2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

PSO-based Modeling Particulate Emission Rates in Nuclear Accidents

D. R. Brasil[1], A. S. Nicolau[2], R. Schirru[3], C. M. N. A. Pereira[4]

[1]*brasil.docm@gmail.com*
[2]*andressa@lmp.ufrj.br*
[3]*schirru@lmp.ufrj.br*,
Universidade Federal do Rio de Janeiro (UFRJ), Brazil
[4]*cmnap.ien@gmail.com*
Instituto de Energia Nuclear (IEN), Brazil

1. Introduction

Nuclear power plants are complex systems that follow the highest safety standards. Its construction, operation and decommissioning is done following protocols that guarantee the safety, prevention and mitigation of accidents. The purpose is to ensure a safe operation, the safety of the public and the environment.

In history around the world three major nuclear accidents can be mentioned: the Three Mile Island accident, which occurred on March 28, 1979, the Chernobyl accident, on April 26, 1986, and the most recent, the Fukushima Daiichi accident, on March 11, 2011. Each of these accidents brought lessons and revisions in the concepts, standards and safety Nuclear Power Plants procedures. Moreover, they showed the importance in the development of atmospheric dispersion models. In order to estimate the source term, and consequently the estimation of the release rate to the atmosphere to support decision making in case of a radiological emergency.

This paper presents a methodology based on Particle Swarm (PSO) algorithm [1] and Gaussian plume dispersion calculation [2] to estimate the particulate contaminants rate emitted by multiple sources, whose values are unknown using only the identified values by receivers distributed around the sources. Here, the PSO was used to optimize (find) the release particulate contaminants values released from 4 broadcasting sources, in order to obtain a solution for the sources emission rate values for a given concentrations data set measured in 9 receptors.

The results found with Particle Swarm Optimization Dispersion Model (PSODM) were effective in solving the problem approached and demonstrate that the proposed methodology is a promising tool in problems of this nature, in the nuclear area.

2. Methodology

Given a nuclear accident with the radionuclides/particulates release into the atmosphere, we want to estimate the radionuclide rates release from each of these sources based on data obtained by receivers (detectors) located around the sources. Knowing the positions and sources emission rates, and having the atmospheric conditions well defined, it is possible to calculate the concentrations in receivers, according to their positions on the ground [3, 4, 5].

To solve this problem, a model was developed using the PSO algorithm coupled with the Gaussian plume dispersion model, called here the Particle Swarm Optimization Dispersion Model (PSODM) [6]. Applying PSODM to the studied problem, each PSO particle is a solution for the particulates emission rate into the atmosphere released by the four sources (*S1*, *S2*, *S3* and *S4*). The output is the solution that the best represents the emission rates of these four sources, that is, it is the solution with the best fitness, which is given by the smallest error between the values measured in the real receivers (*VR*) and the values measured in the calculated receivers (*VC*) [6]. The Eq. 1 represents the PSO fitness and calculates the mean squared error between the actual data measured and those estimated by the PSO.

$$fitness = \left[\frac{1}{N}\sum_{i}^{N}(VR_{Ri} - VC_{Ri})^2\right]^{1/2} \tag{1}$$

To evaluate the fitness function, the values of the velocity and position vectors are calculated at each iteration. The value of the new velocity is obtained by Eq. (2), where the iteration t+1 is given by the vector vij^{t+1}. The new position of the particle is obtained by Eq. (3), which presents xij^{t+1} as the position vector in iteration t+1.

$$v_{ij}^{t+1} = wv_{ij}^{t} + c_1r_1^{t}(pbest_{ij} - x_{ij}^{t}) + c_2r_2^{t}(gbest_j - x_{ij}^{t}) \tag{2}$$

$$x_{ij}^{t+1} = x_{ij}^{t} + v_{ij}^{t+1} \tag{3}$$

The Fig. 1 presents the PSODM flowchart, developed based on the standard PSO flowchart, that presents two steps. The first step is given by the PSODM initialization performing the particle loop, where the random particles (*p*) of the velocity (*vij*) and position (*xij*) vectors are initiated. Then, the *forward2* program (plume dispersion) [2] is applied to calculate the concentrations of the four sources in the nine receivers at ground level. Afterwards, the fitness function is evaluated using the mean squared error. If fitness (*p*) is less than fitness (*pbest*) then *pbest* is replaced by particle p. In the second step, the loop takes place up to the maximum of the iterations evaluating if fitness (*pbest*) is less than fitness (*gbest*), then *gbest* is replaced by *pbest*. Thus updating the particle's velocity and position. When reaching the maximum number of pre-defined iterations, the PSODM stops running providing the best value found for *gbest*, which is the best result found for the problem.

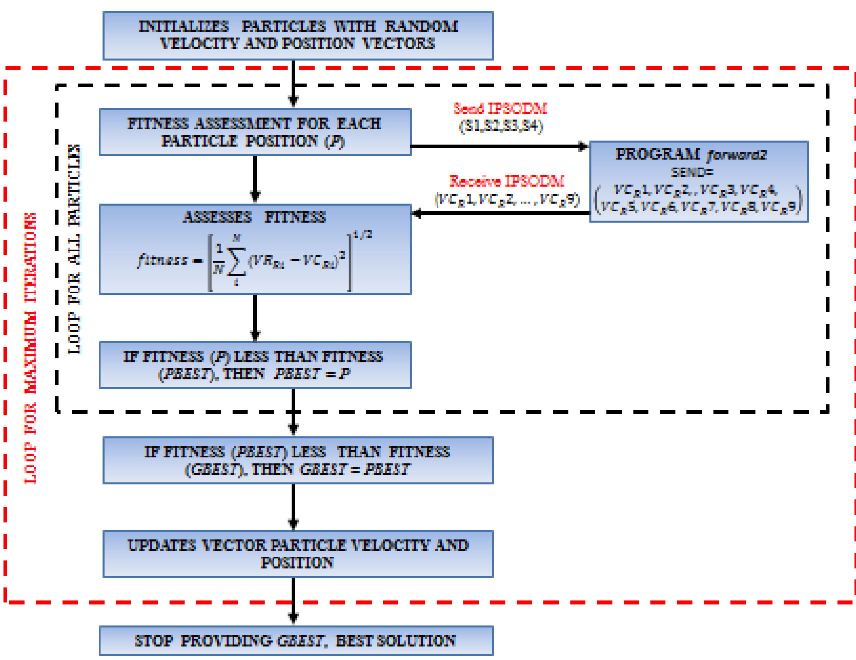

Figure 1: PSODM flowchart [6].

The PSO is applied to Eq. 4 [3], which estimates the particulate emission rate using the values obtained in the receivers around the sources. The Eq. 4 is a derivation of the Gaussian plume solution, which takes into account the deposition and sedimentation velocities in the soil. Using the linear least squares method the expected results for the emission concentrations rates of the four sources are found.

$$C_{(r,y,z)} = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{w_{set}(z-H)}{2K} - \frac{w_{set}^2 \sigma_z^2}{8K^2}\right) \times \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) - \frac{w_o \sigma_z \sqrt{2\pi}}{K} \exp\left(\frac{w_o(z+H)^2}{K} + \frac{w_o^2 \sigma_z^2}{2K}\right) \operatorname{erfc}\left(\frac{w_o \sigma_z}{\sqrt{2}K} + \frac{z+H}{\sqrt{2}\sigma_z}\right)\right] \quad (4)$$

where, $w_o = w_{dep} - (0.5) w_{set}$ e $erfc_{(x)} = 1 - erf_{(x)}$ is a complementary error function.

PSODM program solves the atmospheric dispersion problem directly, using Eq. (4); Calculates the concentration value of particulates emitted by four sources at ground level in *mg/m³*. Given set of nine receptors located at ground level; Sums the particulate concentrations from each source at ground level as input data using Eq. (5); Find the concentration at each receptor considering $A * d_t * w_{dep}$ to obtain a total mass deposition in *mg* over the time interval d_t by Eq. (6).

```
glc =glc + ermak (xmesh-source.x (i), ymesh-source.y (i), 0,0, source.z (i), source.Q
    (i), Uwind, Wdep, Wset)                                                    (5)

dep = dep + (A * dt * Wdep)*ermak( recept.x-source.x(i), recept.y-source.y(i),
    recept.z, source.z(i), source.Q(i), Uwind, Wdep, Wset )                    (6)
```

3. Results and Discussion

The PSODM model was developed using python. Different sensitivity tests of PSO parameters such as inertia weight *w*, number of particles (population), number of iterations and values of constants c_1 and c_2 were performed. The seed for each algorithm round was made randomly using python's random function.

Table I presents the best results found with the PSODM, for values of *w* equal to 0.2, with the population varying between 60 and 200, c_1 equal to 1.6, c_2 equal to 2.4, and iterations equal to 1000. Five tests were performed with different seeds for each parameter presented in the Table I. It is observed that the PSODM presents better fitness results using a population value equal to or greater than 60, and number of iterations in 1000.

Table I: PSODM results [6].

		Results Obtained – Mean Values			
p	Fitness	Source - S1	Source - S2	Source - S3	Source - S4
60	6,7382086744091E-20	34,99999993	79,99999999	4,99999992	4,99999933
80	6,7382086744091E-20	34,99999993	79,99999999	4,99999992	4,99999933
100	6,7382086744091E-20	34,99999993	79,99999999	4,99999992	4,99999933
150	6,7382086744091E-20	34,99999993	79,99999999	4,99999992	4,99999933
200	6,7382086744091E-20	34,99999993	79,99999999	4,99999992	4,99999933

Note: values of sources S_1, S_2, S_3 e S_4 em kg/s.

4. Conclusions

This article presents an optimization model called PSODM, based on the particle swarm algorithm (PSO), and Gaussian plume model in order to determine the rates of particulates into the atmosphere by multiple contaminant sources, after a release accident using the concentration values collected by receivers distributed around these sources. The good results found with the PSODM show that the developed model is a good tool to determine the release rate of sources, through measurements using devices that detect the presence of radionuclides in the atmosphere.

Acknowledgements

We would like to acknowledge Brazilian Navy, CNPq (National Research Council, Brazil) and FAPERJ (Foundation for research of the state of Rio de Janeiro), for their support to this research.

References

[1] Eberhart R. C. e Kennedy J. A new optimizer using particle swarm theory. 1995.

[2] STOCKIE, J. M. "Mathematics of Atmospheric Dispersion Modelling", *SIAM Review*, n. 53, pp. 349-372 (2011).

[3] ERMAK, D. L. “An analytical model for air pollutant transport and deposition from a point source”. *Atmospheric Environment*, v. 11, n. 3, pp. 231–237 (1977).

[4] LUSHI, E. and STOCKIE, J. M.. “An inverse Gaussian plume approach for estimating contaminant emissions from multiple point sources”. *Atmospheric Environment*, 44: 1097–1107 (2010).

[5] JANNETTI, P. Air Pollution Modelin, Theories, *Computational Methods And Available Software*. New York, Springer Science – Business Media, LLC (1990).

[6] BRASIL, D. R. *Uma Modelagem Baseada no PSO para Estimativas das Taxas de Emissão de Particulados em um Acidente Nuclear*. Master's dissertation, COPPE/UFRJ, 2021.