DEVELOPMENT OF ARKADIA-SAFETY FOR SEVERE ACCIDENT EVALUATION OF SODIUM-COOLED FAST REACTORS

M. AOYAGI[1], M. SONEHARA[1], S. ISHIDA[1], A. UCHIBORI[1], K. KAWADA[1], Y. OKANO[1], T. TAKATA[1*]

[1]Japan Atomic Energy Agency, O-arai, Japan

Email contact of corresponding author: aoyagi.mitsuhiro@jaea.go.jp

1. INTRODUCTION

Development of Advanced Reactor Knowledge- and Artificial Intelligence (AI)-aided Design Integration Approach through the whole plant lifecycle (ARKADIA) has been started in Japan Atomic Energy Agency [1]. ARKADIA can automatically provide possible solutions of design, safety measures, and a maintenance program to optimize the lifecycle performance of advanced reactors by using the state-of-the-art numerical simulation technologies. In the first phase of this project, ARKADIA-Safety is developed for the purpose of automatic optimization of the severe accident (SA) management and its feedback to the plant design of sodium-cooled fast reactors (SFRs). This paper describes the overview of ARKADIA-Safety and its application for SA evaluation.

2. OVERVIEW OF ARKADIA-SAFETY

The principal simulation system in ARKADIA-Safety is the SPECTRA (Severe-accident PhEnomenological Computational tool for TRansient Assessment) code. SPECTRA has been developed for integrated analysis of the event progression during the SA in SFRs [2]. ARKADIA-Safety also employs the AI technology and the knowledge-base system in order to perform automatic optimization of the SA management and its feedback to the plant design. The knowledge-base system is constructed from the data obtained through the previous fast reactor development programs such as Monju or the future research and development [1].

SPECTRA has two basic modules of thermal-hydraulics for in- and ex-vessel. The in-vessel basic module employs a multi-dimensional compressible two-phase flow model to simulate thermal-hydraulics of the liquid sodium coolant and its vapor. The ex-vessel basic module employs a lumped mass model to simulate inter-room heat and mass transfer focusing on the atmospheric behavior. The two basic modules are coupled each other in the SA simulation.

Specific phenomena during the SA are analyzed by the individual physical modules. The in-vessel specific phenomena include core fuel melting combined with neutronics, molten fuel relocation behavior and fission product (FP) transfer. The ex-vessel ones are sodium fire, sodium-debris-concrete interaction (concrete ablation), hydrogen combustion, and FP transfer. The effects of the individual phenomena are given as the heat and mass sources in the thermal-hydraulics calculation by the in- and ex-vessel basic modules.

The numerical models in SPECTRA especially the in-vessel model give priority to fast calculation rather than the detailed modeling as compared with existing similar tools such as SIMMER [3]. This feature enables parametric analyses for the events involving a wide range of uncertainties.

3. EVALUATION OF THE SEVERE ACCIDENT

Fundamental capability of SPECTRA is demonstrated through the application to the hypothetical loss of reactor level (LORL) event in a loop type SFR as shown in Fig. 1. This event starts from coolant leakage from the primary piping to ex-vessel room-A. Then, coolant level of the reactor vessel becomes lower followed by temperature increase of the core fuel and its melting. The gray particles shows the molten fuel which is simulated

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[*] Present affiliation: The University of Tokyo

by the fuel relocation module employing the particle method. Meanwhile, sodium fire occurs in ex-vessel room-A. If the reactor vessel failure occurs in ex-vessel room-B, sodium and fuel discharge occurs followed by concrete ablation on the floor of this room. These ex-vessel phenomena are also simulated by the corresponding individual modules respectively. In this way, SPECTARA can simulate in- and ex-vessel events continuously.

In order to enhance the capability of SPECTRA for sodium fire and concrete ablation, their integrated model is now under development [4]. In the simulation shown in Fig. 1, SPECTRA has no capability for the overlapped event involving both sodium fire and concrete ablation at the same room. The reason is that heat transfer in the floor portions is calculated separately by the sodium fire module in room-A and by the concrete ablation module in room-B. In the new integrated model, heat transfer in the floor portions is calculated in the single module where heat sources due to sodium fire and concrete ablation are given from their individual calculations. The integrated model also calculates mass transfer of liquid sodium and concrete ablation as shown in Fig. 2.

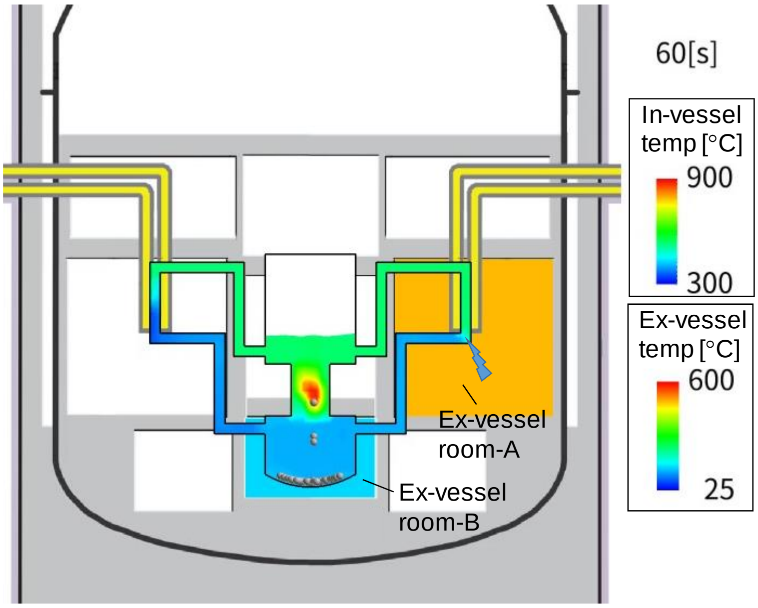

FIG. 1. Demonstrative SA simulation.

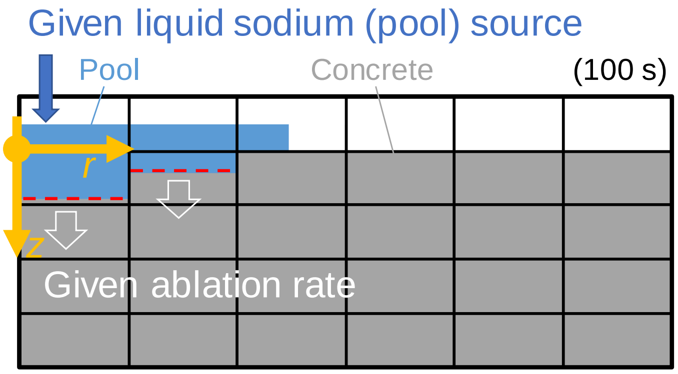

FIG. 2. Simulation result of mass transfer in the floor portion where liquid sodium source and concrete ablation rate are given hypothetically.

One of the key features of ARKADIA-Safety is to perform automatic optimization of plant design parameters by utilizing the SPECTRA simulation. For this purpose, the AI tool based on the artificial neural networks has been implemented into ARKADIA-Safety. For instance, increase in the size of the containment vessel (CV) mitigates temperature and pressure rise along with the sodium fire inside the CV. However, the plant cost increases depending on the CV size. Optimization of this problem is simply quantified by introducing the two factors $e1$ and $e2$. The object function for optimization is defined by $e1 + e2$ with the constraint conditions of $e1 < 1$ and $e2 < 1$. The safety factor $e1$ is assumed to be proportional to the atmospheric temperature in the CV: $e1 = T\_calc / T\_base$. Here, T_calc is the maximum temperature during sodium fire in the CV calculated by SPECTRA. T_base is set to 300°C. The economy factor $e2$ is assumed to be proportional to the CV volume: $e2 = V\_input / V\_base$. Here, V_input is the input parameter in the SPECTRA calculation. V_base is set to 3000 m^3.

The definitions of these factors will be elaborate in the future work utilizing the knowledge-base system in ARKADIA-Safety.

The results of optimization are plotted in Fig. 3. The red star shows the optimal point found out by the AI tool automatically after 51 iterative runs shown by the green circles. Without this AI tool, the optimal point of the CV volume which is denoted by blue, red, and yellow lines can also be given by the user's effort through the parameter search. The optimized CV volume and the object function $e1+e2$ are 2036.6 m^3 and 1.3868, respectively, by the AI tool. Their exact values without the AI tool are 2036.5 m^3 and 1.3868. The corresponding result is obtained by the AI tool where the user set just the initial conditions.

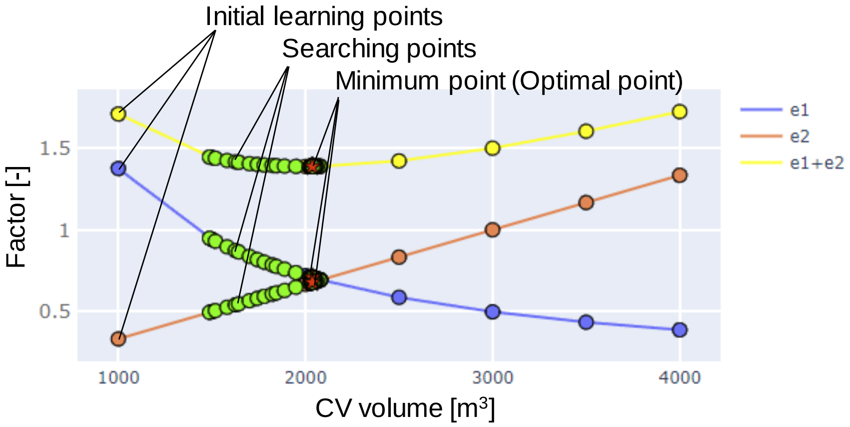

FIG. 3. Example of the optimization problem by ARKADIA-Safety.

4. CONCLUSION AND FUTURE PLAN

ARKADIA-Safety has been developed for the purpose of automatic optimization of the severe accident management and its feedback to the plant design of sodium-cooled fast reactors. Its functional capability for calculation of a hypothetical severe accident condition is simulated. The AI tool which has been implemented into the ARKADIA-Safety enables to optimize the plant design parameter, such as the volume of CV. In the future enhancement, capability for the overlapped event of sodium fire and concrete ablation will be improved by their integrated model. The optimization by the AI tool will be extended to multivariable problems.

ACKNOWLEDGEMENTS

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