Description of the Source term reconstruction Model SSTR in RODOS

Version 1.0 (JRodos2019)

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Abbreviations, acronyms, denotations

ADM	Atmospheric Dispersion Model
KIT	Karlsruhe Institute of Technology (KIT)
MELCOR	fully integrated, engineering-level computer code developed by Sandia National Laboratories for the U.S. Nuclear Regulatory Commission to model the progression of severe accidents in nuclear power plants
Reconstruct KitIntern	SSTR SUM model
RODOS/LSMC	Local Scale Model Chain of RODOS

Abstract

A software tool for simple and fast estimate of source term using gamma dose rate measurements "at the fence" has been developed within WP4 of PREPARE Project by VUJE AS (Slovak Republic) and UCEWP (Ukraine) teams under the leadership of NCSR Demokritos (Greece).

([1], [2])

In 2019 the tool has been tested and extended at KIT. The purpose is a tool integrated in RODOS usable in emergency case.

This document is a short description of the first version including results of validation tests.

Theory and Methods

The Fukushima accident on 11 March 2011 pointed out the need of source term estimation for decision support systems using measured data outside the nuclear facility. In case of a severe nuclear accident, the source term may not known but is extremely important for the assessment of the consequences to the affected population. Therefore the assessment of the potential source term is of uppermost importance for emergency response.

Networks monitoring the ambient gamma dose rates are widespread used for public protection ([3]). There are different methods of source term reconstruction using gamma dose rate measurements ([4] -[9]).

One method uses data assimilation technique. (e.g. [5]), which allows to reflect uncertainties in meteorological data in an intrinsic way. An other method is inverse modelling. The drawback of this method is that it is ill-conditioned, which is indicated by a large condition number ([9]); that means: tiny differences in measurement values or model estimation due to input uncertainties may result in a drastically different source term estimation.

Therefore there is the need for a proper regularization with the aid of first guess estimations of the release rates ([8]), constraints ([7]) or other regularization methods ([6]).

Separation of the species can be achieved only from their different atmospheric transportation properties or from different physical half-life in the case of nuclides. These effects are reflected in the SRS matrix, however, they are very weak. ([6])

Nuclear facilities are in general equipped with gamma dose rate measurement stations at their perimeters.

The SSTR model implemented in RODOS is designed to use gamma dose rate data of stations nearby the release source. This constraint reduces the travel time of the contaminated particles to ca. 10 minutes. During this time the weather conditions do not change significantly. Therefore the uncertainty of weather conditions has been eliminated from modelling.

The disadvantage of this model ansatz is that during 10 minutes the differences of radionuclide properties (radioactive decay, deposition velocities) will result in only small differences in the gamma dose rate data. Therefore the SSTR model is not well suited to estimate the nuclide vector from the gamma dose rate measurements.

A reasonable assumption for the atmospheric dispersion of the radionuclides is a linear dependancy of the local gamma dose rate from the release rates. ([6]) The resulting linear model can be written as equation

$$\mathbf{y} = \mathbf{H} \cdot \mathbf{x} \qquad (1)$$

x is the source term vector of dimension N, N the number of radionuclides

y is the gamma dose rate measurement vector of dimension M, M the number of sensors showing a signal.

M is the source-receptor-sensitivity (SRS) matrix of dimension M×N.

The SSTR model reduces the total number of possible emitted radionuclides by representative radionuclides for 10 MELCOR nuclide groups. The SSTR model calculates the SRS-matrix **H** using pre-calculated data resulting from atmospheric dispersion simulations with RODOS for 1Bq release source terms for each representative of the 10 MELCOR nuclide groups.

Details of the SSTR Model

The SSTR model runs in a loop of 10-minutes cycles. In each cycle there is a diagnosis step followed by an analysis step. The effect of deposited activity is not considered in the actual version. This constraint is acceptable because the maximum value of dose rate from the ground is approximately equal to 1⁄4 of maximum value of dose rate from cloud for Cs-137. ([2])

But this means: There will be no effect of precipitation seen in the SSTR-results.

Diagnosis Step

The near range atmospheric dispersion simulation is determined by the atmospheric conditions in the planetary boundary layer and the release height. The pre-calculated data have to cover all possible dispersion scenarios. The SSTR model reads in the diagnosis step the relevant scenario parameters and calculates the elements of the corresponding source-receptor-sensitivity (SRS) matrix using the pre-calculated data and reflecting the gamma dose rate data of the perimeter stations. The pre-calculated data reflects the following parameters:

Wind direction

For the small region around the nuclear facility the assumption of isotropic conditions for the atmospheric dispersion is reasonable. This model feature allows to reduce the pre-calculated dispersion simulations for only one direction on a very fine grid. In the diagnosis step SSTR reads from the meteorological information the direction of the 10m-surface wind and maps the station positions by rotation from the stationary coordinate-system into the coordinate-system used by the atmospheric dispersion simulation.

Surface wind speed

The pre-calculated dispersion simulation data deliver information for the following 10 intervals of the 10m-surface wind (unit [m/s]):

1 : [0.0 < u10 <= 0.3]

2 : [0.3 < u10 <= 1.0]

3 : [1.0 < u10 <= 2.0]

4 : [2.0 < u10 <= 3.0]

5 : [3.0 < u10 <= 4.0]

6 : [4.0 < u10 <= 6.0]

7 : [6.0 < u10 <= 8.0]

8 : [8.0 < u10 <= 12.0]

9 : [12.0 < u10 <= 16.0]

10 : [16.0 < u10]

In the diagnosis step SSTR reads from the meteo information the 10m-surfeace wind and estimates the corresponding wind speed interval from the pre-calculated data.

Pasquill-Gifford stability category

The pre-calculated dispersion simulation data deliver information for the 6 Pasquill-Gifford stability categories. In the diagnosis step SSTR reads from the meteo information the stability category and uses the corresponding pre-calculated data.

Building height

The SSTR model is designed for the source term estimation of severe accidents. Therefore the building height of the nuclear facility is used as release height. SSTR reads the building height of the nuclear facility from the RODOS Database. The code for unknown building height in the RODOS Database is “-1”. For unknown building height SSTR uses 50.0m as release height.

The pre-calculated dispersion simulation data deliver information for the following 5 intervals of building height (unit [m]):

1 : [0.0 < HRB <=45.0]

2 : [45.0 < HRB <=55.0]

3 : [45.0 < HRB <=65.0]

4 : [65.0 < HRB <=75.0]

5 : [75.0 < HRB]

In the diagnosis step SSTR determines the corresponding building height interval from the pre-calculated data.

One should have in mind the interval borders used inside the SSTR model for surface wind speed and building height preparing gamma dose rate data via dispersion simulations for tests. Investigation of the dependency of SSTR results from building height with a scenario of a noble gas release showed only a weak effect.

Analysis Step

Equation (1) is a system of M linear equations for N unknowns for each 10-minutes cycle. The SSTR model is designed to deliver a source term of type “Released activity for selectable nuclide groups” with 10 MELCOR groups. Therefore there are 10 unknowns. The number of stations with gamma dose rate data above the threshold defines M. This means: The value of M is scenario dependant. The plume of a release in unstable atmosphere (PG-class A) is much broader than that of a release in stable atmosphere (PG-class E). Therefore M will normally be larger for PG-class A than for PG-class E.

The SSTR model has two different analysis modes:

- The original methodology hereinafter referred to as the "PREPARE-model"
- a simple methodology using the nuclide vector information for 10 MELCOR groups given by the user hereinafter referred to as the "SUM-model”

Both methodologies are based on pre-calculated normalized dose rates for all detector points, several release heights, given meteorological situations and for unit released activities of representative nuclides. The source term for a 10 minute period is estimated from measured gamma dose rates reflecting the actual meteorological situation. The effect of gamma dose rate by deposited activity is not taken into account yet.

The PREPARE modelling

The PREPARE model delivers a special solution of a system of M linear equations for 10 nuclide groups. The number of equations is given by the number of detectors receiving a signal in the 10-minutes period. In normal case with $M<10$ the resulting source term may differ from the real source term. The modelling has been extended in order to reflect nuclide vector information. But this mode is of primarily experimental nature.

Equation (1) is a set of M linear algebraic equations for N unknowns. There are different cases to consider:

- $M<N$, no degenerate equations :

  there is either no solution or a solution space of dimension N-M consisting of a particular solution $\mathbf{x_p}$ added to a linear combination of vectors. Tests for site Borssele show that in many scenarios less than 10 stations will deliver gamma dose rate information. In this case the PREPARE model can only deliver a particular member of the solution space for the estimated source term which may differ strongly from the real source term.

- M = N, no degenerate equations :

  there is one solution

- $M>N$:

the set of equations is overdetermined. In general there is no solution for the equation. But there is a set of normal equations which will deliver a best fit.

The SUM model

Estimation of the nuclide vector from gamma dose rate measurement information is difficult because the week effects of different atmospheric transportation properties and physical half-life of nuclides on separation of species. Often there is a good guess of the type of accident, which leads to a reasonable assumption of the nuclide vector of the source term.

The SUM model uses existing nuclide vector information to overcome the lacking results information delivered by the PREPARE-model. With known nuclide vector there is only one free parameter. In case of M>1 the set of equations is overdetermined. The SUM model delivers a best "compromise" solution.

Despite the fact that the basic concept of the SUM model is simple the estimation of the releases is not easy. The model evaluates the applicability of a gamma dose rate measurement of each station for the release estimation.

The constraint of a constant nuclide vector in time has to be in mind using results of the SUM model for source terms with temporally variable nuclide vector like FKA. ([12])

User input interface

The tool delivers a source term of type "Released activity for selectable nuclide groups" with 10 MELCOR groups. The JRODOS-version displays the release estimation in different plots. The actual JRODOS-version displays the mean values only. The confidence intervals will be shown in a future JRODOS-version.

The user defines in the user interface of the tool the time interval of interest. The tool delivers the source term for consecutive 10 minutes periods for the specified time interval. Figure 1 shows a typical input window of the user interface.

The PREPARE model evaluates the release of the different nuclide groups itself for each time-step. It is able to reconstruct the source-term with varying nuclide vector. Therefore the user shall not specify for the PREPARE model the nuclide vector. The user shall only indicate those nuclide groups with no release by the value 0. All other values should be 1.

The SUM model instead assumes a constant nuclide vector specified by the user. The user may split the release time interval for source-terms with varying nuclide vector in different consecutive time intervals.

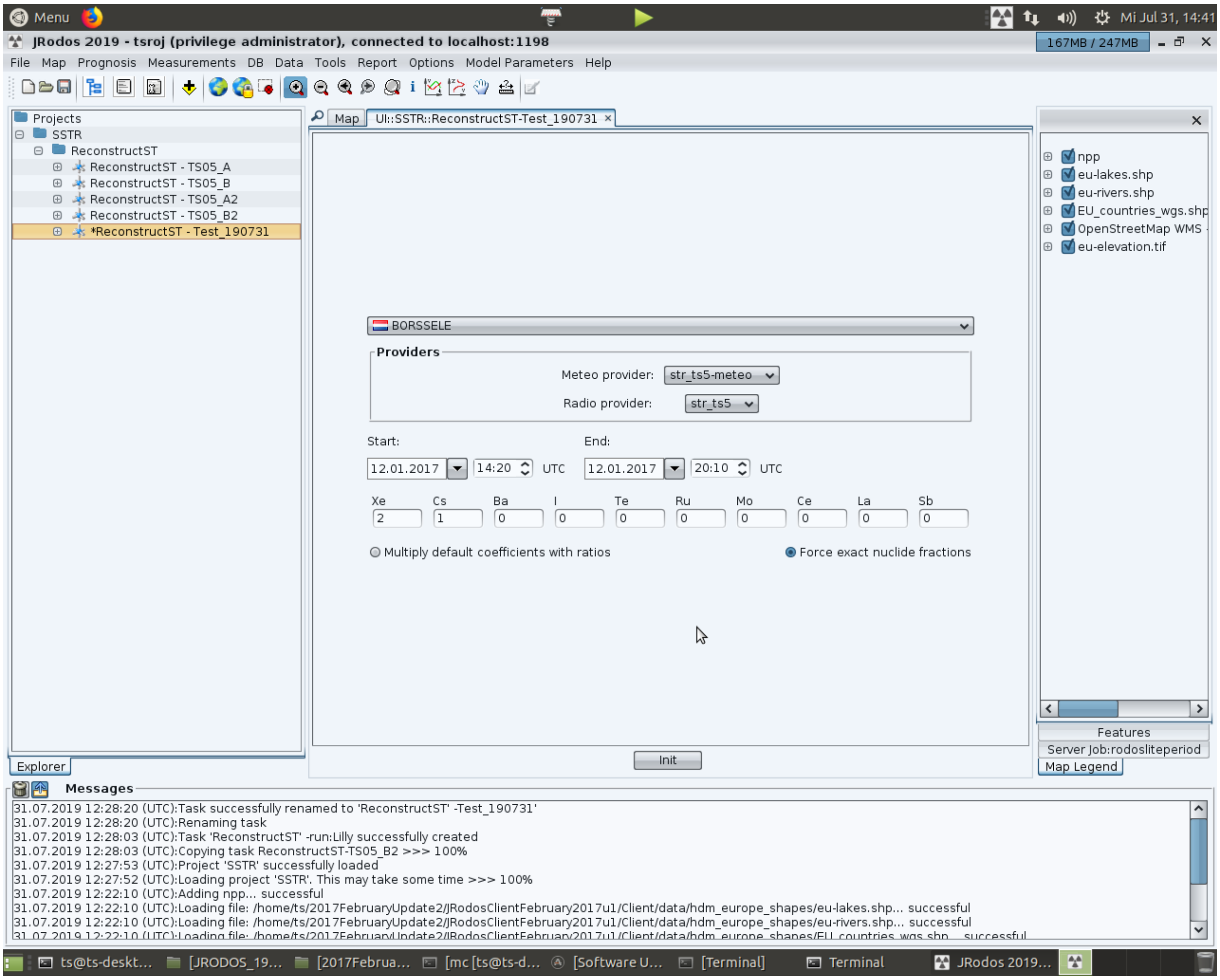

Figure 1: User Input Window

Validation Tests

Simple test case

A simple test scenario has been used in order to test the tool. Measured gamma dose rate values have been created by a RODOS/LSMC-run. These data have been used for source term reconstruction. The effect on the areas affected by the countermeasure actions proposed by RODOS have been demonstrated. The test performed by an earlier implementation of the SSTR model is described in [10].

SSTR tests with RODOS Version 2019

The results of one of the test runs [11] with the SSTR model in RODOS Version 2019 are shown in this section.

Scenario 39: Site Borssele, 12. Jan 2017 14:00 – 20:00

Source term : Xe-133 1E17Bq ; I-133 1E16Bq ; Cs-137 1E15Bq

Meteo by user : (10m ; 225° ; 2m/s ; PG-Class D ; 0mm/h)

The comparisons of the estimated source terms by the SSTR model with the original one show good agreement. Especially the SUM model reproduces the source term nicely in case of constant nuclide vector in time.

The gamma dose rate values at station 012 of a dispersion simulation with the source term estimation delivered by the SSTR model show also good agreement.

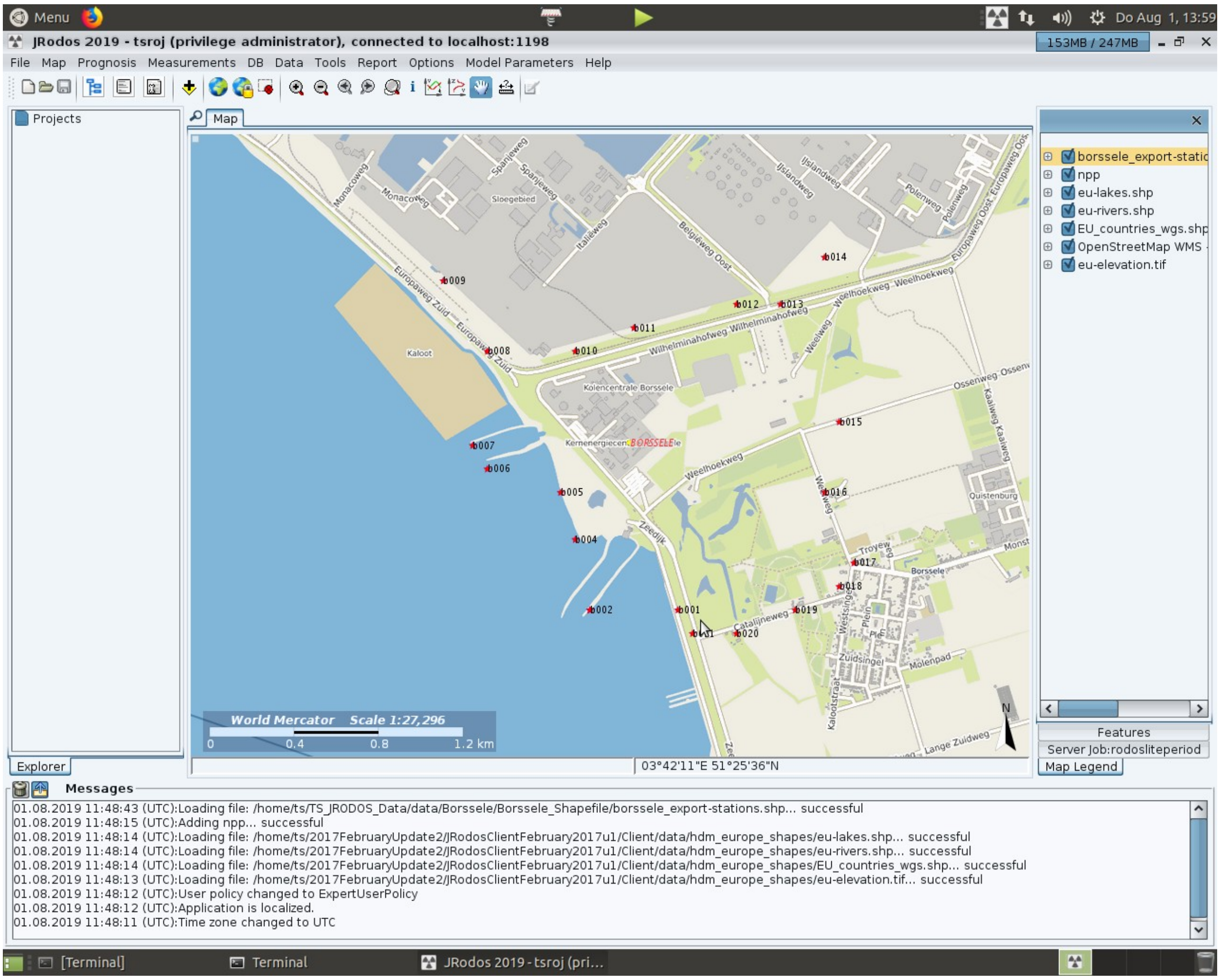

Figure 2: Gamma Dose Rate Stations around Site Borssele

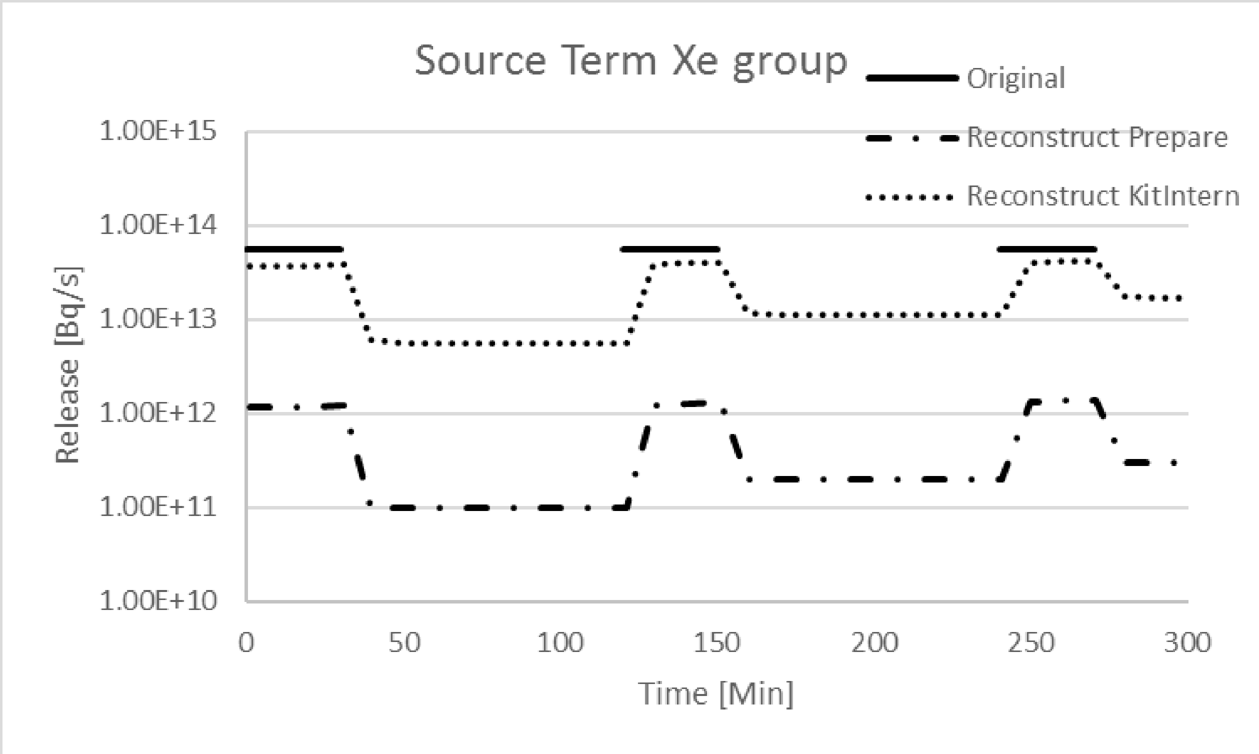

Figure 3: Release for noble gas group of MELCOR 10 source term

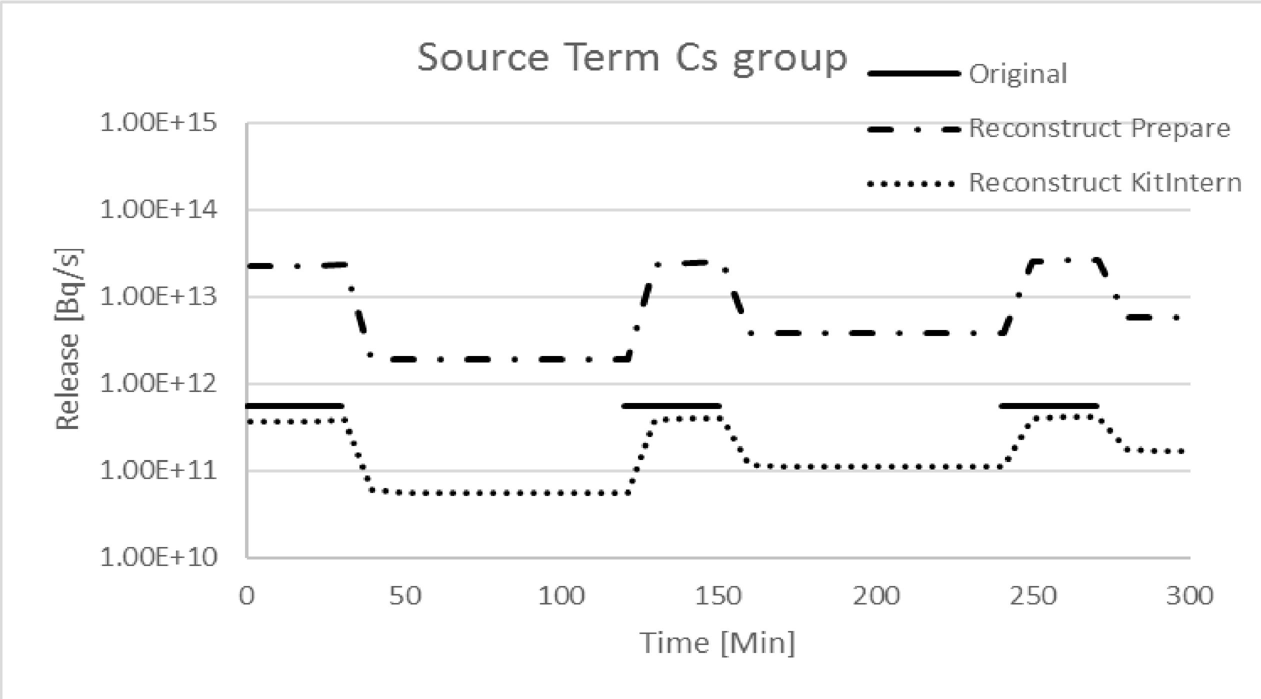

Figure 4: Release for aerosol group of MELCOR 10 source term

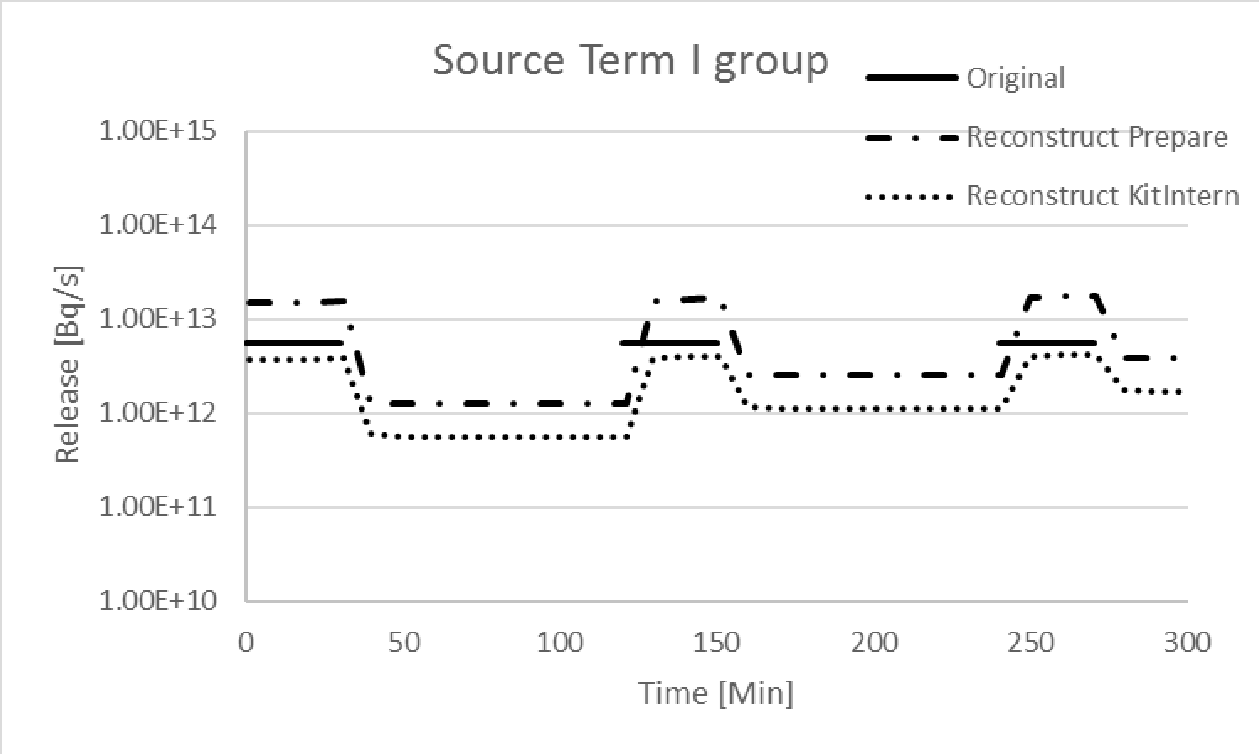

Figure 5: Release for iodine group of MELCOR 10 source term

Comparison of “measured” gamma dose rate data with estimated gamma dose rate data by the SSTR model for station 012.

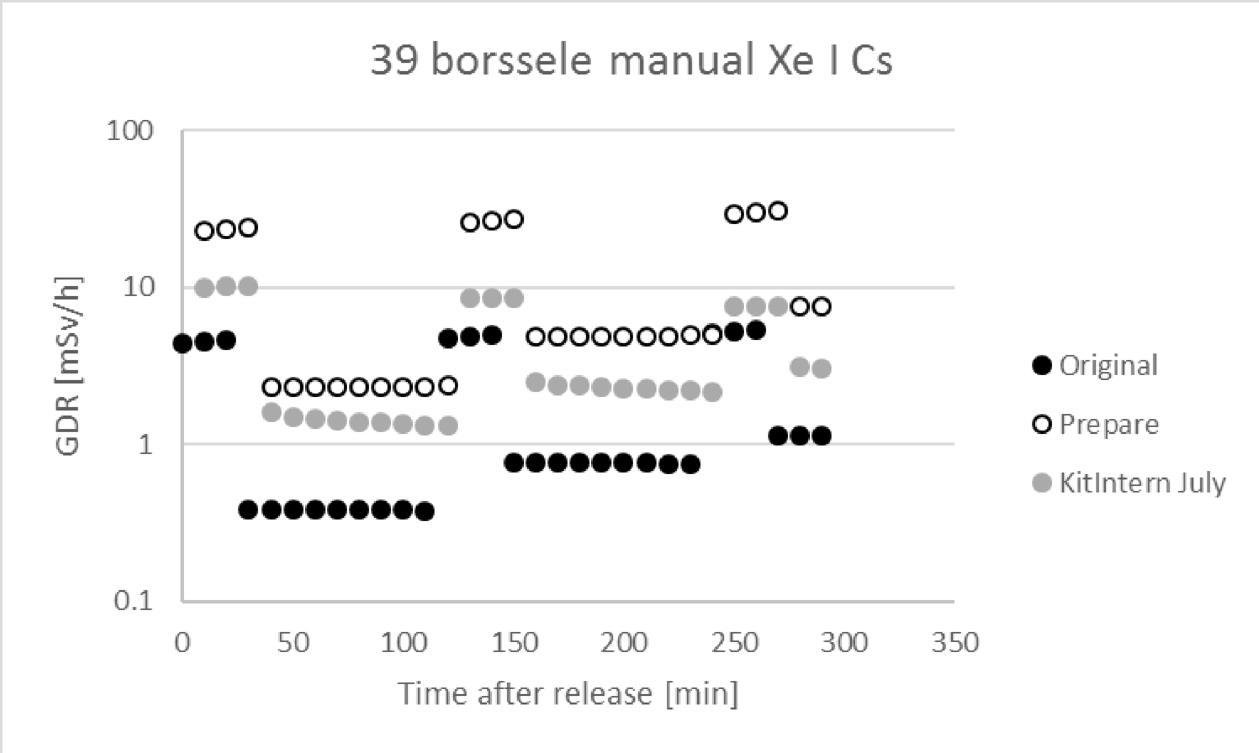

Figure 6: gamma dose rate for station 012

Summary and Outlook

A first implementation of a software tool for simple and fast estimate of source term using gamma dose rate measurements "at the fence" ([1], [2]) in RODOS has been described. Validation tests indicate that the SSTR model may be helpful reconstructing an unknown source term in case of severe accident.

Improvement of the SSTR model may be accomplished by:

- consideration of deposition effects (dry and wet)
- compilation of improved pre-calculated data for the different RODOS-ADM

References

[1] Juraj Duran, Tatiana Duranova, Jarmila Bohunova , Ivan Kovalets, Dmytro Trybushnyi *Software tool for simple and fast estimate of source term using gamma dose rate measurements at the fence,* PREPARE(WP4)-(16)-06, 2016

[2] Juraj Duran, Jarmila Bohunova, Tatiana Duranova *Methodology and computational methods for simple estimate of source term using gamma dose rate measurements at the fence*, PREPARE(WP4)- (13)-03

[3] Bundesamt für Strahlenschutz (BfS) *The Integrated Measuring and Information System (IMIS),* https://www.bfs.de/EN/topics/ion/accident-management/bfs/environment/imis/imis.html

[4] Michael Hutchinson, Hyondong Oh, Wen-Hua Chen *A review of source term estimation methods for atmospheric dispersion events using static or mobile sensors,* Information Fusion 36 (2017) 130–148

[5] V. Tsiouri, I. Kovalets, S. Andronopoulos, J.G. Bartzis *Emission Rate Estimation through Data Assimilation of Gamma Dose Measurements in a Lagrangian Atmospheric Dispersion Model*, Radiation Protection Dosimetry 148 (2012) 34-44

[6] O. Tichy, V. Smidl, R. Hofman, N. Evangeliou *Source term estimation of multi-specie atmospheric release of radiation from gamma dose rates*, Q J R Meteorol. Soc. 144 (2018) 2781-2797

[7] O. Saunier, A. Mathieu, D. Didier, M. Tombette, D. Quelo, V. Winiarek, M. Bocquet *An inverse modeling method to assess the source term of the Fukushima Nuclear Power Plant accident using gamma dose rate observations*, Atmos. Chem. Phys. 13 (2013) 11403-11421

[8] I. Kovalets, S. Andronopoulos, R. Hofman, P. Seibert, I. Ievdin, O. Pylypenko *Advanced Source Inversion Module of the JRODOS System*, Chapter 10 in book : *Pollutants from Energy Sources - Characterization and Control*, Springer (2019) 149-186, ISBN: 978-981-13-3280-7

[9] X. Zhang, W. Raskob, C. Landman, D. Trybushnyi, Y. Li *Sequential multi-nuclide emission rate estimation method based on gamma dose rate measurement for nuclear emergency management*, Journal of Hazardous Materials 325 (2017) 288-300

[10] T. Schichtel *Source term reconstruction for RODOS*, RODOS Technical Note KIT-190329-1

[11] Tests performed by the RODOS team

[12] H. Löffler, O. Mildenberger, M. Sogalla, T. Stahl *Aktualisierung der Quelltermbibliothek des Entscheidungshilfesystems RODOS für Ereignisse im Leistungsbetrieb - Vorhaben 3609S60009*,

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