The predictions of two fallout models: Comparison of dose rate and dose calculations.

Arto Jäppinen[1], Jouni Jäppinen[2], Juhani Lahtinen[3], Ilkka Valkama[2]

[1]Defence Forces Technical Research Centre,
Explosives and NBC Technology Division
P.O. Box 5, FI-34111 Lakiala, Finland

[2]Finnish Meteorological Institute
P.O.Box 503, FI-00101 Helsinki, Finland

[3]STUK- Radiation and Nuclear Safety Authority
P.O.Box 14, FI-00881 Helsinki, Finland

Abstract

Two dissimilar mathematical models, SILAM and ALAMA, intended to fallout predictions were compared at in one real meteorological situation. Two improvised nuclear explosion yield scenarios were prepared for calculations. The earliest fallout times-of-arrivals, dose rate values at H+1 and total dose calculations were compared up to 100 and 500 kilometres depending on the explosion yield. Comparison of the results of the two models in chosen quite simple meteorological situation showed close agreement of predictions.
Keywords: nuclear, fallout, prediction, dose, dose rate

1 Introduction

In the present world, the possibility of terrorist actions is a serious threat to any nation. One of the worst scenarios is that such terrorist acts may even involve nuclear detonations. Responding correctly during the first hours after a nuclear detonation is of utmost importance to reduce casualties from radioactive exposure. To be able to respond, the national decision makers need a tool (e.g. a numerical model) to simulate atmospheric transport/deposition of the radioactive debris released from a nuclear detonation.

The character of the fallout hazard from a terrorist nuclear detonation is very different from tactical military ones. The fallout plume is much smaller, extending from few tens to few hundreds of kilometres downwind, depending on the yield. The width of the plume is also narrower, depending on near ground level wind conditions. The acute lethal radiation dose occurs almost entirely within the first few hours. Time dependent dose rates are essential to support a rapid response to a terrorist nuclear detonation.

Existing models for explosive releases are either simple first order models, or complex coupled systems. The choice of model will depend on a number of issues such as:

- the application of the results to the scenario being considered,
- the level of detail required, the duration and distance over which the dispersion is to be considered,
- the model assumptions, limitations, and uncertainty,
- the level of specification of the input data for the scenario.

2 Release scenario

The scenarios describe releases (source terms) from two improvised nuclear explosions ("bombs" 0.1 kt and 10 kt) on a commercial shopping centre. The total amount of nuclear material (^{235}U and ^{238}U) was several tens of kilograms. The effective yields are 0.1 kt and 10 kt, corresponding to the fissions of about 5.5 grams and 550 grams of uranium, respectively. We assume here that all radioactive substances are created in the fissions of ^{235}U, i.e. any induced radioactivity and fissions of ^{238}U are ignored.

The fallout models were run with real, measured weather data. Actual synoptic observations or mast profiles from eight meteorological stations, ranging from 2 to 100 km in distance from ground zero, were available. The weather over the ground zero area was cloudy, with sporadic rain towards the evening. Atmospheric stability was neutral or slightly unstable. The air pressure was around 1009 hPa. The winds were at first from south-east (c. 150 degrees), turning later towards east and remaining between east (90 degrees) and north-east (c. 50 degrees) for the rest of time. The wind speeds were moderate, ranging from 5 to 7 m/s.

The Basic Wind Reports based on soundings made at Jokioinen and Vantaa in Southern Finland was used by the Gaussian model. Numerical Weather Prediction Model (NWP) data from FMI's HIRLAM model was used by the Lagrangian model.

3 Models

The ALAMA fallout model is used in PVTT's SUKEVA software (Lightweight planning and warning tool for hazardous events) [1] and also at the Radiation and Nuclear Safety Authority (STUK). The model predicts rapid fallout gamma ray activity from surface burst nuclear explosion. The model calculates the H+1 hour "normalized" gamma ray dose rate and 24 hour dose contour lines at the surface both upwind and downwind from ground zero. The "normalized" dose rate assumes that all fallout is deposited at H+1 hour, regardless of whether this is actually the case or not. Explosion energy yield range is 10^{-3} to 10^{5} kt. The model uses analytical equations derived by Norment [2].

The model is based on a curve fit to calculated activity deposition rate data. The model computes gamma radiation from dry ground-deposited particulate fallout from the nuclear cloud cap and stem. This radiation builds up from weapon debris fission products and from induced activity in the fallout. The downwind and upwind distribution function for deposition fallout are analogous to Gaussian distribution, the crosswind distribution of fallout pattern is Gaussian. The model input data requirements are the weapon yield, the speed and direction angle of an effective wind vector and the wind shear parameter. The model calculates the effective wind vector, which is the weighted sum of vectors representing the basic wind data for each two kilometre layer. If the basic wind data is not available, the average wind speed and direction are given, and then the model uses the table for wind shear parameters.

The ALAMA results were compared with those from Finnish Meteorological Institute's (FMI) current operational emergency dispersion model SILAM [3]. The SILAM model is a Lagrangian dispersion model that applies an iterative advection algorithm and a Monte-Carlo random-walk diffusion representation. The type of the source term can be selected by the user from several options; point, area, volume or "mush-room" (for nuclear explosions). The treatment of aerosol is based on a modal representation of the aerosol size spectrum and state-of-the-art parameterizations of the dry and wet deposition processes. The current model setup is the following: 3D iterative advection with 4-D interpolation of all parameters to actual particle locations, a well-mixed ABL random-walk method, a 5-15 minutes model time step for a 25 km spatial resolution, the combination of dry parcel and critical Richardson number methods for the ABL height assessment (unless this parameter is directly available from the meteorological input), a meteorological input with a 3-hour temporal resolution and the best available spatial one (currently, 10km). The transport modules have been tested in the EU-funded ENSEMBLE project (http://ensemble.ei.jrc.it/), the ETEX project (http://rem.jrc.cec.eu.int/etex/) and the Nordic NKS MetNet (http://hirlam.fmi.fi/MetNet) project.

The SILAM radiation dose assessment module contains a database of 496 nuclides, 80 dose pathways (dependent on the source and receptor locations and type of radiation), and 23 human target organs; it allows computation of the decay chains, the environmental removal (migration) of nuclides after deposition, and of external and internal exposure doses. External dose pathways include direct irradiation from cloud and fallout (gamma and beta); internal pathways include inhaled radio-nuclides. The dose rate conversion factors for the external exposure of human organs to photons and electrons are based on NRPB data.

The system can utilize meteorological data either from Finnish HIRLAM weather prediction model HIRLAM (for transport times up to 54 h), or that from the European Centre of Medium-Range Weather Forecast (ECMWF, for long term simulations). The HIRLAM model produces 54-hour long forecasts four times a day covering Europe, Northern Atlantic and Western Russia. The ECMWF model provides hemispherical coverage and long term forecasts

4 Calculations

The points of reference for the results were on concentric arches from the ground zero at 5 distances (1, 5, 10, 50 and 100 km) for 0.1 kt and 6 distances (1, 5, 10, 50, 100 and 500 km) for 10 kt.

From both model, the following ground level output (or as many of the quantities as available) was required (T_0 = time of detonation):

- H = Earliest fallout time-of-arrival (preferable unit is h)
- D_{ref} = Maximum or the 95-percentile reference (fallout) dose rate value at (T_0 + 1 h) (total dose, ^{131}I + ^{137}Cs, in Sv h^{-1})
- D = Maximum or the 95-percentile total dose (^{131}I + ^{137}Cs) from fallout received by an unshielded adult within 48 hours after fallout time of arrival (Sv).

Comparison of the results of the two models showed close agreement of predictions. The width of the plume was deduced as a subjective measure, based on the number of points at each distance arch covered by the plume. The values obtained compare rather well. The SILAM plume is usually broader, as is to be expected considering the respective approaches of the models. The locations of the maximum values at each arch (i.e. the central axis of the plume) compare very well. The centre of the plume lies inside few kilometres. The actual dose values are almost the same, except for largest distance (500 km), where SILAM gives larger dose values.

5 Discussion

Two nuclear incident scenarios were set-up in order to compare and evaluate two dispersion models. While using very different approaches (Lagrangian vs. Gaussian) and weather data usage (NWP data vs. effective wind vectors), the models produce very similar predictions of the dispersion and dose. Rather small differences, c. 1-2 orders of magnitude, were observed between the dose estimates given by the models. The widths of the plume at various distances, as well as the location of plume central axis, compared well.

The results seem to infer that “simple” models are as applicable as more “advanced” ones in emergency applications, especially in the near field. It must also be noted, that ”simple” models are operational faster and easier to use, which is an important asset in an emergency.

However, since the weather situation was very simple one (Pasquill D, very slight variation in wind speed and direction and no precipitation), the case evidently was favourable to the Gaussian type of approach. It is well known that the Gaussian models ignore the real pattern of dispersion with wind meandering, actual developments of vertical and horizontal mixing along the day, thus tending to underestimate the wet deposition etc. Lagrangian models, on the other hand, tend to over-estimate the peaks inside the pollution plume, with simultaneous under-estimation of the horizontal plume size, partially missing the low-concentration areas. In SILAM both effects are probably due the simplifying approaches to the random-walk computations, but are similar to the phenomena reported by many other random-walk models. The effect is not large, and is acceptable for emergency simulations.

The ALAMA model has been developed to rapidly and with minor input parameters to predict fallout gamma ray activity from surface burst nuclear explosion. At the minimum only estimated weapon yield and wind speed and direction are needed to make predictions for hazard areas and rough dose rate and dose contour lines. Predictions are usually sufficient to rescue purposes. As the weather situation was a very simple one with a steady wind direction, the comparison evidently was favourable to the ALAMA model.

References

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