LONG-RANGE DISPERSION AND DEPOSITION ESTIMATES FROM A SIMPLE GAUSSIAN PLUME MODEL COMPARED WITH ESTIMATES FROM A 3-D LAGRANGIAN PARTICLE MODEL.

E.R. Lutman, R.A. Hill, S.R. Jones, P. McDonald
Westlakes Scientific Consulting, Moor Row, Cumbria, CA24 3LN.

INTRODUCTION

Predictions of the long-range dispersion of routine atmospheric discharges are often made using the comparatively simple Gaussian plume atmospheric dispersion models such as those based on NRPB-R91 (*Clarke R.H.*, 1979). These models are designed to model dispersion for distances up to a few tens of kilometres (*Clarke R.H.*, 1979), however, because they are simple and economical to run, they are sometimes applied to modelling long-range dispersion. A previous study (*Lutman E.R. et al.*, 2004) investigated whether Gaussian models predict long-range concentrations from routine releases sufficiently accurately by comparing the results of a simple dispersion model to those of a more physically realistic, though computationally expensive, proprietary Lagrangian particle based model. The Lagrangian particle based model used in this investigation was the UK Meteorological Office's medium to long-range dispersion model, the 'Nuclear Accident Model', NAME.

This work extends the previous study by comparing dispersion curves calculated using the NAME model and those calculated using an implementation of the NRPB-R91 model.

METHODOLOGY

The methodology of the present study is similar to that of *Lutman E.R. et al.* (2004). Dispersion factors and deposition factors (i.e. for a 1 Bq s^{-1} discharge) calculated by a simple Gaussian plume model are compared to those calculated by the NAME model for a continuous release of radionuclides from a hypothetical stack in the centre of the Sellafield site in Cumbria, UK. The NAME model was used to calculate dispersion (*Nelson N. et al.*, 2002) from two release heights; 10 m and 120 m. Dispersion factors (Bq m^{-3} / Bq s^{-1}) and dry and wet deposition rates (Bq m^{-2} s^{-1} / Bq s^{-1}) were calculated using a model grid covering north-west Europe. Dispersion and deposition factors were extracted in this study over a polar grid for downwind distances ranging from 5 km to 1000 km and at 30^o intervals. Thus dispersion and deposition curves were produced for each meteorological sector. The radionuclides of interest are ^{85}Kr, ^{41}Ar and ^{137}Cs, which represent a range of radionuclide behaviour: long- and short-lived, non-depositing and long-lived depositing radionuclides (see Table 1).

For comparison, the NRPB-R91 model was used to predict dispersion and deposition factors for the same radionuclides, and for the same stack heights and downwind distances as described above.

THE GAUSSIAN PLUME MODEL

A straightforward implementation of the 'R91' Gaussian plume dispersion algorithm (*Clarke R.H.*, 1979; *Jones J.A.*, 1981a) was used. For each atmospheric stability category, it is assumed that for a snapshot in time, the plume is described by a Gaussian distribution both in the horizontal and vertical planes. This methodology is applied to annually averaged concentrations by evaluating the distribution of activity in sectors defined by the meteorological data available. The horizontal distribution of activity is assumed to be constant over a sector of angular width, α, as described by *Clarke R.H.* (1979). Dispersion factors were calculated for each stability category though in this study a uniform wind-rose was used, therefore, $\alpha = 360^{o}$.

Table 1. Characteristics of the radionuclides modelled (adapted from Nelson N. et al., 2002)

Radionuclide modelled	Radionuclides represented	Dry deposition velocity (m s^{-1})	Wet deposition	Description
^{41}Ar	^{41}Ar	-	No	Short-lived, unreactive
^{85}Kr	^{3}H, ^{14}C, ^{85}Kr	-	No	Long-lived, unreactive
^{137}Cs	^{35}S, ^{60}C, ^{90}Sr, ^{95}Nb, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{239}Pu, ^{241}Pu, ^{241}Am	1×10^{-3}	Yes	Long-lived, reactive

Several R91 model configurations were performed. First, a 60 % category D Pasquill-Gifford stability class distribution (see Table 2) was assumed, as recommended for the UK by *Clarke R.H.* (1979) (60% D).

In addition, the results were calculated for two roughness lengths, Zo = 0.3 m (representative of agricultural land) and Zo = 0.01 m (suitable for transport over the sea). Finally R91 values were calculated for 100% stability category D and a distribution of wind-speeds as recommended by *Jones J.A.* (1981b), see Table 2.

The simple parameterisation of dispersion used in the R91 model is in contrast to that used in the NAME model, which simulates the changes in meteorological conditions during transport. NAME is a Lagrangian multiple particle model (*Maryon R.H. et al.,* 1999) which imports high resolution spatial and temporal resolution meteorological data and simulates the release and spread of discharges by releasing a large number of ‘air parcels’ into the model atmosphere. These ‘air parcels’ are then advected in three dimensions by the model wind field and experience diffusion along their trajectory using random walk methods.

Table 2. Statistical meteorological data assumed for 60 % stability category D distribution (from Clarke R.H., 1979).

Pasquill Gifford stability category	Wind-Speed (m s^{-1})	Frequency
Category A (convective)	1	0.006
Category B	2	0.06
Category C	5	0.17
Category D (neutral)	5	0.6
Category E	3	0.07
Category F	2	0.08
Category G (very stable)	1	0.014

DEPOSITION

Dry and wet deposition processes are modelled in NAME and in the R91 model, and a comparison of the differences between the methodologies is presented in *Lutman E.R. et al.* (2004).

Dry deposition

The R91 model uses a source depletion model as described by *Jones J.A.* (1981a). In NAME, the flux of pollutant to the ground is proportional to the concentration of the pollutant within the boundary layer. The depositing radionuclide ^{137}Cs was assigned a dry deposition velocity of 10^{-3} m s^{-1}.

Wet deposition.
Wet deposition is modelled in R91 using a wet deposition coefficient, Λ, (which does not distinguish between rainout or washout processes) where the total amount of material remaining in the plume, Q, at time t is calculated from the original amount discharged, Q_o:

$$Q = Q_o \exp - (\Lambda t) \qquad (1)$$

The value of the wet deposition coefficient for ^{137}Cs is a constant value of 10^{-4} s^{-1}, which approximately corresponds to a rainfall rate of 1 mm h^{-1}. The intermittent nature of rainfall is not replicated in R91, instead, a fraction of activity is discharged during conditions of rain, and experiences rain continuously during dispersion downwind. The remaining fraction is discharged in dry conditions, which remain dry as it travels downwind.

In contrast, NAME uses hourly rainfall rates derived from weather radar and other sources. Washout and rainout processes are described separately using scavenging coefficients, which are a function of rain-rate (see *Nelson N. et al.* (2002) for further details).

RADIOACTIVE DECAY
Radioactivity is accounted for in both models according to the governing decay equation. R91 substitutes a modified source strength into the Gaussian dispersion equation, where

$$R_p = \exp\left[- l \, \frac{x}{u_s} \right] \qquad (2)$$

In NAME, the activity that each air parcel carries is depleted by radioactive decay.

RESULTS
The results are presented in Figure 1. Predictions from NAME (symbols) can be compared to predictions from R91 (curves).

The effect of dispersion
The effects of dispersion are illustrated by the results for ^{85}Kr, a non-depositing radionuclide, which show that R91 over-predicts air concentrations increasingly with distance for the 60% D cases. In contrast, the predictions for 100% stability category D lie within the range of predictions by NAME. This is consistent with the recommendations of *Jones J.A.* (1981b) who stated that concentrations at long distances are determined by neutral conditions. Roughness length has a greater effect on air concentrations for releases from high stacks than from low stacks. Conversely, variability of wind-speed has a greater effect on air concentrations for releases from low stacks which show the best agreement with the NAME data for the case with varying wind-speed. This is also consistent with the recommendations of *Jones J.A.* (1981b) who recommended that long-range dispersion should be modelled using neutral stability and a range of wind-speeds.

The effect of dry deposition
The effects of dry deposition are shown in the ^{137}Cs dry deposition factors. Dry deposition rates are over estimated by the “60% D” case for distances beyond 50 km. The 100% D cases

with constant wind-speeds show the best agreement with the NAME results. All R91 configurations over-predict dry deposition rates at 750 km downwind and beyond.

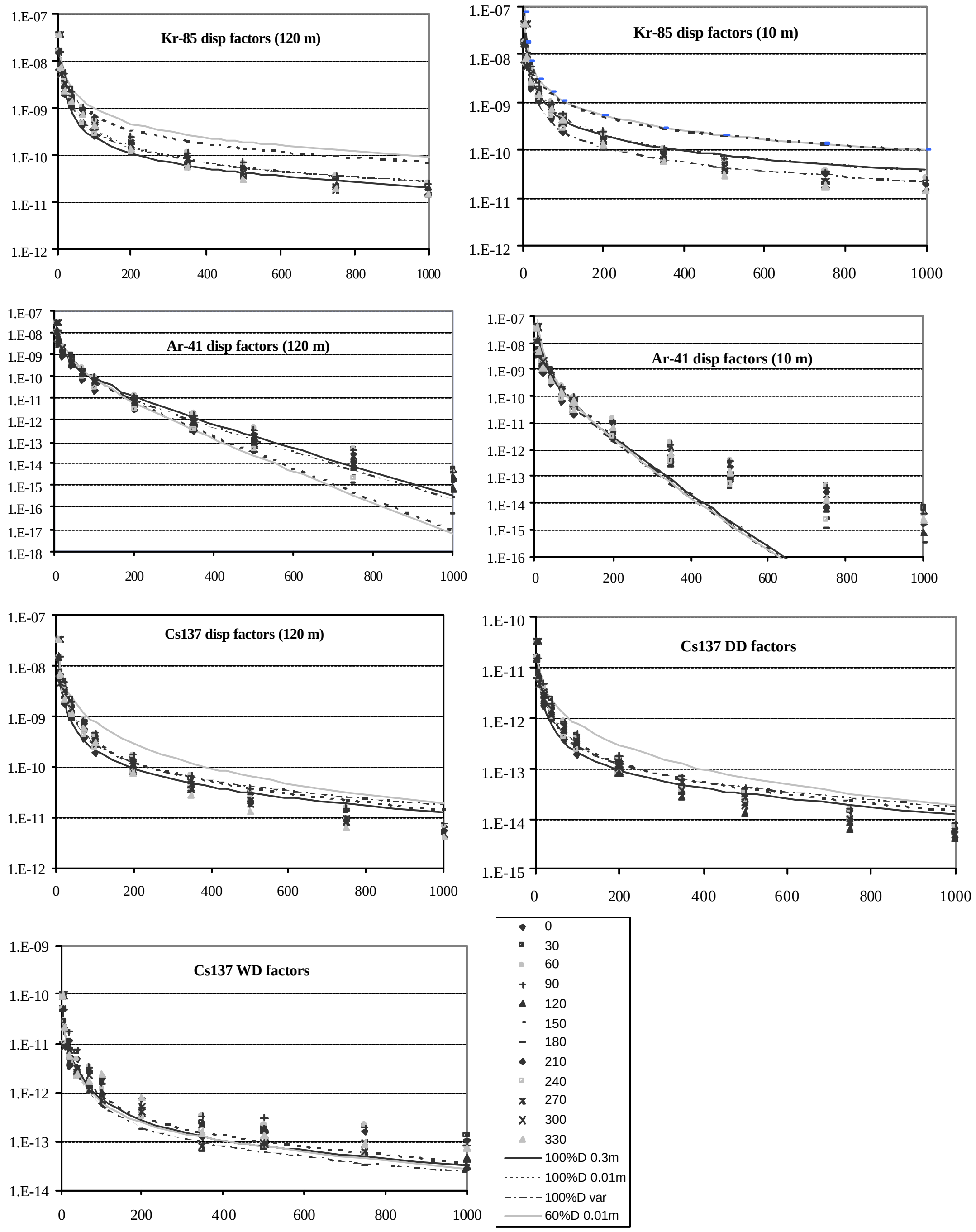

Fig. 1; Dispersion factors (Bqm^{-3}/Bqs^{-1}) and dry and wet deposition factors ($Bqm^{-2}s^{-1}/Bq\ s^{-1}$).[1]

The effect of wet deposition

Wet deposition rates for ^{137}Cs are under-predicted compared to the NAME results increasingly with downwind distance. There are two distinct elements to modelling wet deposition using a dispersion model, which NAME and R91 treat differently. The first involves the calculation of the deposition rates in those sections of the plume experiencing rain. The second involves parameterisation of the intermittent nature of rainfall in time and

[1] Results from NAME for each wind direction are shown by symbols. R91 results are shown by curves.

space. *Lutman E.R.. et al*. (2004) noted that the differences between the wet deposition rates observed by NAME and R91 can be explained mainly by the simplification in the description of meteorology in the R91 model. The R91 model assumes that the meteorology is unchanging, i.e. a fraction of activity is discharged during conditions of rain and experiences rain continuously, while the remaining activity is discharged in dry conditions, and experiences no rain during the model run. The wet deposition coefficient, Λ, is scaled by the fraction of time for which it rains, here assumed to be 10 % of the time. Consequently, the 10 % of the discharge which experiences rain will be deposited at close range and there will be no further rainout downwind.

The effect of half-life

The effect of half-life is illustrated by ^{41}Ar, a non-depositing radionuclide with a half-life of 1.8 hours. For a 120 m release height, the R91 100% D results are in good agreement with the NAME results for a roughness length of 0.3 m for both constant wind-speed and varying wind-speed. However, for a 10 m release height, the R91 results underestimated the dispersion factors compared to NAME. This is because the R91 model uses wind-speeds at the effective stack height and therefore the plume experiences a longer travel time compared to NAME, which uses the actual wind-speeds from the Unified Model, which are closer to the geostrophic wind-speed.

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