1.37 NUCLEAR TOOLS FOR CHARACTERISING RADIOLOGICAL DISPERSION IN COMPLEX TERRAIN: EVALUATION OF REGULATORY AND EMERGENCY RESPONSE MODELS

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INTRODUCTION

Australia's national nuclear facility, managed at Lucas Heights in Sydney by the Australian Nuclear Science and Technology Organisation (ANSTO), operates a research reactor (named HIFAR) used in the production of radioactive materials for a range of medical, industrial and research applications. As part of its environmental management strategy, ANSTO continuously monitors airborne emissions from stacks involved in its production process. A program of meteorological measurements enables estimates to be made of the downwind concentration of airborne pollutants, for computation of effective doses to individuals due to routine releases of airborne radionuclides in time-integrated models, and for input into real-time dispersion models for emergency response purposes. The modelled effective dose rates to members of the public are compared to notification levels set by its regulating agency ARPANSA (Australian Radiation Protection and Nuclear Safety Agency).

ANSTO has an emergency response system in which an atmospheric dispersion model is used to guide the deployment of health physics survey teams in case of any accidental releases. In future it is planned to provide more quantitative model outputs which may assist to make more specific emergency management decisions. It is the purpose of this research to determine which atmospheric dispersion model works best in our region. Hills and valleys typify this region, with some maritime influences like sea breezes. A number of dispersion models are being evaluated at the site of Lucas Heights, south of Sydney, NSW Australia using a continuous time series of environmental gamma radiation monitoring data. These data are radionuclide specific and for the preliminary results to be presented here we have chosen the unique Ar41 tracer which is only produced by the research reactor. Additionally, three-monthly radionuclide emissions of Xe133 and Xe135 from a radiopharmaceutical production facility are used in the regulatory model PC-Cream (*Simmonds, J.R., G. Lawson, A. Mayall* 1995) and compared with the monitoring data over a one-year period.

METHODOLOGY

In order to investigate atmospheric dispersion processes in the complex terrain surrounding Lucas Heights, ANSTO has installed a network of three meteorological stations and four environmental gamma monitoring stations (Figure 1). Meteorological data have been collected since the start of site operations in the 1960s but more recently in digital form since 1991. Meteorological statistics such as average wind speed, wind direction and standard deviation of wind direction (σ_θ) are collected every 15 minutes, stored in-situ and radio telemetered to a central location for transmission to various locations including the emergency operations centre. The meteorological data and Ar41 source release data provide the inputs to the atmospheric dispersion models to be evaluated.

To date in a preliminary assessment we have evaluated two variations of the RIMPUFF dispersion model (*Mikkelsen, T., S.E Larsen, S. Thykier-Nielsen,* 1984; *Thykier-Nielsen, S., S.*

Deme, T. Mikkelsen, 1998) from Riso National Laboratories in Denmark. This model has been developed specifically for nuclear applications. In particular it can model dispersion of

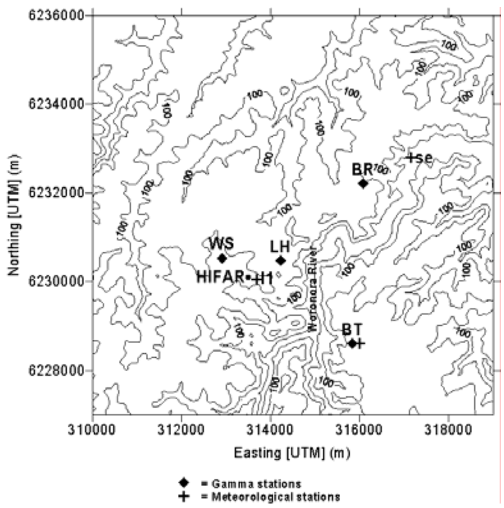

Figure 1. The Lucas Heights region showing locations of meteorological and environmental gamma monitoring stations with topographic features.

radionuclides and estimate the gamma radiation doses using calculations of gamma ray exposure from a finite pollution cloud simulated by releasing a continuous series of puffs. This is the type of gamma radiation field detected by the radiation monitors. The two variations of this model have involved changing the input wind field module, using that supplied by Riso (LINCOM) (*Troen, I. and A.F. de Bass* 1986) and another module (NUATMOS) developed by *CAMM* (1993). The LINCOM model only uses data from one height (10m) whereas NUATMOS allows a vertical profile, but has only been used with 10m data in tests conducted so far. In addition, only one set of dispersion model options has been used in RIMPUFF, specifically the dispersion scheme that simulates horizontal and vertical dispersion using a Pasquill stability category calculated using the *USEPA* (1987) method based on wind direction fluctuation standard deviations, σ_θ, wind speed and time of day.

The GR150 gamma radiation detection system was developed by Exploranium Canada (*Grasty, R.L., J. Hovgaard, and J.R. LaMarre* 2001). This allows gamma dose rates ($nGyh^{-1}$) to be collected every 15 minutes for radionuclides of interest i.e. Ar41, Xe133, Xe135, skyshine, air kerma rates and the naturally occurring isotopes U, K and Th. Background levels are calculated by using local meteorological data to determine when the wind transports radionuclides from defined sources towards or away from the detectors. Case studies were chosen by identifying major peaks in the Ar41 data time series from November and December 2002. Approximately 20 cases were processed for impacts at the nearby LH gamma monitoring station (0.82 km from the HIFAR reactor) and another 20 cases for the more distant BT station [2.78 km] across the Woronora river valley (see Figure 1). Environmental gamma data integrated over three quarters in 2002 and the last quarter of 2003 are also compared to estimates from the long-term radiological impact assessment model PC-Cream.

RESULTS

Emergency Response Model Evaluation

The 20 cases studied at each of the monitoring stations in late autumn and early summer covered all times during the day and as a result were modelled under different atmospheric stability, wind speed and dispersion conditions. The difficulty was how to stratify the cases in terms of these variable conditions in order to assess the model performances. A plume with a finite volume containing gamma ray emitting radionuclides has an impact on the detector from a distance of about 300m. There will be maximum impact when the plume centre-line is immediately above the detector but there can also be an impact from lower concentrations of radionuclides in the fringes of the plume. Frequently the behaviour of the gamma monitor traces with time indicated not a smooth impact of a plume on the detector but multiple impacts (see the Type 2 trace in Figure 2). This may have been indicative of winds meandering in the vicinity of the detector whereas a smooth, discrete shaped peak probably indicates a consistent shift in wind direction with time which sweeps the plume across the detector. Based on the wind data from the "11" station at Lucas Heights (see Figure 1), three different wind variation types were identified: Type 1 – a consistent sweep in one direction across the detector; Type 2 – constant plume presence within the detector range; Type 3 – wind meander in and out of the detector range.

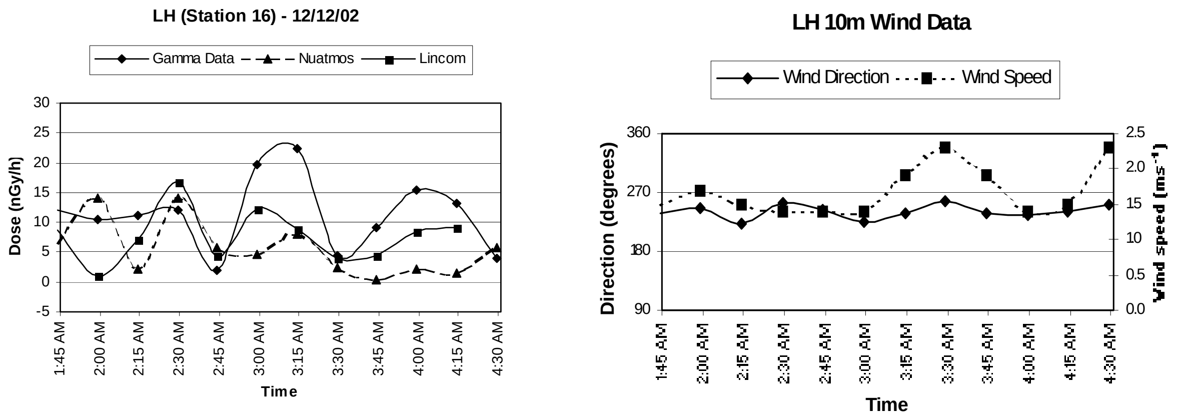

Figure 2. Examples of gamma radiation and model results vs wind variation "Type 2" category (plume remains within detector range)

Statistics were analysed from the inter-comparison of measured gamma peaks and model estimates (Table 1). Ratios of the model peak estimates have been calculated against those in the gamma data (gamma:model), sometimes for two peaks in more complicated cases. Time offsets between the occurrence of model and observed gamma peaks have been calculated within the limitations of the 15 minute time resolution of the systems and the fact that some observed and modelled peaks were relatively flat over several time periods. At the closer station (LH at 0.82km from the source) the agreement between observed and modelled peak magnitudes is within a factor of 3 in 75% of cases for LINCOM and 50% for NUATMOS. At the more distant BT Station (2.87km) there is a wider spread of results. Five cases (not presented here) did not have any modelled plume peaks and several other cases (included here) have very large ratios that demand further detailed analysis in the future. At this station, modelled peak magnitudes are within a factor of 3 of the observed gamma peak values in 39% of cases for LINCOM and 67% for NUATMOS. It should be noted that a factor of less than one indicates a conservative result for the model (gamma<model: see Table 1). In these cases, estimates using LINCOM are more conservative than NUATMOS closer to the source whereas NUATMOS is more conservative across the valley at the more distant detector. At both the LH and BT stations 73% of observed peaks arrived within ±15 minutes of model estimates using LINCOM whereas this agreement decreased to 51% using NUATMOS.

Table 1. Statistics on agreement between models and observed gamma radiation data

Station	Peak1:Lincom	Peak1:Nuatmos	Peak1:Lincom	Peak1:Nuatmos
	Fraction (%) within a factor of 3		Fraction (%) with ratio < 1	
Main Gate	75	50	45	30
BT	39	67	22	39

Routine Release Model Evaluation

The calculation of background levels of environmental gamma radiation for the radionuclides (using meteorological data) generates an average that is subtracted from the raw data to form a calibrated dataset. However, there is a standard deviation (fluctuation) associated with this average which reflects both natural variations in background levels and the intrinsic accuracy of the NaI detector. If the calibrated data are integrated over a sufficiently long period, the net influence of these statistical fluctuations is expected to be small (but will not be exactly zero). The three-month integrated dataset discussed below includes the effects of these statistical fluctuations.

In Table 2, data comparing the modelled and measured doses (µSv) are presented for the last three quarters of 2002 and the last quarter of 2003. Reliable environmental gamma radiation data was not available in the first three quarters of 2003, due to instrumentation problems.

Table 2. Comparison of measured and modelled (PC-Cream) three month doses (microSieverts)

Location	Radionuclide	Model data	Measured data	Model data	Measured data	Model data	Measured data	Model data	Measured data
		2002q2		2002q3		2002q4		2003q4	
LH (0.82km)	Ar41	1.99	1.83	1.84	1.53	0.49	0.73	0.75	0.36
	Xe133	0.11	0.06	0.12	0.09	0.05	0.00	0.18	0.02
	Xe135	0.15	0.09	0.15	0.08	0.07	0.08	0.16	0.29
BT (2.78km)	Ar41	0.18	0.11	0.19	0.18	0.08	0.06	0.08	0.05
	Xe133	0.01	0.01	0.01	0.02	0.00	0.00	0.02	0.02
	Xe135	0.01	0.00	0.01	0.00	0.01	0.00	0.02	-0.02
WS (0.73km)	Ar41	-	-	0.35	0.25	-	-	0.98	0.48
	Xe133	-	-	0.00	0.01	-	-	0.02	0.04
	Xe135	-	-	0.00	0.01	-	-	0.02	0.05

A dash indicates no available data

Three-month integrated measured doses with magnitudes less than approximately 0.05 µSv in Table 2 were below the statistical accuracy of the method, for the reasons discussed above, and consequently cannot be considered for the purposes of this study. This includes all measured doses of Xe133 and Xe135 at the BT and WS sites (notably, the slightly negative value for Xe135 in quarter 4 of 2003 at the BT site is not statistically significant). The Ar41 release is the main contributor to annual doses. In general the modelled estimates are higher than the measured doses (i.e. more conservative). For all detectors, the modelled Ar41 doses are a maximum factor of 2.1 higher than those measured. A similar factor applies to the more significant Xe133 and Xe135 doses at the LH detector site.

SUMMARY

The results of preliminary studies to compare observed gamma radiation data and the emergency response models using Ar41 released from a research reactor indicate the following:

- The LINCOM wind field model performs better (more cases within a factor of 3) and is more conservative at the close receptor. There is agreement of peak predicted and observed arrival times to within ±15 minutes in 73% of cases.
- The NUATMOS wind field model has improved performance and is more conservative at the more distant detector. There is agreement of peak predicted and observed arrival times to within ±15 minutes in 51% of cases.

These results need to be confirmed in future studies with a large number of cases under a variety of meteorological conditions. In particular the influence of the valley on the plume trajectories has to be investigated for cases where there was no apparent impact predicted by the models, even though gamma radiation peaks were observed at the more distant station. It is also possible that only running the models for about an hour or so before the peak was observed did not allow for possible re-circulation of pollutants from earlier releases. These studies are ongoing.

The results from comparison of long term impacts of the routine releases using the regulatory model, PC-Cream, indicated good agreement between the model and measurements. In general for Ar41, which contributes most to the annual doses in the area, the agreement is within a factor of two, with the model estimates being conservatively high.

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