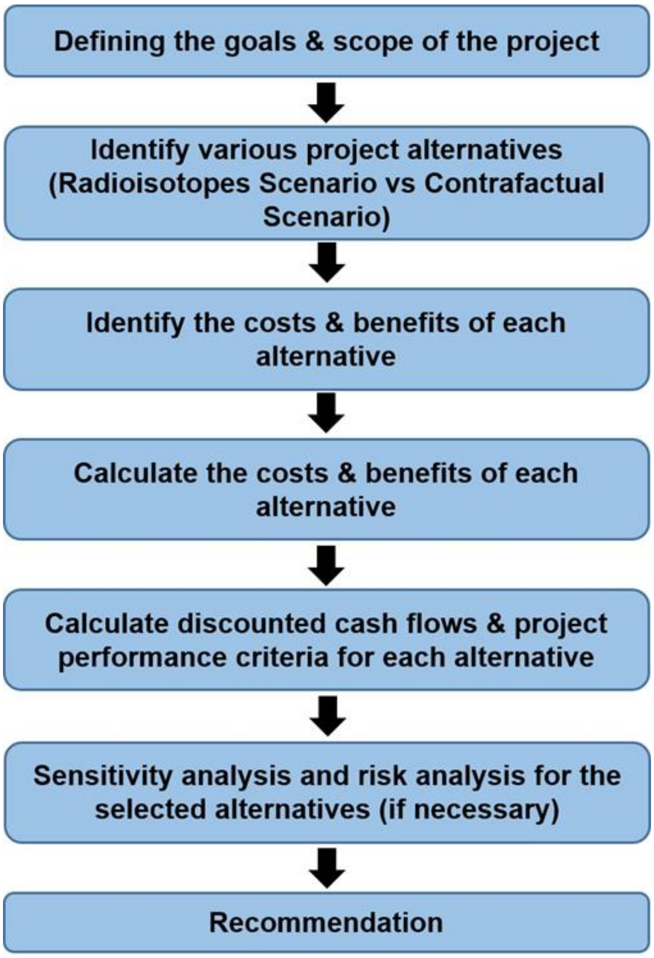

Figure 2. Steps in CBA

2.2 Incremental Approach

In this research, CBA compares a proposed scenario (with the project) alongside a counterfactual (without the project) baseline scenario. The incremental approach requires that (20):

1. firstly, a counterfactual scenario is delineated as the potential outcome that would occur in the absence of the project, i.e. revitalization of RSG-GAS and its supporting facility. For this scenario, projections are generated for all cash flows associated with operations in the project area for each year throughout the project's lifetime.
2. secondly, projections of cash flows are made for the situation involving the proposed project. This takes into account all the investment, financial and economic costs and benefits resulting from the project (here we take into account only the financial costs).
3. finally, the CBA only considers the difference between the cash flows in the proposed and the counterfactual scenarios. The financial performance indicators are calculated on the incremental cash flows only.

Both incremental IRR and incremental NPV require cashflows from both scenarios and that the project lifetime must be the same. Steps to acquire them are:

1. calculate the net-cashflow for each of the scenarios (the proposed and counterfactual scenarios).
2. calculate the net-cashflow difference between the two options.
3. calculate the incremental NPV and incremental IRR from the net cashflow difference (**Table 1** and **Table 2**).

The proposed scenario is said to be feasible when: incremental NPV > 0 and incremental IRR > discount rate applied.

Table 1. Net-Cashflow Tabulation of Both Scenarios for Calculating the Incremental NPV

Scenario	Time horizon					NPV
	T_0	T_1	T_2	...	T_N	
Counterfactual (A)	C_{A0}	C_{A1}	C_{A2}	..	C_{AN}	NPV_A
Proposed (B)	C_{B0}	C_{B1}	C_{B2}	..	C_{BN}	NPV_B
Incremental (i)	C_{i0}	C_{i1}	C_{i2}	..	C_{iN}	NPV_i

C = net cashflow

Table 2. Net-Cashflow Tabulation of Both Scenarios for Calculating the Incremental IRR

Scenario	Time horizon					NPV
	T_0	T_1	T_2	...	T_N	
Counterfactual (A)	C_{A0}	C_{A1}	C_{A2}	..	C_{AN}	NPV_A
Proposed (B)	C_{B0}	C_{B1}	C_{B2}	..	C_{BN}	NPV_B
Incremental (i)	C_{i0}	C_{i1}	C_{i2}	..	C_{iN}	NPV_i

C = net cashflow

Figure 3. Counterfactual Scenario

The NPV is calculated the formula as follows:

$$NPV = C_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_N}{(1+r)^N} \quad \text{eq. 1}$$

where *C* is the net cashflow and *r* is the discount rate applied. Meanwhile, the IRR is calculated by iterating the value of *r* such that the NPV becomes 0 (zero).

2.3 Scenario Development and Data

In this study two scenarios were used, namely the Counterfactual scenario and the Radioisotope Scenario as the proposed scenario.

2.3.1 Counterfactual scenario

This scenario is a business-as-usual form scenario, it is assumed that the reactor operates concerning the production status of the year 2020. The allocation of the reactor in this scenario is for the production of both radioisotopes and non-radioisotopes (topaz stone irradiation and demineralized water production). The time horizon in this scenario spans from 2023 to 2030 (Figure 3), after which the reactor ceases operation due to the expiration of its operating license.

In the year 2020, there were 6 types of Radioisotopes produced, namely: Iodine-131 (I-131), Samarium-153 (Sm-153), Molybdenum-99 (Mo-99), Phosphorus-32 (P-32), Gadolinium-153 (Gd-153), and Lutetium-177 (Lu-177). However, in this study, it is assumed that only 4 types of Radioisotopes are produced: Sm-153, Mo-99, I-131, and P-32. This assumption is based on the consideration of the unavailability of production cost data for Gd-153 and Lu-177 Radioisotope. RSG-GAS Radioisotope Production in 2020 is stated in

Table **3**, referring to production data released by the Center for Radioisotope and Radiopharmaceutical Technology (PTRR) - BATAN in 2020.

The output of non-radioisotopes, in this case, we called other products are assumed to be one-third of the post-revitalization projections by the expert team from the Directorate of Nuclear Facility Management, National Research and Innovation Agency. The other products are stated in Table 4.

Table 3. RSG-GAS's Radioisotopes Production 2020

No	Radioisotope	Target	Total Radioactivity (mCi)
1	Sm-153	Samarium (III) Oxide (Sm_2O_3)	349,622.34
2	Mo-99	Molybdenum (III) Oxide (MoO_3)	23,730.17
3	I-131	Tellurium dioxide (TeO_2)	59,565.05
4	P-32	Sulfur	2,954.16

Table 4. RSG-GAS's other production 2020

No	Product	Unit	Total
1	Topaz irradiation service	kg	500
2	Demineralized water	Liter	350

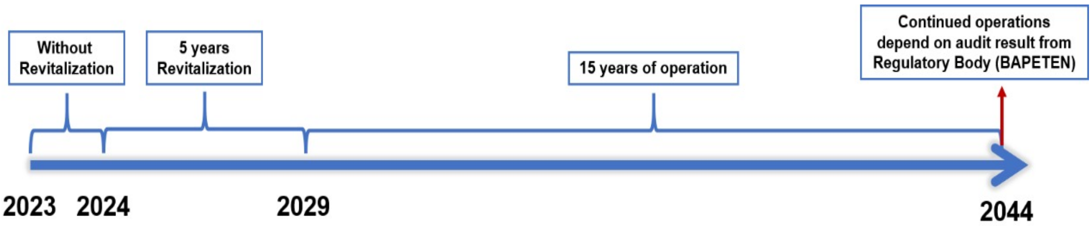

Figure 4. Radioisotope Scenario

Table 5. Annual RSG-GAS's production Post Revitalization (2030 – 2044)

Product	Unit	Quantity
Radiopharmaceuticals		
Product 1: I-131 MIBG	mCi	2,000
Product 2: I-131 Oral	mCi	300,000
Product 3: Sm-153 EDTMP	mCi	100,000
Product 4: P-32 Medis	mCi	15,000
Product 5: Mo-Tc Generator	Unit	720
Radioisotopes		
Product 6: Mo-99	mCi	120,000
Product 7: Ir-192	Unit	120
Product 8: I-131	mCi	1,000,000
Product 9: Sm-153	mCi	1,000,000
Product 10: P-32	mCi	45,000

2.3.2 Radioisotope Scenario

The Radioisotope Scenario represents a revitalization, and post-revitalization, the reactor will be exclusively dedicated to the production of radioisotopes and radiopharmaceuticals. Revitalization is assumed to require a period of 5 years (2024 – 2029) and post-revitalization, RGS-GAS and its supporting facilities operation is projected to be extendable for 15 years (2030 – 2044) and the continuation of operations thereafter depends on the audit findings from the Nuclear Energy Regulatory Agency (BAPETEN). The timeframe of the radioisotope scenario is shown in Figure *4*.

In 2023, RSG-GAS has not yet been revitalized, so production data for this year is assumed to be the same as in the Counterfactual Scenario. Post-revitalization, the facility is assumed to be exclusively dedicated to the production of Radioisotopes and Radiopharmaceuticals, excluding topaz irradiation and demineralized water. The operation of the reactor post-revitalization is projected to be extendable for 15 years (2030 –

2044). After revitalization, the reactor is projected to enhance the production capacity of Radioisotopes and Radiopharmaceuticals compared to pre-revitalization, both in terms of quantity and the increasing variety/types of Radioisotopes and Radiopharmaceuticals produced. The annual RSG GAS production post revitalization is stated in **Table 5**.

The selling price of Radioisotopes, Radiopharmaceuticals, and the irradiation service fee in both scenarios adhere to the Non-Tax State Revenue (NTSR or PNBP-Ind.) based on the Ministry of Finance's Regulation No. 185/PMK.02/2021 regarding the Types and Rates of Non-Tax State Revenue that are volatile in the National Research and Innovation Agency, except for the Ir-192 price referring to the estimates of the DPFK expert team.

2.4 Cost Data

Both in the counterfactual scenario and in the radioisotope scenario, an initial investment of RSG-GAS and its supporting facility for radioisotope production is considered a sunken cost or ignored because this cost will not change regardless of the choices made. Hence only investment costs for revitalization and production costs are considered in both scenarios.

2.4.2 Cost Data in Counterfactual Scenarios

The costs in this scenario are only operational costs, which include: production costs per product type (Radioisotopes, Radiopharmaceuticals, topaz irradiation, and demineralized water), fuel costs, and maintenance costs. Radioisotope production costs are fixed costs which include: raw material costs, direct labor costs, and production overhead costs. Meanwhile, Radiopharmaceutical production costs include fixed costs and variable costs, which are costs of production materials for packaging per unit. The taxonomy of Radioisotopes and Radiopharmaceuticals production costs is stated in **Table 6**

Production costs for each type of Radioisotope and other products refer to the calculations of the expert team from DPFK – BRIN. **Table 7** Below are the total production costs in the contrafactual scenario.

Table 6. Taxonomy of Production Cost of Radioisotope and Radiopharmaceutical

No	Cost component for Radioisotope production
A	**Fix Cost Financing**
A.1	**RAW MATERIAL COST**
	- Target preparation material
	- Post-irradiation process material
	- Process material
	- Quality Control material
	- Cleaning agent
	- etc.
A.2	**DIRECT LABOUR COST**
	Personal Protective Equipment (PPE)
	Administration
	Labor cost
	Work permit cost
A.3	**OVERHEAD PRODUCTION COST**
	Production facility cost
	Irradiation cost/ Capsule Batch
	Operational cost for supporting facility
	Certification and licensing cost
	Waste disposal cost
B	**Variable Cost**
	Production cost for the packaging/unit
Total cost of radioisotope production = cost A	
Total cost of Radiopharmaceutical production = cost A + cost B	

Table 7. Production Costs in Counterfactual Scenarios

Product	Unit	Quantity	Unit Price (IDR)	Total (IDR)
Radioisotopes				
Product 1: Sm-153 (i)	mCi	349,622.34	7,817	2,732,903,783.00
Product 2: Mo-99 (i)	mCi	23,730.17	8,000	189,841,360.00
Product 3: I-131 (i)	mCi	59,565.05	12,975	772,830,196.00
Product 4: P-32 (i)	mCi	2,954.16	8,000	23,633,280.00
others				
Product 5: Topaz	kg	500	500,000	250,000,000.00
Product 6: Demineralized water	liter	350	500	175,000.00
	Total production cost in Counterfactual Scenario			**3,969,383,619.00**

Table 8. Operational Cost in Counterfactual Scenario

No	Cost operation	Total (IDR)
1	Production cost	3,969,383,619.00
2	Fuel cost	12,000,000,000.00
3	Maintenance cost	5,000,000,000.00
Total operational cost in Counterfactual Scenario		**20,969,383,619.00**

Table 9. Investment cost for revitalization

Installation	Detail	Proposed Budget (IDR)
RSG-GAS Reactor	* Modernize Analog I & C system to Digital	190,000,000,000.00
	* Revitalize Radiation Monitoring System	60,000,000,000.00
	* Refurbish electrical equipment (5 installations)	50,000,000,000 .00
Total 1		**300,000,000,000.00**
Radioisotope Production	* Revitalize RadMon System	10,000,000,000.00
	* Replace larger radiation filter to stack	10,000,000,000.00
Total 2		**20,000,000,000.00**
Total Revitalization cost		**320,000,000,000.00**

As for fuel costs, because every year around IDR 23.8 billion is spent on fuel and the reactor operates at 15 MW power (half of full power), the fuel costs in the counterfactual scenario are assumed to be around ½ of the total fuel costs, namely IDR 12 billion. The maintenance costs are assumed to be based on calculations by the DPFK – BRIN Expert team, namely IDR 5 billion. So, the total operating costs of IDRI-FP in the counterfactual Scenario are around IDR 20.97 billion as stated in **Table 8**.

2.4.2 Cost Data in Radioisotope Scenarios

In this scenario, we projected revitalization of the RSG-GAS and its supporting facility, focusing exclusively on the production of radioisotopes post-revitalization, excluding other pre-revitalization products. Consequently, the costs rise. The estimated investment cost for revitalization is IDR 320 billion, comprising IDR 300 billion for the revitalization of RSG-GAS and IDR 20 billion for the revitalization of Building No 11 (Supporting Facility), as shown in

Table 9. The investment drawdown is assumed to be flat throughout the revitalization period (at IDR 64 billion per year). During the

revitalization period, the reactor is assumed to be shut down and there is no production condition.

The estimates of Radioisotope and Radiopharmaceutical production amount after revitalization as well as production costs per product type refer to calculations carried out by the DPFK – BRIN Expert Team, as stated in **Table 10.**

As for fuel costs and maintenance costs, they are assumed to be the same as fuel costs and maintenance costs in the counterfactual scenario. So, the total operating costs in the Radioisotope Scenario are estimated at around IDR 50.85 billion as stated in Error! Reference source not found..

2.5 Revenues Data

2.5.1Revenue Data in Counterfactual Scenario

Income (or in this case, we call revenue) in the counterfactual scenario is calculated by multiplying the production quantity in this scenario by the NTSR price. The estimated total income in the counterfactual scenario is stated in **Table 12**.

It can be seen that the revenue of RSG-GAS and its supporting facilities in the counterfactual scenario is around IDR 5 billion per year.

Table 10. Production cost

Products	Unit	Quantity	Price/unit (IDR)	Total (IDR)
Radiopharmaceuticals				
Product 1: I-131 MIBG	mCi	2,000	13,043.00	26,086,116.00
Product 2: I-131 Oral	mCi	300,000	13,043.00	3,912,917,450.00
Product 3: Sm-153 EDTMP	mCi	100,000	7,858.00	785,783,050.00
Product 4: P-32 Medical	mCi	15,000	8,000.00	120,000,000.00
Product 5: Mo-Tc Generator	Unit	720	8,000,000.00	5,760,000,000.00
Radioisotopes				
Product 6: Mo-99	mCi	120,000	8,000.00	960,000,000.00
Product 7: Ir-192	Unit	120	9,484,000.00	1,138,080,000.00
Product 8: I-131	mCi	1,000,000	12,975.00	12,974,558,167.00
Product 9: Sm-153	mCi	1,000,000	7,817.00	7,816,730,500.00
Product 10: P-32	mCi	45,000	8,000.00	360,000,000.00
Total production cost				**33,854,155,283.00**

Table 111. Operation cost

No	Operational cost	Total (IDR)
1	Production cost	3,854,155,283.00
2	Fuel cost	12,000,000,000.00
3	Maintenance cost	5,000,000,000.00
Total operational cost of Radioisotope Scenario		**50,854,155,283.00**

Table 12. Revenue Gained in the Counterfactual Scenario

Product	Unit	Quantity	Unit NTSR	NTSR price (IDR)	Total (IDR)
Radioisotopes					
Product 1: Sm-153 (i)	mCi	349,622.34	IDR/ mCi	7,000.00	2,447,356,380.00
Product 2: Mo-99 (i)	mCi	23,730.17	IDR/ mCi	8,000.00	189,841,360.00
Product 3: I-131 (i)	mCi	59,565.05	IDR/ mCi	12,000.00	714,780,600.00
Product 4: P-32 (i)	mCi	2,954.16	IDR/ mCi	60,000.00	177,249,600.00
Other					
Product 5: Topaz	kg	500	IDR/ kg	3,000,000.00	1,500,000,000.00
Product 6: Demineralized water	liter	350	IDR/ liter	1,000.00	350,000.00

Total revenue	**5,029,577,940.00**

Table 13. Revenue Gained in the Radioisotope Scenario

Product	Unit	Quantity	Unit NTSR	NTSR price (IDR)	Total (IDR)
Radiopharmaceuticals					
Product 1: I-131 MIBG	mCi	2,000	IDR/ mCi	1,300,000.00	2,600,000,000.00
Product 2: I-131 Oral	mCi	300,000	IDR/ mCi	180,000.00	54,000,000,000.00
Product 3: Sm-153 EDTMP	mCi	100,000	IDR/ mCi	35,000.00	3,500,000,000.00
Product 4: P-32 Medical	mCi	15,000	IDR/ mCi	75,000.00	1,125,000,000.00
Product 5: Mo-Tc Generator	Unit	720	IDR/ Generator	6,000,000.00	4,320,000,000.00
Radioisotopes:					
Product 6: Mo-99	mCi	120,000	IDR/ mCi	8,000.00	960,000,000.00
Product 7: Ir-192	Unit	120	IDR/ Unit	42,000,000.00	5,040,000,000.00
Product 8: I-131	mCi	1,000,000	IDR/ mCi	12,000.00	12,000,000,000.00
Product 9: Sm-153	mCi	1,000,000	IDR/ mCi	7,000.00	7,000,000,000.00
Product 10: P-32	mCi	45,000	IDR/ mCi	60,000.00	2,700,000,000.00
Total Revenue					**93,245,000,000.00**

2.5.2 Revenue Data in Radioisotope Scenario

As for revenue in the Radioisotope Scenario, it is calculated by multiplying the quantity of production in this scenario by its NTSR price. The estimated total revenue in this scenario amounts to IDR 93,245,000,000.00 as shown in **Table 13**.

In this scenario, the selling price of Ir-192 is IDR 42,000,000.00 per unit, which is not the NTSR value, but an estimate by the expert team from DPFK – BRIN. This value is based on the import price of Ir-192, which is IDR 46,000,000.00 per unit (excluding shipping costs and import taxes). The NTSR value of the Mo-Tc Generator is smaller than its production cost (IDR 6,000,000.00 versus IDR 8,000,000.00), thus serving as a basis for input to the government to consider increasing the tariff for Mo-Tc Generator's NTSR.

RESULTS AND DISCUSSION

Despite some limitations, this research addresses gaps and introduces innovations in the literature, significantly influencing the results. The study primarily focuses on the financial aspects of radioisotope production at the RSG-GAS post-revitalization, potentially overlooking other non-financial factors that could impact the project's overall success and sustainability. The analysis is based on certain assumptions regarding operating costs, revenue generation, and discount rates, which may not fully capture the dynamic nature of the radioisotope market and the operational complexities of the reactor. The study does not delve into the potential risks and uncertainties associated with radioisotope production, such as regulatory changes, market fluctuations, or technological advancements that could affect the project's profitability and long-term viability. The research does not consider the environmental and social implications of radioisotope production at RSG-GAS, which are essential factors to assess the project's overall sustainability and societal impact. The study's findings are based on the information available at the time of analysis and are subject to change based on evolving market conditions, regulatory requirements, and technological advancements in the nuclear and radioisotope production sectors.

The choice of discount rate, as implemented at 3.25% in this study, holds significant implications for the evaluation of nuclear projects, including the revitalization efforts undertaken for RSG GAS. The implementation of a 3.25% discount rate in a nuclear project (21–23) could be influenced by various factors such as the capital-intensive nature of new energy power projects, the debate surrounding the choice of discount rate in projects with long-term impacts like nuclear power, and the importance of having a theoretically founded estimate of the discount rate for CBA (24). Discount rates play a crucial role in evaluating projects with costs and benefits spread over many years, like nuclear energy projects that incur major costs at the end of their operational life. The choice of discount rate is essential for determining the NPV and the overall efficiency of a project, especially in the context of environmental management and energy crisis pressures. Therefore, the 3.25% discount rate (21–23,25–27) could have been selected based on considerations of project longevity, capital intensity, and theoretical foundations for estimating social discount rates.

The project performance criteria results of the Radioisotope Scenario will be compared with the project performance criteria results of the counterfactual scenario, as stated in

Table 14. In this study, a discount rate of 3.25% was implemented, referring to the long-term government bond interest rate and based on the literature review. This discount rate reflects risk and opportunity costs in the project evaluation.

Table 14. The project performance criteria results

Performance criteria	Radioisotope scenario	Counterfactual Scenario	Incremental
NPV (million IDR)	115,364.83	-114,320.28	229,685.11
IRR	6.8%	N/A	12.4%

In comparing the project performance criteria results between the radioisotope and counterfactual scenarios, it becomes evident that the chosen discount rate profoundly influences project feasibility and viability. Based on the results, it is observed that in the counterfactual scenario, the project is deemed infeasible, as indicated by the negative NPV of -IDR 114,320.28. In contrast, in the radioisotope scenario, the project is considered feasible, demonstrated by a positive NPV of IDR 115.36 million and an IRR of 6.8% (greater than the discount rate). A negative NPV arises from cash outflows surpassing cash inflows, suggesting a financial loss in the future (Negative NPV signals unprofitable investment). This concept is crucial in financial decision-making and project evaluation, as it helps assess the profitability and viability of investments.

Incremental values represent the difference between the performance criteria values in the radioisotope scenario and in the counterfactual scenario. Specifically, the positive incremental NPV and IRR demonstrate that the radioisotope scenario not only covers its costs but also generates additional economic benefits. The counterfactual scenario, characterized by a negative NPV, indicates a financial loss if the reactor continues operating without revitalization. In contrast, the radioisotope scenario shows a positive NPV and IRR, signifying profitable and financially sound operations post-revitalization. Based on these results, it can be concluded that it is deemed worthwhile to pursue the radioisotope scenario project with an investment cost of 320 billion Rupiah compared to maintaining the counterfactual scenario. The substantial incremental values justify the revitalization expenditure, ensuring long-term financial sustainability and enhanced economic returns from the RSG-GAS reactor operations.

Apart from tangible benefits, as input for further research, several intangible benefits are also identified which are projected to be obtained by the revitalization project of RSG GAS and its supporting facility as well as post-revitalization operations for Radioisotope and Radiopharmaceutical production, namely as follows:

a. The RGS-GAS product holds economic value
b. Enhance opportunities for research and development
c. Publications generated by experts from research activities at RSG-GAS and supporting facilities will contribute to the advancement of scientific knowledge

d. Being a source of national pride in the progress and advancement of knowledge in the field of Health.
e. The presence of technological innovation.
f. Avoiding the cost of importing radiopharmaceuticals.
g. Avoiding the loss of lives in productive-age patients.
h. Enhancing the Human Development Index
i. Reducing foreign exchange outflows.

These intangible benefits underscore the broader impacts of the revitalization project, contributing to both national progress and economic stability.

This study underscores the importance of financial analysis in guiding decision-making for radioisotope production projects. Policymakers need to assess economic viability, profitability, and investment value when considering similar projects in the nuclear industry. The findings highlight the significance of revitalizing aging reactors like RSG-GAS to enhance performance, ensure long-term financial sustainability, and generate additional economic benefits through radioisotope production. These insights can inform policymakers on the importance of reactor modernization and revitalization efforts.

Furthermore, the research results can serve as a basis for policymakers to consider adjusting tariffs for radioisotopes, such as the Mo-Tc Generator's NTSR, based on revenue data and financial performance indicators from the radioisotope scenario. This could potentially influence pricing policies and revenue generation strategies in the nuclear sector.

Policymakers can use the study's insights to prioritize investments in radioisotope production projects that demonstrate positive financial outcomes, aligning with national goals for economic development, technological advancement, and innovation in the nuclear field. The financial analysis presented in the study can guide policymakers in allocating resources effectively, optimizing capital usage, and making informed decisions regarding nuclear reactor operations, revitalization projects, and radioisotope production initiatives to maximize economic returns and societal benefits.

CONCLUSION

The results show the estimated total annual revenue in the counterfactual scenario is stated to be IDR 5,029,577,940.00, on the other hand, the Radioisotope's scenario amounts to IDR 93,245,000,000.00.

It is observed that in the counterfactual scenario, the project is deemed infeasible, as indicated by the negative NPV of IDR 114,320,284,197.00 and thus no IRR is acquired. The negative NPV illustrates that the costs in the counterfactual scenario outweigh its benefits, or that the reactor has no proper financial performance before revitalization.

In contrast, in the Radioisotope scenario, the project is considered feasible, demonstrated by a positive NPV of IDR 115,364,829,741 and an IRR of 6.8% (exceeding the discount rate of 3.25%), or suggesting that the financial benefit surpasses the costs.

When two scenarios are compared, the gap between cashflows of the radioisotope scenario and the counterfactual scenario gives an incremental NPV of IDR 229,685,113,938.00 and incremental IRR of 12.4%, indicating that the investment made for revitalization is justified.

This study emphasizes the crucial role of financial analysis in guiding decisions for radioisotope production projects, particularly in assessing economic viability and profitability. The findings highlight the benefits of revitalizing aging reactors like RSG-GAS for improved performance and long-term financial sustainability, offering significant economic advantages. These insights can inform policymakers on the importance of reactor modernization, tariff adjustments for radioisotopes and strategic investments to align with national economic and technological goals.

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