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# The effect of $SF_6$ release rate, animal species and feeding conditions on estimates of methane emissions from ruminants

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## ABSTRACT

In New Zealand methane ($CH_4$) emissions are estimated using the sulphur hexafluoride ($SF_6$) tracer technique. This involves inserting a calibrated source of $SF_6$ gas into the rumen. The technique does not measure $CH_4$ directly but estimates emissions from the ratio of $CH_4$ to $SF_6$ in breath samples collected continuously from above the nose of each animal. Methane estimates obtained using this method tend to be more variable than measurements obtained using respiration calorimetry. The absolute release rate of $SF_6$ from the rumen could contribute to this variation.

Data were extracted from a database containing details of 22 separate New Zealand experiments where the $SF_6$ technique was used to estimate $CH_4$. Experiments were divided into four groups according to species and feeding situation, with each group analysed separately. Data were analysed using a linear mixed model with a fixed effect of $SF_6$ release rate, and random effect of experiment. In indoor fed cattle and sheep daily $CH_4$ production was positively related to $SF_6$ release rate ($P < 0.05$) but there was no relationship between $SF_6$ release rate and daily $CH_4$ production in grazing animals. In grazing sheep and cattle there was no significant effect of $SF_6$ release on $CH_4$ emitted per kg DMI. In cattle kept indoors $CH_4$/kg DMI was positively related to permeation tube flow rate ($P < 0.05$) but there was no significant effect of $SF_6$ release on $CH_4$ emitted per kg DMI in indoor fed sheep.

**Keywords:** methane; SF6 tracer technique; ruminants.

## INTRODUCTION

Under the terms of the Kyoto Protocol, the New Zealand Government has a target of not increasing greenhouse gas (GHG) emissions above their 1990 levels during the 2008 – 2012 period. Agriculture plays a large part in the New Zealand economy, and is responsible for 49% of total carbon dioxide ($CO_2$) equivalent GHG emissions (New Zealand Climate Change Office 2004). Methane ($CH_4$) emissions arising from enteric fermentation and animal waste make up 32% of national GHG emissions (New Zealand Climate Change Office 2004). Monte Carlo analysis indicates that the biggest influence on the level of uncertainty in the national methane emissions inventory is uncertainty surrounding the quantity of $CH_4$ emitted per kg of dry matter intake (DMI) (Clark *et al.,* 2003). The principle reason for this is the large animal-to-animal variation in $CH_4$ emission per kg DMI found when any group of animals is measured (Ulyatt *et al.,* 1997). The reasons for this variation have not been well studied but it is known to be common across animal species, that animals are not consistent in the amount of $CH_4$ emitted per kg DMI across time and diets, and that measurements made using the $SF_6$ tracer technique tend to be more variable than measurements made using calorimetry (Ulyatt *et al.,* 1997; Boadi *et al.,* 2002; Pinares-Patino *et al.,* 2003).

The sulphur hexafluoride ($SF_6$) tracer technique for estimating $CH_4$ emissions was developed in the United States of America by Johnson *et al.* (1994) and adapted for use in grazing animals by Lassey *et al.* (1997). It is the only method currently available for measuring methane emissions from grazing ruminants and from large groups of ruminants simultaneously. The method relies on the release of a known quantity of $SF_6$ from a pre-calibrated permeation tube inserted into the rumen of the test animal and the collection of a representative breath sample. Breath samples are collected daily from each test animal in an evacuated polyvinyl chloride canister placed around the neck. This is held in place by a halter attached to the animal's head and the breath sample is drawn into the canister via a capillary placed above the nose. The capillary restricts the amount of air being sucked into the canister, so that it is half filled over twenty-four hours. Typically measurement periods are four days in length and methane emissions are calculated based on the average of four contiguous 24 hour periods.

The breath samples collected in the canisters are analysed for $SF_6$ and $CH_4$ concentrations in a laboratory using gas chromatography. The release rate of the tracer gas, $SF_6$, and the ratio of tracer to $CH_4$ in the animal's breath are used to calculate the $CH_4$ emissions of each animal by the following equation:

$$Q_{CH4}=Q_{SF6} \text{ x } [CH_4]/[SF_6]$$

Where $[CH_4]$ and $[SF_6]$ denote the concentrations from the breath sample above the background atmospheric concentrations of these gases, and $Q_{SF6}$ is the release rate of $SF_6$ from the permeation tube.

Having a well calibrated source of $SF_6$ released into the breath stream is critical to the efficacy of the technique. Permeation tubes are individually manufactured, and each tube has a unique release rate (Lassey *et al.,* 2001). In cattle these release rates typically range from 2-7 mg/day and in sheep from 1-2

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mg/day. While great care is used during the manufacturing process it has not yet proved possible to manufacture permeation tubes to a specified $SF_6$ release rate. While it has not been ascertained if the absolute release rate of tubes contributes to the measured animal to animal variation, preliminary empirical evidence suggests that in cattle at least, release rate can have an influence on $SF_6$ estimates of methane emissions (Johannes Vlaming unpublished data).

AgResearch, in conjunction with National Institute of Water and Atmospheric Research Ltd (NIWA), has carried out $CH_4$ experiments using the $SF_6$ tracer technique in New Zealand since 1996. Results of all experiments conducted by AgResearch and NIWA from 1996 up to and including 2003 have been entered into a database of $CH_4$ trials. It includes data on animal species (sheep, cattle), feeding location (indoor, outdoor), $SF_6$ release rate, herbage intake, and diet quality. The aim of this study is to analyse data from previous experiments to ascertain if there is a general relationship between absolute permeation tube release rate and estimated $CH_4$ emissions.

## MATERIALS AND METHODS

The database comprised information from twenty-two experiments, covering a total of 643 observations from both sheep and cattle (Table 1). There was a large range in both $CH_4$ (g/day and g/kg dry matter intake) and $SF_6$ release rates (mg/day). For example, the range in $CH_4$ for dairy cattle was 82 – 558 g $CH_4$/day, and the $SF_6$ release rate was 1.5 – 6.8 mg $SF_6$/day, while for sheep the range in $CH_4$ was 10.5 - 70.8 g $CH_4$/day and in $SF_6$ release rate was 0.50 – 3.19 mg $SF_6$/day. Diets were mainly fresh pasture, although one dairy trial (indoors) used ensiled pasture, a mixed ration was used on another dairy trial and some of the indoor sheep trials used lucerne chaff or forage crops. The $CH_4$ values for indoor dairy cattle are an average of four repeat measurements in consecutive weeks.

Experiments were divided into four groups according to species and feeding situation. Each group was analysed separately because of the range in $CH_4$ output between sheep and cattle and, to a lesser extent, between the two feeding types. Methane output was analysed as both g/day and g/kg dry matter intake (DMI), using a linear mixed model with a fixed effect of $SF_6$ release rate, and random effect of experiment. The permeation tubes represent a range of measured release rates with non-arbitrary values and non-zero means, making them suitable as a covariate (fixed effects factor) rather than a random effect. Experiment was included as a random effect in the model due to the large variation (48%) in the data between experiments. For most groups, there was substantial variability in response among experiments, making it necessary to account for the variability due to this factor. Natural logarithms of the $CH_4$ response in g/day - and for some groups, g/kg DMI - were used for analysis in order to stabilize the variance, which increased with the mean. Genstat software was used to fit the mixed model and test for, and estimate, the effect of $SF_6$ release rate on methane output.

## RESULTS

The release rate of $SF_6$ was found to have an influence on estimated $CH_4$ emissions but the effect was complex. In cattle, daily $CH_4$ production was positively related to $SF_6$ release rate in indoor fed cattle ($P < 0.05$) but not in cattle kept outdoors (Figure 1). The same effect was apparent in sheep where $CH_4$ production (g/day) was positively related to permeation tube flow rate ($P < 0.05$) in sheep kept indoors but not in grazing sheep.

When expressed per unit of DMI, $SF_6$ release rate had a significant effect on indoor fed cattle only ($P < 0.05$) (Figure 2).

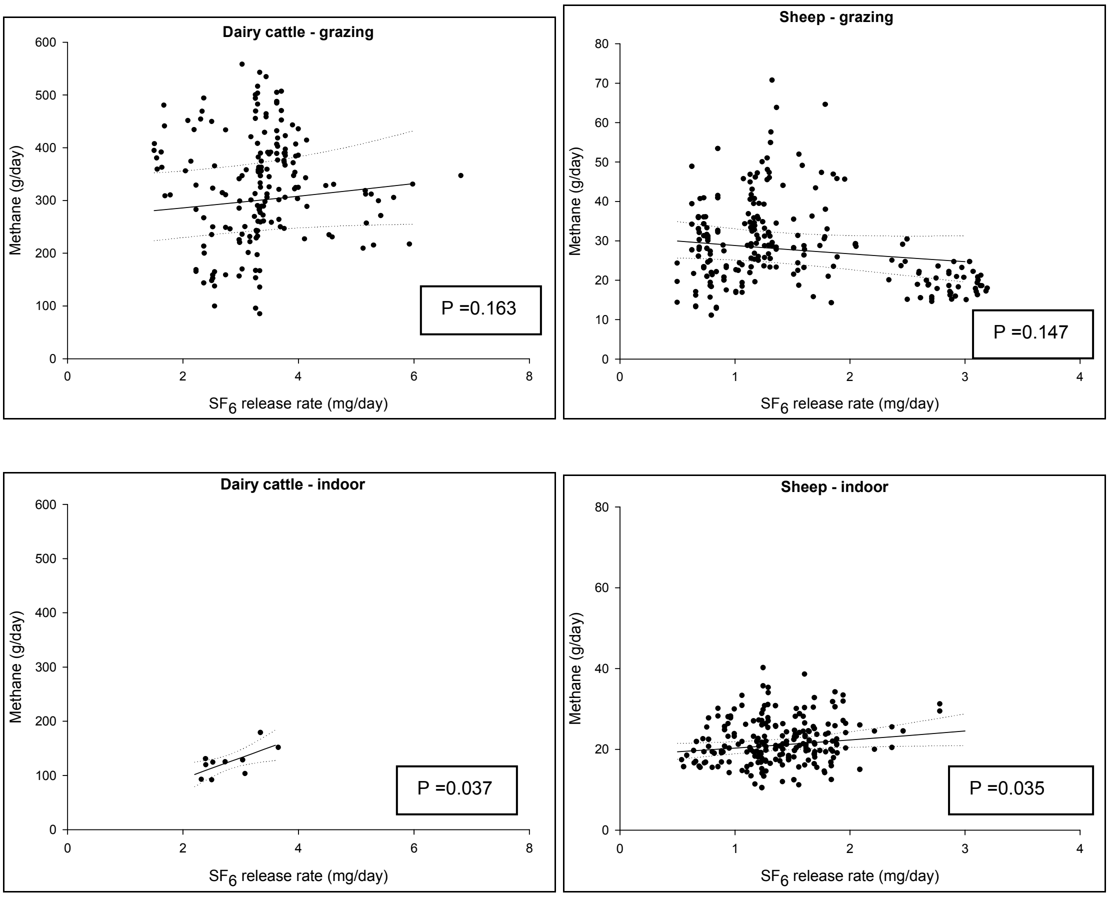
## DISCUSSION

The hypothesis being explored in the analysis presented here is that $SF_6$ permeation tube release rate can influence estimates of $CH_4$ emissions obtained using the $SF_6$ tracer technique. The analyses suggest that in some circumstances this is the case.

**TABLE 1:** A summary of methane ($CH_4$) production per animal, $CH_4$ production per kg DMI and $SF_6$ release rate for cattle and sheep measured indoors and outdoors using the $SF_6$ tracer technique. Data comprise a total of 643 observations taken between 1997 and 2003. Data are mean ± SD.

| Species | Feeding situation | Number of observations | $CH_4$ (g/day) | $CH_4$ (g/kg DMI) | $SF_6$ release rate* (mg/day) |
|---|---|---|---|---|---|
| dairy | grazing | 176 | 326.35±101.39 | 19.81±4.41 | 3.34±0.88 |
| dairy | indoor | 10 | 124.82±26.50 | 13.34±2.74 | 2.80±0.46 |
| sheep | grazing | 248 | 29.17±10.46 | 17.80±6.15 | 1.42±0.77 |
| sheep | indoor | 209 | 21.95±5.54 | 18.54±4.37 | 1.40±0.43 |

**FIGURE 1:** Regression[1,2,3] of estimated g methane per day on permeation tube release rate in different animal species and feeding situations.




[1] The level of probability shown indicates if the regression coefficient is significantly different to zero
[2] Estimate $\pm$ SEM.
[3] Predictions of methane output (averaged over the different experiments) were obtained for various flow rates to obtain the fitted model for each group. These predictions together with 95% confidence intervals for them were back-transformed where necessary, and the lines and confidence bands plotted on the non-transformed data

A significant positive effect of $SF_6$ release rate on daily $CH_4$ estimates was found with both indoor located cattle and sheep. The absence of a significant relationship in outdoor feeding situations may simply be a reflection of the greater degree of control possible in indoor feeding situations. For instance, indoor fed animals often have less ability to influence both the quantity and quality of the diet they consume and outdoor environmental conditions may also influence the efficiency of the breath sampling procedure.

The situation is different when $CH_4$ emissions are expressed per kg DMI. In grazing animals there was no relationship between $SF_6$ release rate and $CH_4$ per kg DMI. However, in cattle measured indoors there was a strong indication that $CH_4$ emitted per kg DMI increased as the $SF_6$ release rate increased but this did not apply to sheep kept indoors.

The interaction between feeding location and $CH_4$ emitted per kg DMI could simply be a reflection of the difficulty of measuring DMI in grazing animals. In the grazing trials summarised here DMI was estimated by a number of different methods (e.g. chromium and alkane markers, pasture cuts, and calculations based on energy requirements) and was unlikely to have been as accurate as measurements made indoors.

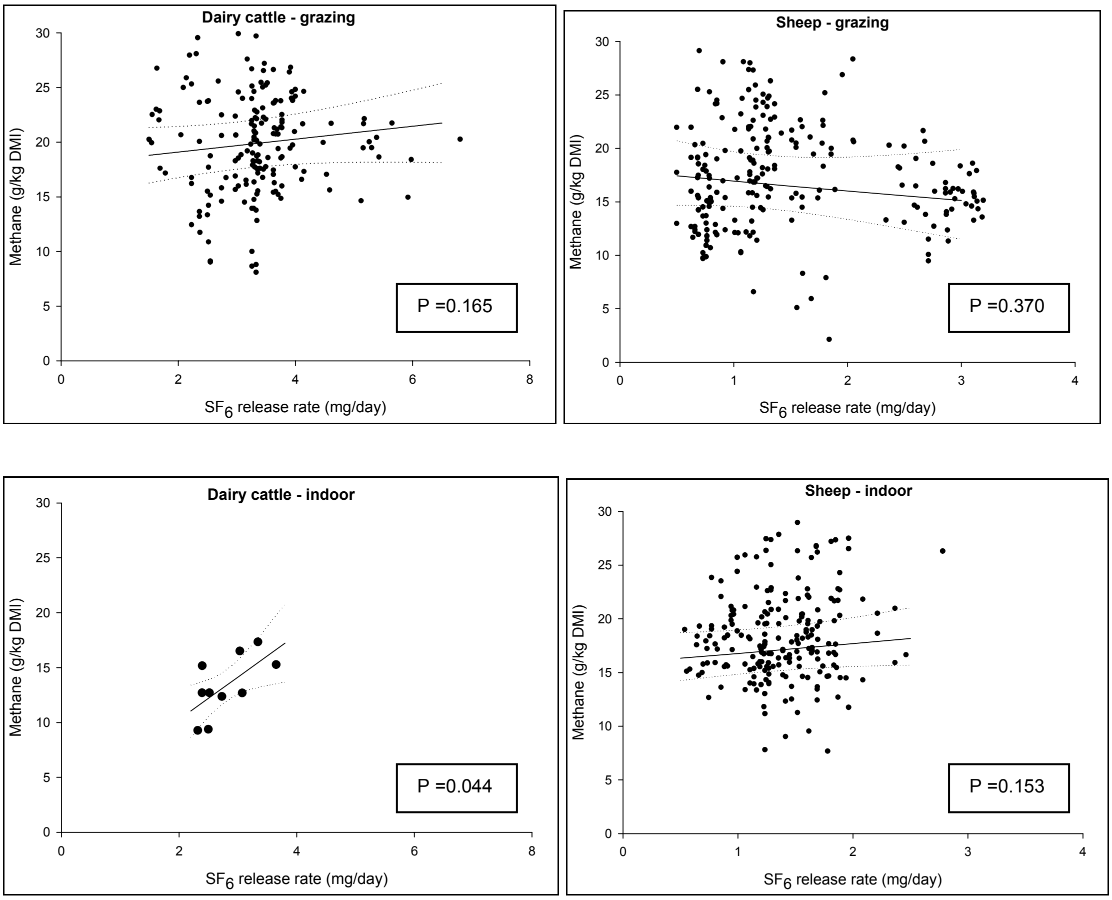
The lack of a significant relationship between $CH_4$/kg DMI in sheep kept indoors is puzzling since there was a significant effect of permeation tube flow rate on $CH_4$ emissions per day. The most probable explanation is that the quantity of $CH_4$ emitted per kg DMI in sheep seems to be related to age (Clark *et al.*, 2003) and the data for sheep used in these analyses included both mature and immature animals. In contrast all cattle in the database were mature animals.

The results for cattle indicate that the influence of $SF_6$ release rate on $CH_4$ per kg DMI can in some circumstances be substantial; the data presented in Figure 2 show an increase of approximately 50% as release rates increased from 2 mg/day to 6 mg/day. However, some caution should be exercised since these data come from a single experiment involving 10 cattle measured on four occasions. The relationship between daily $CH_4$ emissions for indoor kept sheep, which indicates a small positive relationship, may give a better indication of the size of the effect.

The positive relationship between $CH_4$ emissions and $SF_6$ release rate implies that the ratio of $CH_4$:$SF_6$ in the collected breath samples rises as the $SF_6$ release rate increases. This is counter-intuitive as it implies a lower efficiency of $SF_6$ recovery as the rate of $SF_6$ release increases. It is not clear why this lower recovery would occur, or what is occurring with the $SF_6$. This gas has a very low solubility, and is a very stable gas, making absorption or chemical interactions unlikely (Bullister *et al.,* 2002).

This examination of experiments in New Zealand where $SF_6$ has been used to estimate $CH_4$ emissions suggests that in some circumstances $SF_6$ release rate can influence estimated $CH_4$ emissions. In New Zealand, a large effort has been put into quantifying $CH_4$ emissions from ruminants using the $SF_6$ tracer technique to underpin the national $CH_4$ inventory. Anything that casts doubt on the accuracy of the technique is a cause for concern. However, work to date suggests that mean values obtained using the $SF_6$ technique are similar to those obtained using direct methods (Boadi *et al.*, 2002) and the effect of $SF_6$ release rate identified here may simply contribute to the greater variability of the technique.

**FIGURE 2:** Regression[1,2,3] of estimated methane/kg DMI on permeation tube release rate in different animal species and feeding situations.

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