HANDLING "DIRTY BOMB"-SCENARIOS WITH THE LAGRANGIAN PARTICLE MODEL LASAIR

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Abstract: An existing systems programme (LASAT) based on Lagrangian Particle Simulation has been adjusted to meet requirements of emergency authorities. The new model (LASAIR, Lagrangian Simulation of the Dispersion and Inhalation of Radionuclides) is able to simulate an explosion of an RDD (Radiological Dispersion Device) with additional radioactive material and computes the transport in the planetary boundary layer as well as dry and wet deposition on the ground. In order to assess the main pathways of radiation exposure to the population, the inhalation, ground- and cloudshine dose to individuals can be computed. The model has been introduced as a rapid decision support system within the Federal Office for Radiation Protection in Germany. LASAIR is applied as well in other (EU-) countries.
One of the most interesting features of the model is the basic meteorological input combined with a powerful and well validated diagnostic flow model and a Lagrangian particle model. LASAIR can be used either as a back-office decision tool or during in field/on scene operations. LASAIR has a special parameterisation of the initial cloud due to explosive material, which is based on explosion experiments on test sites of the German Armed Forces in 2003 and 2007.
A comparison to the well known EU-model RODOS as well as to other models (HEAT, HOTSPOT, TATOO) has started in 2008 and first results will be presented. They clearly demonstrate the ability of the Lagrangian Particle Models (LPM) especially compared to Gaussian Models (GM) or Gaussian Puff Models (GPM).

***Key words**: dispersion, Lagrangian particle model, dirty bomb, LASAIR, LASAT, radiation pathway*

1. INTRODUCTION

Terrorists might impose pressure with a well directed act of violence against the population or a government to enforce their illegal demands. An often discussed possibility is to deploy explosive material combined with radioactive substances somewhere in public areas; this is often called as a "dirty bomb-" or a RDD- (Radiological Dispersive Device) scenario.

Police authorities need to have an adequate understanding of the possible impact concerning in this case radioactive contamination in the surrounding areas or the main contamination pathways leading to the exposure of the population and to the possible counter measures. This can be achieved e.g. by simulating the explosion and dispersion of the radioactive material.

An appropriate model (LASAIR, Lagrangian Simulation of the Dispersion and Inhalation of Radionuclides) has been developed in the past years. This paper will discuss whether LASAIR compared to other models is able to answer the basic questions concerning a "dirty bomb"-scenario.

2. GENERAL PROCEDURE OF SIMULATING "DIRTY BOMBS" SCENARIOS WITH LASAIR

The general understanding of a "dirty bomb" is a combination of an amount of explosives and some radionuclides, unskilled attached together by terrorists. It is the task of the responsible authorities to find and to eliminate this kind of threat to protect the population. A possibility to minimise the threat of a "dirty bomb" is e.g. by simulating the explosion and the possible dispersion of the radioactive material, which helps to predict potential levels of radioactive contamination in the surrounding areas and the main contamination pathways. This gives a general understanding of the possible exposure to the population and leads to a selection of possible and proper countermeasures; it has been proposed as well by other authors e.g. Musolino, and Harper, 2006.

Conducted by the German Federal Office for Radiation Protection (BfS) and in charge of the German Federal Ministry for Environment, Nature Preservation and Reactor Safety (BMU) the programme LASAIR [Walter, 2001] has been developed which is able to give a first and rapid overview of atmospheric dispersion, ground activity, deposition and different exposition pathways (inhalation, groundshine and cloudshine) after an instant or continuous release of radioactive material. The systems programme can be used by radiation emergency authorities that are responsible for emergencies within the different German States (Länder). The programme has been developed in the year 2000 and was continuously upgraded until now.

LASAIR has been used in various exercises and has proved to be a valuable tool for decision makers as well. In April 2008 the latest version LASAIR 3.0.7 has been released. Because of the implemented topographical maps LASAIR is intended to be used basically in Germany but can be applied as well in other (EU-) countries using general available Geobrowsers.

LASAIR is based on the Lagrangian particle simulation of an existing systems programme [LASAT] (Janicke, 1983, 1985, 2008) and has been adjusted especially to meet the requirements for handling a "dirty bomb" scenario. A distinctive feature of LASAIR is the assessment of an initial cloud after an explosion as function of the explosive mass.

This parameterisation was determined from two series of explosion experiments with a range of 0,5–100 kg PETN that have been conducted at German Army test sites in 2003 and 2007. It is a simple formula that computes the height and the diameter of a cloud in a form like a cylinder, which is transformed to a cuboid with similar volume. A similar procedure is included in HOTSPOT or has been published in Apikayan et al 2008 (see article of Yaar) only for the height of the cloud. In contrast to the parameterisation in HOTSPOT our experiments show a significant smaller initial cloud size which will lead to higher radionuclide concentrations especially in the close vicinity.

Furthermore, a possibility of an artificial variation of the measured wind direction data has been implemented in LASAIR to take into account uncertainties within the measurement of the wind direction on the scene, extracting e.g. the maximum of the air concentration activity of a certain radionuclide lateral to the drift direction according to the different wind directions. This feature allows a quick overlook on possibly affected areas as consequence of varying wind directions or uncertainties within the wind measurements. Special attention has been directed to the usage of the programme in emergency cases. The programme is extremely easy to handle and allows the user only a strictly straight forward step by step usage in order to grant a maximum security feeding the programme with input data.

Another speciality of LASAIR can be seen in the procedure that usually is run through during an “dirty bomb”-scenario:

detection and localisation of a „dirty bomb“

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application of LASAIR (meteorology) with 1 Bq emission

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determination of activity and radionuclide

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application of LASAIR based on iterative improved measurements of activity

↓

radiation exposition

Each new measurement of the activity or of the radionuclide spectrum in the “dirty bomb” would usually require a new model run on the computer to determine the exposition that lasts from seconds to several minutes depending on the model, the kind of algorithms implemented (Lagrange, Gaussian) and the computer platform. In order to save PC processing time LASAIR computes first the meteorology and the dispersion based on a 1 Bq emission and afterwards the programme stops to allow the user to define the source term (in Bq). The advantage of this procedure is the possibility to use a step by step procedure in the course of the measurements starting from overview to detailed measurements and use theses results immediately in LASAIR, which gives an output for the dispersion and all exposition pathways within a second later provided that meteorological conditions have not changed. This feature can be used as well in order to check a worst case scenario. By computing a dispersion from a RDD according to a given meteorological situation it can be checked easily what activity of a distinctive or of a sum of radio nuclides would be necessary to reach a certain threshold where countermeasures are appropriate or necessary.

3. COMPARISON OF FIVE DIFFERENT MODELS AS VERIFICATION FOR LASAIR

The results from a comparison of different dispersion models has been used to answer the question if LASAIR is able to handle a “dirty bomb” scenario. The comparison has started in the beginning of 2008 when four different participants with their models have agreed to join the comparison:

HOTSPOT	(see reference Homann, 1994 or HOTSPOT 2.0.6),
HEAT	Hazard Estimation After Tbm engagement (Version 5.5),
LASAIR	Lagrangian Simulation of Dispersion and Inhalation of Radionuclides,
RODOS	Real-time On-line Decision Support system (RODOS, 2008) with dispersion model ATSTEP,
TATOO	Threat Analysis Tool

The models HEAT, LASAIR and TATOO are based on the Lagrange algorithm whereas HOTSPOT and RODOS use the Gaussian algorithm.

Four different meteorological cases have been selected for a study in spring 2008, one situation has been processed completely until July 2008. This was case “C02”, a neutral to slightly unstable condition (stability category: C) in flat terrain with a small roughness length (0,2 m). The general meteorological parameters that are used within the comparison are listed below. The meteorological conditions have been kept as simple as possible in order to understand best the computation processes of the dispersion models.

Meteorological Conditions for the comparison in case “C02”:

wind speed	3 ms^{-1}
wind reference height	10 m

wind profile	adjusted to LASAIR boundary layer model for HEAT and TATOO, adjusted to windspeed in 10 m for HOTSPOT and RODOS
wind direction	constant
roughness length	0,2 m (varies in RODOS in the first three cells downwind)
atmospheric stability	C, neutral to slightly unstable
height of inversion	800 m (RODOS approx. 1000 m)

As all models have been developed for different purposes it was necessary to find general basic input parameters that each model was able to handle; they are listed below.

Basic input parameters in the comparison for all models

size of aerosols	$0 \leq x \leq 10$ µm	90%	
size of aerosols	10 µm $\leq x$ µm	10%	
amount ox explosives		n.n.	see 1) and 2)
nuclide		Cs^{137}	
dose coefficient		$3{,}9\ 10^{-8}$ SvBq-^{1}	3)
source activity		$1{,}9\ 10^{13}$ Bq	
breathing rate		$3{,}8\ 10^{-4}$ m^3s^{-1}	3)

1) The amount of explosives must not be published in this publication because of part of the computation results are classified; persons that are interested in the numbers have to state their legal interest and will be provided with the data by the author.
2) The amount of explosives in LASAIR differs slightly to the other models due to the implemented parameterisation of the initial cloud (see below).
3) As default values RODOS uses the dose conversion coefficient for the retention class F of $4{,}6\ 10^{-9}$ $SvBq^{-1}$ (and the other models the value for retention class S), and a lower breathing rate of $2{,}6\ 10^{-4}$ m^3/s according to ICRP-71. This means that the calculated doses are lower by factor of 12,4 as soon as the default values are not harmonised.

Atmospheric dispersion models in general are able to use different shapes for the source term (point, area, line, volume) as input parameters. To use the dispersion models in the context of a "dirty bomb" a kind of initial cloud after an explosion has to be defined. This shape and volume of the initial cloud depends basically on the amount and kind of the explosives (TNT or PETN) and expresses also the area where devastating effects on man and the environment in the close vicinity might happen. But a physical-mathematical parameterisation for the initial dispersion after an explosion still is not known. Based on explosion experiments the initial cloud dispersion in LASAIR can be calculated up to a maximum explosive mass of 10 kg PETN, which still leads to a smaller initial cloud size compared to the default values of the other models and consequently to a higher inhalation dose. To harmonise the initial phase, all other models that use distinctive parameters to calculate the volume of the initial cloud have been fixed with a distinctive maximum height of the cloud.

The first idea to compare only the activity concentration in air as function of the distance from source has been placed back because the results of the different models were not comparable due to different output data averaging in time and in space. To harmonise the output would have caused too much workload and time for programming which would have delayed the comparison. The best solution for a reasonable comparison was to compare the inhalation dose which is computed by all models.

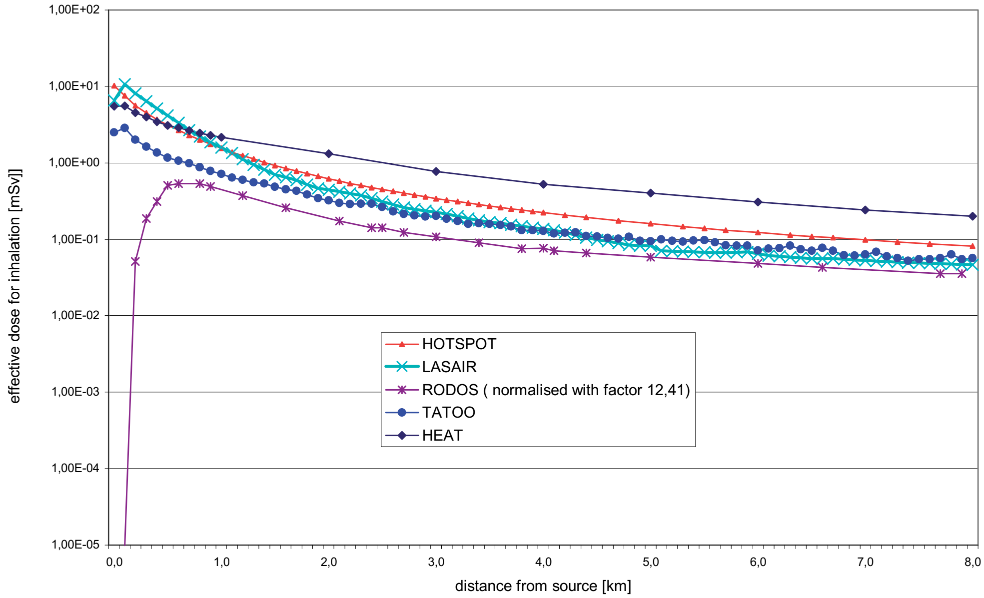

Figure 1. Comparison of the results from five different dispersion models regarding the effective inhalation dose [mSv].

4. DISCUSSION OF THE COMPARISON RESULTS

Under the chosen meteorological conditions basically the results show that all models differ only in the close vicinity of the explosion area up to a downwind distance of approx. 700 m. Figure 1 indicates clearly, that HOTSPOT and LASAIR compute the highest, almost equal dose numbers in the near range downwind and that HEAT and TATOO do not have much difference (approximately factor 2–4) to these models. In opposite to all the other models, RODOS calculates lower inhalation doses in the short distances to the place of explosion. Concerning this result it was found that RODOS assumes a lift from the ground, which leads to lower concentrations or activity near the ground.

In longer distances the results of all models show a good agreement. within approximately a factor of less than 10. In downwind distances of more than 2 km from the source, TATOO and LASAIR have rather similar numbers, HOTSPOT computes numbers that are only slightly higher and TATOO is higher as well.

Summarising the Lagrangian particle models (LPM) and the Gaussian model HOTSPOT show a very good agreement for this meteorological condition even though each LPM has been developed individually and independently by different institutions. The sharp bends that can be seen in the results of LASAIR and TATOO at a distance of approximately 100 m downwind are due to the fixed mesh resolution of the comparison; this graph will be refined in the continuation of the study by using smaller mesh sizes. The model RODOS shows the lowest numbers over all downwind distances.

5. CONCLUSIONS

The model LASAIR has been developed since several years and has proved its ability during various applications and exercises in the scope of "dirty bomb"-scenarios. It's a simple tool that is easily to handle and needs only basic relevant meteorological and radiological input information. It is based on a powerful dispersion model (LASAT) that is used in other important applications for the assessment of the radiation exposure in Germany as well; this means that a certain level of harmonisation in this scientific area has been achieved. LASAIR runs on an ordinary laptop and therefore can be used either close to the site of crime or as a back office tool.

The comparison for a specific meteorological situation shows that LASAIR is able to handle a "dirty bomb"-scenario and provides reasonable results compared to other models. This comparison will be continued with other meteorological conditions. Additional interesting problems might be considered like the initial cloud size, its behaviour as a function of the explosive mass and the effects on the inhalation dose.

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