

A Novel Fluid Network Analysis Program Featuring Flexible Modeling and an Extensible Architecture for Research Reactors

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1. Introduction

Accurate prediction of coolant flow distribution is essential for the thermal-hydraulic safety and performance of research reactors. A review of existing Safety Analysis Reports (SARs) reveals two primary analysis approaches: the explicit dual-modeling method, which uses separate global and local models, and the implicit integrated network method, which models the entire core as a single automated network. While both methods are established, they present limitations in flexibility and extensibility.

This paper compares these methodologies to derive key requirements for an improved analysis tool. Based on these findings, we introduce a novel 1-D incompressible fluid network analysis program developed to enhance accuracy and efficiency by addressing the shortcomings of traditional approaches through a highly flexible templating system and a user-extensible physics plug-in architecture.

2. Analysis of Flow Distribution Methodologies

This study selected the methodologies described in the SARs for the OPAL (Open Pool Australian Light-water) reactor at ANSTO, Australia, and the HOR reactor at TU Delft as representative cases for the explicit dual-modeling and implicit integrated network methods, respectively. The main features of each methodology are summarized in Table I.

The analysis confirmed that while explicit modeling is stable, it lacks flexibility for complex geometries. The implicit network method excels in realistic simulation but has limitations in allowing users to extend physical models or intuitively control the modeling process.

3. Development of a Fluid Network Analysis Program

To reflect the requirements derived from the above analysis, a new fluid network analysis program was developed with the goals of accuracy, flexibility, extensibility, and usability. According to the development roadmap, the core engine and an interactive results viewer have been completed.

Table I: Comparison of Flow Distribution Analysis Methodologies

Category	Method A: Explicit Dual-Modeling (OPAL Case)	Method B: Implicit Integrated Network (HOR Case)
Modeling Approach	Top-down, purpose-oriented	Bottom-up, system-integrated
Core Analysis Code	MTR_PC (CAUDVAP, TERMIC)	SHORT (FLAC, COBRA)
Network Configuration	Manual and explicit configuration of global/local models based on analysis purpose	Automatic network generation based on grid plate element information
Shroudless Core Treatment	Gaps between assemblies modeled as simplified external channels	Detailed modeling as an integrated network including bypass and cross-flow
Advantages	Clear analysis purpose; stable analysis based on verified correlations	Realistic simulation of complex flow paths (e.g., bypass); modeling automation
Limitations	Limited simulation of complex geometries and inter-assembly flows; Manual modeling process is time-consuming.	High dependency on the internal 'black-box' logic of the code; Difficult for users to extend or modify physics models

3.1. Development Philosophy and Key Features

1. **Accuracy:** Adopts the Global Gradient Algorithm (GGA), a stable numerical analysis method, as the core solver to ensure reliable analysis results.
2. **Flexibility:** Implements a template (.fnt) and nested assembly function to efficiently model complex and repetitive network structures. This is highly effective for rapidly modeling and modifying various core configurations.
3. **Extensibility:** Supports a plug-in architecture that allows users to dynamically add their own physics models, such as friction factors and minor loss coefficients, as Python scripts (.py). This provides an open analysis environment not limited to specific correlations.
4. **Usability:** Unlike the methodologies in Table I, which primarily use text-based I/O, this program supports multiple interfaces for diverse user workflows. It provides a complete GUI for visual modeling and interactive analysis, as well as a Command Line Interface (CLI) for batch processing and automated scripting. Analysis results can be exported to standard text formats (e.g., CSV) for data interoperability. Fig. 1 illustrates the overall analysis workflow of the program.

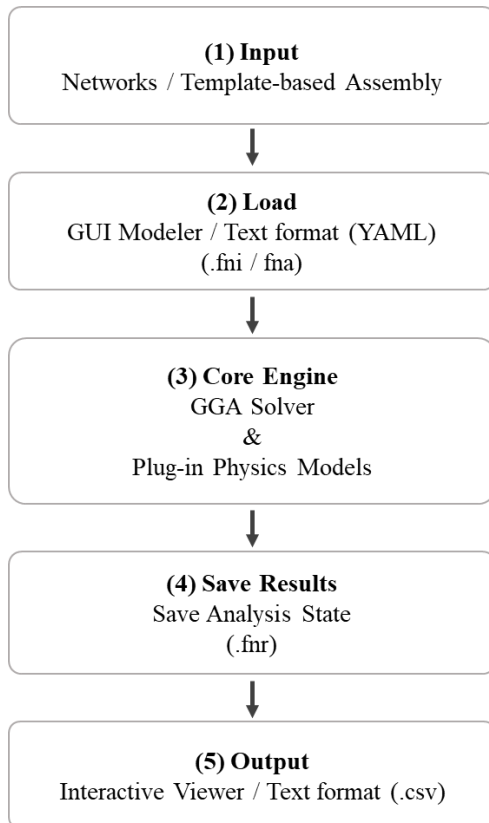


Fig. 1. Conceptual Diagram of the Novel Program's Analysis Workflow

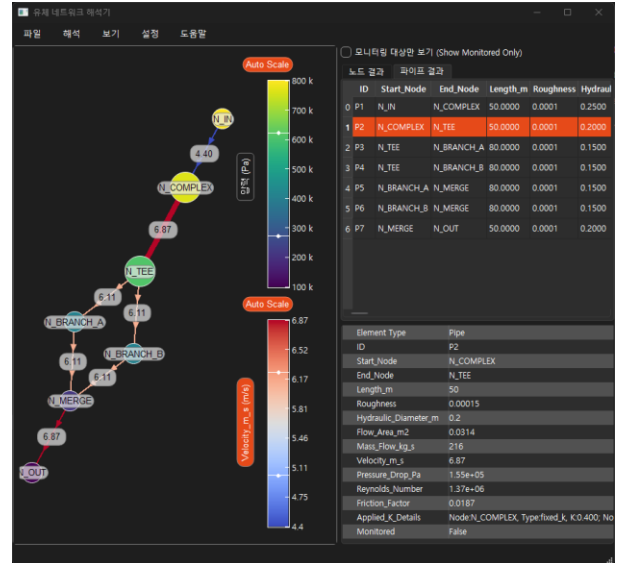


Fig. 2. Example of the Interactive GUI Results Viewer

4. Conclusion and Future Work

This study compared key methodologies for research reactor core flow distribution analysis and presented the development direction and core features of a new analysis program that integrates their advantages and supplements their weaknesses. With its template-based flexible modeling, plug-in-based extensibility, and support for both GUI and CLI workflows, this program has the potential to overcome the limitations of existing analysis environments. Ultimately, it is expected to significantly reduce the time and effort required for the safety analysis of new and existing research reactors, while improving the fidelity of the simulation results.

Future work will focus on implementing a Modeler function within the GUI to allow users to create and edit networks directly, thereby establishing an integrated analysis environment where the entire process, from input to result analysis, is completed within the GUI.

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