Model “PROLOG” for countermeasures efficacy assessment and its calculation algorithm verification on the base of the Chazhma Bay accident data

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ABSTRACT

Methodical approaches used in the computational model “PROLOG” are given in the paper. This model is intended for assessing radiological situations and an efficiency of counter measures after short term radioactive releases. Basic local Gaussian dispersion algorithm is supplemented with modules for assessing a plume rise, dry deposition velocities, effect of buildings and complex terrain, etc. The modules provide a compromise between simplicity, shortage of initial data and adequacy of the model in case of real accident. Approaches to assess the dose and countermeasure efficiency are presented as well.

Plume rise, complex terrain and contaminant polydispersity modeling approaches were tested on the basis of comparison of calculation and experimental results for dose rate and Co-60 surface contamination measured after the Chazhma bay accident in 1985.

Keywords

Counter measures efficiency, complex terrain, radioactive contamination, Gaussian dispersion algorithm.

INTRODUCTION

One of the most important problems of the emergency response is a fast estimation of a radiation situation, expected irradiation and countermeasure efficiency. Such evaluations require a correct estimation of atmospheric dispersion and radioactive particle deposition. Most of the existing models capable of carrying out such calculations demand a number of specific parameters that are usually not available in real-time mode in emergency situations.

The code «PROLOG» is intended for estimation of short term releases (Bogatov, S., Kiselev, A. and Shvedov, A., 2011). It is based on the Gaussian model for atmospheric dispersion that is supplemented with the modules for accounting of aerodynamic shadow of a detached building, complex terrain effect, contaminant polydispersity, plume rise and its depletion due to dry and wet deposition.

This paper describes the results of the model testing using the data of the nuclear accident at the nuclear submarine that took place in the Chazhma bay (Far East) on August 10, 1985. We compared the measured and calculated values of the gamma dose rate and surface fallout density.

CHAZHMA BAY ACCIDENT

At the Chazhma bay shipyard, during a scheduled maintenance, a chain reaction occurred at the nuclear submarine . The released energy was estimated to be equivalent to 10^{19} nuclear fissions. The energy burst was fast, and the main part of the released radionuclides was in the overheated steam-air mix. Since the spontaneous chain reaction occurred in the fresh nuclear fuel, the radionuclide composition of the release contained short–lived fission products (krypton, xenon, iodine) and activation products (mainly, ^{60}Co). The weather conditions at the time of the accident were as follows: southeastern wind with velocity of 5 m/s, periodical drizzling rain, atmospheric stability class D by Pasquill (Sivintsev, Yu., Vaculovsky, S, Vasilyev, A., Vysotsky, V., Gubin, A., Danilyan, A., Kobzev, V., Kryshev, I., Lavkovsky, S., Mazokin, V., Nikitin, A., Petrov, O., Pologikh, B. and Soric, Yu., 2005).

COMPUTATIONAL MODEL "PROLOG"

Plume rise

The method (Belikov, V., Goviznin, V., Semenov, V., Sorokovikova, O., Starodubtseva, L. and Fokin, A., 2008) was used for plume rise assessment. This approach is based on solution of self-consistent differential equations of ideal gas state and equations of energy and momentum conservation taking into account air ingress into the cloud that allows determining the contaminant plume parameters at any time. We used the following initial parameters: ambient air temperature at the release height – 293 K; steam mass in the cloud – 46 kg, Pasquill stability class – D, wind velocity – 5 m/s. The calculations gave the rise of the release 320 m.

Contaminant polydispersity

In case of the steam-air mix release, an assumption on the contaminant polydispersity is to be applied. We assumed that main contaminant in consideration, radionuclide ^{60}Co, contained in condensation drops. We assumed also that the drop size distribution in the release corresponded to the drop distribution at the mouth of water-cooling tower (Hanna, S., Biggs, G. and Hosker Jr, R., 1982). This distribution was interpolated using 1-micrometer step, extrapolated to zero and limited by a maximum particle size of 260 micrometer (figure 1). This limitation is based on the lack of information about the fallout density and dose rate inside 1-km zone of the accident site. We used the following assumption: the drop condensation starts, when the cloud reaches its maximum height.

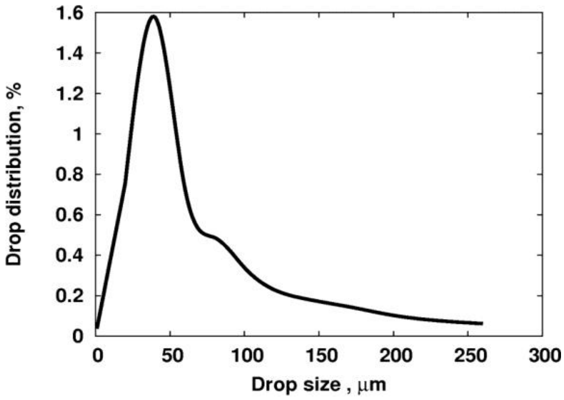


Figure 1. Drop size distribution in the release

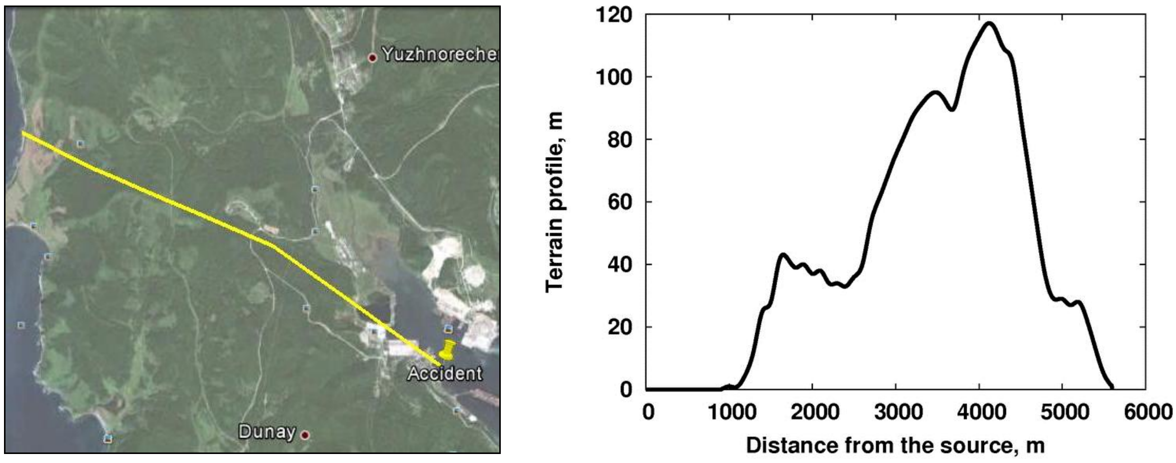
Complex terrain approach

The model (U.S. EPA, 1995) was used to calculate the radionuclide atmospheric transfer in case of a complex terrain. If the relief roughness exceeds the release height, a sector average approach that implies a uniform lateral (crosswind) concentration across a 22.5 degree sector is used. A deflection of the plume by the rough terrain features at stable atmospheric conditions similar to the considered ones was simulated applying an attenuation correction factor to the concentration with height in the sector of concern (U.S. EPA, 1995).

Notwithstanding a large initial height of the release, the rough terrain approach is necessary to take into account a crossing of terrain and the descending heavy contaminant cloud.

Modeling results

The calculated values of fallout density and dose rate along the fallout axis were compared with the experimental data of 1991. The measurements showed that contribution of ^{60}Co into the dose rate was dominant, and the contaminant depth distribution in the soil was exponential with a character length of 2 cm, that corresponded to dose factor $1.34 \cdot 10^{-15}$ $Sv \cdot s^{-1} \cdot Bq^{-1} \cdot m^2$ (Beck, H., 1980). The terrain height along the plume axis was defined using the Internet service GoogleEarth^{TM} (see figure 2).



a) **b)**

Figure 2. a) Axis of radioactive fallout related to the Chazma bay accident on GoogleEarth™ satellite photo; b) Terrain profile along the fallout axis.

Using the results of the dose rate (see figure 3) for accepted size distribution of steam condensate drops (see figure 1), we calculated that the ^{60}Co-activity in the release was $2.7 \cdot 10^{13}$ Bq at the time of the accident. This value corresponds to the previously obtained result of 320 Ci ($1.2 \cdot 10^{13}$ Bq) (Arutyunyan, R., Danilyan, V., Vysotsky, V., Gichev, D., Kiselev, V., Maksimov, A., Pavlovski, O., Sarkisov, A. and Tokarchuk, D., 1998). The calculation and measurement results are presented in figure 3.

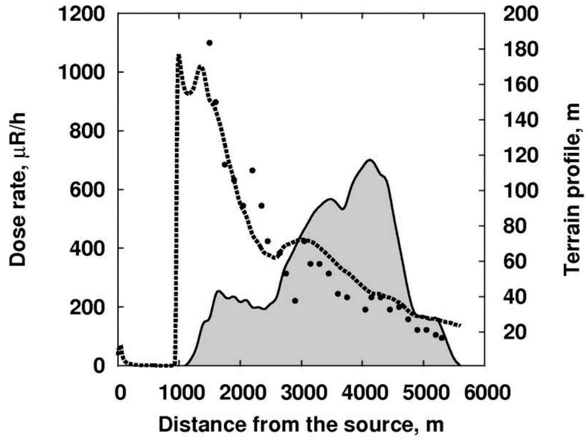


Figure 3. Calculated (solid curve) and measured (points) dose rate values along the fallout axis (summer 1991)

Using the calculated activity of ^{60}Co in the release, one can calculate the surface contamination density (see figure 4).

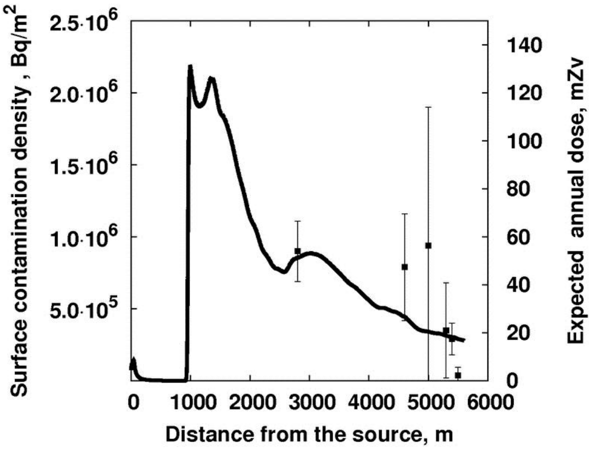


Figure 4. Calculated (solid curve) and measured (dots with error bars) surface contamination density (summer 1991) and effective dose expected for the first year after the accident along the fallout axis

The expected annual dose for the first year after the accident due to external and internal irradiation is also presented in figure 4.

CONCLUSION

Using the combined approaches for atmospheric dispersion modeling of the code “PROLOG”, we successfully estimated the consequences of the nuclear submarine accident in the Chazhma bay. On the basis of available information on reactor parameters, power release assessment and assumption on the particle size distribution in the release, we obtained the ^{60}Co-activity released, dose rate and surface contamination density distribution along the fallout axis that agree with experimental results within the measurement uncertainties. Earlier calculations that assumed a single-size contaminant and without taking into account complex terrain did not allow us to obtain satisfactory agreement with experimental results.

Using the presented model allowing to obtain the results with a minimal initial information, the first assessments of radiological consequences can be obtained shortly after an accident. The given approach allows prompt assessing of the practicability of the countermeasure applications and selecting those measures, whose efficiency would be strongly dependent on their timeliness.

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