Environment Waikato Technical Report 2006/05

Real Life Emissions Testing of Pre 1994 Woodburners in New Zealand

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1 Introduction

This report presents the results from a collaborative project between Environment Waikato and a FRST-funded research programme “Protecting New Zealand’s Clean Air”, primarily being carried out by NIWA with a number of collaborators/ subcontractors including Environet Limited.

The aim of the study was to establish appropriate emission factors[1] to represent average real life emission rates for wood burners that were installed prior to 1994. Reliable emission factors are essential for air quality practitioners as they underpin emissions inventories that are commonly used to identify sources and discharges of contaminants to air.

The pre-1994 woodburner age category was selected because of compatibility with a large number of home heating emission inventories carried out during 2004 and 2005, which include a pre 1994/1995-burner age category. It also ties in loosely with the introduction of the New Zealand/ Australia burner test standard NZS 7403 (1992). Although there were no legislative requirements for burners to be tested, by 1994 a reasonable number of burners had been tested relative to this standard.

Although emission factors for wood burners have been used for many years a recent study (Scott, 2005) suggests the possibility of some issues with historical methods of establishing emission factors. These have generally been based on one of two approaches:

1. Reliance on simulations of real life emission testing carried out in a laboratory situation in New Zealand, supplemented by selected overseas emission testing data (e.g., Wilton, 2001);
2. Reliance on overseas emission testing results with particular emphasis to work done in the United States (e.g., Scott & Gunatilaka, 2003).

The first method largely relies on emission factors for domestic home heating that have been derived based on a relatively small sample of laboratory simulations of real life operation of burners. The simulations were carried out by laboratory technicians and may not adequately account for variations that occur as a result of incorrect operation and installation. The second method relies on the burner designs and fuel types being similar in the US to what is used in New Zealand.

A new method for testing solid fuel burners “in situ” was established by Applied Research Services for the SMF burner testing collaboration (Scott, 2005) and is detailed in Appendix A. This allowed for an evaluation of emissions from a burner operated in the home by the householder.

Under the National Environmental Standards for Air Quality (NES), AS/NZS4013 authorisation of low emission woodburners is required to verify, during laboratory testing, that less than 1.5 grams of particles are discharged for each kilogram of wood burnt (1.5 g/kg). Woodburners are not permitted to be installed in urban areas of New Zealand unless they meet this discharge criterion and a thermal efficiency standard. While the authorisation limit is 1.5 g/kg, an emission factor of 3 g/kg is commonly used as an estimate of real life emissions for this group of appliances.

However, based on tests from a limited number of appliances, Scott (2005) suggests that in a “real-life” situation some appliances may well produce emissions that are substantially higher than the “real-life” emission factor of 3 g/kg. Unfortunately the small

[1] In this report, **emission factor** refers to a measure of air particulate (PM_{10}) discharge for every measure of fuel consumption or period of activity: ie. grams of PM_{10} per kilogram of fuel burnt, or grams of PM_{10} per hour of combustion activity.

number of burners in Scott's (2005) study was insufficient to identify a robust emission factor for low emission woodburners and further testing of these appliances is required.

The difference between laboratory and real life emissions may be because of variability of woodburner operation, installation characteristics or fuel type and quality in real life circumstances. Because this variability applies to woodburners of all ages, emission factors currently used for older woodburners are also uncertain and real life testing is required to improve the reliability of emission factors for all ages of woodburners. The objective of this investigation is to establish a real life emission factor for pre-1994 woodburners.

2 Programme Design and Methodology

The main limitation of previous testing is the small number of burners and tests conducted, for both "in situ" sampling and burner simulations in the laboratory. To overcome this limitation in this investigation, twelve burners were selected for testing and each was monitored for at least seven days. The seven days is required to give a reasonable amount of data per burner to account for daily variations in emissions.

The burner testing was carried out in conjunction with the Ministry for the Environment (MfE) "warm homes" pilot project for Tokoroa for 2005. The MfE project involves the replacement of 19 existing older burners and open fires (in separate households) with NES-compliant burners, wood pellet fires and non-solid fuel alternatives. There were a number of advantages in this collaboration:

- Selection of households for inclusion in the project was done via the warm homes assistance package. This reduced the time involved in identifying houses for inclusion whilst also giving households an incentive for being involved.
- The operational characteristics should be similar for both the pre 1994 burner category and the NES burner category, as the same operator is used for both appliance types. There is a valuable opportunity to follow up this investigation with a Stage 2 emissions testing project, perhaps in winter 2006, to identify a real life emission factor for the replacement NES-compliant burners.

Applied Research Services (ARS) operated two samplers at separate households during the sampling period July-September 2005. In total 12 burners were tested for at least seven days each. Filters were changed daily and weighed at ARS' laboratory in Nelson. Further details of the sampler design and operation principle are included in Appendix A, along with an evaluation of performance compared with AS/NZS4013 compliant equipment.

Testing was carried out using firewood belonging to the home owners and burners were operated by the householders as they would in real life, on each day of the testing period. Householders were asked to make records of fuel weight, loading times and burner temperature settings (e.g., proportion of each day on high, medium and low).

3 Results

3.1 Mass Emission Rates – Grams per Kilogram

Raw data are included in Appendix B. Figure 1 shows that the g/kg data are positively skewed with outliers, so a parametric measure of central tendency is not appropriate. Instead, the median and 95% confidence intervals of the median were used to determine a real-life emission factor for the pre-1994 woodburners.

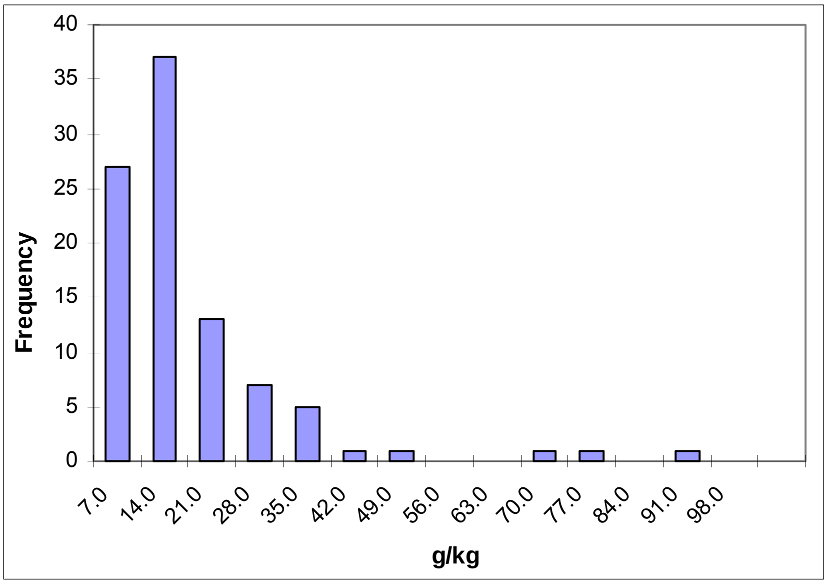

Figure 1 **Histogram showing frequency distribution of mass emissions from all woodburners (n=number of observations per 7 g/kg interval).**

As described in Berthouex and Brown (1994), rank numbers of the upper and lower 95% confidence limits of the median were calculated following Equation 1 where: p=percentile value (median percentile = 0.50); n=number of observations; and $z_{\alpha/2}$ = 1.96 for 95% confidence interval.

Equation 1

$$Rank_{upper} = p(n+1) + z_{\alpha/2}\sqrt{np(1-p)}$$

$$Rank_{lower} = p(n+1) - z_{\alpha/2}\sqrt{np(1-p)}$$

The sample median is **10.4 g/kg**, with upper and lower 95% confidence limits of 11.5 g/kg and 8.9 g/kg respectively. It is suggested that if Stage 2 testing of low-emission woodburners is completed in 2006, a non-parametric method such as the Mann-Whitney U-test should be used to ascertain whether there is a significant difference between the Stage 1 and the 2006 Stage 2 samples.

Some woodburners were tested for longer than the planned seven day period. For example, data were collected from Appliance 9 for eleven days and the relative importance of appliances in the statistical analyses may therefore have been weighted in favour of those with longer operating periods. To evaluate this effect, the median was calculated again, using only the first seven days of data for each burner. This resulted in a median of 10.5, which differs little from the result when all samples are included in the analysis. Therefore it was considered appropriate to use all the data in analyses, to maximise precision of the confidence interval.

3.2 Alternative Emission Rate – Grams per Hour

As with the g/kg data, the distribution of emission rates expressed in units g/hr is positively skewed (Figure 2).

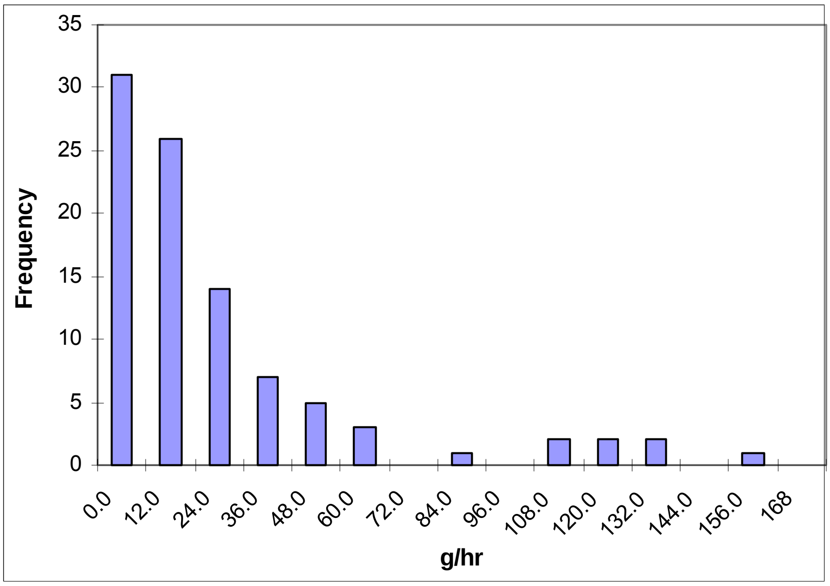

Figure 2: Histogram showing distribution of emissions, in units g/hr, from all woodburners. (n=number of observations per 12 g/hr interval).

Following the procedure in Section 3.1, the median hourly emission rate is **18.5 g/hr** with lower and upper 95% confidence limits of 14.3 g/hr and 23 g/hr respectively. If the number of samples from each burner is limited to the first seven days, to avoid weighting issues, the median is 18.9 g/hr. Therefore the weighting issue has a minor impact on the hourly emission rate, as was the case for the median g/kg emission rate.

3.3 Summary of Results

The median emission rates and 95% confidence limits are summarised in Table 1.

Table 1: Median and 95% confidence limits of emission rates from pre-1994 woodburners-

	Median emission rate	Lower 95% Confidence limit	Upper 95% Confidence limit
g/kg	10.4	8.9	11.5
g/hr	18.5	14.3	23.0

4 Implications for Air Quality Management in New Zealand

Establishing robust emission factors for particulate emissions from domestic home heating is vital for the management of air quality in many urban areas of New Zealand. In particular, the difference in emission rates between older burners and NES compliant burners will have a significant impact on the extent of additional management required to meet the NES in many urban areas.

This study suggests an emission rate of around 10 g/kg is appropriate for pre 1994 wood burners. Emission rates previously assumed for this age category of burners have ranged from around 11 g/kg for most urban areas to 13 g/kg for Tokoroa. Emission rates for the latter area were assumed to be slightly higher because of the older age of the burners in use in Tokoroa.

The initial "in situ" testing of NES compliant burners (Scott, 2005), raised concerns that the NES design criterion for wood burners may not result in improvements in PM_{10} from domestic home heating as older burners were replaced with NES compliant burners at the end of their useful life. At the time, the equivalent test methodology had not been applied to any other categories of burners. However, as indicated above, emission factors for older burners used in emission inventories and air quality management evaluations are of similar magnitude to the factors derived in this study.

At present, it is uncertain whether the "in situ" testing of NES compliant burners carried out by Scott (2005) provides a representative indication of the likely emission rate for this burner age category. Scott (2005) states that "*results were not necessarily representative of low emission wood burners as a class of appliances, and as such emission factors could not be developed. Nevertheless, the data indicate that in a "real-life" situation some appliances may well produce emissions that are substantially higher than the "real-life" emission factor commonly assumed for low emission wood burners*". If Scott's (2005) results are indicative of emission rates for NES compliant burners, improvements in particulate concentrations projected to occur as a result of replacement of older burners may not be realised. Priority should therefore be given to further testing of NES compliant burners and establishing a robust emission factor for particulate emissions from these appliances.

In summary, the results support the particulate emission factors that are currently used for older burners in air quality management exercises. However, it is still uncertain what emission rates are appropriate for NES-compliant burners under real-life operation.

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Appendix A. Applied Research Services Technical Bulletin 72 – Portable Emissions Sampler Methodology

The portable emissions sampler captures particulate emissions using a method based on Oregon Method 41 (OM41). This method is also known as the Condar Method.

Principle of Operation

The sampling head includes a dilution system to dilute and cool the flue gas. This simulates the dilution and cooling that occurs when flue gases mix with ambient air and results in condensation of oily compounds such as polyaromatic hydrocarbons which can then be captured on the filter.

In practice, flue gases are drawn into a manifold through the sample probe. Dilution air is also drawn into the manifold through small holes in its face. The diluted gases are then drawn through two filters which collect the particulate emissions.

Details of the Sampler

General

The sampler includes a sampling head (detailed below) which captures the sample of particulates. In addition flue temperature is measured, flue gases are analysed continuously for oxygen and carbon dioxide content and the carbon dioxide content of the diluted gas stream is analysed. The sampler also contains gauges to monitor and set gas flows through the sample head and flue gas analysers, canisters of drying agent to remove water vapour from the gas streams, a gas meter to quantify the sample flow and a vacuum sensor to monitor filter loadings. The sampler is interfaced to a laptop computer which activates the sampling pump when the heater is operated and the flue temperature rises. The computer is also used to log data.

Sampling Head

The sampling head consists of a stainless steel dilution manifold (length 100 mm, internal dia 49 mm) fitted with two end caps. One end cap is fitted with a short probe with a glass insert. The probe is inserted into the flue so that the inlet is near the flue center. Dilution air is admitted to the manifold via 12 x 1 mm dia holes in the face of the end cap. The sample is collected on two 47 mm glass fibre filters (Gelman Type A/E Cat No 61631) mounted on two filter holders fitted to the other end cap of the manifold.

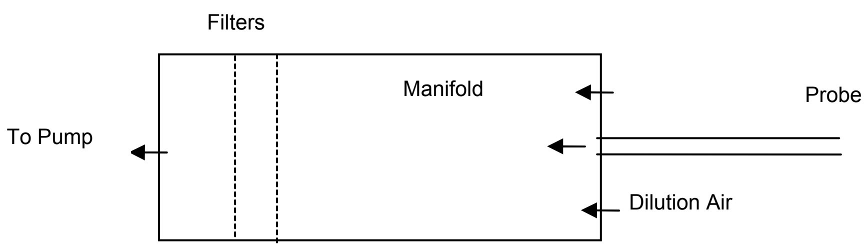

Figure 1. Schematic Of Sampling Head

Apart from the probe and manifold assembly the sampling assembly is the same as used in AS/NZS 4012/3. As with NZS4013 two glass fibre filters are used to collect the particulate materials. The flue gas composition is also measured and is used to calculate the total volume of gas which has passed up the flue per kg of fuel burnt. The total emissions can then be calculated from rate at which material is collected on the filter and the dilution ratio.

Comparison of Results Obtained with AS/NZS 4012/3

Laboratory tests of wood burners for compliance to particulate emissions standards in New Zealand are currently carried out according to methods set out in the joint Australian/ New Zealand standard AS/NZS 4012/3. The test involves capture of the entire gas stream exiting the flue which is then passed to a dilution tunnel where it is mixed with room which provides dilution and cooling. The particulate sample is drawn from the end of the dilution tunnel. Because the velocity of gas in the dilution tunnel is more easily measured than that in the flue the amount of particulate generated is relatively easily calculated.

During the comparative tests the portable emissions sampler was set up in the test room and run at the same time as the laboratory test rig.

Results

The graph below shows the results of nineteen runs carried out on a range of heaters. Of these seventeen (squares) were obtained during tests where fuelling was carried out in accordance with the requirements of AS/NZS 4012/3 and three (triangles) were carried out during five hour runs and a “real life” fuelling regime in accordance with SMF Contract Application Number 2205. Results are particulate emissions in g/kg.

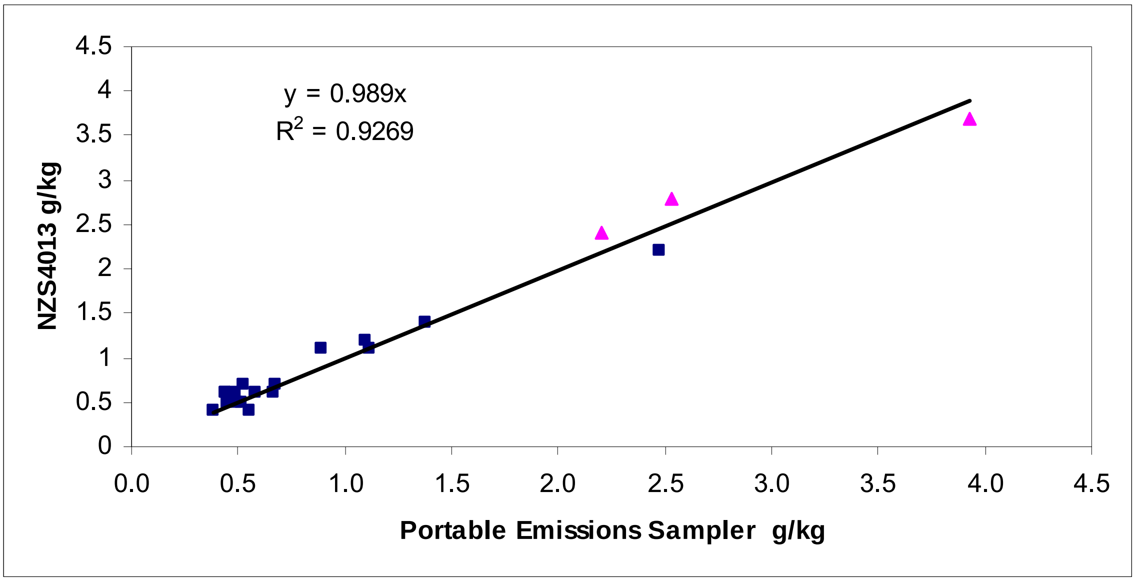

Figure 2 Comparison of Results Obtained with Portable Emissions Sampler and AS/NZS 4012/3

The results show that a good correlation exists between results obtained with the two methods.

Applied Research Services Ltd, P.O. Box 687, Nelson, New Zealand
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Appendix B. Applied Research Services Report 05/1281: Results of In Home Monitoring of Particulate Emissions from Wood Burning Heaters in Tokoroa.

Report 05/1281 **October 20th, 2005**
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Customer:	**National Institute of Water and Atmospheric Research** **C/- Environet, 11 Lachie Griffin Rise, RD1, LYTTELTON**	**Environment Waikato** **P.O. Box 4010** **Hamilton East** **HAMILTON**
Attention:	**Emily Wilton**	**Jeff Smith**

Results Of In Home Monitoring of Particulate Emissions from Wood Burning Heaters in Tokoroa

Part I – Pre 1994 Heaters

1.0 Overview

This report presents the results of measurements of particulate emissions from twelve wood burning heaters installed in Tokoroa. The sampling program was jointly funded by Environment Waikato and the Foundation for Science Research and Technology (administered by Emily Wilton of Environet on behalf of the National Institute for Water and Atmospheric Research).

The heaters selected were all installed prior to 1994. Each heater was monitored for a period of at least seven days during which time the householder was requested to operate it as they would normally. An automatic sampler drew a sample of particulate emissions while the heater was operating.

The sampling program was run by Applied Research Services Ltd. Staff involved were James McCann (Tokoroa) and Wayne Webley (Nelson). Sampling took place during winter 2005.

2.0 Methodology

2.1 Selection of Heaters

All households were participants in a Warm Homes Pilot Project funded by the Ministry for the Environment and coordinated by Norman Smith (Senior Adjunct Associate, Rocky Mountain Institute). Households were selected by Norman Smith on the basis that they had a suitable heater and were willing to participate in the emissions testing program.

Information supplied by Norman Smith for the heaters is given in Table 1.

Table 1 Information On Heaters Tested

Heater	Make	Age (yrs)
1	Kent Tilefire	>11
2	Norseman	17
3	Kent Tilefire	20
4	Kent Tilefire	29
5	Kent	>11
6	Kent	15
7	Zealandia F1-11	30
8	Kent	23
9	Brugger	24
10	Masport Panorama Series II	16
11	Kent	16
12	Logaire Phoenix	16

2,2 Emissions Sampling

A portable emissions sampler was installed in each household for the duration of the tests. Details of this sampler are given in our Technical Bulletin number 72 which is appended to this report. Results from the sampler can be used to calculate an emissions rate in g/kg (dry wood basis) independently of any information recorded by the householder.

2.3 Additional Information

Householders were requested to record the weight of wood they added while operating the heater. In addition our technician recorded the moisture content of a representative sample of the wood being burnt. This information was used to estimate the fuel consumption rate and this in turn was used to calculate the emissions rate in g/hr from the g/kg figure obtained directly from the sampler.
Additional information was collected during the program. This included the frequency of fueling, number of pieces added, control settings, type of fuel added, condition of the burner, presence of wetback, estimated flue height and termination. The analysis of this additional information is beyond the scope of this report and may be reported elsewhere.

3.0 Results

Results from the study are given in Table 2. The emissions rate in g/kg is obtained directly from measurements recorded by the portable emissions sampler. It is the grams of particulate emissions per kilogram of fuel burned, where the fuel weight is expressed on a dry weight basis. This is the same basis as used in AS/NZS 4013 for laboratory measurements of particulate emissions.

The g/hr figure is calculated from the g/kg figure and the fuel consumption rate expressed as kg of fuel (on a dry weight basis) per hour. The latter figure is based on records of fuel weights kept by the householders and representative measurements by our technician of the fuel moisture content of the household wood supply.

Table 2 Particulate Emissions Results

Heater	emissions rate g/kg	g/hr
1	22.9	41.6
	18.7	53.2
	29.1	36.1
	14.3	36.1
	18.4	20.5
	8.1	17.9
	28.9	39.3
	12.6	25.9
2	10.7	22.0
	12.3	18.9
	10.8	10.1
	6.6	18.7
	7.4	9.9
	8.9	11.0
	10.4	16.7
	10.5	16.5
	9.4	12.7
3	15.8	33.7
	23.8	44.5
	10.6	14.4
	5.8	9.8
	16.1	25.0
	14.5	31.9
	15.7	20.6
4	8.2	11.6
	5.4	9.2
	2.9	4.6
	1.0	1.6
	8.4	25.3
	3.0	4.9
	11.3	36.5
5	5.3	4.6
	3.9	3.1
	6.6	3.7
	8.9	18.2
	3.5	4.4
	10.9	14.5
	9.3	16.2
6	29.9	34.4
	21.8	51.0
	90.6	164.6
	68.2	137.3
	5.6	18.8
	5.3	13.2
	13.0	35.7
	8.6	21.3
7	3.5	3.3
	4.9	3.4
	15.8	57.8

Heater	emissions rate	
	g/kg	g/hr
	2.8	1.4
	5.8	3.5
	12.4	21.5
	45.4	124.4
	3.6	2.6
8	25.4	110.5
	74.8	118.4
	35.7	137.9
	30.0	66.6
	21.6	93.1
	14.2	29.1
	32.0	128.6
	1.9	4.7
9	2.3	1.9
	2.4	2.6
	11.9	11.0
	7.0	5.4
	11.6	7.5
	9.3	12.5
	7.2	6.9
	8.1	8.9
	10.5	13.2
	4.0	6.4
	11.5	17.5
10	9.1	26.0
	10.0	20.9
	9.7	17.3
	6.1	10.1
	6.0	27.6
	4.0	8.5
	2.8	7.6
	14.3	61.0
11	23.6	39.9
	9.3	11.3
	4.5	14.3
	6.5	25.0
	21.1	33.0
	10.9	23.9
	15.6	34.1
12	9.5	25.5
	19.6	62.4
	11.5	54.4
	12.0	18.5
	15.0	58.4
	7.0	13.6
	8.4	11.3
mean	14.0	29.8
median	10.4	18.5

<u>This report</u>:

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