DEPOSITION 2001: SOFTWARE FOR CALCULATING PERFORMANCE OF AEROSOL SAMPLING SYSTEMS

Andrew R. McFarland, James L. Rea, Jason Thompson, Anand Mohan, Nagaraj Ramakrishna

Department of Mechanical Engineering, Texas A&M University, College Station, TX. Division of Business and Computer Sciences, Blinn College, Brethren, TX.

ABSTRACT

The DEPOSITION code is acceptable methodology for estimating aerosol particle transport through sampling systems by the NRC, by ANSI N131-1999 and by EPA for DOE facilities. A new version of the code is being developed and should be available for release by November 1, 2000. The code allows calculation of aerosol transport efficiencies of sampling systems that contain one or more of the following components: inlet nozzle, straight tube, bend, contraction, expansion and flow splitters. In comparison with previous versions of the code, this release is more user-friendly from the point of view of data input and output, and new models have been used for prediction of aerosol penetration through bends and splitters. Hence, an example of the use of DEPOSITION 2001 is given, and how for quality assurance purposes, results are shown that compare hand calculations and code predictions for aerosol penetration through each of the individual components.

INTRODUCTION

The United States law (40 CFR 60, Subparts H and I) requires continuous emission monitoring of stacks and ducts at U.S. Federal facilities that can potentially release significant quantities of radionuclides to the environment. The criterion to determine whether a stack must be continuously monitored is based on the dose that can potentially be acquired by the most effective off-site individual. The maximum dose is 10 rem in a year, and any emission point that can potentially cause more than 1% of the limit must be monitored. Meteorological modeling is used to calculate dose, and source term used in the meteorological modeling is based on the form of releasable radionuclides (solid, powder, liquid, vapor) and the assumption that air pollution control equipment is ineffective. The latter assumption is equivalent to an accidental release of the radionuclides. The U.S. Environmental Protection Agency is empowered to assure that facilities are in compliance with these requirements.

For stacks and ducts that must be continuously monitored, the present US law states that the sampling of emissions, when extractive sampling is used, shall be performed in accordance with the guidance of an American National Standards Institute standard, ANSI N131-1969. Although the goal of this standard was to obtain representative samples of the radionuclides emissions, the goal was not achieved. As the name suggests, the standard was adopted by ANSI in 1969, and during the past 30 years it has been shown to be inadequate by numerous studies and technological advances. These deficiencies include:

- Poor sampling characteristics for supramicrometer-sized aerosol particles. Under the assumption that control equipment is rendered inoperative, the aerosol size distribution emitted by a stack or duct is that associated with normal conditions upstream of the control equipment. Typically these sizes are in the range of 1 to 10 μm aerodynamic diameter (AD), depending upon the type of operation that causes radionuclides to be aerosolized.

ANSI-1969 preserves sharp-edged isokinetic nozzles for extraction of aerosol samples from the gas flow in the stack or duct. For larger-sized ducts, multiple nozzles mounted on rakes are generally used in an attempt to obtain spatially representative samples. However, the loss of aerosol particles in these probes is large – Fan et al. (1992) tested a nozzle from an ANSI-1969 compliant rake and found that 75% of 10 μm were inadvertently deposited on the inner wall of the nozzle. ANSI-1969 has also been used for the design of extractive sampling systems by licensees of the US Nuclear Regulatory Commission. As an example, the typical tubing used to transport extractive samples from the stack of a nuclear power reactor to the collection location is 52 m (170 feet) in length and is 6 mm (1/4 inch) diameter tubing. While such a system may be compliant with ANSI-1969 requirements, aerosol particles would not penetrate the tubing and reactive gases (e.g., iodine) would not penetrate in a manner that would either provide an adequate basis for a timely alarm or for assessment of the magnitude of the release.

- Standard is design based rather than performance based. Details are given on the design of nozzles and rakes; however, there are no requirements placed on performance. For example, a probe could have an inlet through which a pin could not pass, and, provided it were operated isokinetically, its use could be acceptable even if virtually no 10 μm AD aerosol particles would penetrate.

- There are no maintenance requirements. Apparatus, once installed does not need to be checked for assurance that it performs satisfactorily. For example, the U.S. DOE Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM is designed for storage of low level wastes in rooms in a layered bedded salt. When mining of the salt is taking place, there is considerable dust in the exhaust ventilation air. When WIPP was being mined in the 1980's, an ANSI-1999 compliant sampling system, which used two rakes of isokinetic nozzles, was installed and operated to establish baseline conditions for air quality before the arrival of nuclear waste. After a short period it was noticed that the nozzles were plugged with salt. Under ANSI-1969, there was no requirement to check for such deposits. WIPP, however, replaced the sampling system with a more robust system that utilized large-diameter shrouded probes (McFarland et al., 1989) and large diameter sampling lines.

- Incompatible with even itself. The 1969 version of ANSI N131.1 is based on the concept of representative sampling; however, the design of the sample transport lines assures that the aerosol samples will be non-representative. In addition, the design recommended for rakes of isokinetic nozzles that span across the stack also assures that the sampling will be non-representative. The flow through a sampling nozzle (and velocity at the inlet plane) is controlled by the suction applied to the sampling manifold, so the velocity in all nozzles of a rake will be approximately the same. However, the velocity profile across a stack is not uniform and so the condition of isokinetcity cannot, in general, be achieved for all nozzles.

The problems with ANSI-1969 were documented by McFarland and Rodgers (1993) who suggested the ANSI-1969 approach should be replaced by new methodology; namely single point representative sampling. The basic concept is that a representative sample can be extracted from a location where contaminant concentration (aerosol or vaporizable radionuclides) and fluid momentum are both well distributed as evidenced by the uniformity of concentration and velocity profiles. This concept was approved by the U.S. Environmental Protection Agency for use at DOE facilities (US EPA, 1994) subject to the requirements:

- The coefficients of variation (CV%) of velocity and test tracers (gas and aerosol particles) must be ≤ 20% over the central 2/3 of the area of an EPA Method 1 (US EPA, 2000) grid. At no point on an entire grid should the concentration of tracer gas be more than 30% higher than the mean concentration. A CV% is the ratio of the standard deviation of a set of measurements to the mean value of the measurements.

- A shrouded nozzle (McFarland et al., 1989), which is used to extract the sample from the stack or duct, must meet well defined performance criteria.

- The sampling system must allow at least 50% of the 10 μm AD aerosol particles to be transported from the free stream in the stack or duct to the collector or analyzer. The computer software, DEPOSITION 2.0 or higher must be used to verify the performance of the sampling system.

The submodels used in Deposition (Depo) were first programmed under funding from WIPP, where the software was used to provide a means for optimizing the performance of sampling systems. Later, the models enhanced, expanded and consolidated into a code that was made generally available under funding from the U.S. Nuclear Regulatory Commission (e.g., Riehl et al., 1996). The NRC adopted the code as suitable methodology for evaluating losses of aerosol particles in sampling systems (US NRC, 1992). The version of the code presented herein is a further upgrade that provides improved sub-models for predicting the performance of various components of the sampling system, and offers better input and output capabilities.

The standard ANSI N131.1 was revised in 1999 (ANSI, 1999) and the concept of single point representative sampling is embedded in it. Proper mixing must be demonstrated for a sampling location to be suitable, and either scale model laboratory tests, field tests, or documentation from tests on a similar emission point can be used to qualify the sampling location. For extractive sampling, acceptable apparatus must allow at least 50% of the sample to penetrate from the free stream in the stack or duct to the location of the collector or analyzer. If aerosol particles can be present in the stack or duct, the default particle size is 10 μm AD. Deposition software is an acceptable method of demonstrating that a sampling system meets the criteria.
By clicking the "Graph" button on the "View" dialog box, a frequency histogram for the particle size distribution will be shown. Usually the mass size distribution parameters, rather than number size, would be input to the program, so the histogram would be the mass fraction vs. particle size.

SAVING SETUPS AND RESULTS

The "File" menu allows the input parameters of the current setup to be saved and reloaded. A sampling system configuration (the combination of the geometrical layout of the transport system and the operational conditions including the particle size distribution) that differs from the default can be stored and retrieved later, thus both saving time otherwise spent re-entering the setup and providing an electronic record of the inputs.

The files are stored in *.mdb format and can be retrieved and displayed through use of Microsoft Access. An example of a dialog box in Microsoft Access is shown in Figure 10. Selection of one of the options (Analysis, Particle, etc.) will display the results in data base format. These results can be transported to other programs as desired.

COMPARISON OF RESULTS FROM USE OF SOFTWARE AND HAND CALCULATIONS

One of the quality assurance steps taken to verify the veracity of the code was to perform independent hand calculations using the sub-models that are embedded in the program, and then repeat the calculations using the software. The results, shown in Table 1, indicate that the models are properly programmed into the code.

ACKNOWLEDGMENTS

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REFERENCES


Table 1: Verification of the Depo Code. A comparison of results from hand calculations and use of code for determining penetration through various sampling system components.

<table>
<thead>
<tr>
<th>Element</th>
<th>Type of Flow</th>
<th>Parameters</th>
<th>Penetration, %, Manual</th>
<th>Penetration, % Depo 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
<td>Turbulent</td>
<td>Dia = 25.4 mm; L = 2 m; Flow rate = 100 L/min</td>
<td>76.4</td>
<td>76</td>
</tr>
<tr>
<td>Bend</td>
<td>Turbulent</td>
<td>Dia = 25.4 m; Bend angle = 60°; Flow rate = 100 L/min; Curvature rate = 4.0</td>
<td>95.5</td>
<td>95.5</td>
</tr>
<tr>
<td>Unshrouded isokinetic probe</td>
<td>Turbulent</td>
<td>Dia = 25.4 mm; Flow rate = 100 L/min.</td>
<td>92.2</td>
<td>92.3</td>
</tr>
<tr>
<td>Shrouded probe</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Probe dia = 18.2 mm; Shroud dia = 40.0 mm; Flow rate = 100 L/min</td>
<td>85.5</td>
<td>85.5</td>
</tr>
<tr>
<td>Constructions</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Outlet dia = 22.86 mm; Flow rate = 100 L/min; Half angle = 45°</td>
<td>99.8</td>
<td>99.8</td>
</tr>
<tr>
<td>Expansions</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Outlet Dia = 30.0 mm; Flow Rate = 100 L/min; Half Angle = 45 deg</td>
<td>98.4</td>
<td>98.4</td>
</tr>
<tr>
<td>Commercial probe (RF2-111)</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Flow rate = 100 L/min.</td>
<td>92.1</td>
<td>92.1</td>
</tr>
<tr>
<td>Commercial probe (RF2-112)</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Flow rate = 100 L/min.</td>
<td>118</td>
<td>118</td>
</tr>
<tr>
<td>Commercial probe (RF2-113)</td>
<td>Turbulent</td>
<td>Tube dia = 25.4 mm; Flow rate = 100 L/min.</td>
<td>121</td>
<td>121</td>
</tr>
<tr>
<td>Splitter</td>
<td>Turbulent</td>
<td>Inlet dia. = 25.4 mm; Outlet dia. = 17.78 mm; Angle = 30°; Flow rate = 100 L/min.</td>
<td>96.6</td>
<td>96.6</td>
</tr>
</tbody>
</table>
Figure 3: The "Transport System" dialog of the "Setup" menu.

Figure 4: The "Element Number" dialog box. When "Probe" is selected a list of probe types is presented, and when "Commercial" is selected, a list of the commercially-available probes is shown.

Figure 5: The "Element Number" dialog box with "Tube" selected.

Figure 6: The "Particle Size Distribution" dialog box with "Monodisperse" and "10.0 \mu m" selected.