Current Status of RASTEP
An Emergency Preparedness and Response decision support tool

Sergey Galushin[a*], Manorma Kumar[c] and Anders Olsson[d]
[a] Vysus Group, Solna, Sweden , sergey.galushin@vysusgroup.com
[c] Vysus Group, Chicago, USA, manorma.kumar@vysusgroup.com
[d]Vysus Group, Malmö, Sweden, anders.olsson@vysusgroup.com

Abstract: RASTEP (RApid Source TErm Prediction) is a fast-running decision support tool developed by Vysus Group in collaboration with the Swedish Radiation Safety Authority (SSM) to support emergency response during nuclear incidents. The tool provides an independent, real-time assessment of accident progression and potential radiological consequences, enabling regulatory authorities and emergency response teams to make informed protective action decisions under conditions of uncertainty.

RASTEP integrates insights from Level 1 and Level 2 Probabilistic Safety Assessments (PSA) with deterministic plant response and source term analyses. At its core, the tool employs Bayesian Belief Networks (BBNs) to represent causal relationships between initiating events, plant status, safety system performance, operator actions, and observed process parameters. By combining pre-analyzed safety information with live plant data, RASTEP continuously updates the likelihood predictions of accident scenarios and associated source terms, even when available information is incomplete.

Designed in alignment with IAEA standards for Emergency Preparedness and Response (EP&R), RASTEP enhances situational awareness by providing rapid and structured decision support during nuclear emergencies. This paper presents an overview of the tool, its underlying methodological approach, and its current development status.

Keywords: Severe Accident, RASTEP, Emergency Preparedness, Risk-Informed

1. INTRODUCTION

Decision-making during nuclear emergencies requires rapid interpretation of plant conditions, projection of accident progression, and estimation of potential radiological consequences. In practice, these tasks are complicated by the fact that available information is often incomplete, uncertain, or evolving over time. Instrumentation may be degraded, signals may be ambiguous, and the time available for analysis is limited.

Traditional approaches to source term estimation rely largely on deterministic simulations or on interpretations of measured radiological data. While these approaches remain essential, they are not always well suited for real-time use during the early stages of an accident, when information is sparse and decisions must be made quickly. In addition, they do not inherently provide a structured way to handle uncertainty or continuously update predictions as new information becomes available.

RASTEP (RApid Source TErm Prediction) has been developed to address these challenges. The tool combines probabilistic safety assessment (PSA) insights, deterministic accident analyses, and real-time plant observations within a unified framework. It provides continuous estimates of accident progression and associated source terms, allowing users to maintain situational awareness and support decision-making under uncertainty (Figure 1).

The development of RASTEP has been carried out by Vysus Group in collaboration with the Swedish Radiation Safety Authority (SSM). The tool is intended to support regulatory bodies, technical support organizations, and emergency response teams by providing an independent and rapidly updating assessment capability.

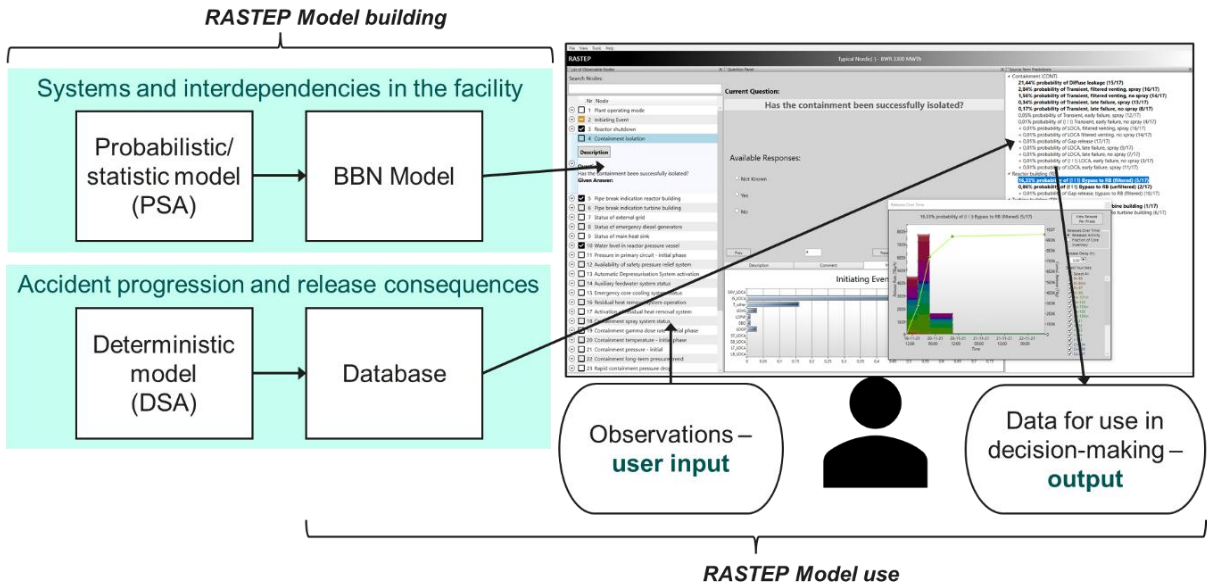

Figure 1. RASTEP Overview

This paper presents a status overview of RASTEP, focusing on its conceptual design, methodological basis and current stage of development and how it can be applied in an emergency response context.

2. CONCEPT AND OBJECTIVES OF RASTEP

RASTEP is designed as a decision support tool that provides rapid, structured insight into accident progression and radiological consequences during nuclear emergencies. Its primary purpose is to assist decision-makers by combining available information with pre-analyzed safety knowledge in a way that supports timely and risk-informed protective actions (Figure 2).

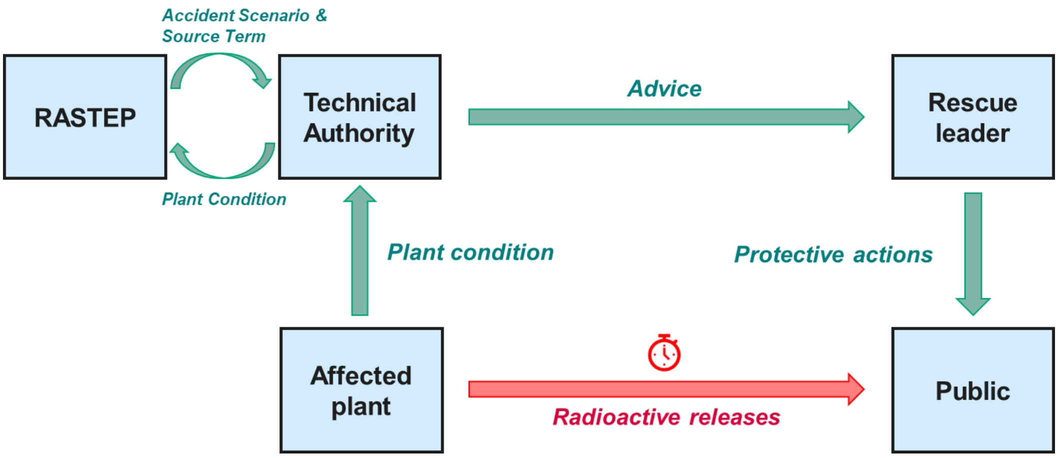

Figure 2. RASTEP in Emergency Preparedness Context [4]

A key objective of the tool is to bridge the gap between detailed safety analyses, which are typically performed offline, and the need for real-time and risk-informed situational awareness during an emergency. To achieve this, RASTEP embeds information from Level 1 and Level 2 PSA, as well as deterministic accident analyses, into a computationally efficient framework that can be evaluated quickly as new observations become available.

The tool is particularly relevant in situations where plant information is incomplete or uncertain, and changes over time. Instead of requiring a complete and consistent set of inputs, RASTEP is capable of using only partial information and still providing meaningful estimates of accident scenarios and source terms. This is achieved through the use of a Bayesian Belief Network (BBN) and its probabilistic structure, which allows it to account for uncertainty and update predictions dynamically.

In addition to supporting real-time decision-making, RASTEP also enables exploratory "what-if" analyses and training applications, allowing users to evaluate emergency preparedness and response strategies under a range of accident scenarios. Users can assess how different assumptions or potential actions may influence accident progression and radiological outcomes. This capability is valuable both during an ongoing event and in preparedness activities such as training and scenario evaluation.

The overall concept of RASTEP aligns with IAEA Emergency Preparedness and Response (EP&R) principles, particularly with respect to the need for timely, transparent, and structured decision support during nuclear emergencies.

3. METHODOLOGICAL FRAMEWORK

3.1. Bayesian Belief Network Approach

The core of RASTEP is based on Bayesian Belief Networks (BBNs), which provide a probabilistic framework for modelling complex systems with uncertainty. In this approach, the system is represented as a network of variables connected by causal relationships. These variables include initiating events, system states, operator actions, and observable plant parameters.

The BBN framework enables the integration of prior knowledge with real-time observations. Prior knowledge is derived from PSA and expert judgement, while observations are provided by the user during an emergency. As new information becomes available, the probabilities associated with different accident scenarios are updated using Bayes' theorem (Figure 3).

This approach allows the model to remain consistent even when some information is missing. Rather than requiring complete data, the model produces the best possible estimate based on the available evidence. This capability is particularly important in emergency situations, where data may be incomplete or uncertain.

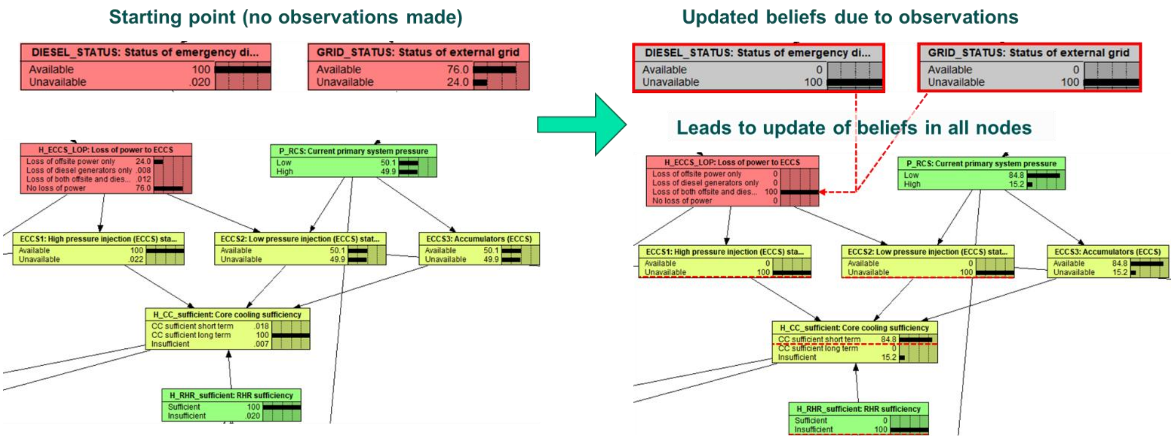

Figure 3. BBN Example – Modelling of Inter-System Dependencies [1]

As demonstrated in the original model development work under the EU FASTNET project [2], BBNs are well suited to representing complex accident scenarios involving multiple interacting systems and uncertain conditions.

3.2. Model Structure and Information Flow

The structure of a RASTEP model reflects the logical progression of a nuclear accident, from initiating events through system responses to potential release of radioactive material. The Bayesian Belief Network is organized into interconnected sub-networks representing key aspects of plant behavior, including initiating events, core cooling, residual heat removal, primary and secondary systems, fuel condition, containment status, and source terms (Figure 4).

Within this structure, variables are represented as nodes that can be either observable or hidden. Observable nodes correspond to measurable quantities or known conditions, such as plant parameters or operator actions. Hidden nodes represent internal states or phenomena that cannot be directly observed, such as the extent of core damage or the occurrence of specific physical processes.

Information flows through the network as observations are entered by the user. These observations update the probabilities of related variables, which in turn influence other parts of the network. This process continues iteratively, resulting in a continuously updated assessment of the overall plant state and the likelihood of different accident scenarios.

The interaction between the user and the model is designed to be simple and efficient. Users provide available information in the form of observations, and the model automatically updates its predictions. This allows the tool to be used effectively in time-critical situations.

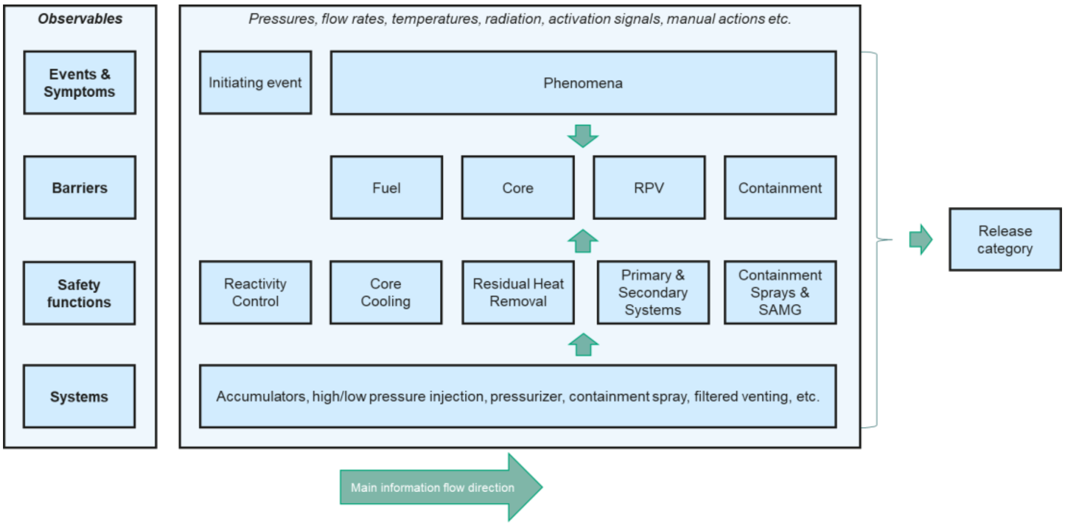

Figure 4. RASTEP Model Structure [4]

3.3. Integration of PSA and Deterministic Analyses

RASTEP combines insights from both probabilistic and deterministic safety analyses. Level 1 PSA provides information on initiating events, system dependencies, and accident sequences, while Level 2 PSA contributes information on containment behavior and release categories. Together, these analyses define the structure of the BBN model and the relationships between different variables.

Deterministic accident analyses, such as those performed using integral codes, are used to characterize plant response under different accident scenarios. These analyses provide detailed information on system behavior, timing of key events, and the evolution of accident conditions. They also form the basis for defining observable indicators, such as pressure, temperature, and hydrogen concentration, which are used as inputs to the model.

By integrating these two types of analyses, RASTEP combines the strengths of probabilistic and deterministic approaches. The probabilistic framework provides flexibility and the ability to handle uncertainty, while the deterministic analyses ensure that the model remains representative of actual plant behavior.

3.4. Representation of Source Terms

The main function of RASTEP is the estimation of source terms associated with different accident scenarios. To achieve this, the model links accident progression paths to a set of predefined source term categories. Each category represents a specific mode of radioactive release to the environment and is associated with pre-calculated source term data.

These release modes are closely aligned with the release categories defined in Level 2 PSA and are characterized by conditions that are important for the assessment of radiological consequences. Such conditions include the progression of core damage following the initiating event, the timing of the release to the environment (e.g. early or late), the status of the containment (intact, degraded, or bypassed), and the availability of consequence mitigation systems such as filtered containment venting and containment sprays. Additional factors influencing the time, magnitude, and duration of the release are also considered, ensuring that the source term representation provides the necessary input for EPR.

The associated source terms include information on radionuclide releases, their temporal evolution, release height, and other parameters relevant for consequence assessment. The severity of each source term can be characterized using metrics such as the cumulative release of key radionuclides (e.g., Cs-137 or I-131).

The results are presented as a ranked set of release categories, enabling users to understand both the most probable outcomes and less likely but potentially more severe accident scenarios, thereby supporting risk-informed decision-making (Figure 5).

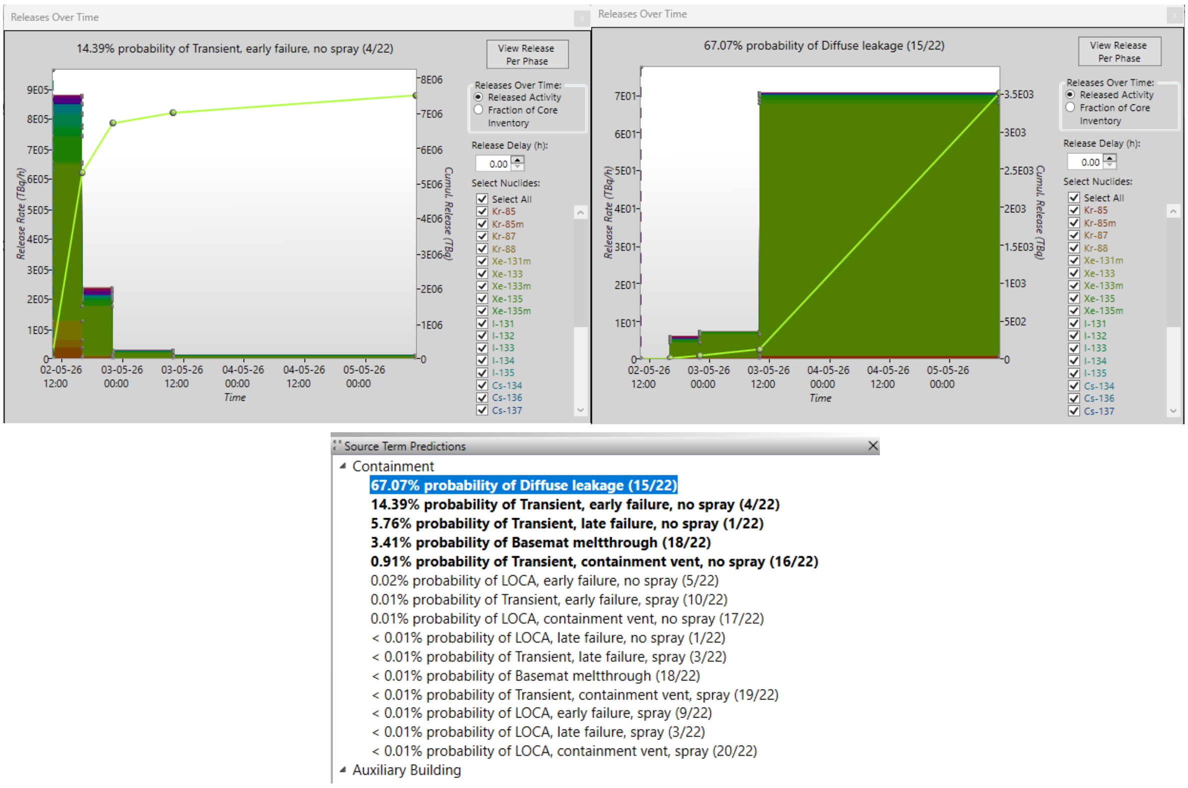

Figure 5. Example of RASTEP Likelihood ranking of Source Terms

4. APPLICATION IN EMERGENCY RESPONSE

RASTEP is intended to support a range of users involved in emergency preparedness and response, including regulatory authorities, technical support organizations, and emergency management teams. Its primary role is to provide rapid and structured insight into accident progression and potential radiological consequences, thereby supporting timely and risk-informed decision-making.

As illustrated in Figure 6, RASTEP operates in the early and intermediate stages of the emergency, linking observed plant conditions to scenario identification and source term estimation. Based on available plant data, the tool interprets the current plant state and identifies the most likely accident scenarios. These scenarios are then mapped to corresponding source terms, which provide the necessary input for subsequent consequence assessment steps, such as atmospheric dispersion and dose calculations.

During an accident, the tool continuously updates its predictions as new observations become available. This capability enhances situational awareness and ensures that downstream analyses, including consequence assessment and protective action evaluation, are informed by the current understanding of the accident progression.

A key feature of RASTEP is its ability to operate under uncertainty. The model explicitly accounts for uncertainties in observations and system behavior and is capable of producing meaningful results even when information is incomplete. This is particularly important in the early stages of an accident, when plant data may be limited but timely input is required for consequence assessment and decision-making.

By providing a structured and transparent framework for analyzing accident scenarios, RASTEP supports core emergency preparedness and response functions. In particular, it enables the assessment of plant status and the estimation of source terms, which form a critical interface between plant analysis and off-site consequence modelling. In this way, RASTEP complements traditional tools by supplying probabilistic and continuously updated inputs to the broader decision-making process, ultimately supporting risk-informed identification of appropriate protective actions.

In addition to real-time applications, RASTEP also supports preparedness activities such as training and scenario analysis. Through exploratory "what-if" evaluations, users can investigate how different plant conditions, system responses, or operator actions influence accident progression and source term development. This capability contributes to a deeper understanding of accident dynamics and strengthens preparedness across a wide range of scenarios.

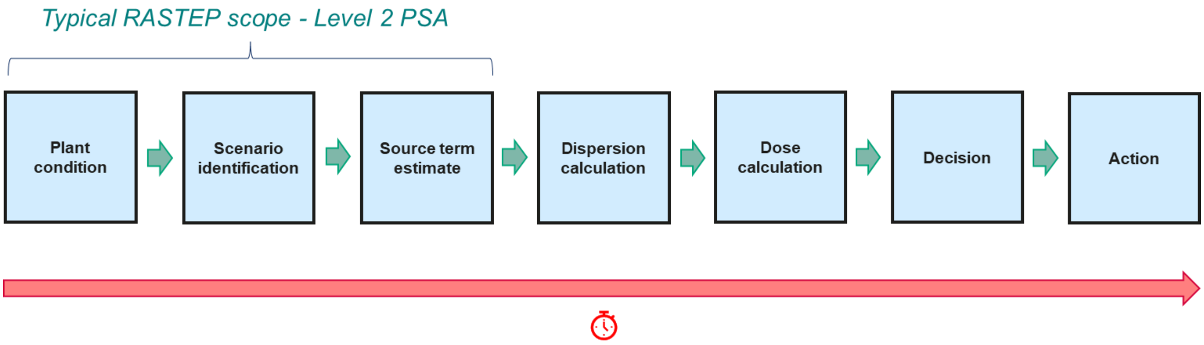

Figure 6. RASTEP in emergency preparedness context [1]

5. DEVELOPMENT AND VALIDATION STATUS

Verification and validation of the model are essential components of the development process. Verification activities focus on ensuring that the model behaves as intended, for example by testing its response to predefined scenarios or specific combinations of inputs. Validation activities involve comparing model predictions with results from deterministic simulations and assessing whether the model provides realistic representations of accident progression.

The results obtained so far indicate that the model is capable of producing consistent and realistic predictions. In particular, it has been observed that the model converges toward correct accident scenarios as more observations are provided [3]. At the same time, the sensitivity of the model to certain key observations highlights areas where further refinement may be beneficial.

Ongoing development efforts are focused on improving the robustness and usability of the tool. This includes automation of validation processes, refinement of model structures, and development of new models for broader spectrum of reactor designs. Work is also being carried out to enhance the integration of the tool into emergency response frameworks and wider range of dispersion and dose calculation tools.

6. CONCLUSIONS

RASTEP represents a tool for real-time source term prediction for nuclear emergencies. By combining probabilistic safety insights, deterministic analyses, and real-time observations within a Bayesian framework, the tool provides a flexible and robust approach to decision support under uncertainty.

The current status of development demonstrates that RASTEP is capable of delivering meaningful and timely insights into accident progression and radiological consequences. Its ability to operate with incomplete information and continuously update predictions makes it particularly well suited for use in emergency response.

Ongoing work will further enhance the capabilities of the tool, including improvements in validation, usability, and applicability to a wider range of reactor designs.

ACKNOWLEDGEMENTS

The RASTEP software development was funded by the Swedish Radiation Safety Authority (SSM).

REFERENCES

[1] Norsys, 1997, NETICA Application for Belief Networks and Influence Diagrams – User's guide, Norsys Software Corp., Vancouver, 1997.

[2] Design and use of Bayesian networks for the diagnosis/prognosis of severe nuclear accidents, FAST Nuclear Emergency Tools (FASTNET project), FASTNET-DATA-D2.3, Report IRSN /2019-00534, 2019.

[3] J.F. Canepa, A.R. Marklund, S. Galushin, A. Olsson, Evaluation of the source term prediction capability of RASTEP against integral plant response code calculations, Probabilistic Safety Assessment and Management PSAM 16, Honolulu, Hawaii, June 26-July 1, 2022.

[4] S. Galushin, "Short Course in Fast Source Term Prediction - Introduction to RASTEP", Presentation materials by Vysus Group, 2024.

[5] S. Galushin, W. Qin, Y. Yang, A. Olsson, "Developing the RASTEP Model: A Methodological Approach and Case Study of the M310 PWR Reactor", Probabilistic Safety Assessment and Management & Asian Symposium on Risk Assessment and Management (PSAM17 & ASRAM2024), October 7-11, 2024, Sendai International Center, Sendai, Miyagi, Japan.