Atom Indonesia

Journal homepage: http://atomindonesia.brin.go.id

Customization of Source Term into JRODOS Compatible XML File Format Using Visual Basic for Nuclear Accident Analysis

S. M. T. Hassan[1*], M. A. Khaer[1], M. A. Hoq[2], M. T. Chowdhury[1], M. M. Rahman[1]

[1]*Institute of Energy Science, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Ganakbari, Savar, Dhaka, Bangladesh*

[2]*Institute of Nuclear Medicine and Allied Science, Bangladesh Atomic Energy Commission, Chattogram, Bangladesh*

ARTICLE INFO

Article history:
Received 4 March 2024
Received in revised form 21 June 2024
Accepted 21 June 2024

Keywords:

JRODOS
Source term
XML
Visual basic
Radionuclide
Nuclear accident analysis

ABSTRACT

A Visual Basic code was developed to generate an XML file in the RODOS format from the provided source term data in Microsoft Excel Spreadsheet. This XML file can be directly used in JRODOS (Java-based Real-time On-line Decision Support) platform. A simple source term model was used to check the applicability of the code. Finally, the code was successfully implemented to reproduce the JRODOS-formatted XML file for a detailed Fukushima Dai-ichi nuclear power plant accidental scenario. This code simplifies a vital analysis step, which would otherwise be very cumbersome, especially for a complex source term scenario involving many radionuclides, release intervals, and release heights of a nuclear accident.

INTRODUCTION

A Source Term (ST) contains essential information about the amounts and timing of released nuclides following any radiological accident [1-3]. It plays the most crucial role in emergency response management, as the ST and the weather pattern determine the spread of released nuclides, affecting the population and the environment, as well as guiding the relocation of affected people. Accurate ST and meteorological data are vital for atmospheric dispersion modeling. The ST represents data on the amounts and types of hazardous material released to the environment including air, water, groundwater, or soil over time. For nuclear reactor incidents, the ST is expressed as fractions of the fission product inventory in the fuel, including their physical and chemical form [2]. The release rate is measured by the nuclides' activity and timing of release.

The importance of correct estimation of the ST of any radiological accident relies on its impact on the spread of radionuclides in the environment, affecting both the intensity of doses and the affected population area.

Various studies have examined methods and practices for estimating ST for radiological accidents in nuclear power plants and research reactors. B.E.R. Lulik et al. [1] developed a simplified approach to quickly estimate the ST for Small Modular Reactors (SMR), utilizing parameters such as fission product yields, fuel composition, radionuclide release fractions, and reactor thermal power. The IAEA safety series, no. 53 [4] provides a detailed explanation of deriving the ST and analyzing the radiological consequences of research reactor accidents. M. Chino et al. [5] estimated the preliminary release rates and total amounts of ^{131}I and ^{137}Cs released into the atmosphere from the Fukushima Dai-ichi nuclear power plant accident from March 12 to April 5, 2011. Ie. Ievdin et al. [6] applied the JRODOS decision support system to assess atmospheric dispersion and deposition from the Fukushima Dai-ichi nuclear power plant accident. T. Kobayashi et al. [7] estimated the ST of atmospheric release from the Fukushima Dai-ichi Nuclear Power Plant accident using atmospheric and oceanic dispersion simulations. H. Terada et al. [8] analyzed regional-scale atmospheric discharge and dispersion of radionuclides during the Fukushima Dai-ichi Nuclear Power Plant accident, to verify the ST. S. Takahashi [9] edited a book of extensive analysis

*Corresponding author.
E-mail address: hassan.tabirul@gmail.com
DOI: https://doi.org/10.55981/aij.2025.1432

on radiation monitoring and dose estimation of the Fukushima Nuclear Accident. G. Katata et al. [10], A. Stohl et al. [11], and P.M. Udiyani et al. [12] worked extensively on the atmospheric release and radiological discharge of the Fukushima Nuclear Accident. M.A. Khaer et al. [13] assessed the radiological dose and emergency planning zones for Bangladesh's TRIGA Mark-II research reactor under a postulated severe accidental condition using the ORIGEN 2.1 code. K. M. Z. Zihan et al. [14] assessed the dose distribution of radio-xenon from a hypothetical accident of the TRIGA research reactor in Bangladesh. S.S. Shiuli et al. [15] evaluated the radiological safety and emergency response of the VVER-1200 type reactor using RASCAL 4.3 and HOTSPOT 3.1.2.

The ST calculations based on incident type can be generally categorized as follows [3]: Nuclear power plant accidents; Spent reactor fuel accidents; Fuel cycle facility/UF-6 accidents; Uranium fires and explosions; Criticality accidents; Isotopic releases (e.g., transportation, materials, etc.).

Accurate estimation of ST and reliable meteorological data are essential to prepare an emergency plan and take appropriate protective actions in the event of any radiological incident. JRODOS is a robust and reliable platform for these purposes.

JRODOS is a real-time online decision support system designed to aid emergency response during radiological accidents [6]. Developed by the Institute for Thermal Energy Technology and Safety (ITES), Karlsruhe Institute of Technology, Germany, JRODOS provides all the necessary information to help protect the surrounding population. It requires accurate meteorological data, a reliable ST, and several other parameters to model a radiological accident at a specific site.

JRODOS has built-in library files containing STs for multiple accident scenarios. Additionally, separate STs can be defined based on six types of release data input: Type F1: Fraction released of initial inventory for selectable nuclide groups; Type F2: Released activity for individual nuclides (noble gases, iodines, aerosols) with inventory reference; Type F3: Released activity for the nuclide groups noble gases, aerosols, and nuclide ^{131}I, together with aerosol fractions; Type F4: Released activity for the nuclide groups noble gases, iodines, and aerosols, together with aerosol fractions; Type F5: Released activity for selectable nuclide groups; Type F6: Released activity for individual nuclides (noble gases, iodines, aerosols) without inventory reference.

For release data input involving "nuclide groups" (Types F1, F3, F4, F5), the values of the fractions or released activities of groups of nuclides at multiple release intervals can be inserted. For inputs involving "individual nuclides" (Types F2, F6), the values of released activities of individual nuclides at multiple release intervals can be inserted, allowing for a more detailed depiction of the complex release phenomenon. For ease of use and system flexibility, it is preferable to use the JRODOS-provided options to define ST of Types F1 to F4 or when dealing with a limited number of individual nuclides (for F2, F6) and release intervals. However, when the number of individual nuclides and release intervals increases, consolidating this information into an XML file formatted according to the RODOS format can simplify tracking and management. This XML file can be directly imported into JRODOS, making it easier to handle complex release scenarios [16].

It is worth mentioning that there are dedicated computational codes [3-4], e.g., RASCAL, ORIGEN 2, MELCOR, SCDAP or SPARC, etc., which can produce the ST data directly, but the produced ST file would have to be converted in a JRODOS recognizable format [16]. To the best knowledge of the authors, no third-party platform could be found to convert the outputs from other ST-generating codes into a format directly usable by JRODOS, which served as the motivation behind customizing a simple visual basic code (Annexure-I) to convert the provided ST data in JRODOS recognizable format.

METHODOLOGY

A simplified sequence of determining the ST and conducting radiological consequence analysis [4] is as follows: Defining the accident scenarios, e.g., Design Basis Accident (DBA) or Beyond Design Basis Accident (BDBA); Specifying the radioisotope content of the reactor core under burnup conditions; Determining the type and extent of fuel damage for the release of radionuclides; Calculating the reactor's time-evolution history for each selected scenario; Determining the fraction of the released radioisotopes, release pathways, release rates from the reactor building, release hour, etc., to finalize the ST; Using the ST, meteorological data, and personnel occupancy (including both occupants of the reactor building and the general public) in atmospheric dispersion modeling and analysis.

The ST can be calculated from the inventory of fission products and burnup using various computational codes, but the result is susceptible to the initial assumptions. Moreover, calculating the ST always involves some uncertainty due to the inherent uncertainties in the calculation models, required model parameters, and boundary conditions set by the modeler.

Thus, the calculated ST needs to be cross-checked and verified using field data collected from various environmental monitoring systems. If realistic assumptions or data are unavailable during the calculation process, conservative assumptions should be made. This approach simplifies the calculation effort significantly, but the prediction might deviate more from the field data.

If estimated correctly, the ST can be used to calculate the environmental consequences of the radiological release and determine the doses received by the population. The ST is often reverse estimated by running analysis coupled with atmospheric dispersion modeling, using meteorological data and radiological data collected from the field [5]. If the calculated result matches the field data, the estimated ST can be used with good confidence. This reliable ST estimation aids in dose calculation from atmospheric dispersion analysis and informing emergency planning measures such as evacuation, sheltering, and iodine prophylaxis. These measures consider both short-term and long-term responses to the radiological release to the environment. This atmospheric dispersion modeling and emergency response planning can be conducted on a single platform such as JRODOS.

JRODOS can import ST data as an XML file using the proper RODOS format. An arbitrary ST was defined directly in JRODOS, and the RODOS format was studied after exporting the file. A code was developed in visual basic programming language (Annexure-I) to follow the RODOS format and generate an appropriate XML file effectively using data on release activities and release intervals.

During the preparation of the ST, JRODOS needs information about the starting time of release, the release intervals, the release height, and the release activities of the nuclides. The visual basic code takes data on release heights and release activities of nuclides for each release interval from the spreadsheet and writes them into the RODOS formatted XML file accordingly.

In JRODOS, the release height corresponds to the height of the stack or the point of release from the reactor building. In cases where the thermal energy of release is unknown, an estimation of the effective release height of the plume can be made by considering the thermal power to zero.

Plume segments become buoyant due to the heat content of the plume and the release velocity from the stack, causing them to rise to heights much greater than their initial release height (stack height). The effective release height H (m) can be evaluated using Eq. (1).

$$H = h + \Delta h_d \tag{1}$$

where h is the stack height (m) and Δh_d is buoyant plume rise (m). The calculation of buoyant plume rise is discussed extensively in [4].

Table 1 shows a simple ST data set from a fictitious nuclear power plant accident, which is also plotted in a logarithmic scale (Fig. 1). The first column indicates the duration of nuclide release in hours [h], while the consecutive columns represent the release rates of respective nuclides, measured in Becquerel per Hour [Bq/hr].

Table 1. A simple and arbitrary ST data of afictitious nuclear power plant accident.

hours	height	^{137}Cs	^{131}I	^{133}Xe
4.5	20	3.70E12	3.70E13	1.50E12
10.5	20	2.70E12	1.70E13	1.10E12
11.0	20	1.10E13	3.00E13	2.20E12
21.0	20	8.40E12	8.40E13	9.00E11

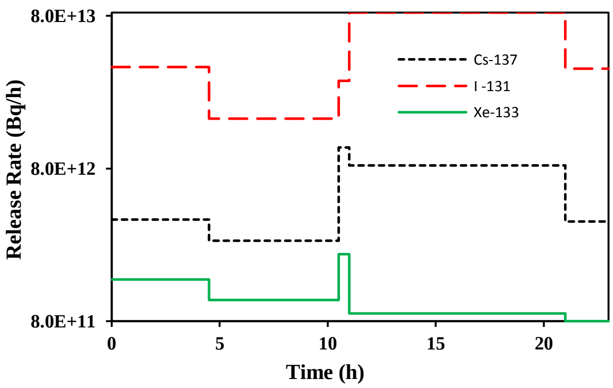

Fig. 1. Plot of the simple and arbitrary ST data of a fictitious nuclear power plant accident from Table 1.

Initially, the release rate drops slightly and remains relatively constant for almost ten and a half hours from the beginning. After this period, the release rates spike for the next half an hour, then the release rates for ^{137}Cs and ^{133}Xe drop again. However, for ^{131}I, the release rate increased even more, assuming favorable conditions. As per the chart in Fig. 1, the accident scenario is as follows: After the accident, the nuclides started to release at zeroth hour; For the first four and half hours, the nuclides were released at a stable rate, measured at 3.7E12 [Bq/h] for ^{137}Cs, 3.7E13 [Bq/h] for ^{131}I, and 1.5E12 [Bq/h] for ^{133}Xe. This high release of Iodine is attributed to the failure of Iodine retention devices in the ventilation systems. After this initial period, the nuclides continued to be released at these rates for the next ten hours. After that, the release rates were dropped for all nuclides and continued at a lower rate for the following two hours.

The data from Table 1 were also used to prepare an ST manually in the JRODOS platform, which is shown in Fig. 2. Figure 3 shows the ST plot produced by JRODOS from an XML file generated. By Visual Basic code (Annexure-II) using data from Table 1. Figure 4 shows the input window for the necessary data to generate a JRODOS-compatible XML file from the ST data in the “CreateXML”.

Sheet in Microsoft Excel. The “SourceTerm” Sheet contains the ST data from Table 1. (not shown in Fig. 4)

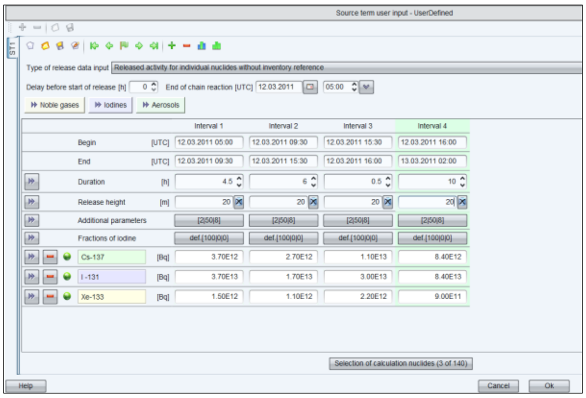

Fig. 2. Preparing ST manually in the JRODOS platform using data from Table 1.

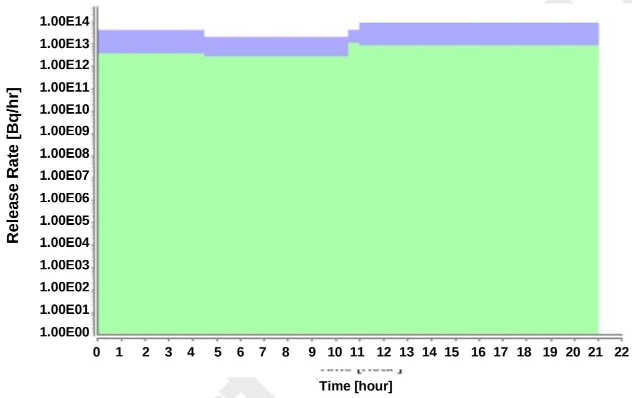

Fig. 3. ST plot produced by JRODOS from visual basic code generated XML file (Annexure-II) using data from Table 1, only ^{137}Cs and ^{131}I data are shown for convenience and colored green and purple respectively.

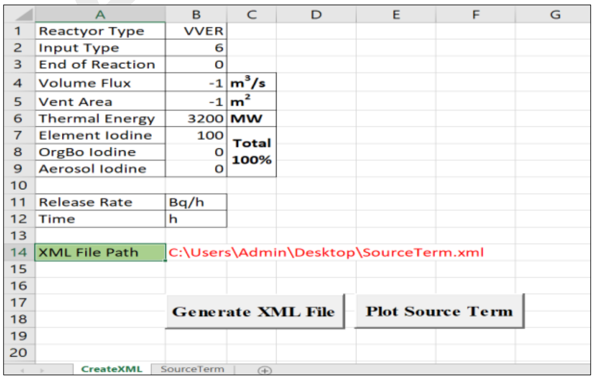

Fig. 4. Data input window to generate JRODOS-compatible XML file from the ST data in the Microsoft Excel.

RESULTS AND DISCUSSION

When manually inserting ST data into the JRODOS platform, as the number of nuclides and the duration of data increases, keeping track of the data becomes increasingly difficult. JRODOS can handle up to 140 nuclides simultaneously, with no apparent limitation on the maximum duration or number of release intervals. A typical ST data set often has more than a hundred nuclides with lots of release intervals depicting an accident scenario when generated from a standard computational code, e.g., RASCAL, ORIGEN 2, MELCOR, SCDAP, or SPARC, etc. [3-4]. With that kind of large data set, using an XML file imported directly into JRODOS is more effective. The developed code effortlessly generates an XML file on demand from any given ST data set. The Fukushima Dai-ichi disaster was studied [6-12], and a list of sample ST data was collected [8] (Table 2). ST data from Table 2 were plotted (Fig. 5) using visual basic (Annexure-I) code and compared with the data reported in [9] (Fig. 6). Furthermore, the ST data from Table 2. were used by the developed code to generate the JRODOS-compatible XML file and upon importing the XML file to the JRODOS platform it generated the ST plot (Fig. 7) over the specified timeline which was in good match with the plot generated by the developed code (Fig. 5) verifying the reliability of the code.

Table 2. Sample ST data from the Fukushima Dai-ichi disaster [9].

hourth	^{137}Cs	^{131}I	hourth	^{137}Cs	^{131}I
4.5	3.7E12	3.7E13	232.0	1.4E13	1.4E14
10.5	1.7E12	1.7E13	258.0	4.7E12	4.1E14
11.0	3.0E14	3.0E15	283.0	8.9E12	7.1E14
42.0	8.4E12	8.4E13	307.0	2.9E12	1.9E14
54.0	3.6E12	3.6E13	342.0	1.2E12	5.6E13
54.5	3.0E14	3.0E15	389.0	1.7E11	4.0E12
64.5	2.3E12	2.3E13	424.0	4.7E12	7.5E12
67.0	1.3E14	1.3E15	438.0	8.8E12	1.5E13
74.0	4.0E13	3.5E14	451.0	1.4E14	1.8E14
77.0	3.0E14	3.0E15	473.0	4.5E12	2.4E13
80.0	8.0E12	8.0E13	508.0	1.6E12	1.8E12
84.0	4.0E14	4.0E15	556.0	5.8E11	1.8E12
121.0	3.0E12	2.1E14	636.0	1.4E11	7.0E11
178.0	1.0E13	4.1E14	786.0	3.5E11	7.0E11
214.0	3.5E13	3.8E14	1195.0	1.8E11	7.0E11

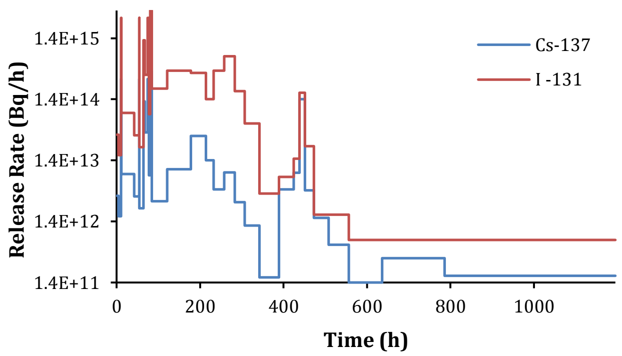

Fig. 5. ST is plotted using the visual basic code (Annexure-I) from ST data [8] in Table 2.

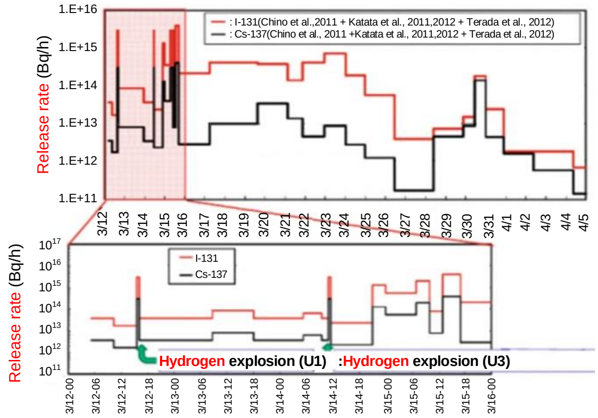

Fig. 6. Estimated ST release to the environment from the Fukushima Daiichi Disaster.

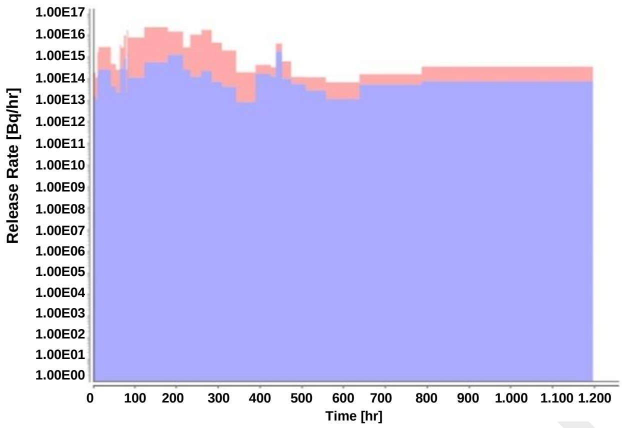

Fig. 7. ST plot produced by JRODOS using the XML file generated by the visual basic code (Annexure-I). ^{137}Cs and ^{131}I data are colored in lavender blue and melon respectively.

The generated XML file was integrated smoothly into the JRODOS platform. However, any deviation from the RODOS format while inserting necessary information in the Excel spreadsheet might make the integration of the produced XML file into the JRODOS unsuccessful. For example, incorrect specification of the “Reactor Type” could render the XML file unrecognizable by the platform. Generally, the available options for “Reactor Type” include PWR, BWR, and VVER The release height parameter must be set to a minimum of 10 m. Should a value between 0 and 10 meters be specified within any release time interval, JRODOS will automatically adjust the release height to 10 m for that time interval. Improper assignment of the "Input Type" parameter (as shown in Fig. 4) might cause an error notification. The “Input Type” values correspond to one of six predefined release types (F1 to F6) discussed in prior sections. Specifically, in the case of F2, JRODOS considers the preset inventory reference.

With operating in mode F2, where the “Input Type” is set to 2, JRODOS performs a validation at each time step to ensure that the cumulative activity is present in the reactor. The calculation incorporates the activity released from the reactor, as well as the effects of radioactive decay and the accumulation of progeny from decay chains within the reactor. For mode F6, if the preset inventory reference is not employed, the "Input Type" must be configured to 6.

One notable limitation of the JRODOS platform is its inability to recognize certain radionuclides. For example, tritium (H-3) is not recognized by JRODOS, and inclusion in the XML file would cause a warning notification. Furthermore, any XML format containing radionuclides not present in the predefined radionuclide library within JRODOS will not be accepted by the JRODOS platform. In such cases, the unrecognized radionuclides should be excluded from the XML file, potentially leading to incomplete analysis results.

CONCLUSION

A visual-basic-based computer code has been developed that effectively converts complex Source Term (ST) data, including numerous radionuclides and release intervals provided in spreadsheet format, into an XML file compatible with the JRODOS. This XML file can then be used as an input for nuclear accident analysis within JRODOS. The newly developed code greatly facilitates the customization of ST data, which is a crucial component in the calculation of atmospheric dispersion of radionuclides released during nuclear accidents. The customization capability allows for the evaluation of various accident scenarios and the optimization of ST parameters.

However, a limitation of the developed solution is its reliance on Microsoft Excel, which is not freely available software. Although the Excel spreadsheet interface is designed to be self-intuitive and user-friendly, alternative approaches could be explored to enhance accessibility. For instance, the developed code could be rewritten using alternative programming languages, such as Python, to ensure broader usability. Panda is an open-source library, a Python package, that allows operations for manipulating numerical data and time series within various data structures. Nevertheless, certain functionalities available through Excel’s built-in command functions may need to be manually implemented in Python. It should be noted that some Excel command functions are version-specific, meaning that certain commands available in newer versions of Excel may not be compatible with older versions, and vice versa. Furthermore, a simple user interface could be developed in phyton to streamline the handling of ST data, thereby enhancing user experience and broadening the code's applicability.

ACKNOWLEDGMENT

The authors gratefully acknowledge and highly appreciate the technical support provided by the Karlsruhe Institute of Technology (KIT), Germany, while working with the computational code JRODOS.

AUTHOR CONTRIBUTION

S. M. T. Hassan and M. T. Chowdhury are the main contributors to this paper. All authors read and approved the final version of the paper.

SUPPLEMENTARY FILES

Supplementary data to this article can be found online at: https://atomindonesia.brin.go.id/index.php/aij/article/view/1432/1157

REFERENCES

1. B. E. R. Lulik, D. Demontigny, E. M. A. Hussein. *Simplified Approach to Source Term Estimation for SMRs*. 38th Annual Conference of the Canadian Nuclear Society and 42nd Annual CNS/CNA Student Conference, Canada (2018) 3.
2. U. S. NRC, Code of Federal Regulations, Title 10, Chap. 1, Sec. 50.2, U.S. Government Printing Office, Washington, D.C (2024). https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0002.html Retrieved in March (2024)
3. A. L. Sjoreen, J. V. Ramsdell, Jr., T.J. McKenna *et al.*, *RASCAL 3.0: Description of Models and Methods (NUREG-1741)*, U.S. Nuclear Regulatory Commission, Washington, D.C. (2001).
4. IAEA, *Derivation of the Source Term and Analysis of the Radiological Consequences of Research Reactor Accidents*, Safety Reports Series No. 53, Vienna (2008) 1.
5. M. Chino, H. Nakayama, H. Nagai *et al.*, J. Nucl. Sci. Technol. **48** (2011) 1129.
6. I. O. Ievdin, O. V Khalchenkov, W. Raskob *et al.*, Intl. J. Energy Clean Environ. **13** (2012) 179.
7. T. Kobayashi, H. Nagai, M. Chino *et al.*, J. Nucl. Sci. Technol. **50** (2013) 255.
8. H. Terada, G. Katata, M. Chino *et al.*, J. Environ. Radioact. **112** (2012) 141.
9. S. Takahashi, *Radiation Monitoring and Dose Estimation of the Fukushima Nuclear Accident*, Springer Open, Osaka, Japan (2014) 28.
10. G. Katata, M. Ota, H. Terada *et al.*, J. Environ. Radioactiv. **109** (2012) 103.
11. A. Stohl, P. Seibert, G. Wotawa *et al.*, Atmos. Chem. Phys. **12** (2012) 2313.
12. P. M. Udiyani, S. Kuntjoro, S. Widodo, Atom Indones. **42** (2016) 63.
13. M. A. Khaer, M. A. Hoq, S. M. T. Hassan *et al.*, Nucl. Eng. Des. **415** (2023) 112727.
14. K. M. Z. Zihan, M. A. Khaer, M. A. Hoq *et al.*, Atom Indones. **48** (2022) 215.
15. S. S. Shiuli, M. A.Khae, M. M. Islamr *et al.*, Int. J. Adv. Nucl. Reactor. Des. Technol. **4** (2022) 70.
16. I. Ievdin, D. Trybushnyi, C. Landman, JRodos Customization Guide, Ver. 3.01, Karlsruhe Institute of Technology, Institut für Kern-und Energietechnik (2017) 52.