# THE EVALUATION AND CHARACTERIZATION OF FUGITIVE EMISSIONS FROM A LARGE INDUSTRIAL SITE.

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## Abstract

The assessment of fugitive emission rates represents a significant challenge to industries in general, and quantification of these emissions forms part of BNFL's authorisation to discharge materials to the atmosphere. This paper describes the method used at Sellafield, and looks in general at studies undertaken to enable a sensitivity analysis into the use of different modelling functionality, configuration and input data on the derivation of the fugitive source term. The work involved wind tunnel studies of dispersion and turbulence characteristics over the site. Results from particle size distribution measurements are also presented along with a description of additional work being undertaken to independently quantify emissions.

## Introduction

Under the terms of a Certificate of Authorisation for the disposal of radioactive waste, British Nuclear Fuels plc (BNFL) discharges gaseous radioactive effluent into the atmosphere from a number of stacks on its Sellafield site. The discharges are required to conform to prescribed limits within specific schedules. While it is possible to account for discharges from monitored stacks, it is not possible to directly account for the unmonitored sources such as open fuel storage ponds. Thus, a procedure, known as the 'Approved Places Methodology', was developed to estimate the unmonitored discharge (AP Emissions) from the discrepancy between model predictions and monitored air concentrations ($\chi$) at four High Volume Air Sampler (HVAS) locations around the site perimeter (see Figure 1) as outlined in Equation 1.

The current methodology [1] involves the use of NRPB-R91 [2] dispersion model to calculate stack dispersion factors (DF) based on an effective stack height (ESH), the downwind distance and a uniform wind rose with 60% category D stability. A DF is calculated for each HVAS location to enable determination of the contribution to the monitored concentration attributable to each source. Similar DF for the fugitive source location enables calculation of the fugitive emission rate. Thus, use of an appropriate DF can be critical. In this paper, programmes put in place to investigate methods of improving the understanding, accuracy and reliability of methods used to predict the Approved Places emission rate are discussed.

$$\text{AP Emissions (Bqs}^{-1}\text{)} = \frac{[\text{Measured } \chi \text{ (Bqm}^{-3}\text{)} - \text{Predicted Scheduled Source } \chi \text{ (Bqm}^{-3}\text{)}]}{\text{Fugitive Source DF (Bqm}^{-3}\text{/Bqs}^{-1}\text{)}} \quad (1)$$

## Improved meteorology

Reporting of fugitive emissions is required on a 3-monthly basis. The effect of the use of annual average generic meteorological data on these shorter time period predictions is unclear. Improved representation of dispersion through the use of measured meteorology, as opposed to generic climatological assumptions, may enhance the accuracy of the Approved

Places Methodology. As there is a 48m meteorological tower adjacent to the site (see Figure 1), it is possible to investigate the use of site-specific data as a means of improving the methodology. An inter-comparison of fugitive emissions predictions obtained using differing averaging periods such as monthly, 3-monthly and annual is also possible.

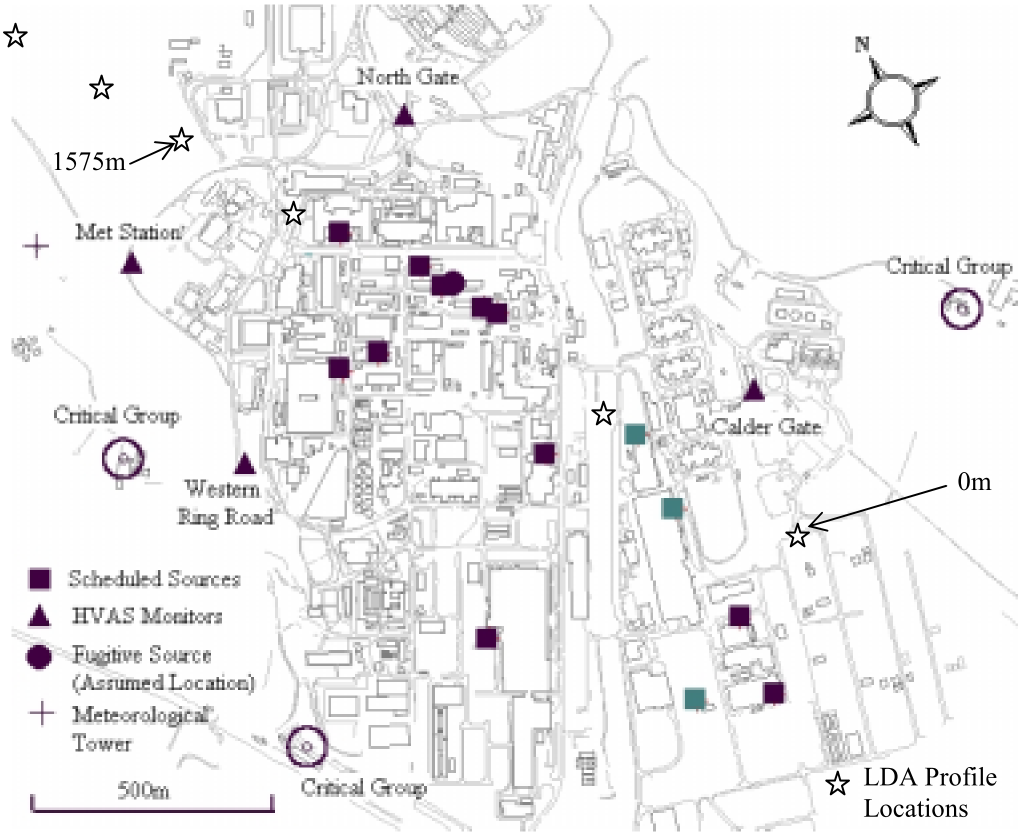


Figure 1: Plan view of the Sellafield site showing the scheduled discharge points, fugitive source, on-site samplers (HVAS) and critical group locations.

## Wind tunnel studies

*ESH*

Average ESH, based on wind tunnel dispersion studies to critical group* locations (see Figure 1) are currently used to account for the effects of buildings and the site in general. Critical group based ESH are generally used for all Sellafield assessments. The HVAS locations however, are generally closer to the sources than the critical group locations, and as such may require more specific ESH. Dispersion from the main fugitive source is especially critical as it is of a low height and situated within a complex region of the site.

To understand the effect of site buildings on dispersion, and determine the most appropriate ESH, wind tunnel dispersion studies of emissions from the most significant sources, including the fugitive source, to the HVAS locations were undertaken. The size and detail of the 1:500 scale Sellafield wind tunnel model can be seen from the photograph of the model shown in Figure 2. With the HVAS being closer to the site, variation of ESH (Table 1) with wind direction (i.e. HVAS location) was found to be significant. As expected, ESH for the taller scheduled source stacks were lower at the HVAS locations than at the critical group distances due to entrainment and down wash of the plumes. This results in earlier interaction of the plumes with the ground and higher ground level concentrations. Consequently the fugitive emission prediction would be lower due to a higher scheduled source component to the monitored concentration (see Equation 1). For the fugitive source, the ESH was higher, resulting in a lower DF and potentially higher fugitive emissions. This conflict requires more detailed analysis to resolve.

Figure 2: The 1:500 Sellafield wind tunnel model within the wind tunnel

| **Source** | **Height (m)** | **Original Critical Group ESH (m)** | **New Individual HVAS ESH (m)** | | | |
|---|---|---|---|---|---|---|
| | | | NORTH GATE | MET STATION | CALDER GATE | WESTERN RING RD |
| SS1 | 122 | 80 | 67 | 30 | 80 | 60 |
| SS2 | 76.2 | 80 | 65 | 35 | 80 | 50 |
| SS3 | 60 | 40 | 25 | 30 | 30 | 25 |
| Fugitive | ~ 8 | (5-10) | 15 | 15 | 15 | 25 |

Table 1: Original critical group based ESH compared with the individual HVAS ESH.

*Turbulence field and stratification*

The wind tunnel studies also investigated the development of velocity and turbulence characteristics over the site using Laser Doppler Anemometry (LDA). Vertical profiles of longitudinal velocity and both the longitudinal and vertical turbulence across the site are presented in Figure 3. The locations of the individual profiles are indicated in Figure 1, with the '0' location effectively representing the incident boundary layer characteristics. The enhancement of the turbulence and change in the velocity profile as the wind passes over the site is evident. While the wind direction is at an oblique angle to the site, and therefore likely to have a more significant effect on the boundary layer characteristics, it is also evident that the enhanced turbulence characteristics persist well downwind of the site. Many studies of cuboids in stratified flow have noted that stability has little effect on the flow structure in the near wake region as turbulence generated by the building perturbation dominates [3]. As a consequence, strongly stratified conditions are unlikely to occur within the actual works area of the site itself or for some distance downwind, with near neutral or unstable conditions predominate. The possible influence of changes to the measured or assumed stability category is another area that warrants further investigation in relation to the fugitive emission prediction. A simple stepped approach would be to reduce the measured stability, initially by one category, or to classify all stable conditions as neutral.

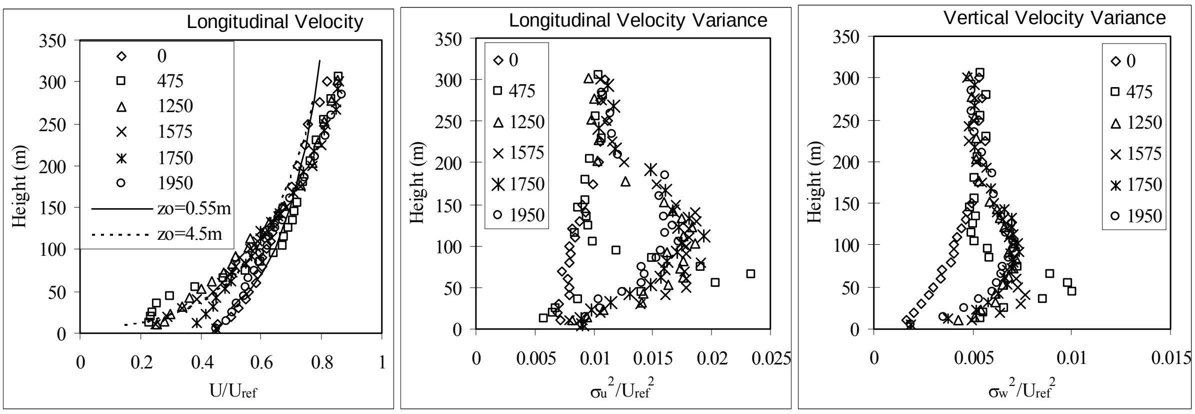


Figure 3: Normalised velocity and turbulence characteristics over the Sellafield wind tunnel model. (Legends show downwind distance in metres)

*Wind tunnel dispersion parameters*

Another model configuration option is the direct use of the HVAS location horizontal and vertical dispersion parameters ($\sigma_y$, $\sigma_z$) and plume height (Hp) measured in the wind tunnel studies. This gives a good description of the plume character particularly for the specific HVAS wind direction, and implicitly incorporates the assumption that atmospheric stability has no effect directly over the Sellafield site.

## LIDAR wind tunnel model validation

The veracity of the wind tunnel model is central to Sellafield's discharge authorisation, which is based on ESH determined from wind tunnel experiments. With modification, demolition and construction of buildings, the Sellafield site is constantly changing. Thus, a program of work designed to validate the wind tunnel model is also underway. This has involved a high-resolution (0.5m) LIDAR survey of the site by the Environment Agency involving approximately 20 over-flights of the site at a height of 850m. Interrogation of the survey data enables determination of site building heights, location and finer detail above approximately 1 m in dimension, equivalent to 2mm on the wind tunnel model. Figure 4 indicates the detail the LIDAR data can provide to enable validation and upgrading of the wind tunnel model. In addition, the LIDAR data is being used to develop a virtual 3-dimensional representation of the Sellafield site. This will enable more simplified recording of changes to the Sellafield site as they occur, with obvious benefits to the modelling of aerial emissions.

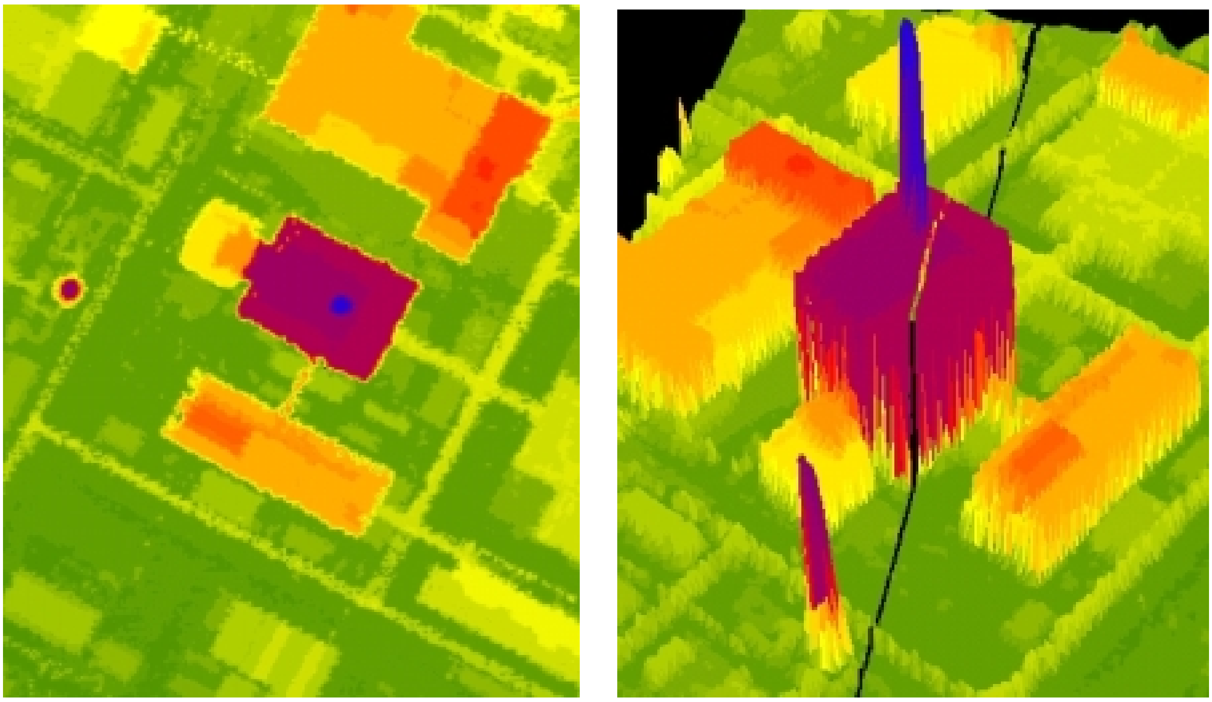

Figure 4: Plan and 3-dimensional views of a section of the Sellafield site produced from the LIDAR data.

**Particle size distribution**

In further work, an eight stage Andersen Cascade impactor, co-located with the North Gate HVAS, has been used to measure the size distribution of airborne particulate material over periods of 1 month. Typical results are presented in Figure 5. $^{137}$Cs was largely found in the range 2.4–3.5 µm, consistent with the fugitive source size (1.9–3.2 µm) [4]. Ultra-fine particles, presumably from the HEPA filtered scheduled releases, were also evident on occasions. Further work involving the modelling of emissions is required to gain a better understanding of these results, and in particular the variation in ultra-fine particulate concentrations.

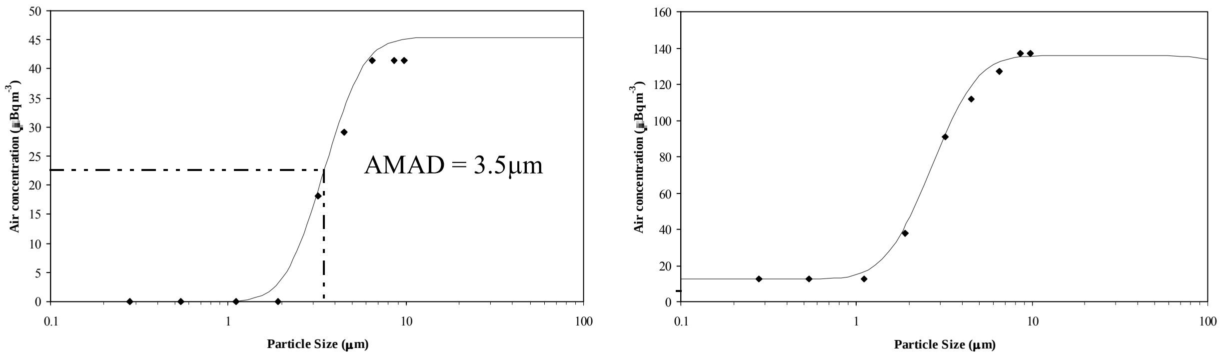


Figure 5: $^{137}$Cs particle size distribution measured using the Andersen Cascade impactor. A log-normal particle size distribution fit is shown as the solid line.

## Further enhancements

Particle size distributions are also being measured over a shorter sample integration time (24 hours) using a high volume cascade impactor. The impactor and a sonic anemometer are located downwind of the primary fugitive source, with a second HVAS and the 48m meteorological tower measuring upwind conditions. Experiments are only possible under north-westerly wind conditions, and the data will enable the use of CFD tools, so improving the realism of numerical modelling methods and providing an independent assessment of the fugitive emission rate.

## Conclusions

Quantification of fugitive emissions forms part of BNFL Sellafield's authorisation to discharge materials to the atmosphere. Work programs aimed at improving the understanding, accuracy and reliability of the methods used by BNFL to predict the fugitive emission rate have been discussed. Wind tunnel studies of dispersion to the HVAS locations indicate these ESH vary from the critical group based ESH. Flow characteristic measurements demonstrate the site also has a very significant effect on the local turbulence, suggesting atmospheric stability effects on dispersion will be minimal. Various methods and assumptions for use in modelling the dispersion are presented. A sensitivity analysis to develop an understanding of the uncertainty of the fugitive emission prediction utilising these assumptions is underway.

Particle size distribution sampling indicated a $^{137}Cs$ distribution of 2.4–3.5 μm, consistent with the fugitive source size. A monitoring campaign based on short sampling periods, enabling the use of CFD methods and an independent assessment of the fugitive emission rate has also been introduced.

## References

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## Acknowledgements

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[*] Critical group – A group of members of the public whose radiation exposure is reasonably homogeneous and is typical of the people receiving the highest dose from a radiation source.