Independence of Multi Module Small

Modular Reactor as Acceptance Criteria

in Determining Adequate Emergency

Planning Zone in Indonesia

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***Abstract.***

*In recent developments, nuclear reactor design has adopted a multi-module design for small modular reactors (SMRs), which consist of several uniform reactor modules placed adjacent to each other inside a reactor building. Determining the Emergency Planning Zone (EPZ) for multi-module SMRs poses some challenges, as there is a risk of all reactor modules failing simultaneously. Several considerations should be applied, such as shared systems, propagation risk between modules, simultaneous hazards on several modules, and collocation within the same sites. These considerations imply that the independence between modules in multi-module design affects EPZ determination. This study aims to formulate adequate acceptance criteria for evaluating multi-module SMR EPZ by defining module independence. The study then attempts to review and compare the acceptance criteria regarding independence stated in existing safety provisions in Indonesia with IAEA standards, and also utilizes regulatory practices implemented by regulatory bodies in other countries. From the review, it was discovered that independence could be defined when there is no interconnection between individual modules in the form of shared safety significant SSC, shared power generation systems, and located within a considerable seismic separation. Furthermore, in evaluating multi-module SMR EPZ, independence between any individual modules can be adopted as the acceptance criteria for EPZ determination.*

# BACKGROUND AND OBJECTIVES

Indonesia has attracted many SMR vendors and designers. Vendors such as Thorcon Power, Seaborg Technologies, NuScale Power, and Copenhagen Atomics have already requested an audience with the Indonesian Nuclear Energy Regulatory Agency (BAPETEN) regarding the design safety, security, and safeguards. Although these vendors have different kinds of SMR technology, the designs share some similarities in using multiple reactor modules.

SMRs with a multiple-module design, or multi-module SMRs, are defined differently from multi-unit NPPs according to the SMR Regulators’ Forum Design and Safety Analysis Working Group Report on Multi-unit and Multi-Module Aspects Specific to SMRs. In this report, a multi-module is defined as a unit of reactor that includes more than one nuclear reactor and allows several modules to be in close proximity to the same infrastructure. These modules could be deployed with shared structures, systems, and components (SSCs) and operate independently from each other. These modules could also be identical to each other.

The SMR Regulators’ Forum report also specifies several safety aspects relevant to multi-module SMRs. These aspects consist of defense in depth, internal and external hazards, selecting initiating events, shared SSCs, risk assessment, human factors, and emergency preparedness [1]. From these aspects, emergency preparedness and response are then studied and reviewed by BAPETEN. Multi-module SMRs in this case could affect the Emergency Planning Zone (EPZ) by the number of reactor modules designed to be built on the site. Even though multi-module SMR design proposes more safety features with a smaller EPZ size, the determination of EPZ size should be reviewed so that the agreed-upon EPZ is more assuring for both the regulatory body and the designer.

Multi-module SMR design consists of several small reactor modules located in close proximity within the same infrastructure. Determining the EPZ for multi-module SMRs poses some challenges where multi-module SMRs have a risk in which all reactor modules fail simultaneously. In this case, the design should present a sensible safety analysis for its accident scenario and postulated radioactive release. For determining the EPZ, several considerations should be applied, such as shared systems, propagation risk between modules, simultaneous hazards on several modules, and collocation within the same sites [2]. These considerations imply that independence between modules in multi-module design affects EPZ determination. Hence, independence should be defined for multi-module SMRs in regulating their EPZ determination.

This study aims to formulate adequate acceptance criteria for evaluating multi-module SMR EPZ by defining module independence. This study then tries to review and compare the acceptance criteria regarding independence stated in existing safety provisions in Indonesia with IAEA standards and also utilizes regulatory practices implemented by regulatory bodies in other countries. The review and comparison conducted in this paper consist of determining the proper limitation on multi-module SMR independence and determining adequate EPZ acceptance criteria for independent multi-module SMRs and non-independent multi-module SMRs.

# METHODOLOGY

This study was carried out using descriptive-qualitative and comparative-analytic methods. The descriptive-qualitative method is used in conducting discussions and studies carried out on main references. The comparative-analytic method is used in evaluating the gaps in Indonesian Regulation in Determining EPZ for Nuclear Power Reactors based on Indonesian Regulation Analysis and Evaluation Guidelines using the Effectivity Assessment on Implementing Regulations, specifically relevance aspects. The relevance aspect analyzed in this study pertains to the relevance of Indonesian Regulation towards multi-module SMR technological advancement. The evaluation results are then analyzed further to formulate solutions and recommendations for enrichment or preparation of applicable laws and national standards [3].

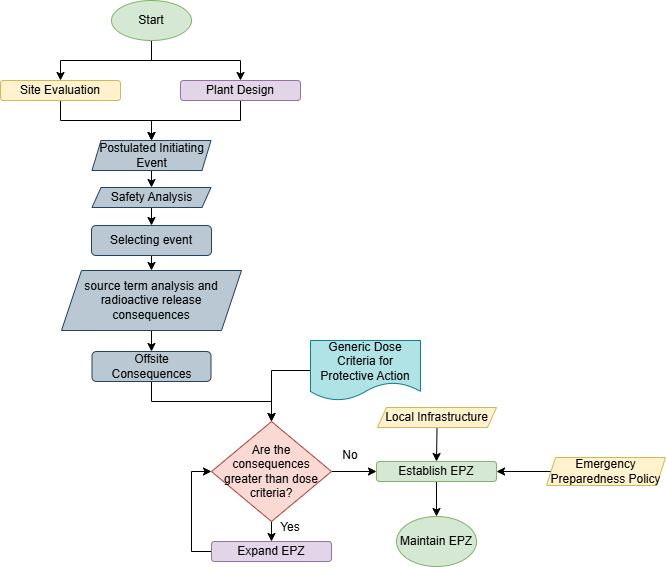
Literature review was carried out for the main references, which consist of Indonesian nuclear regulation, IAEA safety standards, and foreign nuclear regulation and regulatory guides. This paper referred to the United States Nuclear Regulatory Commission (US-NRC) and the Canadian Nuclear Safety Commission (CNSC) regulations in order to benchmark the existing regulation in Indonesia with regulatory bodies that already have some experience in handling multi-module SMR design certification with different approaches.

This review was then used to describe and summarize the main concerns and important points in defining independence in determining the EPZ for multi-module SMRs. The main concern, which will be described and summarized, focuses on how independence of the modules in multi-module design affects the source term determination and EPZ acceptance criteria for determining adequate EPZ. These two concerns were selected because technological advancements applied in SMRs claim the possibility of decreasing EPZ by reducing the source term and using an advanced probabilistic approach in determining EPZ.

# LITERATURE REVIEW

## General Concept of Emergency Planning Zone Determination

Appendix I in the IAEA EPR-NPP Public Protective Actions 2013, titled 'Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor,' presents the methodology suggested for determining the EPZ. This methodology is based on the conservative severe accident scenario used in large LWRs and utilizes a deterministic approach in calculating and analyzing the EPZ. The result of this methodology is the suggested emergency zone planning zone. Fig. 1 reflects the methodology outlined in this document. [4].



*FIG. 1. Workflow of determining EPZ in NPP [4]*

Fig. 1 depicts the EPZ determination process, which involves gathering various data and information beforehand. The colors in the diagram represent different sources from which the data and information can be obtained. Yellow indicates site-specific data, blue signifies design-specific data for the reactor design, and gray indicates data obtained through analysis and evaluation by combining specific site data and reactor design-specific data. Turquoise represents existing regulations regarding general dose criteria. The results of the analysis are reflected in purple and green.

Determining the EPZ requires comprehensive data and information regarding the site characteristics of the plant and detailed information regarding plant design. Plant design is necessary to estimate the risk level that could occur in an accident scenario, leading to radioactive release. In this case, accident scenarios and radioactive releases can be analyzed and postulated using safety analysis to determine the source term in the form of magnitude and the composition of radionuclides released from the reactor. The source term heavily depends on the plant design, which can vary between different designs, safety features, and layouts.

The source term is then used to calculate the offsite consequences using meteorological data from site characteristics to evaluate how far the radioactive release would spread offsite from the plant. If the radioactive release from the source term could spread offsite from the plant, the effective dose received within the radioactive release distance and the frequency of the occurrences of the released scenario are then calculated and evaluated to determine the EPZ for the plant. [5].

## Indonesian Nuclear Regulation

In preparing nuclear installation sites, the Indonesia Nuclear Energy Regulatory Agency (BAPETEN) regulates the determination of emergency planning zones in two BAPETEN Chairman Regulations (BCR). These regulations are BAPETEN Chairman Regulation No. 1 of 2010 on Nuclear Emergency Preparedness and Response Programme and BAPETEN Chairman Regulation No. 4 of 2019 on Nuclear Installation Site Evaluation on Airborne and Waterborne Radioactive Material Dispersion Aspects.

Determining EPZ according to Indonesian regulation consists of four steps based on BCR No. 4 of 2019. These steps include collecting data and information for modeling radioactive material dispersion, evaluating radiological consequences for residents, and determining an emergency preparedness program. BCR No. 4 of 2019 regulates the determination of the source term in collecting data and information for modeling the dispersion of radioactive material.

Both of these regulations apply to EPZ determination for all types of reactors without any exemption for recent technological advancements. Acceptance criteria for EPZ in BCR No. 1 of 2010 are determined with respect to reactor thermal power and radioactive release modeling in BCR No. 4 of 2019. However, there are still some issues regarding these main concerns for SMR designs that employ multiple module reactors.

In this regard, multi-module SMRs are likely to face regulatory disputes in determining the EPZ. The EPZ acceptance criteria are categorized by reactor thermal power. This acceptance criteria could face issues when applied to evaluating a multi-module SMR EPZ with a total power output in the range of 100–1000 MWth, which consists of several reactor modules with thermal power less than 100 MWth. Additional provisions to clarify this issue should then be proposed.

## IAEA Safety Standards

IAEA published General Safety Requirement Part 7 on Preparedness and Response for a Nuclear or Radiological Emergency as a requirement for formulating the Nuclear Emergency Preparedness Programme in nuclear facilities and radioactive material utilization facilities. This safety requirement emphasizes the importance of performing hazard assessments of nuclear facilities, which are necessary to provide a graded approach basis for preparing the emergency preparedness and response programme [6]. However, this requirement does not provide detailed provisions for performing hazard assessments. In response, IAEA published the EPR-NPP Public Protective Actions 2013, titled 'Actions to Protect the Public in an Emergency due to Severe Conditions at a Light Water Reactor.' IAEA has yet to publish other safety standards or related documents that provide safety provisions for determining multi-module SMR EPZ.

In light of this, IAEA formed the IAEA SMR Regulators’ Forum to assess and formulate appropriate provisions. The forum finds that the existing IAEA safety standards and related documents are sufficient to determine the EPZ of SMRs. EPZ determination for multi-module SMR design is one of the concerns discussed in the SMR Regulators’ Forum Report. The size of the EPZ for multi-module design may be impacted by the number that will be built at the site [7]. A large-scale offsite radioactive release for multi-module SMRs could be less possible if the design allows for independent operation of each individual module.

IAEA also published the IAEA TECDOC 1652, titled 'Small Reactors without On-site Refuelling: Neutronic Characteristics, Emergency Planning and Development Scenarios,' to propose a risk-informed, performance-based methodology for determining EPZ. In this methodology, the first proposed approach is to estimate the EPZ for each reactor individually based on safety performance, considering applied safety innovations and technological advancements. The second proposed approach is to estimate the frequency of exceeding the generic dose criteria for all accident scenarios. Using this methodology can enable a risk-informed, performance-based licensing approach for SMRs. Additionally, this methodology can redefine the EPZ radius without compromising the level of risk. [8].

## Determining EPZ in United States

In determining the EPZ, the United States stipulates provisions within the source term regulation framework. Source term, as defined in 10 CFR 50.2, refers to 'the magnitude and mix of the radionuclides released from the fuel, expressed as fractions of the fission product inventory in the fuel, as well as their physical and chemical form, and the timing of their release.' The source term is then specified into an accident source term for analyzing large radioactive releases, taking into account the safety and containment performance of the design.

For multi-module SMR designs, the United States already regulates the EPZ within 10 CFR 52.47. This regulation mandates that every difference and configuration in operating the modules must be accounted for in the safety analysis to ensure the safe operation of any module. Furthermore, 10 CFR 100.11 stipulates requirements regarding the consideration of independence between all operating modules. For independent modules, the EPZ must be fulfilled with respect to each reactor individually. This results in EPZs that overlay the EPZ area calculated for each module. If the modules are interconnected, the EPZ calculation shall be based upon the assumption that all reactor modules release postulated fission products simultaneously. This requirement provides sufficient clarity to be adapted as a requirement for multi-module SMR EPZ. However, to adopt this requirement, BAPETEN still needs to determine the boundaries for independence and interconnection between all reactor modules.

## Determining EPZ in Canada

In Canada, the Canadian Nuclear Safety Commission (CNSC) regulates the determination of EPZ using a risk-informed approach. The CNSC sets requirements and provides guidance on how to meet them, and the applicant or licensee may present a case to demonstrate that the intent of a requirement is addressed by other means. Such a case must be supported with suitable evidence. This regulation provides flexibility for every reactor type and design to demonstrate their determined EPZ, including multi-module designs. Additionally, Canada does not have any regulations regarding a minimum EPZ size. The EPZ is treated as a result of safety analyses in combination with the protection strategy used by offsite stakeholders [9].

In Canada, sizing of the EPZ falls under province’s authority in collaboration with multiple supporting organization. Province authority then assessed the safety analyses, dose assessment, and other external factor such as demography and geography.

# FINDINGS AND DISCUSSION

For multi-module SMR designs, independence is a key feature to ensure that the risk posed by the design can be isolated within one module, simplifying risk mitigation efforts. Although there is still a possibility of accidents occurring in multiple or all modules for independent designs, the probability of such events is low and may even be negligible [10]. Despite the importance of module independence in determining EPZ for multi-module SMR designs, there has been a lack of studies or papers discussing module independence in this context.

Indonesia's regulations already use reactor thermal power as a means to scale EPZ according to BCR No. 1 of 2010. However, independence of the modules should be defined and explained concisely to ensure proper determination of EPZ for multi-module SMRs. This means that EPZ criteria for multi-module SMRs could be categorized based on the total power output spectrum with larger EPZ size, or categorized based on the individual power output spectrum with a lower EPZ. BAPETEN, as Indonesia's regulatory body, should define the level of independence of individual modules in multi-module SMR designs to categorize them within the individual power output spectrum.

Reactor modules in multi-module designs can be arranged as either modules that operate integrally with shared SSCs and interconnected systems to maximize economic viability, or as independent individual modules that operate using each module's own SSCs. Independence between individual reactor modules is a key difference that can affect consequences when an initiating event occurs. Although probabilistic safety assessment for multi-unit reactors could be used to approach risk quantification for multi-module designs regardless of their arrangement, this method is still in development. Therefore, independence of multi-module reactors could be an additional consideration for determining the EPZ. Independence could be the parameter that distinguishes which design arrangement EPZ should be classified using total power output or using the overlaid EPZ of each individual module's thermal power output [9].

Several recommendations exist to define parameters regarding independence for multi-module reactors. According to US-NRC, safety-significant SSCs should not be shared between individual reactor modules for the design to be considered independent. If SSCs are shared between individual reactor modules, the design must demonstrate that the shared SSCs will not degrade the safety function of the design. For multi-module SMR designs, at least two shared SSCs should be considered: sharing of the balance of plant system and sharing of the reactor building system [11].

One example of limiting the sharing of power generation systems among individual modules is to avoid accumulating the total thermal power output in only one system. This configuration could pose additional risks in terms of complexity, interdependency, common cause failure, loss of redundancy, and synchronization to reach balanced load. Thus, if the design employs sharing of the balance of plant, then the source term and EPZ acceptance criteria should be classified using total power output [12].

Multi-module designs also allow reactors to be located in close proximity to each other within reactor buildings. To demonstrate independence for each individual reactor, the design must show that each reactor, along with its safety systems, is located within a considerable seismic separation. This ensures that the close proximity of each individual reactor will not compromise the safety of other reactors in the event of a seismic event [13].

# CONCLUSION

When evaluating multi-module SMR EPZ, independence between individual modules can be adopted as the acceptance criteria for EPZ determination. This consideration is crucial to ensure that the release of radioactive material from one module in any accident scenario does not affect other modules. It also implies that any interconnection, including shared safety-significant SSCs and unconsidered close proximity of components between modules, could compromise the independence of the multi-module SMR source term and acceptance criteria. Interconnections may lead to the source term determination considering the design as one large reactor system.

BAPETEN, with its existing power classification for EPZ acceptance criteria, could apply independence consideration in EPZ acceptance criteria for multi-module SMR EPZ. By applying this independence consideration, the EPZ radius of independent multi-module SMRs would differ from the EPZ radius of interconnected multi-module SMRs. In an independent SMR design, the EPZ could be accepted as the overlay radius of each individual EPZ. Conversely, the EPZ for interconnected designs should be accepted as one large reactor unit. This approach ensures that the EPZ acceptance criteria still credit the technological advancement without compromising the risk level of the design..

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