Case Study with CARC software for Verifying Compliance with Atmospheric Release Criteria of Nuclear Installations

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INTRODUCTION

For the purpose of harmonization, a new approach and the CARC software (Calculating Atmospheric Release Criteria) were developed for defining and calculating the atmospheric release criteria for nuclear safety analysis. The developed methodology is in line with the Council Directive 2014/87/Euratom [1] about preventing the release of radioactive material from nuclear facilities.

With additional assumptions and modifications of the already existing formulas, we established a methodology capable of being used in practice for existing and operating nuclear power plants and also for other nuclear facilities. This new methodology has several advantages, as it is easy to implement, does not introduce new sources of uncertainty and saves computational burden. The software is capable of taking into account site specific long-term meteorological measurement data and it determines a selected percentile of the doses resulting from all of the considered meteorological cases. [2]

METHODS

BASIC APPROACH

The basis of the approach is that with appropriate boundary conditions the doses at the receptor points can be determined by the following schematic equation:

$$\Delta = S \cdot T \cdot E \qquad (1)$$

where Δ: is the dose representative of the radiation exposure, S: is the source term of the released activity, T: is the transport factor (transmission), E: is the exposure factor (dose conversion factors). Due to this separation, the compliance with the release criteria can be verified with a straight forward multiplication of the three factors. In the case of site selection for a new nuclear power plant, the site with appropriate T and E characteristics has to be chosen. Despite the fact that these site specific conditions might change in the long term, factors T and E are to be updated only during periodical safety analysis review, e.g. once every 10 years, or when significant change in the parameters occur.

MODELS

The atmospheric transport of the radioactive material is computed with a Gaussian plume model with Pasquill characterization of the atmospheric stability. Dry and wet deposition is considered with source depletion assumed to be uniform along the z-axis of the plume.

Exposure pathways taken into account by the software include cloudshine and inhalation from plume passage, groundshine from deposited material and ingestion of contaminated foodstuff. Skin dose and inhalation of resuspended material is not taken into account.

External dose from cloudshine and groundshine is computed by semi-infinite volume model and infinite plane model.

COMPARISON WITH CRITERIA

For comparison with safety criteria, computation need to be conducted for all the necessary release cases, pathways, distances and nuclides.

The software determines the transport factor for all meteorological data points given in the input and determines a selected percentile for the air activity concentration and ground deposition. Separate values of the transport factor are determined for each release case (c) distance (d) and nuclide (i). Then, the exposure due to unit concentration is computed for the selected nuclides (i), pathways (p) and residence times (t). These factors are multiplied with the release source term and summed up for all nuclides and pathways:

$$\Delta^{c,d,t} = \gamma \sum_{p} \sum_{i} S_i^c T_i^{c,p,d} E_i^{p,d,t} \qquad (2)$$

The γ safety factor compensates the uncertainty of some elements of the calculation. The criteria is fulfilled if all Δ values are below the limit.

As safety criteria can differ from country to country, in this assessment, as an example we assume the 1 year dose criteria to be 20 mSv.

CASE STUDY

CALCULATION

To present the application of the program, calculations were performed with a hypothetical release scenario for Design Extension Conditions (DEC) taken from the international CONFIDENCE project [3]. The release quantities are shown in Table 1. Iodine considered to be 100% in aerosol form. Effective release height was 50 m and heat content was 0 MW. The date of the release was assumed to be 1st of July.

Table 1: Released activity of the hypothetical DEC scenario [3]

Nuclide	Xe-133	I-131	I-132	Te-132
Released activity [Bq]	6.91E+17	5.42E+13	6.35E+14	1.73E+13
Nuclide	**Cs-134**	**Cs-136**	**Cs-137**	**Ba-137m**
Released activity [Bq]	4.70E+12	1.77E+12	3.17E+12	2.37E+12

Two types of calculations were performed, the first with fixed meteorological parameters and the second with a 1 year long meteorological measurement data. The fixed meteorological parameters were the following: wind speed: 5 m/s, wind direction: 0°, Pasquill class: D, precipitation: 5 mm/h). In case of using real meteorological measurement data, the 95th percentile of the result for all the meteorological data points was computed.

The effective dose from cloudshine, groundshine, inhalation and ingestion was computed for the 1st year after the release at 800 m in 0° direction and different habit data for the residing reference group were considered. The age of the representative person was 30 years. The dose criteria for the first year was assumed to be 20 mSv for a DEC scenario as an example.

PERTURBED PARAMETERS

The habit data that were perturbed in the study were the residence time outdoors, the type of building, the intensity of activity outside and the local food consumption. For the different types of buildings, various shielding parameters were used to account for the building material and distance from the ground. For the intensity of activity, different inhalation rates corresponding to light, moderate and high intensity was assumed. The parameters are shown in Table 2. The plume is considered to pass while the reference person is outside, so no shielding was assumed for inhalation and cloudshine.

Table 2: Habit parameters and their perturbed values

Parameter	Default	Perturbation
Time spent outdoors	1h	2h; 4h; 6h
Type of building (shielding factor for groundshine [4])	Wood frame (0.4)	Block or brick (0.2); Multi story 1st floor (0.05); Multi story upper floor (0.01)
Intensity of outside activity (breathing rate [5])	Light Intensity (0.735 m³/h)	Moderate Intensity (1.59 m³/h); High Intensity (2.963 m³/h)
Foodstuff (quantities chosen arbitrary)	No consumption	Leafy veg. (20 kg/y); Potatoes (70 kg/y); Root veg. (15 kg/y); Fruit veg. (25 kg/y); Milk (115 kg/y); Beef (25 kg/y)

REFERENCES

[1] Euratom: Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations, 2014.

[2] Rudas, C. et al.: Evaluation of an improved method and software tool for confirming compliance with release criteria for nuclear facilities, Annals of Nuclear Energy 159, 2021.

[3] De Vries, H. et al.: Published sets of probability maps of threshold exceedance for scenarios provided to WP4, WP5 & WP6 → 2. CONCERT Deliverable D9.4. 2019.

[4] IAEA: Generic Procedures for Assessment and Response during a Radiological Emergency, IAEA TECDOC 1162, Vienna 2000.

[5] U.S. EPA.: Exposure Factors Handbook 2011 Edition (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.

RESULTS

RESULTS FOR FIXED METEOROLOGICAL DATA

The effective dose results for the different parameters are show in Table 3, 4 and 5.

Table 3: Effective 1y dose with different times spent outside and types of buildings for fixed meteorological data

Time spent outdoors	1h	2h	4h	6h
Effective dose	9.22 mSv	9.35 mSv	9.63 mSv	9.91 mSv
Ratio with default		101%	105%	107%
Type of building	**Wood frame**	**Block or brick**	**Multi story 1st floor**	**Multi story upper floor**
Effective dose	9.22 mSv	8.16 mSv	7.36 mSv	7.15 mSv
Ratio with default		88%	80%	78%

Table 4: Effective 1y dose with different activity intensities outside for fixed meteorological data

Intensity of activity	Light	Moderate	High
Effective dose	9.22 mSv	9.88 mSv	10.94 mSv
Ratio with default		107%	119%

Table 5: Effective 1y dose with the consumption of different foodstuff for fixed meteorological data

Foodstuff	Leafy veg.	Potatoes	Root veg.
Effective dose	21.42 mSv	11.22 mSv	10.25 mSv
Ratio with default	232%	122%	111%
Foodstuff	**Fruit veg.**	**Milk**	**Beef**
Effective dose	11.28 mSv	16.02 mSv	10.10
Ratio with default	122%	174%	110%

RESULTS FOR 1 YEAR LONG MET DATABASE

The 95th percentile of the 1 year dose results for the different parameters are show in Table 6 and 7.

Table 6: The 95th percentile of the effective 1y dose with different times spent outside and types of buildings

Time spent outdoors	1h	2h	4h	6h
Effective dose	8.82 mSv	8.85 mSv	8.89 mSv	8.94 mSv
Ratio with default		100%	101%	101%
Type of building	**Wood frame**	**Block or brick**	**Multi story 1st floor**	**Multi story upper floor**
Effective dose	8.82 mSv	8.61 mSv	8.47 mSv	8.43 mSv
Ratio with default		98%	96%	96%

Table 7: The 95th percentile of the effective 1y dose with different activity intensities outside

Intensity of activity	Light	Moderate	High
Effective dose	8.82 mSv	9.67 mSv	11.10 mSv
Ratio with default		110%	126%

DISCUSSION

Our aim was to determine the effect of different habit data on the dose assessment. In case of fixed meteorological data, the consumption of different foodstuff had the largest effect on the results ranging between ratios of 111-232% compared to the default case with no consumption. However, when a long meteorological measurement database and a selected percentile was used, the effect of most of the considered habit data was significantly lower. While the proposed 20 mSv safety criteria was exceeded in case of fixed meteorological data (consumption of several foodstuffs), with utilizing longer meteorological data and a percentile, the result of the assessment was more robust and was not affected greatly by the perturbations of the habit data.