‘Dirty bomb’ attack in a city area: requirements to estimate consequences of contaminant dispersion

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INTRODUCTION

In the EC/FP6 project EURANOS, the ERMIN model has been developed to predict the consequences in an inhabited area of contaminant releases to the atmosphere from nuclear power plant accidents (Andersson *et al.*, 2008). This model is now fully parameterised and integrated in the ARGOS decision support system. However, in recent years, also the possibility of a malicious attack involving dispersion of radioactive matter, especially through the detonation of a so-called ‘dirty bomb’, has attracted increasing attention. Inhabited areas could be seen as likely targets for such incidents, as this is where most people could be affected. The immediate vicinity of the site of a ‘dirty bomb’ detonation would be likely to be monitored very extensively - practically like a forensic site - and in this type of area it would also be impossible to reliably model the distribution of contaminants, due to the dominance of large contaminated shrapnel. However, depending on a number of parameters, a considerable part of the contamination could be finely dispersed and contaminate a rather large area. To predict and assess the extent and radiological impact of such contamination as well as the outcome of countermeasures, a consequence assessment tool essentially based on the same concepts as ERMIN is required, and is under development in ARGOS. However, it is important to note that the contaminants and their behaviour would differ significantly from what would be observed after a nuclear power plant accident. The implications of this are discussed in this paper. Also, in relation to atmospheric transport modelling new high resolution tools are required since the contaminant particle dispersion following a ‘dirty bomb’ attack would often take place at relatively low altitude, where the plume would interact with buildings and other obstacles.

METHODS AND RESULTS

In the following a discussion is given of some important issues that are dealt with in the development and parameterisation of the new extension of the ARGOS decision support system for ‘dirty bomb’ scenarios.

Primary contaminants

To estimate the health consequences of any contaminating incident dispersing radioactive aerosols in the atmosphere, it is essential to first consider which radionuclides might be implicated, at which source strengths, and with which initial physicochemical forms. In connection with a terror attack involving a ‘dirty bomb’ explosion, in principle, a very large number of different sources could be at play, although the list of well-suited and possibly available sources would for various reasons be considerably shorter. Table 1 shows some of the existing sources that would be considered most likely to be applied, if they fell into the wrong hands (e.g., Harper *et al.*, 2007; Ferguson *et al.*, 2003). Primary factors of importance are physical half-life, type of radiation emitted, photon/particle yield and energies, physicochemical forms, and availability of sufficiently strong (but not too strong) sources.

Table 1. Some particularly important radionuclides for consideration for 'dirty bomb' scenarios, including typical physicochemical forms of large existing sources and max. source strength estimates.

Radionuclide	Typical physicochemical form of large existing sources	Existing strong sources and their strengths
^{60}Co	Metal (can be dissolved in acid - liquid)	Sterilisation irradiator (up to 400,000 TBq). Teletherapy source (up to 1000 TBq).
^{90}Sr	Ceramic ($SrTiO_3$) - insoluble, brittle, soft (Mohs hardness: 5.5), can be powdered	Radioisotope thermoelectric generator (1000-10.000 TBq).
^{137}Cs	Salt (CsCl) (can be dissolved - liquid)	Sterilisation irradiator (up to 400,000 TBq). Teletherapy source (up to 1000 TBq).
^{192}Ir	Metal – soft - Mohs hardness 6.5 (can be powdered), insoluble in water	Industrial radiography source (up to 50 TBq)
^{226}Ra	Salt ($RaSO_4$) (can be powdered), very low solubility	Old therapy source (up to 5 TBq)
^{238}Pu	Ceramic (PuO_2) - insoluble, can be powdered	Radioisotope thermoelectric generator (up to 5,000 TBq).
^{241}Am	Pressed ceramic powder (AmO_2)	Well logging source (up to 1 TBq).
^{252}Cf	Ceramic (Cf_2O_3) - insoluble	Well logging source (up to 0.1 TBq).

Dispersed long-lived gamma emitters can potentially give rise to a severe long-term dose problem, but there are limits as to how strong sources can be handled and brought to dispersion, even if terrorists consider it unimportant to survive themselves. As an example, a 1000 TBq ^{60}Co source would at a distance of 1 m result in a dose rate of some 260 Sv/h - i.e. lethal dose within minutes. Naturally, for longer transportation periods, lead shielding arrangements could reduce dose rate very much, but it would be highly problematic to construct the device. A pure beta emitter like ^{90}Sr would be comparatively easier to shield, but even so, Bremsstrahlung doses would often not be trivial, requiring special constructions.

An example of strong and carelessly 'orphaned' sources is the ^{90}Sr elements (typically in the range of 1000 - 10,000 TBq), originally applied in radioisotope thermoelectric generators, which have in recent years on several occasions been retrieved by village inhabitants in the former Soviet Union (Andersson, 2005). For comparison, it has been estimated that the total release of ^{90}Sr from the Chernobyl accident was about 8000 TBq (Sohier, 2002).

Aerosolisation and particle sizes

Recent experimental work by Harper *et al.* (2007) has clearly demonstrated that the fraction of contaminants aerosolised in an explosion depends strongly on the elemental properties of the contaminants, their initial physicochemical forms, and the more or less successful construction of the explosive device. For instance, for contaminants in ceramic form, aerosolisation fractions of 2-40 % have been reported. This was in general found to produce a particle size spectrum with much of the contaminant mass in the 30-100 μm range, and a smaller peak in the 2 μm range. This type of size distribution was also measured after the Thule accident in 1968. The Thule explosion was essentially similar to that of a 'dirty bomb': a conventional explosion dispersing a solid, possibly ceramic, radioactive material with a very high melting point. In the Thule case, only 1.3 % of the particles were larger than ca. 18 μm, but these carried nearly 80 % of the activity (Eriksson, 2002). In the context of atmospheric dispersion over larger areas, it is the smaller particles that are of primary concern (depending on initial plume rise height), since gravitational settling of the larger particles will occur very rapidly and over short distance. If for instance ^{60}Co is in metallic form, extremely little will be aerosolised, but if the contaminants are in liquid form, as much as 80 % may be aerosolised as small, respirable particles (Harper *et al.* (2007). To describe external doses from deposition of atmospherically dispersed contaminants on different surfaces over larger city areas, deposition velocity data libraries have been developed for ARGOS for different intervals of the particle size range 0.5 - 100 µm, on background of theory and experiments. Natural weathering functions for relevant particle sizes must also be implemented, since those implemented with ERMIN generally relate to the small soluble Cs particles observed after the Chernobyl accident, whereas 'dirty bombs' would often involve dispersion of much larger, not readily soluble particles that are much more rapidly weathered off. Also deposition velocity data to human skin, hair and clothing, and corresponding natural clearance functions, should be included, since the deposition of particularly larger contaminant particles could result in high skin beta doses and gamma doses to the body (Andersson *et al.*, 2004).

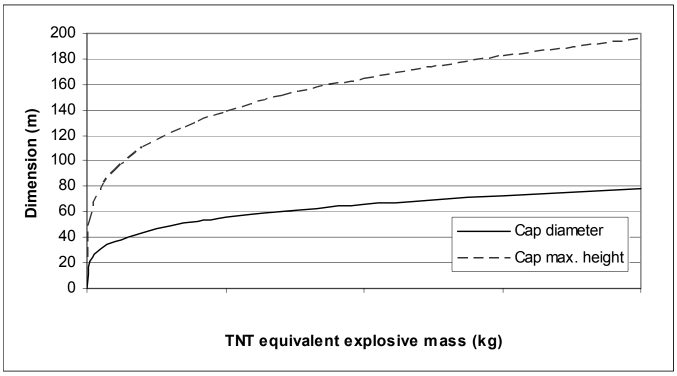
Weather

Weather is important in several contexts. The new ARGOS model including larger particle sizes operates with five different weather categories at deposition (light rain, heavy rain, dry weather, dry weather with snow cover, snowfall), acknowledging that scavenging with precipitation is a very powerful deposition mechanism. In heavy rain scenarios indoor deposition problems will be comparatively trivial, but in dry weather, indoor air concentrations of small particles can be quite high, and since people normally spend some 85 % of the time indoors (Andersson *et al.*, 2004), this is significant, and is accommodated in ARGOS. Indoor air concentrations are for particles smaller than about 5 µm largely governed by ventilation and indoor deposition rates, but for larger particles, filtration in the building structure becomes increasingly important (Andersson *et al.*, 2004; Long *et al.*, 2001).

Plume rise

Plume rise height obviously has great influence on the size of the affected area, and determines the significance of plume interaction with environmental structures (e.g., buildings). Parameterisation for ARGOS relates to several independent blast studies. The 'qualitative' curves for initial plume top height and cap diameter shown in Fig. 1 are based on data from the US 'Roller Coaster' tests conducted in April-June 1963 to investigate the effect of accidental conventional explosions spreading radioactive material from a nuclear bomb.

Figure 1. Plume top height and cap diameter following the detonation of a 'dirty bomb', as a function of TNT equivalent explosive mass. 'Qualitative' curves based on the US 'Roller Coaster' test data from 1963.



Dispersion

In mesoscale dispersion models like ATSTEP and RIMPUFF, inhabited areas are simply modelled as areas with enhanced overall roughness and deposition rates compared with open areas. Using the UDM urban dispersion model from the UK Defence Science and Technology Laboratory, Astrup *et al.* (2005) demonstrated the inadequacy of this approach for the low altitude dispersion that follows, e.g., a 'dirty bomb' explosion in an urban centre. Here, the initial plume interaction with buildings and other obstacles can be decisive for the plume shape and dispersion pattern. Therefore, a new high resolution implement based on

Gaussian puffs at street scale, and taking into account trapping and spreading of parts of a plume around obstacles (Fackrell, 1984), is being developed for implementation in ARGOS.

CONCLUSIONS

Model requirements for predicting the radiological impact of a ‘dirty bomb’ explosion in a city have been investigated for extension of the ARGOS decision support system.

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