

TESTING THE SAMPLING EFFICIENCY OF A NUCLEAR POWER STATION STACK MONITOR\*

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Abstract

The test method comprises the injection of known amounts of monodisperse particles in the stack air stream, at a suitable point upstream of the sampling installation. To find a suitable injection point, the gas flow was mapped by means of a tracer gas, released in various points in the stack base. The resulting concentration distributions at the stack sampler level were observed by means of an array of gas detectors. An injection point that produced symmetrical distribution over the stack area, and low concentrations at the stack walls was selected for the particle tests.

Monodisperse particles of 6, 10, and 19  $\mu\text{m}$  aerodynamic diameter, tagged with dysprosium, were dispersed in the selected injection point. Particle concentration at the sampler level was measured. The losses to the stack walls were found to be less than 10 %. The particle concentrations at the four sampler inlets were calculated from the observed gas distribution. The amount calculated to be aspirated into the sampler piping was compared with the quantity collected by the sampling train ordinary filter, to obtain the sampling line transmission efficiency.

Introduction

Installations for the monitoring of ventilation stack releases of radioactive gases and particles should be tested periodically. This report describes experiments with a relatively simple method to investigate the relation between particles passing in the stack and particles collected on a monitoring filter. The stack sampler employed for the experiments was of the normal Swedish design, consisting of four isokinetic probes connected to a 100 mm diameter transport pipe, and filters and radiation detectors, sampling from the transport pipe. Figure 1 shows the stack and the room below the stack where the ventilation air flows come together, the stack base chamber. At the stack sampler level, four isokinetic probes sample the stack air, and a 100 mm pipe conducts the combined air flows (64 l/s) to the monitor room. Assuming equal flows in the probes, the inlet concentration is

$$C_{in} = \left( \sum_{i=1}^4 C_i \right) / 4$$

The mean concentration of particles in the stack over the time can be expressed as

$$C_{mean} = M / Q t$$

where M is the quantity of particles passing the stack in the time interval t. Q is the air flow in the stack, 164  $\text{m}^3/\text{s}$ . If the particle concentration varies over the stack area,  $C_{in}$  and  $C_{mean}$  will generally differ by a factor  $f$

$$C_{in} = f C_{mean}$$

$f$  is called the "form factor" to indicate that it depends on the shape of the concentration profile and the disposition of the sampler probes.

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In the monitor room several secondary samples are drawn isokinetically from the transport pipe into filters and other monitoring devices (0.5 - 0.7 l/s each). Particle concentration in the air reaching the filters is generally lower than in the stack air, due to losses in the pipes etc. This is expressed by the transmission efficiency  $\eta$

$$C_{out} = \eta C_{in}$$

The purpose of the work reported here was to test a method to determine the sampling efficiency, which includes the form factor as well as the transmission efficiency. By means of these factors the stack release is calculated as

$$M = C_{mean} Q t = \frac{C_{in}}{f} Q t = \frac{C_{out}}{\eta f} Q t$$

Due to the strong dependence on particle size the investigation could also be called determination of upper size limit of the sampling installation.

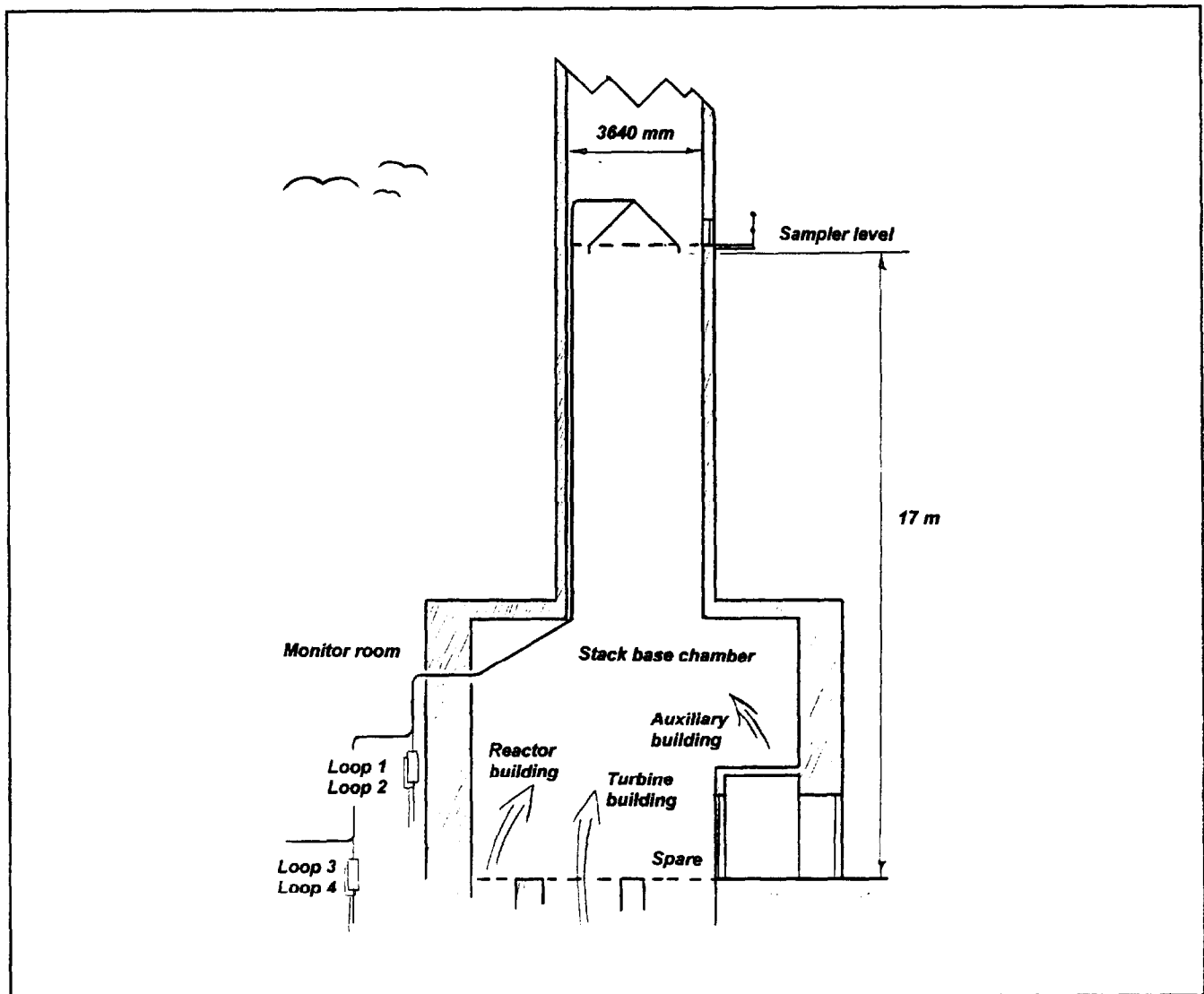


Figure 1. The stack base chamber, the stack, and the installation for air sampling.

The flow pattern

To find the form factor the air flow in the stack was mapped by means of a tracer gas. It was equally important to find a suitable injection point for the subsequent tests with particles. Suitable means in this context that at most a small fraction of the test aerosol is lost on the way from the injection point to the sampler section in the stack, but at the same time it is reasonably well distributed over the sampling section.

Ethanol was chosen as the tracer gas, for which simple solid state sensors are available, sensitive down to the ppm level (Scimarec AF 63, Japan). These sensors are no precision devices, but they are small, rugged, easy to apply, and cheap. 9 sensors were mounted on a cross-shaped frame, connected to a data logger, and hoisted to the sampler level. Ethanol was then injected by means of a compressed air atomizer in a number of points in the stack base chamber. Each injection consumed 1 litre of ethanol and took 10 minutes. Figure 2 shows some of the concentration patterns observed at the sampler level. The three ventilation air streams are evidently not well mixed when they reach the sampler. The arithmetic mean of the observed concentrations was calculated, to be used as a substitute for  $C_{mean}$ , and by interpolation also the concentrations at the four sampler inlets, and  $C_{in}$  ( $C_{mean}$  should not be taken from the injection rate, because of drift in sensor calibration). From this the form factor for the different injection points is obtained. These are provided in the key to Figure 2. In spite of the uneven distributions, the form factor is confined to the range 0.74 - 1.24.

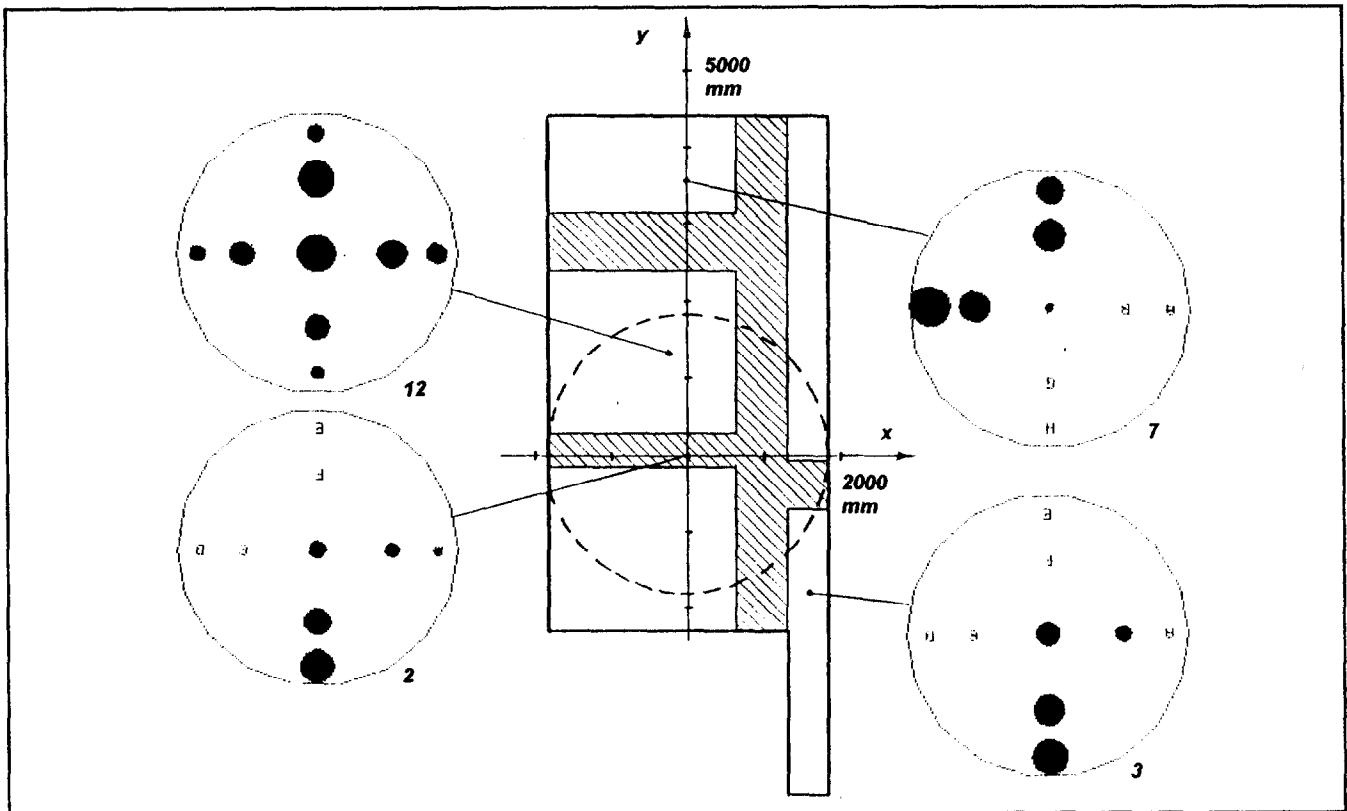


Figure 2. Observed tracer gas concentrations in the 9 measurement points at the sampler level, and the calculated form factors  $f$  for the sampler installation. The dot areas are proportional to concentration.

	$x, mm$	$y, mm$	$f$
Injection 2: On the centerline of the stack	0	0	0.74
Injection 3: In ventilation channel Auxiliary Building	1575	-1800	0.82
Injection 7: In ventilation channel Reactor Building	0	3500	1.00
Injection 12: In ventilation channel Turbine Building	-250	1300	1.24

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### The particle tests

Monodisperse styrene - divinylbenzene particles were obtained from DYNO Particles, Norway. The particles were sulfonated and tagged with dysprosium, as a preparation for activation analysis. Three different sizes were employed, with the following properties:

#### Particle properties

Manufacturer's designation	Q-673	Q-501	Q-851
As received:			
Diameter, $\mu\text{m}$	4.6	8.6	15.3
Standard deviation, %	1.1	0.9	1.8
After sulfonation:			
Diameter, $\mu\text{m}$	4.9	9.1	16.3
Density, $\text{kg/m}^3$	1595	1316	1300
Dysprosium, g/kg of particles	109	39.5	35.6
Aerodynamic diameter, $\mu\text{m}$	6.2	10.4	18.6

The dysprosium was very strongly connected to the particles, with less than 1 % in the liquid phase of the particle suspension.

The particles were to be dispersed from a methanol suspension, and it was feared that the particles would acquire an electrical charge in the process. The charge of the smallest particles after dispersion in a test chamber was therefore measured. With pure methanol (conductivity  $0.15 \times 10^{-3} \text{ 1}/\Omega\text{m}$ ) a mean charge of about 300 electrons was observed. By adding a small amount of potassium chloride solution to the suspension the conductivity was increased about 10 times, which decreased the particle charge by a similar factor. Such a low charge is not expected to influence particle deposition.

From the droplet spectrum of the atomizer it was calculated that if the particle concentration in the dispersion was  $10^{14} \text{ particles/m}^3$  then only about 1 % of the particles generated would be duplets or higher combinations. This was confirmed by measurements. The atomizer was a Lechler 156.330.30.16, the dispersion gas carbon dioxide, the gas pressure 300 kPa, and the methanol flow 8 g/s.

One of the objectives of these tests was to demonstrate that it is possible to conduct the test aerosol to the sampler level without significant losses. With the tracer gas tests it had been observed that injection at the coordinates  $x=-250 \text{ mm}$ ,  $y=1300 \text{ mm}$  (Figure 2) gave a symmetrical pattern at the sampler level, with lower concentration at the walls. These conditions would favour low particle losses to the stack walls, and the above coordinates were used for the particle injections.

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Particles were dispersed in the stack base chamber, and the particle flow at the sampler level measured by means of eight filter samplers. The form factor for these extra samplers and the chosen injection point was estimated at 0.92. An "injection efficiency" can be calculated as

$$H = \frac{\text{Concentration at sampler level}}{\text{Injected concentration}} = \frac{C_{A..H} / 0.92}{M_{inj} / t Q}$$

where

$C_{A..H}$	Mean concentration measured by the eight samplers
$M_{inj}$	Injected amount
$Q$	Stack flow
$t$	Injection time in seconds

The following results were obtained. The (rather uncertain) results from a calculation of the losses by means of turbulent deposition theory are also provided in the table.

### Injection efficiency

Injection number	1	2	3	4	5	6
Particle size, $\mu\text{m}$	6.2	6.2	10.4	10.4	18.6	18.6
Dy injected, mg	27	33	54	53	191	190
Efficiency, measured	1.10	1.13	1.03	1.12	0.85	0.97
Efficiency, calculated	1	1	1	1	0.96	0.96

The measurements indicate that the particles are overrepresented in the filter samples. The reason could be an incorrect form factor, or non-isokinetic sampling. The important conclusion of this test is, that the injection losses are no greater than 10%, even for the largest particles. The calculation of deposition indicated that the reduced deposition velocity,  $k^+$ , for the largest particles had its maximum value, 0.2. Still larger particles, currently considered in connection with new monitor installations, might not deposit faster in the stack.

### Sampling line transmission efficiency

During the six injections mentioned above particles were also collected with the ordinary filter of the sampling installation. The transmission efficiency is calculated as

$$\eta = \frac{C_{out}}{C_{in}} = \frac{1}{f} \frac{C_{out}}{C_{mean}} = \frac{Q}{q} \frac{1}{f} \frac{1}{H} \frac{\text{Collected amount}}{\text{Injected amount}}$$

where

$f$	Form factor $C_{in}/C_{mean}$
$Q$	Stack flow
$q$	Filter flow
$H$	Injection efficiency

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The following results were obtained

### Transmission efficiency

Injection number	1	2	3	4	5	6
Particle size, $\mu\text{m}$	6.2	6.2	10.4	10.4	18.6	18.6
Efficiency $\eta$ , %						
Loop 2	13*	62	7	8	2	4
Loop 3	47		8		3	
Loop 4	45		7		6	
DEPOSIT calculation	65	65	16	16	0.2	0.2

\* probably a gross error

In the table above is also cited the particle transmission calculated with the computer program DEPOSIT 2.0, ref 1. The computer program predicts reasonably well the particle size dependence, considering that the sampling system might be rather dirty, and that the adhesion at contact with the pipe surfaces might be incomplete for the largest particles.

### Conclusions

It was demonstrated that in a simple but real geometry a test aerosol could be brought to the sampling section of the monitor installation with only small losses. The mean concentration can then be calculated from the injected quantity of particles, and separate sampling in the stack is not necessary. This simplifies testing considerably. Instead flow mapping with a tracer gas must be performed, to determine a suitable injection point for the test aerosol, and to find the form factor. But it is much easier to measure a gas than to measure particles.

### Reference

1. Fan, B J et al. Aerosol particle losses in sampling systems. Paper 6-3, 22nd DOE/NRC Nuclear Air Cleaning and Treatment Conference. Denver, Colorado, USA, August 1992.

DISCUSSION

**BARLOW:** My question is, if you had field conditions where the number of very large particles was very small, would you get any statistical effects which would render that 2-3% penetration (that you observed in your experiments using similar amounts in each particle size) very variable so that on some days you might get, say, 50% through?

**STRÖM:** One or two large particles may well be responsible for the bulk of the radioactivity in the sample under real conditions. The statistical nature of the sampling process in the stack will produce variations in the sample. Penetration through the sampling line is strongly size dependent, and statistical variation will only be added in the narrow transition range.

**DUVALL:** In your last slide you showed poor transmission for large particle sizes, i.e., those over 10  $\mu\text{m}$ . I think it is a very important point because it illustrates the limitation of extractive sampling and a need to assure that large particles are not slipping through cracks in HEPA filters that develop between the filter medium and frame and so go undetected by extractive sampling. These large particles carry a large contribution of the radioactivity in the stack effluent to atmosphere. This illustrates a linkage of requirements for emission monitoring with requirements for air cleaning.

**STRÖM:** Particles from damaged filters are especially difficult to monitor, because such particles can be parts of the dust cake or the filter, and consequently very large. Sampling for filter damage requires special techniques.