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SOURCE TERM ASSESSMENT SOFTWARE FOR ATMOSPHERIC RELEASES OF RADIOACTIVE GASES AND AEROSOLS DURING DISMANTLEMENT OR DEMOLITION OF BUILDINGS AND STRUCTURES WITH RADIOACTIVE CONTAMINATION

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The article summarizes the main results in the development of a source term assessment software for atmospheric releases of radioactive substances during dismantlement or demolition of contaminated buildings and structures. The software allows to give consideration to some physical features of the term source formation given some actual scenarios of demolition or dismantlement technological process. These include formation of aerosols and dust caused by dropped materials, formation of aerosols due to contaminated materials cutting, release suppressing by fixatives, etc. The software application allows to calculate the amount of activity released into the environment, as well as the characteristics of the particle spectrum depending on the diameter. This data can be used as input one for the transport module of computational and forecasting software being designed to ensure the radiation safety of nuclear power facilities both during their operation and decommissioning, including the assessment of atmospheric release parameters, modeling atmospheric transport of radioactive substances, estimation of radiation situation parameters and decision making on the necessity and effectiveness of countermeasures.

Keywords: *source term assessment, dismantlement and demolition of buildings, radiation situation, atmospheric transport models, safety case for nuclear power facilities.*

Introduction

In terms of radioactive releases into the atmosphere, their source term assessment is believed to be a key task in evaluating possible consequences of abnormal radiation occurrences. Availability of information about the source term enables to calculate relevant parameters of the radiation environment using atmospheric transport modeling, based on which decisions on the implementation of certain countermeasures are made.

The software tool considered in this article was designed for source term assessments performed at the stage of dismantlement or demolition of decommissioned nuclear facilities (including the nuclear legacy ones), and can be also used to solve similar problems in the field of radioactive waste (RW) management. Its development was seen as an attempt of providing engineering solutions to problems in this area of research and practice.

Modern practices [1, 2, 3] of estimating atmospheric emissions during demolition of buildings and structures contaminated with radioactive substances were analyzed. It was found that except for the application of a few empirical data on formation, release and suppression of aerosol emissions no approaches being comprehensively supported by a constant base are available to date. This is explained by a number of facts, namely: small number of studies in this area and, therefore, no measurement data obtained during practical operations performed at industrial sites; great variability of operational conditions; design and engineering features of each dismantled (demolished) facility. For this reason, an approach suggesting the use of a five-factor formula [3] was chosen for such source term assessment. All components of this formula depend on demolition/dismantlement process features, including the flowchart of operations performed (for example, material cutting, retrieval of generated waste (hereinafter referred to as cleanup)). For all considered dismantlement scenarios, the possibility of applying emission reduction tools and operations is provided for in the software: these are being set forth by scenario modifiers affecting the total release of radioactive substances into the atmosphere. The modifiers allow to account for the influence of some additional demolition factors on the activity releases into the atmosphere, for example, such as the use of pollution detectors, misting, etc.

When estimating the amount of radioactive releases into the atmosphere, both with and without dust suppression measures, the developed software allows to account for the dismantling methods being applied, as well as the type of dismantled construction materials. The software is implemented using a scripting technology. Under a single scenario, this technology allows to upgrade, modify and develop new tools and scenarios without their recompilation using a common template. Moreover, via staged superimposition of scenario modifiers it allows to describe parameters of resulting aerosols and account for non-linear effects of these modifiers on aerosol parameters. The software can be adapted to solve problems associated with other not previously considered methods of demolition/ dismantlement given any type of buildings and structures. To do this, appropriate experimental or expert parametric support of such methods is required. The software can be also integrated into more complex calculation and forecasting software packages. In this case it can be used as a preprocessing module supporting atmospheric impurity transfer models with input data on the source term parameters.

Provided below is the description of the developed software and its extension mechanisms (supplementation/ modification of tools and scenarios). Some of the parameterizations provided for under the first version of the software are based on empirical data from [1] which was focused on estimating radioactive releases into the atmosphere during dismantlement of a plutonium production plant (hereinafter — PPP) in the US.

Source term assessment method

As noted above, ST (source term) standing for the atmospheric release of radioactive substances is determined by a five-factor formula proposed in [3]:

$$ST = MAR \times DR \times ARF \times RF \times LPF, \qquad (1)$$

where MAR (material at risk) is the maximum or expected amount of radioactive substances that can be affected by a given physical impact;

DR (damage ratio) is MAR fraction being actually affected by demolition (dismantlement) of building structures. It is estimated based on the reaction of structural materials to the type and level of impact. Values assumed for PPP are as follows [1]: 0.1—0.9 — for cutting with shears, 0.5 — for the explosive method;

ARF (airborne release fraction) stands for DR fraction released into the air in the form of aerosols available for subsequent transport in the atmosphere. In [2], it was estimated that ARF can range from $6 \cdot 10^{-6}$ to $3 \cdot 10^{-3}$;

LPF (leak path factor) stands for ARF fraction (airborne release fraction) that has passed through the deposition system (air ducts, industrial premises), emission reduction system (misting, contaminant retainers), trapping and filtering system (HEPA filters, sand filters) and escaped from technological premises, tanks and protective shielding. This parameter is derived from calculations, experimental measurements or expert assessments and depends on the material, air transport mechanism, losses due to precipitation and effectiveness of dust suppression and filtration methods. For example, the value adopted in [1] for the PPP accounted for 0.1;

RF (respirable fraction) stands for the fraction of radioactive material being present in the form of air particles carried by air and inhaled by humans. It's commonly assumed that the equivalent aerodynamic diameter for the particle respirable fraction amounts to 10 μm or less [3]. Given an external physical impact, this parameter depends on a large number of factors. To take into account particle sizes, integral parameter RF in this study was replaced by relevant distributions (table 1) of particle masses in the emission over aerodynamic equivalent diameters corresponding to the polydisperse distribution.

Table 1. Particle mass distribution over the diameter ranges

The range of particle diameters, μm	Share from the total particle mass in the release* (stage of building demolition)	Share from the total particle mass in the release [1] (removal of waste resulted from demolition)
0–2.5	0.807	0.11
2.5–5.0	0.129	0.09
5.0–10.0	0.049	0.15
10.0–15.0	0.010	0.13
15.0–30.0	0.0044	0.26
> 30.0	0.0006	0.26

* Distribution of particle mass by diameter is calculated based on a hypothesis assuming that the mass of particles relative to their size is described by a lognormal distribution with a median of 1 μm.

Based on the given spectrum of radioactive particles in air (table 1), a modified formula was applied in the software to take into account the influence of dust suppression and polydispersity methods:

$$ST(MR) = MAR \times (damageMAR(MR) + notDamageMAR(MR)). \quad (2)$$

Here:
damageMAR is the damaged part of material, which can be expressed as follows:

$$damageMAR(MR) = DR \times ARF \times MR \times LPF; \quad (3)$$

notDamageMAR is a fraction of material not being directly affected by the demolition method, but solely subjected to the concomitant vibrational effects of heavy equipment, shocks, movements, etc. This value can be expressed as follows:

$$notDamageMAR(MR) = (1 - DR) \times ARF \times MR \times LPF. \quad (4)$$

In the above formulas (3) and (4): DR, ARF, LPF are defined above, but taking into account scenario modifiers that affect the total release of radioactive substances into the atmosphere;
MR (Mass Ratio) stands for the ratio of particle masses from a given range of particle diameters to the total mass of particles in the release, taking into account scenario modifiers;
(1 – DR) is the fraction of material not being directly affected during the demolition phase.
Initial values of DR, ARF, LPF, MR coefficients are set in the input file of the software. During software operation, these coefficients are modified in accordance with the selected scenario of demolition/dismantlement.

Input file description

Input file describes a series of demolition stages and the subsequent cleanup stages. It has an XML file extension. Names of scenarios can be used as keywords, the list of which can be expanded.

When filling in the input file, the particle distribution by size required for the calculation is entered, the stages of demolition are described step by step and, if necessary, after one or several stages of demolition, a cleanup stage is introduced.

In the particle size distribution, the entered interval values describe the diameter of dust particles in micrometers. Table 1 (first column) presents default interval values (in microns). For the demolition stage indicated were the following parameters: its duration (in hours), radionuclide inventory and their activities in the structure materials being subjected to physical impacts, as well as a list of available modifiers for the current scenario. The demolition scenario is set forth using the following key words: Shears — for demolition using shears (hydraulic, mechanical), Explosive — for demolition via explosive method, Storage — for storage of damaged materials. Key words specifying possible scenario modifiers, are as follows: Fixative_xxx for contamination fixatives (xxx — the number of fixation layers: 0 — no fixatives, 1 — one layer or 2 — double layer), Misting — for water mist and Coolant — for cutting tool cooling.

Under scenario assuming storage of materials generated as the result of demolition, two options are provided for: outdoor and indoor storage. Both options allow taking into account the mechanism of secondary dust elevation, for which specific ARF values are used. Otherwise calculations are carried out with basic ARF parameter specified in the input file.

The input file also sets the initial parameters of equation (2) that can be subsequently changed over (converted, replaced with a different empirical value or, in some cases, reset) depending on the availability and type of scenario modifiers. In this case, LPF parameter (fraction of material that passed through the deposition, emission reduction, trapping and filtration systems and escaped technological premises, tanks and protective shielding) is specified as a set of values with each one corresponding to its own interval in the size range of particles released into the atmosphere during demolition (dismantlement) of a building. Due to the conservatism of assessments, default LPF values are taken equal to 1. However, if relevant measurement data or expert estimates are available, the values can be redefined. When specifying particle spectrum (MR) characterizing the ratio between the mass of particles of a given size and the total mass of particles that entered the air during the demolition phase of a building, the particle fraction belonging to each size interval is calculated based on a hypothesis suggesting that the mass of the formed particles relative to their size is described by a lognormal distribution with a median of 1 μm (table 1, second column). The specified distribution can be also replaced by a customized one.

Scenarios dealing with the cleanup of materials generated after facility demolition are as follows: their cleanup in general case (density of the material subject to removal and the height from which it can possibly fall down are to be set), outdoor cleanup (used if there is additional data on wind speed and humidity), outdoor cleanup of steel sheets and concrete blocks.

For each cleanup scenario, duration of work (in hours), applied scenario modifiers and LPF and MR parameters (similar to the demolition stage) are considered as input data. Due to the conservatism of assessments performed, default LPF values are assumed to be equal to 1. Particle spectrum MR specified as the ratio between the mass of particles of a given size and the total mass of particles released into the air as a result of cleanup efforts performed, is set in accordance with the data given in [1] and presented in Table 1 (third column). The indicated distributions can be also customized by user.

Implemented building demolition (dismantlement) scenarios

A separate external file is responsible for the implementation of each scenario (demolition methods). This allows the user to develop demolition scenarios in a customized way, introduce changes to existing ones and add new scenarios without recompiling the program. Calculation procedures enabling to identify components of the formula (2) considering the influence of scenario modifiers on the final result are stored within a file describing each scenario.

Specific demolition (dismantlement) scenario is selected by a keyword, and its parameters stored in an external file are communicated to a common template. For each scenario, an array of possible scenario modifiers that modify the parameters of formula (2) is determined. Scenario parameters allow to consider the adequacy and influence of a particular modifier given the considered demolition stage. For example, cutting tool cooling cannot be used if an explosive method is considered.

General template contains the values of DR, ARF, MR, LPF parameters, as well as data on duration of demolition or cleanup stages and the particle diameter, which are set taking into account the use of all available scenario modifiers under corresponding template procedures. In addition, the template contains a special logical indicator depending on which the material either experiences a direct impact during demolition or only some complementary vibrational effects of heavy equipment, shocks, movements, etc. The value of this indicator is also set under a separate procedure.

Implementation of a demolition scenario using hydraulic shears

In the input file, keyword "Shears" should be used as such to select a demolition scenario using shears.

Relevant procedures are available to set the values of DR, ARF, MR, and LPF parameters and their modifications, also via the use of all available scenario modifiers from the input file. User is able to customize the procedures taking into account the empirical data available on these parameters.

Under the procedure applied for setting and modifying the DR value, all modifiers are taken into account as a multiplier to the value from the input file or entered by user.

Under the procedure applied for setting and modifying the value of the material fraction released into the air (ARF), the value communicated by the scenario modifier taking into account the secondary dust elevation (for example, by introducing the efficiency of a dust suppression system) is added to the current ARF parameter value taken from the input file or entered by user. The remaining modifiers are taken into account as a multiplier.

In the procedure for setting and modifying the ratio between the mass of particles from a given diameter range and the entire mass (MR), the modifiers affect each range of particle diameters in a different way, while the modifiers are taken into account as a multiplier.

In the procedure for setting and modifying the fraction of material passed through dust suppression systems (LPF), all modifiers are also taken into account as a multiplier.

Implementation of explosive demolition scenario

In the input file, keyword "Explosive" should be used as such to select a demolition scenario using the explosive method.

During explosive demolition, "Cutting Tool Cooling" modifier is not applicable. Therefore, under the explosive method, the effect of this modifier is omitted with a warning shown on the screen indicating the impossibility of its application. For the rest, setting and modification procedures for DR, ARF, MR and LPF parameters are similar to the tools applied under the shear demolition scenario discussed earlier.

Implementation of damaged material storage scenario

In the input file, keyword "Storage" should be used as such to select damaged material storage scenario. In this case, each procedure for setting and modifying parameter values is checked for material damage through a logical indicator. If the undamaged part of material is considered, then all the coefficients of the equation (4) are considered being equal to 0, since only the damaged part of materials is subject to aerodynamic capture and secondary dust elevation.

For the rest, the procedures for setting and modifying DR, ARF, MR and LPF parameters are similar to the tools applied under the shear demolition scenario. As for the procedure enabling to set and modify the fraction of material released into the air (ARF), the available opportunity for searching the modifier responsible for outdoor or indoor storage of material among all scenario modifiers specified in the input file is seen as its particular feature. If the storage modifier is not found, a warning on its unavailability appears and the value of ARF parameter is taken from the input file. If the storage modifier is set, then the ARF value is set by this modifier.

Implemented scenarios for the cleanup of demolition materials

To evaluate the source term under cleanup efforts, formula (1) is modified into (5), since this case suggests that the entire material is affected and DR = 1:

$$ST = MAR \times ARF \times RF \times LPF. \qquad (5)$$

Parameters from formula (5) have the same physical meaning as in formulas (1)—(4).

Cleanup template procedures are similar to the demolition (dismantlement) ones. They establish and modify the values of the main parameters from equation (5). Procedures allowing to specify and modify the fraction of material that has passed through dust suppression systems (LPF) and to set and modify the mass ratio of particles from a given diameter range to the entire mass (MR) are similar to the tools applied under the shear demolition scenario. The only difference between the cleanup options provided below is the procedure for setting and modifying the value of material fraction released into the air (ARF). Therefore, hereinafter the focus will be placed on this procedure only.

Implementation of general cleanup

In the input file, keyword "CollectGarbage_Common" should be used as such to select this scenario.

During building demolition (dismantlement), some materials will be dropped, lifted into the air by crane or manipulator and further emplaced into containers during cleanup. Expression (6) from [3] is used to evaluate ARF if crushing of solid aggregated substances (concrete, cement) resulting from brittle fracturing due to material's free fall from a height with relevant parameter values is considered:

$$ARF = A \times P \times g \times h, \qquad (6)$$

where: A is an empirical parameter being equal to $2 \cdot 10^{-11}$ [$cm^3/(g \cdot cm^2)/c^2$];
P is sample density [g/cm^3];
g stands for the acceleration of gravity at a sea level, 980 [cm/s^2];
h is the drop height [cm].

The indicated dependence is implemented under setting and modification procedure for the material fraction released into the air (ARF). Drop height and material density is specified in the input file.

A test calculation was performed to get a clearer view of the term source formation patterns under this cleanup scenario. A problem focused on the removal of contaminated concrete blocks (activity — 200 MBq, concrete density — 2.5 g/cm^3) with ARF parameter assessment according to general formula (6) was specified as a test one. Under this study, the distribution of particle mass by diameters given in Table 1 (third column) was used. Figure 1 shows the obtained dependence of the activity released into the environment at a level corresponding to the manipulator height.

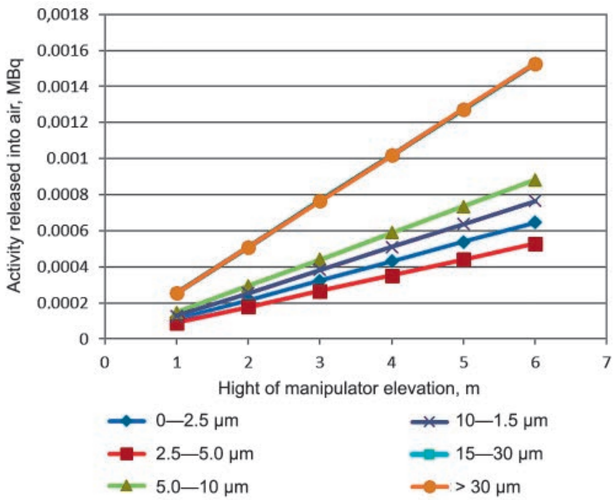

Figure 1. Dependence of the term source activity on the height of manipulator elevation for the considered diameter ranges

Implementation of outdoor cleanup scenario

In the input file, keyword "CollectGarbage_ Street" should be used as such to select the outdoor cleanup scenario.

This type of material cleanup is used if wind speed and material moisture content are known.

To estimate the fraction of material released into the air (ARF) equation (7) proposed in [2] was applied. This equation allows to take into account the impact of wind and moisture content on the material:

$$ARF = 1.6 \cdot 10^{-6}(WS/2.2)^{1,3}/(M/2)^{1,4}. \qquad (7)$$

Here WS stands for the wind speed [m/s];
M is the moisture content of material [%].

The indicated dependence is implemented under setting and modification procedure for the material fraction released into the air (ARF). Wind speed and material moisture content are specified in the input file.

For this cleanup option, a term source test calculation was performed for atmospheric releases due to the cleanup of material with a contamination level of 200 MBq. Under this test calculation, different wind speeds and material moisture contents were indicated. Figure 2 demonstrates how the aerosol activity released into the environment depends on the wind speed under considered ranges of particle diameters with a constant moisture content of 2 %.

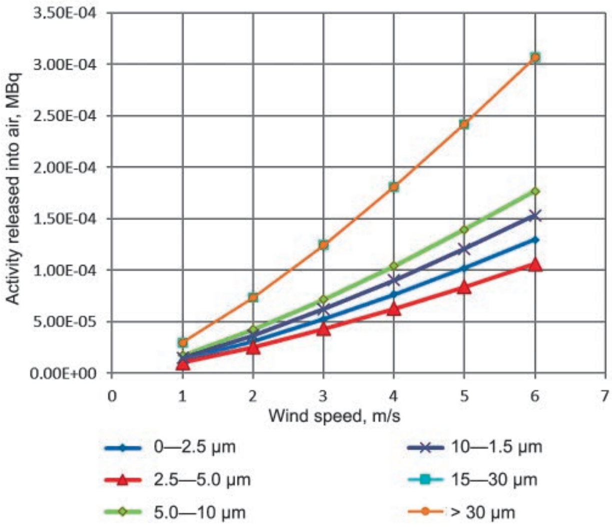

Figure 2. Dependence of the term source activity from the wind speed at a constant moisture content of material

Demolition and removal of resulting materials is carried out at wind speeds of less than 15 mph (6.7 m/s) [1], although if dilapidated buildings and structures are demolished [5], the wind speed can be even higher due to wind gusts.

Figure 3 illustrates how the term source activity depends on the moisture content of material at a constant wind speed of 3.2 m/s.

The graphs show the power-law dependence of ARF parameter on wind speed (Figure 2) and the inverse power-law dependence on the material moisture content (Figure 3) in accordance with expression (7). Similarly to Figure 1, the mutual arrangement of the lines depends on the distribution

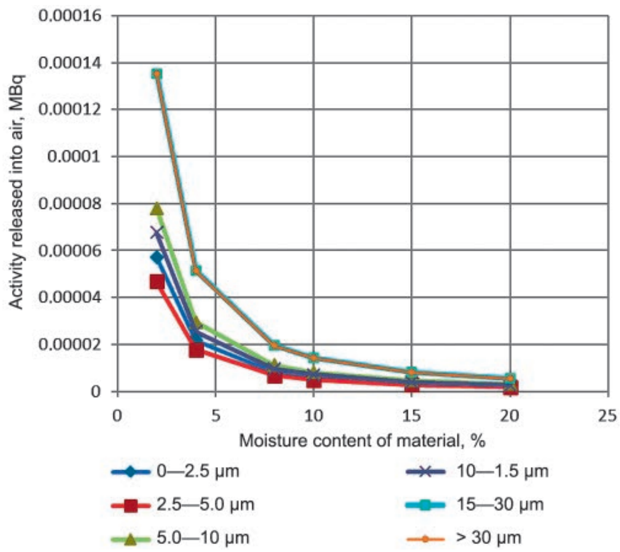

Figure 3. Dependence of the term source activity from the moisture content of material at a constant wind speed

of particles in the release over the diameter ranges shown in the third column of Table 1 (cleanup after demolition stage).

Implementation of outdoor concrete block removal

In the input file, keyword "CollectGarbage_ Street_ Concrete" should be used as such to select the outdoor concrete block removal scenario.

For dropped down materials, namely if concrete walls are considered, the fraction of contaminant released into the air (ARF) is assumed to be equal to $2.3 \cdot 10^{-6}$ [1] (for an average wind speed of 3.2 m/s [4]).

Implementation of outdoor metal sheets removal

In the input file, keyword "CollectGarbage_ Street_ Metal" should be used as such to select the outdoor metal sheet removal scenario.

Metal structures are less susceptible to dust formation than crushed concrete or crushed stone, therefore, in the procedure setting the material fraction released into air (ARF), a value of $1 \cdot 10^{-6}$ is assumed for the metal in accordance with the recommendations provided in [1].

Scenario modifier template

This template involves procedures describing the effect of scenario modifiers on DR, ARF, LPF, and MR parameters and the return multipliers affecting these parameters. Each specific scenario modifier is described in a separate file. In general, modifiers can affect all 4 parameters (DR, ARF, LPF, and MR) from expression (2). Since the distribution of particles by diameter is seen as an important point in the assessment of source term parameters considering the releases from dismantlement/demolition operations, additionally was introduced the possibility of a separate modifier effect on the release of a certain aerosol fraction.

Particle diameters and a logical indicator showing whether the considered part of the material is affected are taken as arguments under scenario modifier template procedures. If the indicator is true, then the material is directly affected by the demolition method; if false, no direct impact of the demolition method is produced on the material suffering only some concomitant effects (movement, shocks, vibration from heavy equipment, vibration from large fragments falling on the floor surface).

Implementation of "fixative" scenario modifier

Fixatives, as their name implies, are used to retain contaminants on material surfaces. At the same time, substances fixing is effective in preventing contaminant migration from surfaces experiencing little or no movement at all [1].

"Fixative_xxx" is the key word entered into the input file to add this modifier to the list of available dust suppression tools for the demolition stage. "xxx" stands for the type of fixative with corresponding values indicating the following: 0 — no fixative; 1 — single layer of fixative; 2 — a double fixative layer.

Below summarized are the effects of fixative produced on the input parameters of a release presented in the form of return multipliers:

- for DR, MR and LPF parameters, a multiplier of 1 is returned, since the fixatives do not affect these parameters;
- for ARF parameter (material fraction released into the air), 0.001, 0.0001 or 0.00001 multipliers [3] are returned for three types of fixative application (no fixative, 1 and 2 layers of fixative, respectively), if considered is the not directly affected part of material (the logical indicator is false), whereas multipliers 0.9 and 1 are used for the material part being directly affected (the logical indicator is true), with fixatives and without them, respectively [3].

Implementation of the "cutting tool cooling" scenario modifier

Under this modifier, water is considered as a cooling medium for the cutting tool, which, as noted in [1], can significantly reduce the contaminant particle releases into the air resulting from cutting operations. "Coolant" is the key word entered to choose the cooling modifier in the input file.

Below summarized are the effects of cutting tool cooling produced on the input parameters of a release presented in the form of return multipliers:

- for DR, MR and LPF parameters, a multiplier of 1 is returned, since cooling does not affect these parameters;
- for ARF parameter (material fraction released into the air), a multiplier of $2.5 \cdot 10^{-4}$ [1] is returned if part of the material exposed is considered (the logical indicator is true).

Implementation of the "misting" scenario modifier

Misting provides efficient removal of coarse particles from the air. However, for smaller particles its efficiency is reduced. "Misting" is the key word entered to choose the cooling modifier in the input file.

Below summarized are the effects of misting produced on the input parameters of a release presented in the form of return multipliers:

- for DR, ARF and MR parameters, a multiplier of 1 is returned, since misting does not affect these parameters;
- for LPF parameter (fraction of nuclides that passed through dust suppression systems), the fraction of the substance that passed through misting is returned, depending on the particle size in accordance with the data presented in Table 2.

Table 2. Fraction of particles that passed through the misting system [1]

Range of particle diameters, μm	Particle fraction that passed through misting
0–2.5	0.95
2.5–5.0	0.60
5.0–10.0	0.30
10.0–15.0	0.25
15.0–30.0	0.25
>30.0	0.25

Implementation of the "aerodynamic capture and resuspension" scenario modifier

Open contaminated surfaces of non-combustible solids (large fragments of facility structures, frame structure or reservoir components made of concrete, metal, glass, etc., the surfaces of which may be hard, deformable or even brittle) when exposed to ambient conditions indoors or outdoors (normally working production ventilation or wind speed in the atmosphere is up to 2 m/s with gusts of up to 20 m/s) can be viewed as a source of secondary elevation (resuspension) [3].

«Storage_Garbage_Room» and «Storage_Garbage_Street» are the key words entered to choose the scenario modifier accounting for outdoor and indoor dust elevation in the input file.

Below summarized are the effects of aerodynamic capture and dust elevation produced on the input parameters of a release presented in the form of return multipliers:

- for DR, MR and LPF parameters, a multiplier of 1 is returned for the fraction of damaged material, since the modifier does not affect these parameters, and a multiplier of 0 is returned for the fraction of undamaged material;
- for ARF parameter (material fraction released into air in 1 hour) in case of damaged material fraction, a multiplier of $4 \cdot 10^{-5}$ is returned when stored outdoors and $4 \cdot 10^{-6}$ when stored indoors [3]. For the undamaged material fraction a multiplier of 0 is returned. In accordance with the data presented in [3], as a result of secondary wind-induced dust elevation the particle size in the release accounts for no more than 10 μm, i. e. all particles belong to respirable fraction.

Output file description

The output file contains calculation results presenting the average activity of the term source accounting for one hour of work, obtained by dividing the calculated activity for the considered stage of work by its duration. Structurally, the output file is a set of activities for each of the demolition and cleanup stages separated according to the given source data.

Activity released into the air as a result of each demolition and cleanup stage is specified in individual data blocks for each stage and containing the name of radionuclide as an attribute and the calculated activity, divided by the particle size ranges.

Examples of calculation results

As an example, a case study of building demolition using hydraulic shears is considered below. Demolition stage parameters are as follows:

- demolition is carried out using hydraulic shears;
- 10 % of structures are damaged during demolition;
- available scenario modifiers include: fixatives; cutting tool fluid coolant; misting;
- the demolition stage lasts 1 hour;
- ARF value for the damaged part of the material with the applied fixatives is assumed to be equal to 0.9; with no fixatives — to 1;
- total contamination amounts to 200 MBq.

Table 3 presents the source term calculation results for scenarios with different combinations of dust suppression tools being applied.

Table 3. Results of activity calculations (MBq/h) for a source term (demolition using hydraulic shears) with different dust suppression methods being applied

Particle diameter range, μm	No dust suppression tools are applied	Single fixative layer	Double fixative layer	Single fixative layer and cutting tool fluid coolant	Single fixative layer, cutting tool fluid coolant and misting	Single fixative layer and misting
0–2.5	16.29	14.544	14.531	0.0181	0.0172	13.81
2.5–5.0	2.60	2.324	2.322	0.0029	0.0017	1.39
5.0–10.0	0.99	0.885	0.884	0.0011	0.00033	0.26
10.0–15.0	0.19	0.170	0.169	0.0002	0.000053	0.042
15.0–30.0	0.09	0.081	0.,081	0.00010	0.000025	0.020
> 30.0	0.012	0.011	0.011	0.000014	0.000004	0.0029

The above results demonstrate that no significant release reduction is achieved when a double layer of fixatives is used compared to a single one. Misting seems to be effective if the particle size is larger than 2.5 microns, and the greatest effect in terms of release reduction is associated with cutting tool cooling systems due to low ARF parameter values.

Another case study considers the task of source term assessment for releases associated with secondary dust elevation during material storage in ambient and indoor conditions:

- total contamination amounts to 200 MBq;
- 10 % of the material is damaged;
- storage time — 1 hour;
- available scenario modifiers: misting.

Table 4 summarizes the results obtained. Table 4 demonstrates that if particle size is larger than 2.5 microns, a 1.5 to 3.5-time reduction of activity raised into the air can be achieved if misting is applied during material storage

Table 4. Results of activity calculations (kBq / h) for a term source associated with secondary dust generation during contaminated material storage

Particle diameter range, μm	Outdoor/ indoor storage	Outdoor/ indoor storage with misting
0–2.5	0.65/0.065	0.61/0.061
2.5–5.0	0.10/0.010	0.06/0.006
5.0–10.0	0.039/0.0039	0.012/0.0012
10.0–15.0	0.0/0.0	0.0/0.0
15.0–30.0	0.0/0.0	0.0/0.0
> 30.0	0.0/0.0	0.0/0.0

Particles being larger than 10 microns are considered as not being subject to secondary dust formation.

The final case study considered is a scenario dealing with the cleanup of generated materials with an activity of 200 MBq. The scenario parameters are as follows:

- 50 % of the materials is removed using the general formula, 50 % is removed outdoors;
- work duration — 1 hour;
- wind speed — 3.2 m/s, moisture content of material — 2 %;
- height from which the removed material falls — 5 m;
- material density — 2 g/cm^3 (concrete);
- available scenario modifiers: misting.

Table 5 summarizes the results of the source term calculation under the above scenario.

Table 5. Results of test activity calculations (kBq/h) for a source term during the removal of materials formed as a result of facility demolition

Particle diameter range, μm	Material removal	Cleanup with misting
0–2.5	0.24	0.23
2.5–5.0	0.20	0.12
5.0–10.0	0.33	0.10
10.0–15.0	0.29	0.07
15.0–30.0	0.58	0.14
>30.0	0.58	0.14

Similar to the previous case study, significant suppression of coarse aerosol fractions (particle diameter being greater than 5 μm) is achieved with misting enabling a 3—4-fold reduction of the near field contamination.

Conclusion

The developed software enables the source term assessment for radioactive gas and aerosol releases into the atmosphere during dismantlement and demolition of buildings and structures contaminated with radioactive substances. Its development is seen as an attempt of creating a computational tool for engineered-based problem solving in this narrow focus field of research and practice. The software estimates radioactive aerosol amounts released into the atmosphere during facility demolition with account taken of relevant dismantlement scenario (hydraulic shear application, explosive method, storage of damaged materials, cleanup), the type of construction materials being demolished, the use of dust suppression tools, such as contaminant fixatives, cutting tool cooling and water misting.

A key feature of the software is seen in its capability of producing customized scenarios with various combinations of dismantlement operation types, as a result of which a process flow chart is formed taking into account the actually applied dust suppression methods.

Flexible program reconfiguration and extension was seen as a main focus during the software development process. Since the software is based on semi-empirical expressions and dependencies, it allows not only to use the available, although very few, literature data on certain technological operations during facility dismantlement, but also to customize the values of the input parameters either according to the measurements results before the dismantlement of a specific facility takes place, or based on expert estimates, increasing the reliability of calculations.

It should be noted that similar dismantlement operations are carried out now in Russia. In particular, in 2016, JSC AECC (Angarsk Electrolysis Chemical Combine) started decommissioning of a production building under the Federal Target Program Nuclear and Radiation Safety in 2016—2030. In this regard, it is necessary to emphasize the importance and advisability of studies to investigate the characteristics of aerosols generated and relevant patterns associated with atmospheric term sources formation during these real-life operations depending on structure types and materials, as well as demolition/dismantlement methods being applied.

Further efforts will be focused on the software testing, verification and possible integration into calculation and forecasting complexes as a pre-processing unit generating the initial data for the module applied to calculate atmospheric transport of contaminants.

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