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SMR-Specific Approach to Radioactive Gaseous Effluent Evaluation

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1. Introduction

For reactor licensing approval, it is critical to evaluate whether the released liquid and gaseous radioactive waste comply with regulatory standards and are released below the permissible concentration levels. To do this, the PWR-GALE code, which applies the NUREG-0017 methodology developed by the U.S. Nuclear Regulatory Commission (USNRC), has been commonly used to assess the radioactive concentrations of liquid and gaseous effluents in Pressurized Water Reactors (PWRs).

However, recently developed Small Modular Reactors(SMRs) include various reactor types other than PWRs, resulting in differences in design requirements and operational characteristics compared to existing PWR designs. Consequently, the existing PWR-GALE code fails to fully account for SMR-specific design considerations, necessitating the development of a new radioactive effluent assessment methodology.

This study aims to develop an evaluation method for gaseous radioactive effluents that reflects the characteristics of SMRs by analyzing and comparing the design requirements of various types of SMRs.

2. Methods and Results

The PWR-GALE code is specifically designed to evaluate both liquid and gaseous radioactive effluents, with separate algorithms for each [1]. First to develop a methodology for evaluating gaseous radioactive effluents in SMRs, we analyzed the structure of the gaseous effluent evaluation algorithm in PWR-GALE. This algorithm structure is shown in Figure 1, which represents the steps and flow of the gaseous radioactive effluent evaluation process.

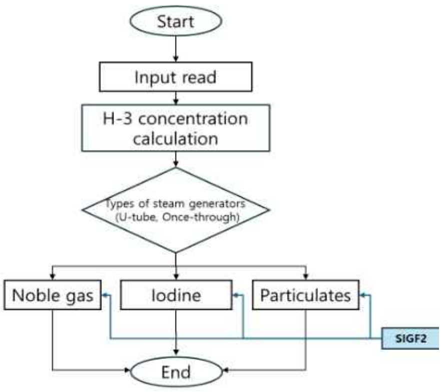

Fig. 1. Structure of the gaseous source code of GALE

In line with the characteristics of Integral Pressurized Water Reactors(iPWRs), several modifications to the PWR-GALE code were suggested by PNNL to improve the assessment of effluents in iPWRs [2]. These modifications, detailed in Table I, address changes in the release rates of neutron activation products, specifically Ar-41, C-14, and H-3. They are based on iPWR-specific operating conditions, such as boron-free operation and the presence of neutron activation products, which reflect the unique design characteristics of iPWRs.

Table I: Changes in Built-in parameters related to the effluent evaluation of iPWR

Parameter	Original Value	Updated Value	Change Description
Capacity Factor	80%	90%	Increased
Tritium Release Rate	0.4 Ci/yr/MWth	0.27 Ci/yr/MWth	Decreased
Ar-41 Release Rate	34 Ci/yr	6 Ci/yr	Decreased
C-14 Release Rate	7.3 Ci/yr	5.9 Ci/yr	Decreased
Unexpected Release Rate	0.16 Ci/yr	1.6×10^{-4} Ci/yr	Decreased
Decontamination Factor of PWR Condensate Decontaminator	50	10	Decreased

The Final Safety Analysis Report(FSAR) of NuScale proposes the sources of gaseous radioactive waste in Figure 2, identifying seven primary pathways for gaseous waste emissions [3]. Each pathway involves different systems through which the radioactive effluents pass before being eleased into the environment. These pathways are influenced by the SMR's design, particularly the containment systems and operational features.

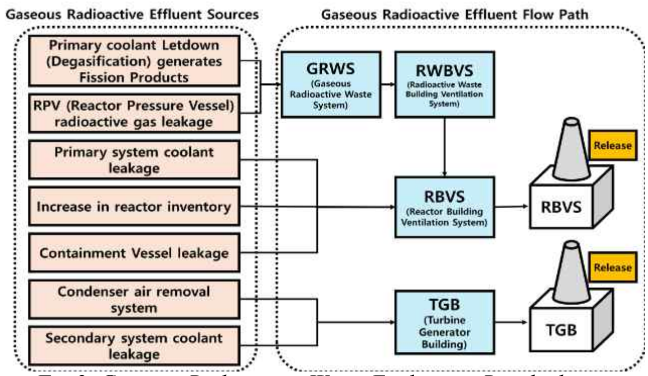

Fig.2. Gaseous Radioactive Waste Evaluation Results by Thermal Power

In NuScale SMR, six reactor modules are assumed to be operational, and the evaluation of liquid and gaseous radioactive waste is performed by using the values provided in NUREG-0017, when they are deemed appropriate. If the values in NUREG-0017 are not applicable, NuScale apply alternative values that reflect the design characteristics of NuScale SMR. As part of the NuScale SMR evaluation, Table 2 outlines the considerations for liquid and gaseous effluent evaluations. These consider the specific operational features of NuScale SMR, such as multiple reactor modules, and provide the basis for calculating the potential emissions of radioactive materials. NPM means NuScale Power Module, which refers to the individual reactor unit in the NuScale SMR design.

Table II: Modifications to the NUREG-0017 Methodology Reflected in the NuScale SMR Effluent Evaluation

	details	NUREG-0017	NuScale SMR
Liquid	Drainage System	7,200 gal/day	9.9 gal/day/NPM
	Secondary System Cooling Drainage Rate	1,400 gal/day	1.9 gal/day/NPM
	Sample Collection System Drainage Rate	0.16 Ci/year	0.071 Ci/year
Gas	Gas Leakage Rate into Reactor Pressure Vessel	3% leakage of daily primary coolant inventory	Use the value from NUREG-0017, adjusted for removal by containment pressure system, 0.47 lbm/hr/NPM
	Leakage of Primary System Coolant into the Containment Building	160 lbm/day	11.8 lbm/day/NPM
	Emergency Core Cooling System Leakage	-	Additional 0.2 wt%/day leakage of primary system coolant considered
	Leakage of Primary System Coolant from Reactor Containment	1,700 Ci/year/μCi/g	125 Ci/year/NPM/μCi/g
	Steam Leakage from Secondary System	1,700 lbm/hr	125 lbm/hr/NPM (Blowdown not considered)

Based on these considerations, an initial comparison and analysis of the gaseous effluent evaluation results was conducted, focusing on how the thermal power of SMRs influences effluent emissions. Considering that the NuScale SMR has a thermal power of 330 MWt and referencing the thermal power of several other SMR designs, thermal power values of 300 MWt, 530 MWt, and 680 MWt were arbitrarily selected for calculations. The results of the gaseous radioactive waste evaluation for these thermal power levels are shown in Figure 3.

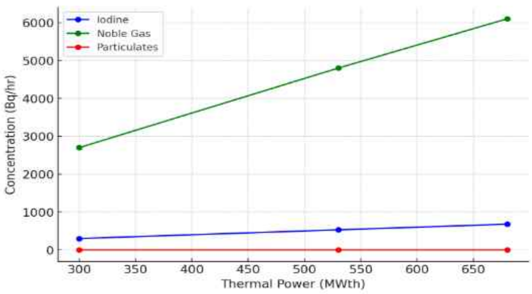

Fig. 3. Gaseous Radioactive Waste Evaluation by Thermal Power

The concentrations of Iodine and Noble Gases increased linearly with higher thermal power levels, while the concentration of Particulates remained constant across all power levels.

As illustrated in Fig. 1, these results indicate that the calculation algorithms applied in the PWR-GALE code are differentiated according to gas type. Specifically, changes in thermal power influence the input parameters, such as tritium concentration, which subsequently affects Iodine and Noble Gas concentrations differently compared to Particulates.

3. Conclusions

This study applied modified parameters derived from first-principles calculations, recent nuclear industry experience, and regulatory guidelines, based on the iPWR design values suggested by PNNL. Additionally, by setting input data referencing design values from various currently developed SMRs, we evaluated the applicability of the PWR-GALE code for assessing gaseous radioactive effluents in SMRs. Future research should clearly present the detailed derivation processes and associated uncertainties of these modified parameters to further enhance the reliability and transparency of assessments. As demonstrated in this analysis, evaluation methodologies must incorporate distinct calculation algorithms reflecting the unique characteristics of each radioactive gas type affected by variations in thermal power and tritium concentration. Integrating these SMR-specific characteristics into future evaluation methodologies will significantly improve the accuracy and reliability of safety and environmental impact assessments, thereby playing a critical role in advancing SMR technology and regulatory processes.

ACKNOWLEDGEMENTS

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