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Evaluation of Environmental Stressors Impact on Introducing Nuclear Power Plant in Bangka Island – Indonesia Using INPRO Methodology

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Abstract

As with other industrial activities, the construction and operation of a nuclear power plant (NPP) will impact the environment because of the changes in the environment within and around the activity location. According to the basic principle of the environment in the INPRO Methodology developed by the IAEA, the acceptability of expected adverse environmental effects arising from an NPP should be within the standard performance envelope for the NPP to be sustainable. Indonesia's progressive development of its nuclear energy system (NES) involves a plan to build a 1000 MW NPP at the candidate site of Bangka Island. The environmental impact of this project was evaluated, including through a nuclear energy system assessment (NESA) using the INPRO Methodology to address long-term sustainability. One environmental impact analysis that needs to be considered is the release of stressors, in which controllability by optimizing actions will reduce the environmental impact of exposure to radioactive materials, toxic substances, and heat in the atmosphere and marine waters. The evaluation is aimed to ensure that the planned NES aligns with the existing NES in terms of controllability of environmental stressors, reduction of total environmental impact, and optimization of measures to mitigate environmental effects. The study concluded that the identified stressors are controllable within the regulatory limits, and effective measures are in place to control and reduce radiation-related effects. Hence, introducing a 1000 MW NPP in Bangka Island meets sustainability criteria from the environmental stressors impact point of view.

Keywords: *Nuclear Energy System; Sustainability, Environmental Stressors, Controllability, Reduction, Optimization.*

INTRODUCTION

Indonesia has been actively pursuing the development of its first nuclear energy system for several decades. The nuclear energy system assessment (NESA) using the

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sustainability criteria in the INPRO Methodology developed by the International Atomic Energy Agency (IAEA) provides an insight into the critical issues for the sustainability of a nuclear energy system (NES). The assessment addresses the sustainability of the planned nuclear energy system in Economics, Infrastructure, Waste Management, Proliferation Resistance, Physical Protection (within Infrastructure), Environment, and Safety [1,2].

Incorporating the nuclear fuel cycle, encompassing the front and back end, aligns with the guidelines of Act No. 10 Year 1997 [9]. All of these components must adhere to the environmental dimension of sustainability as part of a broader commitment to global sustainability. This embodies a commitment to securing the well-being of future generations by ensuring that the development carried out by the current generation does not harm future generations to fulfill their needs with a sustainable, healthy environment [10]. Nuclear power plays a role in sustainable development by providing essential energy with relatively minimal impacts on air, water, land, and resources [11]. The evolution of nuclear technology should prioritize improvements in its environmental aspects while considering societal significance and the comparative environmental sustainability of alternative technologies.

The NES to be deployed in Indonesia is intended to support the national energy security. The advantages nuclear energy offers include a wide range of technology options, a higher level of safety, competitive power generation costs, and successful implementations of NPP in other countries. These advantages act as catalysts to accelerate the development of nuclear power plants (NPPs) in Indonesia [3].

The introduction of nuclear energy in Indonesia also aims to relieve the pressure caused by the rising domestic demand for oil and gas, allowing these resources to be utilized for export and other significant purposes. NPPs can stabilize the electricity supply, reduce dependence on oil and gas resources, and protect the environment from the harmful pollutants associated with fossil fuel usage.

NPPs' operation also impacts the environment, namely the release of stressors, which should be anticipated and estimated early at the design stage. The release of environmental stressors, including radionuclides, toxic substances, and heat, into the atmosphere and sea waters must be controlled and comply with national and international standards to obtain environmental acceptability.

To address the complex issues, concerns, and obstacles associated with nuclear power programs, including environmental impact, waste management, capital investment, political commitment, public acceptance, safety, and fuel cycle, Indonesia conducted a NESA using the INPRO Methodology.

There have been several studies in other countries regarding the environmental impact of stressors using the INPRO methodology. In a study by M. Kovačić et al. in 2017, the authors emphasize the importance of considering environmental factors in decision-making processes and the need for sustainable practices in the nuclear energy sector [4]. A study by A. Singh et al. 2012 assessed the potential environmental impacts and the effectiveness of mitigation measures [5]. J. Lee et al. 2019 highlight the effectiveness of the INPRO methodology in assessing and managing the environmental impact of NPPs, underlining the importance of sustainability principles, optimization techniques, and best practices in minimizing environmental footprint [6]. The study on environmental impact in Turkey also contributes to understanding environmental impact assessment in the nuclear energy field. It emphasizes the significance of sustainable practices in developing and operating NPPs in the country [7].

Bangka Island is one of the evaluated sites for NPPs in Indonesia, and two locations were selected, namely in West Bangka and South Bangka Regencies. This study aims to evaluate the extent of fulfillment of the INPRO Methodology's Basic Principles, User Requirements, and Criteria related to the environmental impact stressors. The ultimate goal is to ensure the sustainability of the planned NPP from the environmental impact viewpoint within the NES in Bangka Island.

METHODS

The comprehensive planning of Indonesia's NES encompasses a variety of elements, including NPP, the front end, and the back end of the fuel cycle, as depicted in Figure 1 [8]. Within this illustration, the considered NES comprises both large reactors (LRs) and small to medium-sized reactors (SMRs). Diverse options are evaluated for the front end of the fuel cycle, such as fuel import, domestic fuel fabrication using imported uranium ore, and partial domestic uranium ore supply for fabrication. Conversely, the back end of the fuel cycle considers two choices: returning spent fuel to the vendor country and conducting final disposal within Indonesia.

The INPRO Methodology provides the method to adhere to the environmental dimension of sustainability through its Basic Principle, that is, acceptability of adverse environmental effects. The acceptability principle of anticipated unfavorable environmental effects is central to the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). This principle underscores the importance of evaluating and ensuring that the potential environmental impacts resulting from an NES are at levels that are deemed acceptable from a broader sustainability perspective.

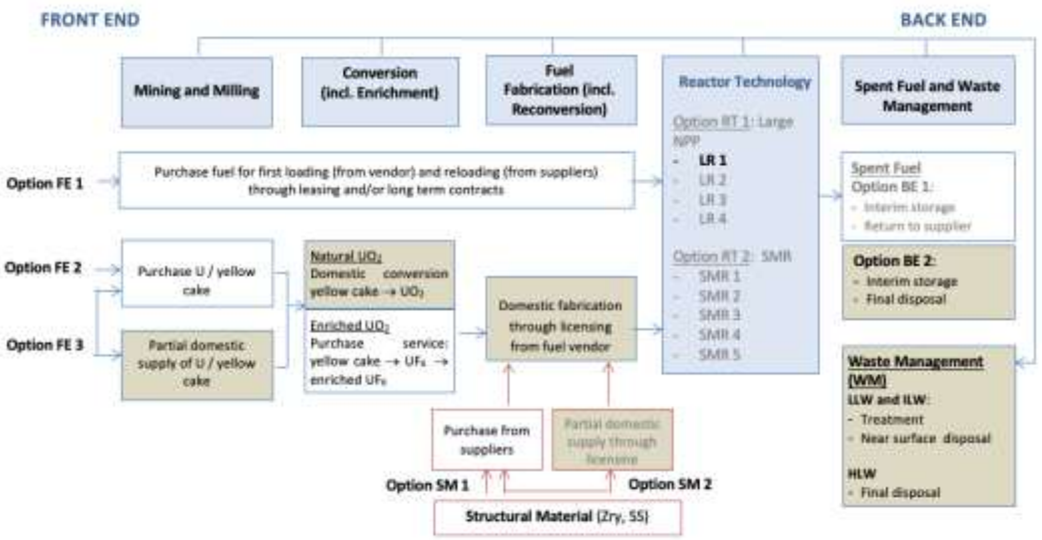

Figure 1. Indonesia Nuclear Energy System [8]

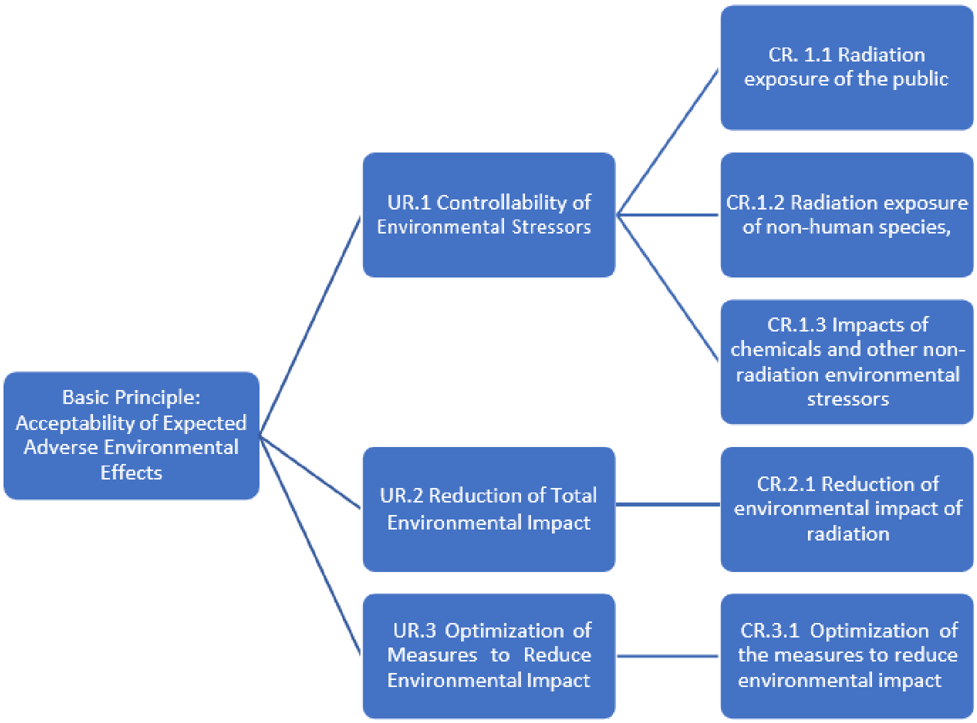

Figure 2. Hierarchical INPRO Methodology of Environmental Impact of Stressors [1]

Achieving this principle involves the consideration of 3 User Requirements (URs), each of which pertains to specific Criteria (CRs) of environmental stressors and their management, as shown in Figure 2.

The sustainability requirements in the INPRO methodology of the environmental impact of stressors necessitate the NES to meet the goals set out in the Basic Principles of long-term NES sustainability. With this methodology, the assessment will determine whether or not the Criteria and User requirements are met. Assessment with the INPRO methodology will identify criteria that are not met and corrective actions needed to meet them [12].

The following summarizes each User's Requirements and Criteria within the INPRO Methodology Basic Principle for the environmental impact of stressors [13].

User Requirement UR1: Controllability of Environmental Stressors

UR1 addresses the controllability of environmental stressors originating from the operation of nuclear energy systems. This requirement emphasizes the capability to manage and control these stressors to mitigate their impact on the environment. The assessment of UR1 involves evaluating 3 criteria.

Criterion CR1.1: Radiation Exposure of the Public

This criterion pertains to assessing potential radiation exposure to the public resulting from nuclear energy system operations. It involves analyzing radiation levels and their potential effects on human health and safety.

Criterion CR1.2: Radiation Exposure of Non-Human Species

This criterion evaluates the potential radiation exposure and impacts on non-human species within the environment. It considers the effects of radiation on ecosystems and biodiversity.

Criterion CR1.3: Impacts of Chemicals and Other Non-Radiation Environmental Stressors

In addition to radiation, this criterion encompasses the evaluation of the impacts of chemicals and other non-radiation stressors on the environment. It considers factors such as pollution, waste, and other forms of environmental disruption.

Overall Assessment of UR1: Controllability of Environmental Stressors

The overall assessment of UR1 involves the comprehensive evaluation of the controllability of environmental stressors, considering the criteria outlined above. It seeks to determine whether the stressors generated by nuclear energy systems can be effectively managed and controlled to prevent significant adverse environmental effects.

User Requirement UR2: Reduction of Total Environmental Impact of Emitted Radioactivity

UR2 focuses on reducing the environmental impact of emitted radioactivity resulting from nuclear energy system activities. This requirement aims to minimize the negative consequences of radioactive emissions on the environment.

Criterion CR2.1: Reduction of Environmental Impact of Radiation

Criterion CR2.1 involves evaluating strategies and measures to reduce the environmental impact of emitted radiation. This includes minimizing radiation exposure, preventing contamination, and enhancing overall radiation safety.

User Requirement UR3: Optimization of Measures to Reduce Environmental Impact

UR3 centers on optimizing the measures employed to reduce the environmental impact of nuclear energy system operations. It underscores the need to identify and implement the most effective strategies for mitigating environmental effects.

Criterion CR3.1: Optimization of Measures to Reduce Environmental Impact

Criterion CR3.1 pertains to evaluating and assessing the optimization measures that have been put in place to reduce the environmental impact of nuclear energy system activities. This criterion considers factors such as best practices, innovative techniques, and technological advancements that contribute to minimizing environmental effects.

Nuclear Power Plant for Case Study

For the assessment purpose, the environmental impact of the stressor was implemented in a Large Reactor (LR1). The basic design features of LR1 include (i) a PWR (Pressurized Water Reactor) type with a power output of 1,000 MWe, (ii) a Generation III+ reactor that incorporates passive safety systems, (iii) a gross power rating of approximately 3,400 MWt and a nominal electrical output of 1,115 MWe, and (iv) utilization of a two-loop reactor coolant system (RCS), where cooling water is circulated from the reactor pressure vessel to two steam generators via four pumps.

The nuclear regulatory body in the vendor country approved this reactor's final design in 2005. The reactor has also been certified to conform with the European Utility Requirement. Four LR1 units are currently operating and commissioning in 2018. The designer of LR1 claimed that it offers significant advantages over existing reactors in various aspects, including economics and safety [14]. Table 1 presents selected general design features of LR1.

Table 1. General Design Features of LR1 [14]

Parameter	LR1
Net electric output (MWe)	1115
Reactor thermal power (MWt)	3415
Plant design life (years)	60
Burnup (GWd/t)	60
Number of coolant loop	2 hot legs, 4 cold legs
Reactor outlet temperature (°C)	321.1
Reactor inlet temperature (°C)	280.7
Operating pressure, abs (MPa)	15.5
Number of fuel assembly	157
Type of fuel assembly	17X17
Mass of UO_2 in core (t)	84.5

Site

The site of the LR1 in the study is at Bangka Island site. Figure 3 shows the location of planned NPPs at Bangka Island site.

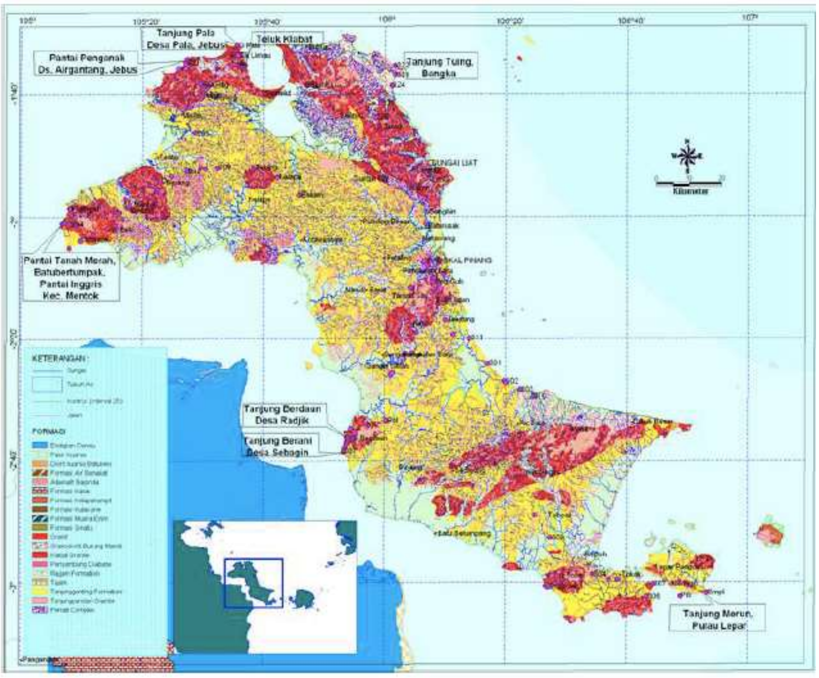

Figure 3. Location of NPP PWR 1000 MW at West Bangka and South Bangka [3]

RESULTS AND DISCUSSION

Controllability of environmental stressors

User requirement UR1 is aimed at gauging the manageability of the environmental stressor, i.e., evaluating stressors stemming from LR1 at the West Bangka site. The manageability of these stressors serves as the principal influence on the environment originating from LR1's operations in the West Bangka area. Consequently, effectively controlling these stressors becomes imperative to curtail their environmental impact. These stressors encompass radioactive gases and aerosols, the potential discharge of radioactive liquids into the marine ecosystem, the release of noxious chemicals into the marine surroundings, and the emission of heat and moisture from cooling towers.

Air Emission and Liquid Discharges from the Reactor during Normal Operation

The West Bangka site was selected as a representative location to assess environmental parameters for the planned NPPsLR1 [3]. The assessment follows guidelines outlined in the BAPETEN Chairman Decree No. 3 Year 2014, which governs environmental impact assessments in the nuclear energy sector [15].

Radioactive material released from the nuclear reactor originates from the core and impurity materials in the cooling system. The core inventory and impurity levels were estimated using the code program ORIGEN 2.1. During regular operation, the source term mainly comes from impurities on the assembly surface and coolant [16]. However, in the event of an accident, the level of radioactive release can be significantly higher. The melted core could lead to a leakage of a certain percentage of the core inventory to the primary coolant, containment, and ultimately to the atmosphere as air emissions. However, this incident falls outside the scope of this assessment, and instead, it pertains to the safety aspect of the INPRO Methodology. Tables 2 and 3 present the air and liquid discharge of gases and aerosols from the reactor LR1 during regular operation, along with their discharge limits set by the national regulatory body [14, 17].

Table 2. Air Emission and its Discharge Limit [14,17]

Radionuclide	Air emission (TBq/y)	Discharge limit (TBq/y)
Ba-139	1.66E-06	1.88E+04
Ba-140	1.61E-06	1.14E+02
Ce-141	1.52E-06	3.65E+02
Ce-143	1.49E-06	1.25E+03
Ce-144	1.42E-06	2.86E+01
Cs-134	2.61E-08	7.83E+00
Cs-137	8.27E-08	5.85E+00
Cs-138	1.72E-06	5.56E+03
I-131	2.70E-03	1.11E+00
I-132	4.00E-03	2.94E+03
I-133	6.11E-03	5.76E+01
I-134	6.78E-03	4.10E+03
I-135	5.69E-03	9.48E+02
Kr-85m	2.37E+03	7.85E+06
Kr-87	4.74E+03	1.75E+06
Kr-88	6.67E+03	7.22E+05
La-140	1.65E-06	6.57E+02
La-141	1.52E-06	6.98E+03
La-142	1.51E-06	3.65E+03

Radionuclide	Air emission (TBq/y)	Discharge limit (TBq/y)
Nd-147	5.89E-07	2.25E+02
Pr-143	1.49E-06	4.10E+02
Rb-88	8.43E-07	1.86E+04
Rb-89	1.10E-06	7.67E+03
Rh-105	1.81E-07	5.17E+02
Ru-103	4.11E-07	3.96E+02
Ru-105	2.00E-07	5.04E+03
Ru-106	7.46E-08	3.24E+01
Sb-129	8.32E-08	3.13E+03
Sr-89	1.10E-06	6.20E+01
Sr-90	7.55E-08	2.80E+00
Sr-91	1.37E-06	2.45E+03
Sr-92	1.42E-06	3.30E+03
Te-129	8.21E-08	2.86E+04
Te-129m	1.25E-08	2.80E+01
Te-131	2.81E-07	2.01E+04
Te-132	4.64E-07	1.74E+02
Xe-133	1.43E+04	3.86E+07
Xe-135	2.97E+03	5.09E+06
Xe-135m	2.59E+03	3.90E+06
Xe-137	1.26E+04	1.49E+07
Xe-138	1.26E+04	1.57E+06
Y-90	7.89E-08	4.78E+02
Y-91	1.59E-06	8.34E+01
Y-91m	7.96E-07	2.17E+04
Y-92	1.43E-06	5.01E+03
Y-93	1.57E-06	2.00E+03

Table 3. Liquid Discharge and its Discharge Limit [15]

Radionuclide	Liquid discharge (TBq/y)	Discharge limit (TBq/y)
Na- 24	6.03E-05	1.37E-01
Cr- 51	6.85E-05	1.31E+01
Mn -54	4.81E-05	3.47E-01
Fe- 55	3.70E-05	1.02E+01
Co- 58	1.24E-04	2.21E-01
Tc- 99m	2.04E-05	4.07E+02

Ru-103	1.82E-04	9.18E+01
Ru 106	2.72E-03	1.16E+02
Ag-110m	3.89E-05	3.28E+00
I-131	5.23E-04	3.83E+01
I-132	6.07E-05	9.74E+01
I-133	2.48E-04	5.04E+01
Cs-134	3.67E-04	1.00E+01
I-135	1.84E-04	6.17E+01
Cs-136	2.33E-05	2.15E-01
Cs-137	4.93E-04	4.25E-01
Ce-144	1.17E-04	2.13E-02

The analysis identifies significant radionuclide stressors for environmental radiological exposure from the LR1 during normal operation, including I-132, I-134, Kr-85m, Kr-87, Kr-88, Xe-138, Xe-133, Xe-135, Xe-135m, Xe-137, and Xe-138, Cs-138, and I-131 for air emissions, and Ce-144, Cs-137, Co-58, Na-24, Mn-54, Cs-136, and Cs-134 for liquid discharge.

Comparing the discharge levels with the limits provided by the regulatory body, liquid discharge from the LR1 is below the limit. Therefore, radionuclide stressor of liquid discharge of the LR1 meets the INPRO Methodology sustainability criteria. In the case of six reactors at the West Bangka Island site, the amount liquid discharge remains below the limit.

Radionuclide Concentrations in the Environment

The concentration of radionuclides in the air and water at the specific site is estimated using the PC-CREAM 08 code based on Gauss Atmospheric Dispersion Model, using the simple formula of Gaussian.

The radionuclide concentrations in the air are compared to the national acceptance limits [18]. The result indicated a release to atmosphere as shown in Table 4. The results for aquatic releases are presented in Table 5. The evaluation parameter for radionuclide concentrations in the atmosphere and marine environment meets the acceptance limits.

Table 4. Radionuclide Concentration in Air

Radionuclide	Air Concentration (Bq/m^3)	Limit (Bq/m^3)[18]
Ce-144	6.46E-08	2.20E+02
Cs-134	1.51E-09	2.00E+01
Cs-137	3.59E-09	1.30E+01
I-131	1.42E-04	5.30E+02
I-132	2.09E-04	6.70E+04
I-133	3.08E-04	1.70E+04
I-134	3.37E-04	1.10E+05
I-135	2.86E-04	3.70E+04

Radionuclide	Air Concentration (Bq/m^3)	Limit (Bq/m^3)[18]
Kr-85m	1.05E+00	NA
Kr-87	2.06E+00	NA
Kr-88	2.89E+00	NA
Mo-99	7.98E-08	2.20E+04
Rh-105	1.20E-08	1.20E+05
Ru-103	2.42E-08	1.00E+03
Ru-106	5.11E-09	1.10E+02
Sr-89	5.67E-08	1.10E+03
Sr-90	3.07E-09	3.90E+01
Tc-99m	6.98E-08	5.90E+05
Te-129m	7.38E-10	1.00E+03
Te-132	2.41E-08	2.30E+03
Xe-133	7.16E+00	NA
Xe-135	1.04E+00	NA
Xe-135m	1.66E+00	NA
Xe-138	6.11E+00	NA
Y-90	3.29E-09	3.20E+04
Y-91	7.34E-08	1.10E+03

Table 5 Liquid Concentration

Radionuclide	Liquid Concentration [14] (Bq/m3)	Limit [18] (Bq/m3)
Ag-110m	2.21E-02	7.30E+04
Ce-144	2.75E+00	2.20E+04
Co-58	7.71E-02	2.20E+04
Cr-51	4.40E-02	8.00E+05
Cs-134	4.40E-02	1.70E+02
Cs-136	1.44E-01	7.00E+02
Cs-137	2.86E+00	2.50E+02
Fe-55	2.21E-02	1.20E+05
I-131	3.63E-01	6.40E+03
I-132	1.10E-01	5.30E+05
I-133	5.73E-01	2.70E+04
I-135	5.95E-01	1.30E+05
Mn-54	2.21E-02	3.10E+04
Mo-99	3.31E-02	5.20E+05

Radionuclide	Liquid Concentration (14) (Bq/m3)	Limit (18) (Bq/m3)
Na-24	1.00E+03	7.00E+05
Ru-103	1.21E-01	3.70E+05
Ru-106	1.65E+00	4.30E+04
Tc-99m	3.31E-02	1.50E+07

Radiological Impact to Human and Non-human

In Table 6, the doses received by a representative person in the population and by workers are presented. The national limits for radiation exposure are obtained from BAPETEN Chairman No. 4 Year 2013, which governs radiation protection and safety in nuclear utilization [20].

The dose to the population is determined based on the critical group identified in reference [14, 21]. On the other hand, the dose to workers is calculated considering occupational radiation exposure during routine inspections and maintenance activities, specifically sludge lancing of steam generators. It should be noted that this represents the highest dose received by workers among the six working categories mentioned in Ref [22].

An evaluation of the potential impact of radioactive discharges from the LR1 on non-human species can be depicted from the Westinghouse UKP-GL-033 [21]. The ERICA tool is used to calculate predicted radioactive gaseous and liquid discharges from the LR1. The resulting potential doses to reference non-human biota are presented in Table 7. The reference biota selected are those available in Indonesia [23]. The annual dose limits for non-human biota are 100 mGy/a and 1 Gy/a for terrestrial and aquatic biota [24], respectively, based on international consensus, which are higher than the assessment results.

Thus, from these tables, the acceptance limits of evaluation parameter on effective annual exposure doses of critical group in the population and in the workers and dose stress on the biota are met.

Table 6. Annual Dose to Human

Dose to	Dose (mSv/a)	National Limits (mSv/a) [20]
Population	0.010	1
Workers	1.02	20

Table 7 Annual Dose to Non-Human

Doses to reference biota species	mGy/a
Bird egg (duck egg)	< 8.76E+01
Bird (duck)	< 8.76E+01
Detritivorous invertebrate	< 8.76E+01
Mammal (deer)	< 8.76E+01
Mammal (rat)	< 8.76E+01

Doses to reference biota species	mGy/a
Reptile	< 8.76E+01
Soil invertebrate (earthworm)	< 8.76E+01
Tree (pine tree)	< 8.76E+01
Shrub	< 8.76E+01
Grasses and herbs (wild grass)	< 8.76E+01
Amphibian (frog)	< 8.76E+01
Flying insect (bee)	< 8.76E+01
Gastropod	< 8.76E+01
(Wading) bird (duck)	2.42E+01
Reptile	3.07E+01
Benthic fish (flat fish)	1.23E+02
Macro algae (brown seaweed)	1.17E+02
Phytoplankton	2.80E-01
Polychaete worm	2.20E+02
Sea anemones/true corals	1.15E+02
Vascular plant	1.07E+02
Bivalve mollusk	1.08E+02
Zooplankton	7.96E-01
Crustacean (crab)	1.10E+01
Mammal	9.64E+01
Pelagic fish	3.39E-01

Toxic Chemicals

Table 8 provides a comparison of the release of toxic chemicals from the LR1 coolant system into the marine environment with the national limits. The table demonstrates that the releases of Hg, Cd, As, Pb, Cr, Zn, Cu, and Fe are all below the threshold limits set by Indonesia. However, it should be noted that there are no national limits established for ammonium hydroxide, ammonium chloride, sodium hypochlorite, hydrazine, and monoethanolamide. Thus, from Table 8, the acceptance limits of evaluation parameter on liquid toxic chemicals discharges to the marine are met

Table 8 Comparison Toxic Chemical of LR1 and National Limit of Indonesia

Stressors	System	Liquid Effluent Stream	Annual average discharge concentration (at controlled waters) (µg/l) [27]	National Limits [25, 26]
1. Ammonium hydroxide	CDS	Condensor Water Box Drain	≤11 µg/l ammonium concentrations reported as nitrogen	-

Stressors	System	Liquid Effluent Stream	Annual average discharge concentration (at controlled waters) (μg/l) [27]	National Limits [25, 26]
	Multiple	Turbine Island Waste Water		
	BDS	Steam Generator Blow Down		
2. Ammonium chloride	SWS	Service Water System Cooling Water		
3. Sodium hypochlorite	CWS	Circulating Water System Cooling Water	≤ 200 μg/l hypochlorite is dosed into seawater only when seawater temperature >10 □C, assumed to be 6 months of the year	-
	SWS	Service Water System Cooling Water		
4. Hydrazine	BDS	Steam Generator Blowdown	0.3 μg/l	-
	CDS	Condenser Blowdown		
5. Monoethanolamine	BDS	Steam Generator Blowdown	0.09 μg/l	-
	CDS	Condenser Blowdown		
6. Boric acid	WLS	Borated ReactorCoolant	≤1 μg/l concentrations reported as total dissolved boron	B : 10 μg/l
7. Zinc acetate	WLS	Borated ReactorCoolant	<3.410^{-05} μg/l of zinc is removed by WLS ion exchange resins. Concentration is reported as total zinc.	Zn: 50 μg/l
8. Trace metal impurities	All	All	0.0027 μg/l Calculation based on 1ppm metal contamination present in all chemicals	
Hg				1 μg/l
Cd				10 μg/l
As				50 μg/l

Stressors	System	Liquid Effluent Stream	Annual average discharge concentration (at controlled waters) (µg/l) [27]	National Limits [25, 26]
Pb				30 µg/l
Cr				50 µg/l
Zn				50 µg/l
Cu				20 µg/l
Ni				-
Fe				30 µg/l

Release of Heat by Cooling Towers

If a mixing zone is to be established, it must provide evidence of not having any negative impact on site integrity. However, according to guidelines from the Environment Agency, a mean temperature change exceeding 0.2 ºC in the water at the site would be considered a 'likely significant effect' [27].

Marine water quality standards in Indonesia are governed by the Ministry of Environment Decree No. 51 of 2004 [27].

In tropical marine environments, coastal organisms often experience high temperatures that approach their upper thermal tolerance limits. According to data compiled by the US EPA [28], many species in the tropics have a tolerance range of approximately 5 °C between their optimal and exclusion temperatures, with sublethal thermal stress observed around 2 °C above the optimum level.

The heat released from the LR1 can reach temperatures of 19-25 ºC, which comply with the heat dissipation requirements in the UK (a subtropical country). In Indonesia, a tropical country, the Ministry of the Environment Regulation No. 8 of 2009 on Effluent Standards for Thermal Power Generation allows for the release of heat into waters up to 30ºC [29]. Therefore, the release of heat from the LR1 in Indonesian marine environments is considered acceptable.

Reduction of Environmental Impact

User Requirement UR2 in the INPRO Methodology is aimed to ensure the reduction of the total environmental impact of emitted radioactivity from a NES by comparing with existing standards. This will minimize risks to the environment and public health, so that environmental sustainability can be attained.

The specific criteria are to evaluate the reduction of environmental impacts associated with radiation. It involves evaluating the design features, operational practices, and mitigation strategies implemented in the NES to reduce the release and dispersion of radioactive materials. In the case of the LR1 Nuclear Power Plant (NPP), the reactor coolant remains confined within the containment structure, with only the decay heat energy being transported outside of it. As a result, the sole remaining possibilities for containment bypass and reactor coolant release are two highly improbable events: a leak occurring within the containment itself and an unlikely occurrence of a steam generator tube leak [30].

The assessment involves comparing the estimated or measured values of radiation related parameters, such as radiation dose rates, contamination levels, and radioactivity concentrations, with established regulatory limits or reference values. It aims to determine whether the NES effectively reduces the environmental impact of emitted radioactivity.

The assessment may consider various aspects, including the selection and implementation of advanced reactor designs, containment systems, waste management strategies, and decommissioning plans.

The assessment of UR2 supports the evaluation of the NES's environmental performance and its alignment with international standards and best practices for radiation protection.

Optimization of Measures to Reduce Environmental Impact

User Requirement UR3 in the INPRO Methodology is aimed at the optimization of measures to reduce the environmental impact associated with a nuclear NES. It involves a combination of technological advancements, efficient operations, rigorous safety measures, and proactive environmental management practices. A balance between meeting energy needs and minimizing the impact on the environment and surrounding ecosystems, is expected to be achieved. Detail monitoring equipment installed within the reactor building is in place as described in the UK AP1000 Environment Report [30]

The assessment process involves examining the design documentation, operational plans, and management strategies to identify the optimization measures implemented. It focuses on areas such as waste management, energy efficiency, water use, air emissions control, and land use optimization.

The assessment may consider factors such as the selection of advanced reactor designs with inherent safety features, efficient cooling systems, waste minimization strategies, and sustainable fuel cycle options.

By optimizing the measures to reduce environmental impact, the NES contributes to the overall goal of sustainable development, ensuring the responsible and efficient use of nuclear energy resources while minimizing the ecological footprint and potential environmental risks associated with its implementation.

Gap and Follow-up Action

In this assessment, the findings indicate that themajority of environmental stressors meet the Controllability, Reduction, and Optimization criteria for reducing environmental impact. However, this does not imply that the facility is entirely free from potential stressors or risks. It highlights the importance of conducting follow-up actions to gain a deeper understanding of significant risks, particularly when there are changes in reactor technology, regulatory compliance, site-specific characteristics, and other relevant factors. The result of the evaluation is as follow.

Table 9. The result of the evaluation

BASIC PRINCIPLE	UR	CR	RESULT
Acceptability of Expected Adverse Environmental Effect	UR.1 Controllability of Environmental Stressor	CR 1.1 Radiation exposure of the public	CR is met
		CR.1.2 Radiation Exposure of non-human species	CR is met
		CR.1.3 Impact of chemical and other non-radiation environmental stressor	CR is met
	UR 2 Reduction of Total Environmental Impact	CR.2.1 Reduction of environmental impact of radiation	CR is met
	UR 3	CR.3.1 Optimization of the	CR is met

	Optimization of Measures to Reduce Environmental Impact	measures to reduce environmental impact	

CONCLUSION

A study on the environmental impact of introducing NPP into the Bangka Island Site using INPRO Methodology has shown that introducing significant reactor LR1 technology is acceptable from the environmental stressors impact point of view. All three requirements and five criteria indicate that the stressors are within the discharge limit. The goal of UR2 is to significantly reduce the environmental impact of emitted radioactivity compared to existing NES designs. The assessment of UR2 supports the evaluation of the environmental performance and ensures alignment with international standards and best practices for radiation protection. User Requirement UR3 in the INPRO methodology focuses on optimizing measures to reduce the environmental impact of a nuclear energy system (NES). Key considerations include waste management, energy efficiency, water use, air emissions control, and land use optimization. The NES aims to achieve sustainability, resource efficiency, and environmental compatibility by optimizing these measures. This supports the NES's commitment to environmental stewardship and ensures it goes beyond regulatory compliance. Ultimately, the goal is to achieve responsible and efficient use of nuclear energy resources while minimizing ecological footprint and potential environmental risks.

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