Comparative Evaluation of Nuclear Fuel Technology in Indonesia using KIND-ET - A Case Study

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INTRODUCTION

Indonesia's unique archipelagic geography, characterized by thousands of islands varying in size and population density, poses significant challenges for developing a unified, large-scale electricity grid. As a result, Indonesia must adopt differentiated strategies for deploying nuclear energy to meet its diverse electricity infrastructure needs. To address these challenges, Indonesia is exploring water-cooled nuclear reactor technologies, such as PWR, for its densely populated areas, while considering gas-cooled HTGR technology for smaller, isolated grids.

Research and development for nuclear fuel fabrication technology are also conducted in Indonesia to support those two types of reactors. Currently, Indonesia has two laboratory-scale facilities:

- Pin-type fuels technology (NFC-1): fabrication facility for PWR fuel.
- Ball-type fuels technology (NFC-2): fabrication facility for HTGR fuel.

A comparative evaluation of two fuel fabrication technologies in Indonesia is conducted using the Key Indicators for Innovative Nuclear Energy Systems-Evaluation Tool (KIND-ET). The presented analysis is performed using the information about current research on fuel fabrication in Indonesia and the expert judgment for Key Indicators (KIs) and scoring. This study also implemented two functional extensions for KIND-ET, Overall Score Spread Builder and Ranks Mapping Tool.

DETERMINATION OF KEY INDICATORS, VALUES, AND WEIGHTING FACTORS

The NFC comparative evaluation was conducted using a three-level objective tree. At the first level, the High Level Objectives (HLOs) chosen for this study were Cost, Performance, and Acceptability. The following assessment areas, 6 Key Indicators (KIs) including their values were then selected as shown in the performance table (Table 1). All HLOs were assigned equal importance in this evaluation, reflected by the same weighting factor values for each HLO. This assumption was also applied to the weights corresponding to the HLOs' assessment areas and the weights of the KIs within those assessment areas, as shown in Table 2.

Table 1. Performance Table

High-level objectives titles	Assessment Areas	Key Indicators	KIs Values	
			NFC-1	NFC-2
Cost	*Economics*	Production cost (**C.1**)	0	1
Performance	*Waste Management*	Toxic, hazardous, and radioactive waste (**WM.1**)	1	0
	Safety	Potential to prevent the release of toxic, hazardous, and radioactive materials (**S.1**)	1	0
		Criticality accident (**S.2**)	1	0
	Environment	Material scarcity (**E.1**)	0	1
Acceptability	*Maturity of technology*	Degree of technology verification (**M.1**)	1	0

Table 2. Weighting Factors

High-level objectives	HLOs weights	Assessment Areas	Areas weights	KIs	KI weights	Final weighting factors
Cost	0,333	*Economics*	1	***C.1***	1	0,333
Performance	0,333	*Waste Management*	0,333	***WM.1***	1	0,111
		Safety	0,333	***S.1***	0,5	0,055
			0,333	***S.2***	0,5	0,055
		Environment	0,333	***E.1***	1	0,111
Acceptability	0,333	*Maturity of technology*	1	***M.1***	1	0,333

RESULTS

Ranking Results

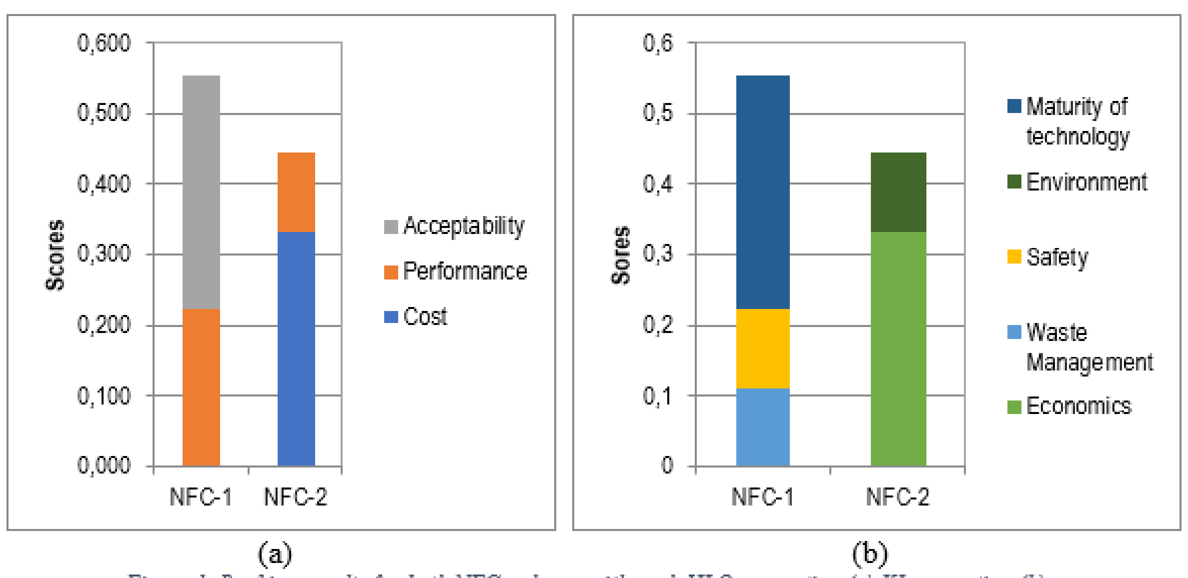

Figure 1. Ranking results for both NFCs, shown with each HLO proportion (a) KI proportion (b).

Weight Sensitivity Analysis

Table 3. Weight Values Variation

HLOs	Weight values		
	Base Case	Modified case 1	Modified case 2
Cost	0,333	0,3	0,3
Performance	0,333	0.3	0,2
Acceptability	0,333	0,4	0,5

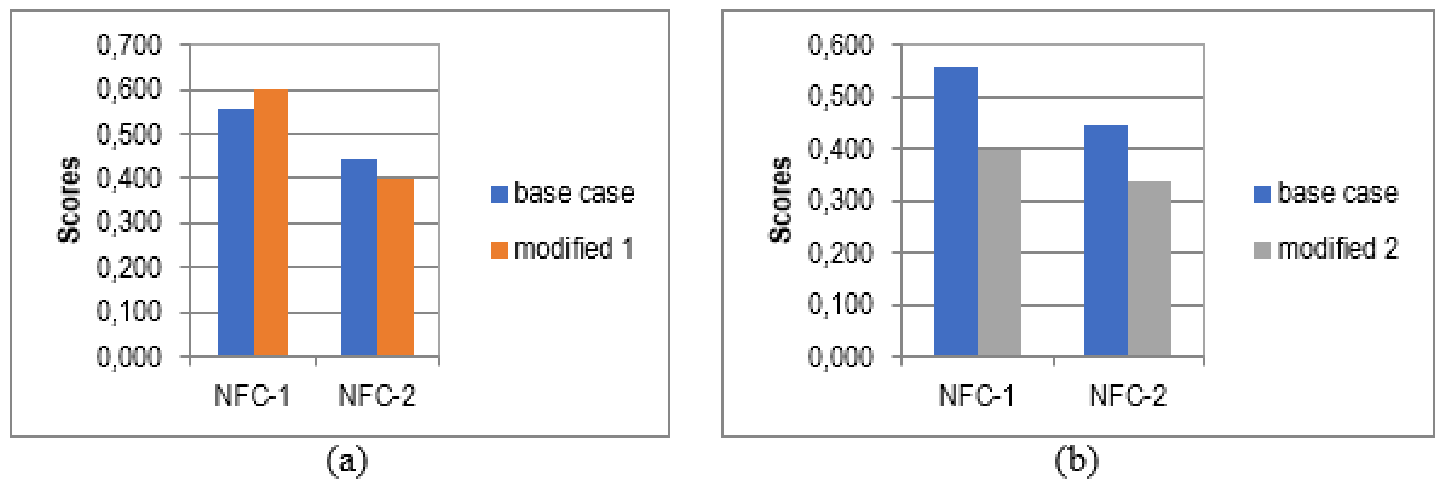

Figure 2. Comparison of ranking results between base case and modified case 1 (a) and modified case 2 (b)

Overall Score Spread Builder

	NFC-1	NFC-2
Mean	0,52595	0,337127
Standart deviation (SD)	0,320926	0,303052
Maximum value (Max)	0,999999	0,999998
Quartile (Q3, 75%)	0,828787	0,569606
Median	0,535472	0,246738
Quartile (Q1, 25%)	0,228385	0,065942
Minimum value (Min)	2,49E-06	8,93E-07
Calculations for chart		
Bottom	0,228385	0,065942
2 Q Box	0,307087	0,180795
3 Q Box	0,293315	0,322869
Whisker -	0,228383	0,065942
Whisker +	0,171212	0,430391

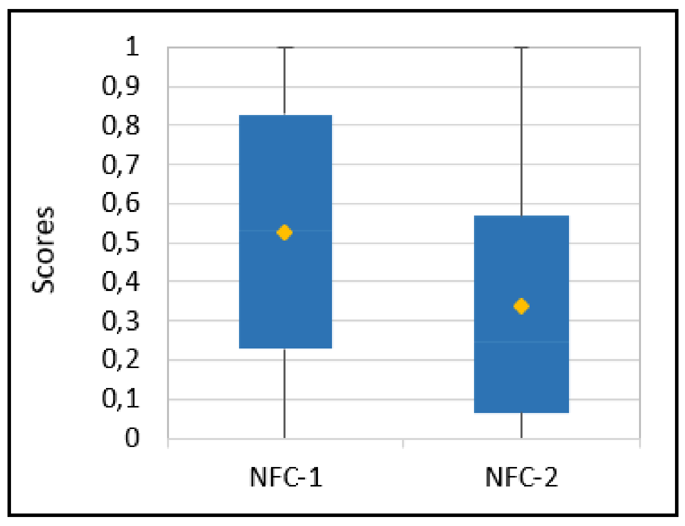

Figure 3. Overall Score Spread Results

Ranks Mapping

	NFC-1	NFC-2
Score for HLO-1	0,000	0,333
Score for HLO-2	0,222	0,111
Score for HLO-3	0,333	0,000

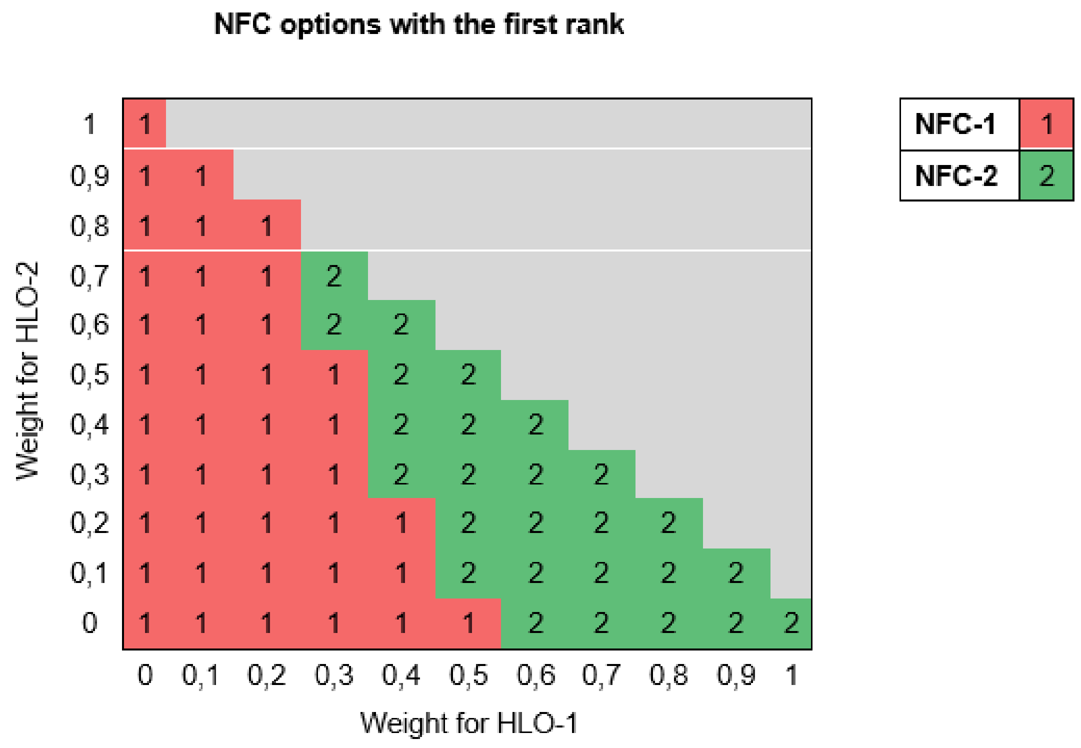

Figure 4. First rank result

CONCLUSION

The Comparative evaluation of two different NFC technologies using the KIND-ET tool showed:

- NFC-1 has a better ranking score than NFC-2.
- Slightly Weighting Factor modification does not change the ranking result.
- Random Weight could affect the ranking of NFC. After all NFC-1 generally has higher scores than NFC-2, but due to weight uncertainties, NFC-2 could surpass NFC-1.
- NFC-1 is superior at low HLO-1 values, but its superiority decreases as the HLO-1 weight increases up to a maximum of 0.5. Conversely, NFC-2 tends to become superior as the HLO-1 weight values increase, starting from a weight of 0.3.