

**A Study of the Fate of Mercury from  
the Placement and Removal  
Of  
Dental Amalgam Restorations**

Final Report

Part II: Survey of Dentists in the Province of Ontario,  
Canada

Placement and Removal of Dental Amalgam Restorations

Presented to the Royal College of Dental Surgeons of Ontario

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## EXECUTIVE SUMMARY

This report is the second part of a study conducted in two parts. Details of Part I are contained in the report available on the RCDSO web site <http://www.rcdso.org> entitled: A Study of the Fate of Mercury from the Placement and Removal of Dental Amalgam Restorations – Final Report Part I: Removal of Dental Amalgam Restorations.<sup>1</sup>

In Part II we present the results of a survey sent to 2000 dentists randomly selected from the RCDSO membership list. Calculations in this report are based on a response rate of 44% (878/2000 dentists).

A summary of the estimated flux of dental mercury in Ontario in 2002 is presented in Figure 4. We estimated that a total of 1,824.84 Kg of amalgam would be placed in the teeth of Ontarians either as new amalgam (707.44 Kg) in previously un-restored teeth or as replacements (1,117.40 Kg) in previously restored teeth. On the other hand, we estimated that 2,515.45 Kg of amalgam would be removed from the teeth of Ontarians in 2002.

The estimated mercury content of the waste amalgam generated in 2002 by Ontario dentists would be 1,258 Kg, which ranges from the low/low (based on the lower 95% confidence limits of the weight of restorations and the number of restored tooth surfaces) estimate of 902 Kg to a high/high (based on the upper 95% confidence limits of the weight of restorations and the number of restored tooth surfaces) estimate of 1,663 Kg. This mercury would be bound within amalgam particles of varying sizes and shapes. Our previous study<sup>1 2</sup> had shown that 30%, of the waste generated during removal of amalgam restorations would be captured by the conventional chair-side solids separators. Therefore, the mercury content of the amalgam waste captured by the chair-side trap is estimated at 377 Kg (499 Kg to 271 Kg) annually, which resulted in 881.Kg (1,164 Kg to 631 Kg) of amalgam bypassing the chair-side solids separators. A further 10%, or 129 Kg (166 Kg to 90 Kg) of the mercury would be contained in relatively smaller amalgam particles captured by the conventional solids separators located just upstream from the vacuum pump. Consequently, 755 Kg (998 Kg to 541 Kg) of mercury bypasses both of the conventional solids separators.

We have presented the current release of mercury by dentists in Ontario; as well, we have presented two scenarios for the quantity of mercury contained in amalgam wastes generated by Ontario dentists based on whether all or none of the registered dentists in Ontario use an ISO:11143 certified<sup>3</sup> separator or equivalent.<sup>4</sup> Currently, 22% of Ontario dentist reported using amalgam separators. We then estimated the current annual release of mercury as 577 Kg (667Kg to 483 Kg); or, 228.61 (264.11 to 191.24) mg/dentist/day. Without ISO certified amalgam particle separators or equivalent the 755 Kg (998 Kg to 541 Kg) of mercury bound in amalgam that bypasses the conventional traps at the chair-side and the vacuum pump would be released to the sewer. Alternatively, if all dentists use a certified amalgam-separating device or equivalent then the discharge of mercury bound in amalgam waste would be reduced to 8.3 Kg (11.0 Kg to 6.0 Kg) annually or 3.29 (4.36 to 2.38) mg/dentist/day. In our calculations we used 98.9% as the average

efficiency of commercial separators. The rationale for using 98.9% as the effective working efficiency is explained below.

During Phase I<sup>1 2</sup> of this study we tested the RASCH 890 amalgam particle separator and obtained an efficiency of 99.4%. A recent laboratory study by Fan and others<sup>5</sup> reports on the efficiency of twelve commercially available ISO certified separators. Therefore, in our calculations for Part II we used the overall average operating efficiency of 98.9% derived from both Fan and others<sup>5</sup> and our own results reported in Part I<sup>1 2</sup>. We have further calculated the release of mercury by dentists based on a scenario where dentists in Ontario comply with the Canada Wide Standard<sup>4</sup> and use amalgam particle separators that meet the ISO:11143:1999 standard<sup>3</sup> or equivalent.<sup>4</sup> Therefore, in this report calculations where separators are used are based on an average efficiency of 98.9% for removal of amalgam particles. The scenario where all dentists comply with the use of separators demonstrates that a major reduction in mercury entering the sewer systems can be achieved.

For the year 2002 we have calculated that Ontario dentists:

- **placed 707.49 Kg of dental amalgam into previously un-restored teeth.** The upper and lower 95% confidence limits for the estimated weight of amalgams placed in previously un-restored teeth were 825.70 Kg and 584.70 Kg, respectively. An alternative description of the data is that the average weight of new amalgam placed in previously un-restored teeth is 707.47 Kg and that there is a 95% chance that the actual weight of amalgam removed lies between 825.70 Kg and 548.70 Kg.
- **placed 1,117.66 Kg of new amalgam into previously restored teeth.** The upper and lower 95% confidence limits for the weight of amalgams placed in previously restored teeth are 1285.18 Kg and 953.37 Kg respectively.
- **removed 2,515.47 Kg of amalgam from previously restored teeth.** The upper and lower 95% confidence limits for the weight of amalgams removed are 2,907.53 Kg and 2,106.32 Kg, respectively.

Less than half the weight of amalgam that was removed from teeth (44.4% or 1,117.66 Kg) was replaced with amalgam; other materials would have been used to restore many of the cavities from which the amalgam restorations were removed.

In total for the year 2002 Ontario dentists will have removed 690.32 Kg more amalgam than will be incorporated into all new restorations combined.

If none of the Ontario dentists used advanced amalgam particle separators up to 60%, or 1,509.27Kg of the amalgam containing approximately 755 Kg of mercury bound in the particles will pass through conventional solids separators and leave the office with the wastewater.

Based on the survey 22% (195/878) of Ontario dentists use advanced amalgam particle separators. Therefore, the current estimated total (95% confidence interval) weight of amalgam particles entering wastewater in Ontario in the year 2002 is 1,153.24 Kg (1,339.19 Kg to 965.40 Kg). This weight of amalgam will contain 576.62 Kg (669.60 to 482.70 Kg), assuming that the amalgam contains 50% by weight mercury.

If all Ontario dentists used advanced particle separators (ISO certified or equivalent) the total loss of amalgam particles into wastewater in Ontario in 2002 would be 16.6 Kg containing approximately 8.8 Kg of mercury (95% confidence interval for the weight of amalgam 19.19Kg-13.90 Kg),

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
EXECUTIVE SUMMARY	iii
TABLE OF CONTENTS	vi
LIST OF TABLES	vii
LIST OF FIGURES	viii
MATERIALS AND METHODS (PART II)	1
RESULTS	2
Response rate	2
Placement and removal of amalgams	3
Placement of amalgam in previously un-restored teeth	3
Placement of amalgam in previously restored teeth	6
Removal of amalgam from teeth previously restored with amalgam	8
The negative balance in the weight of amalgams placed and removed	9
Estimated annual release of mercury bound in amalgam particles	13
Sensitivity analysis of the quantity of amalgam placed and removed	15
REFERENCES	20

## LIST of TABLES

Table 1	Summary of the mean (standard deviation) and total numbers of new amalgams placed in previously un-restored teeth by 878 dentists and estimates for all Ontario dentists	4
Table 2	Summary of the weight (Kg) of new amalgams placed annually in previously un-restored teeth by 878 dentists and estimates for all Ontario dentists	5
Table 3	Summary of the mean (standard deviation) and total numbers of amalgams placed in previously restored teeth by 878 dentists and estimates for all Ontario dentists	6
Table 4	Summary of the weight (Kg) of amalgams placed annually in previously restored teeth by 878 dentists and estimates for all Ontario dentists	7
Table 5	Summary of the mean (standard deviation) and total numbers of amalgams removed from previously restored teeth by 878 dentists and estimates for all Ontario dentists	9
Table 6	Summary of the weight (Kg) of amalgams removed annually from previously restored teeth by 878 dentists and estimates for all Ontario dentists	10
Table 7	Summary of the weight (Kg) of amalgams released to local sewers when amalgam wastes are discharged either directly or through a separator annually by 878 dentists and estimates for all Ontario dentists	13
Table 8	Summary of the numbers and 95% confidence intervals of amalgams placed or removed from previously restored teeth annually by 878 dentists and estimates for all Ontario dentists	14
Table 9	Sensitivity analysis of the estimates of the weight (Kg) of amalgam placed or removed annually by all Ontario dentists in 2002	16

## LIST OF FIGURES

Figure 1	Net change in the 2,515.47 Kg of amalgam removed from teeth Ontario dentists in 2002	11
Figure 2	Annual estimated flux of the weight (Kg) of amalgam placed and removed in tooth surfaces by Ontario dentists	12
Figure 3	Sensitivity analysis of the weight (Metric Tons) of amalgam placed or removed by Ontario dentists in 2002	17
Figure 4	Annual quantity *(range) of mercury incorporated into new amalgams and released to sewer from the removal of old amalgams	18



## **MATERIALS AND METHODS (Part II)**

A questionnaire was sent to 2,000 dentists who were randomly selected from the membership list of all the 7,150 dentists registered to practice dentistry in Ontario. Prior to selection of the 2000 dentists, the names of all dentists (235) who were not registered to an Ontario address were purged from the membership list. In this report estimated annual placement and removal of amalgams by Ontario dentists refers to estimates derived for the 6,915 dentists who were registered to an address in Ontario.

The questionnaire was used to gather information about placement and removal of amalgam and the disposal of amalgam wastes. Each dentist was asked to record the actual numbers of 1-, 2-, 3-,  $\geq$  4- surfaced amalgam restorations and core amalgam build-ups placed or removed during the current week, which was defined as the seven days immediately after the questionnaire was received. Data from the questionnaires were entered into Epi Info 2000 and transported into Excel in Microsoft Office 2000 and then into SAS System for Windows V8 for editing and analysis.

The weight of amalgam placed or removed over the one-week period was obtained by multiplying the total number of restorations in each group (1-, 2-, 3-,  $\geq$  4- surfaced amalgam restorations and core amalgam build-ups) by the weight respectively of 1-, 2-, 3-,  $\geq$  4- surfaced restorations and core build-ups. The weights of 1-, 2-, 3-,  $\geq$  4-surfaced amalgam restorations and core amalgam build-ups was determined and reported previously in Part I of this study.<sup>1,2</sup>

The total weight of amalgam removed or placed weekly was computed by summing the weights of 1-, 2-, 3-,  $\geq$  4- surfaced amalgam restorations and core build-up amalgams removed or placed by all dentists. To compute the weight of amalgam placed or removed annually, we multiplied the weight of amalgam produced by each dentist with the number of weeks that the dentist had reported working in a year. We imputed zero weeks for the 41 dentists who did not complete the questionnaire and the 147 dentists who neither placed nor removed amalgam during the current week; as well, we imputed the modal number of weeks (48 weeks) reported by other dentists who responded to the question on the number of weeks they each worked in a year for those dentists who had either removed or placed amalgam during the current week but did not respond to this question.

Three case scenarios were used to compute the weight of amalgam released to the sewer by Ontario dentists: For the first scenario, we assumed that 60% of the weight of amalgams removed annually will bypass the solids separator at the chair-side and the solids separator (sometimes called the vacuum filter) up-stream at the vacuum pump; we<sup>1</sup> had previously established that 30% of wastes generated during the removal of amalgam restorations are trapped in the solids separator at the chair-side and that a further 10% are trapped in the solids separator up-stream at the vacuum pump. Some dentists reported that they use amalgam separators; the use of separators will further reduce the quantity of amalgam wastes that the dentist generates. Therefore, for the second scenario – current level of discharge based on whether a dentist uses an amalgam separator or not – we created an algorithm that reduced the weight of amalgam wastes

that bypassed the solids separators at the chair-side and the vacuum pump by 98.9% (average efficiency of ISO:11149 certified amalgam separators in the market).<sup>1 2 5</sup> Finally, we derived the weights of amalgam wastes released into the sewer under the assumption that all dentists use amalgam separators.

The estimated annual weights of amalgam placed and removed were subjected to sensitivity analyses by computing the weights based on the total and 95% confidence limits of the estimated weights and numbers of 1-, 2-, 3-,  $\geq$  4-surfaced amalgam restorations and post and core amalgam build-ups placed or removed annually. The analyses yielded the following nine possible weights:

- 1) Upper 95% confidence limit of the weight of a restoration and the upper 95% confidence limit of the numbers of restorations placed or removed;
- 2) Upper 95% confidence limit of the weight of a restoration and the average total numbers of restorations placed or removed;
- 3) Upper 95% confidence limit of the weight of a restoration and the lower 95% confidence limit of the numbers of restorations placed or removed;
- 4) Average total weight of restorations placed and the upper 95% confidence limit of the numbers of restorations placed or removed;
- 5) Average total weight of restorations placed and the average total numbers of restorations placed or removed;
- 6) Average total weight of restorations placed and the lower 95% confidence limit of the numbers of restorations placed or removed;
- 7) Lower 95% confidence limit of the weight of a restoration and the upper 95% confidence limit of the numbers of restorations placed or removed;
- 8) Lower 95% confidence limit of the weight of a restoration and the average total numbers of restorations placed or removed; and
- 9) Lower 95% confidence limit of the weight of a restoration and the lower 95% confidence limit of the numbers of restorations placed or removed.

In this study we have assumed that the placement of amalgam restorations does not significantly contribute to the weight of amalgam wastes released to the wastewater stream.

## **RESULTS**

### **Response Rate**

Five hundred and fifty or 27.5% of the dentists responded to the first mailing of the questionnaire. The questionnaire was mailed a second time to those dentists who did not respond initially. Subsequently we obtained 328 more responses that resulted in an overall study response rate of 44% (878/1994); six questionnaires could not be delivered at the address on the register of the Royal College of Dental Surgeon of Ontario (RCDSO).

We determined if those dentists who had responded to the first mailing were representative of the 2000 dentists to whom we had mailed the questionnaires by comparing whether or not the respondent had been registered to an address in metropolitan Toronto and whether the respondents was registered as a specialist or not. Based on these two criteria, the 550 dentists who responded to the first mailing were found to be representative of the dentists on the RCDSO register. Compared to non-respondents, fewer respondents were registered to an address in metropolitan Toronto; the proportions of non-respondents and respondents who were registered to an address in metropolitan Toronto were 32.0% and 28.4%, respectively. However, the difference was not statistically significant ( $p = 0.09$ ). Similarly, the proportion of dentists who were registered as specialists (including those who held academic licenses) was similar ( $p = 0.19$ ) between non-respondents and respondents; the proportions were 11.0% and 12.7%, respectively. At the time of writing this Report we had not determined, based on the above-mentioned criteria, if there was any bias in responses of the entire 878 respondents.

### **Placement and removal of amalgams**

Of the 837 (95.33%) dentists who completed the questionnaire, 81 or nearly 10% were specialists. Of the 878 dentists who responded to the survey, 4.67% (41) did not complete the questionnaire for a number of reasons. In this group of 41 dentists, 16 had retired or were no longer in the practice of dentistry. Six dentists were temporarily out of practice because they were on maternity leave or were relocating. Eleven reported that they were specialists or graduate students. Three no longer use amalgam. Two dentists reported that they did not work in clinical practice. Two other dentists reported that they only worked part-time and another dentist reported working only in emergency care.

Of the remaining 837 dentists who completed the questionnaire, 18% (147) neither placed nor removed amalgam during the current week. The majority 80% (65/81) of dentists who had neither placed nor removed amalgam restorations during the current week were specialists. The Oral Surgeons, Orthodontists, Oral Pathologists and Periodontists who responded to the questionnaire did not place or remove amalgam restorations; however, Endodontists occasionally remove amalgam to gain access to the root canal system whilst Oral Surgeons extracted teeth that contained amalgam. The three groups of specialists who placed or removed amalgams during the current week were Dental Public Health Dentists providing clinical care, Prosthodontists and Pedodontists.

### **Placement of amalgams in previously un-restored teeth**

Table 1 presents the average and total numbers of restorations placed weekly and annually by 878 dentists who responded to the interview; as well, the table shows the estimated annual numbers of new amalgams placed as 1-, 2-, 3-,  $\geq 4$ -surfaced amalgam restorations and post and core amalgam build-ups in previously un-restored teeth by

Ontario dentists in 2002. Based on the findings we have estimated that, on the average, Ontario dentists will place 949,152 amalgam restorations in previously un-restored teeth: 225,982 one surface, 490,688 two surfaces, 169,279 three surfaces, 52,623 four or more surfaces, and 10,580 post and core build-ups.

Table 1 Summary of the mean (standard deviation) and total numbers of new amalgams placed in previously un-restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surfaces restored	Mean *(SD) and Total numbers of restorations						
	Placed by 878 dentists						†Estimates for
	Weekly			Annually			all dentists
	Mean	SD	Total	Mean	SD	Total	Total
1-surfaced amalgams	0.70	2.36	616	32.68	110.57	28,689	225,982
2-surfaced amalgams	1.54	4.86	1,355	70.96	226.29	62,301	490,688
3-surfaced amalgam	0.54	2.28	473	24.48	104.90	21,496	169,279
4-surfaced amalgams	0.17	1.10	149	7.61	48.90	6,684	52,623
Core build-up amalgams	0.03	0.35	29	1.53	16.41	1,342	10,580

\* Standard Deviation

† Annual estimates

Table 2 presents the weight of amalgam placed by 878 dentists and the estimates for all Ontario dentists. As seen in Table 1, on the average the 878 respondents placed 8.89 kg of amalgam annually as 1-surfaced amalgam restorations. The upper and lower 95% confidence limits of the weights of new 1-surfaced amalgam restorations placed in previously un-restored teeth annually were 11.76 Kg and 5.74 Kg, respectively. The estimated total (95% confidence limits) weights of amalgam placed in 2002 as 2-, 3-,  $\geq 4$  surfaced amalgams and core amalgam build-ups were 41.74 Kg (48.58 Kg, 34.89 Kg), 24.50 Kg (27.94 Kg, 20.85 Kg), 12.23 Kg (13.78 Kg, 10.63 Kg), and 2.46 Kg (2.76 Kg, 2.13 Kg), respectively. We computed the total (95% confidence limits) weight of amalgam placed as the sum (sums of the lower and upper values of the 95% confidence limits) of the weights of restorations in 1-, 2-, 3-,  $\geq 4$ , surfaced restorations and post and core build-ups. Overall, we computed that the 878 dentists would place 89.83 Kg of amalgam in 2002. The upper and lower 95% confidence limits were estimated as 104.84 Kg and 74.24 Kg, respectively. An alternative description of the data is that the average weight of new amalgam placed in previously un-restored teeth was 89.83 Kg and that there was a 95% chance that the actual weight was between 104.84 Kg and 74.24 Kg. We estimated that, collectively, all 6,915 dentists registered with an Ontario address would place on the average 707.49 Kg of new amalgam in previously un-restored teeth in 2002; the upper and lower 95% confidence limits for the estimated weight of amalgams placed were 825.70 Kg and 584.70 Kg, respectively. Since modern alloys for dental amalgam require 45 to 50% by weight of mercury for preparation of amalgam we are

assuming that these amalgam restorations contained 50% by weight of mercury bound in the alloy.

Table 2 Summary of the weight (Kg) of new amalgams placed annually in previously un-restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surface restored	Based on the mean and 95% confidence limits of the weight of a restoration	Total quantity of amalgams placed in previously un-restored teeth		
		By 878 dentists weekly	By 878 dentists annually	Annual estimates for all dentists
1-surfaced amalgam restorations	Upper 95% confidence limit	0.25 Kg	11.76 Kg	92.62 Kg
	Mean	0.19 Kg	8.89 Kg	70.02 Kg
	Lower 95% confidence limit	0.12 Kg	5.74 Kg	45.21 Kg
2-surfaced amalgam restorations	Upper 95% confidence limit	1.06 Kg	48.59 Kg	362.69 Kg
	Mean	0.91 Kg	41.74 Kg	328.74 Kg
	Lower 95% confidence limit	0.76 Kg	34.89 Kg	274.79 Kg
3-surfaced amalgam restorations	Upper 95% confidence limit	0.61 Kg	27.94 Kg	220.05 Kg
	Mean	0.54 Kg	24.50 Kg	192.96 Kg
	Lower 95% confidence limit	0.46 Kg	20.85 Kg	164.21 Kg
≥4-surfaced amalgam restorations	Upper 95% confidence limit	0.31 Kg	13.78 Kg	108.53 Kg
	Mean	0.27 Kg	12.23 Kg	96.32 Kg
	Lower 95% confidence limit	0.24 Kg	10.63 Kg	83.72 Kg
Core amalgam restorations	Upper 95% confidence limit	0.06 Kg	2.76 Kg	21.74 Kg
	Mean	0.05 Kg	2.46 Kg	19.37 Kg
	Lower 95% confidence limit	0.05 Kg	2.13 Kg	16.78 Kg
Total for 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	2.29 kg	104.84 Kg	825.70 Kg
	Mean	1.96 Kg	89.83 Kg	707.49 Kg
	Lower 95% confidence limit	1.62 Kg	74.24 Kg	584.70 Kg
Total weight of mercury incorporated into new 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	1.14 Kg	52.42 Kg	412.85 Kg
	Mean	0.98 Kg	49.92 Kg	353.74 Kg
	Lower 95% confidence limit	0.81 Kg	37.11 Kg	292.35 Kg

Therefore, there is a 95% chance that in Ontario, based on our findings, that the estimated annual total weight of mercury, which was 353.74 Kg, contained in new amalgams placed in previously un-restored teeth by Ontario dentists could vary between a high of 412.85 Kg and a low of 292.35 Kg. Consequently, we estimate that Ontario dentists' daily use of mercury incorporated into new amalgam used to restore previously un-restored teeth as 140.15 mg/dentist/day; there is a 95% chance that the actual weight of mercury used daily by each dentist ranged from a high of 163.57 mg/dentist/day to a low of 115.83 mg/dentist/day; this is based on the assumption, for the purposes of this calculation, that all 6,915 registered dentists work 365 days in a year.

### Placement of amalgams in previously restored teeth

The weekly and projected annual numbers of various types of previously restored teeth replaced with amalgam are presented Table 3. The total numbers of 1-, 2-, 3-,  $\geq$  4, surfaced restorations and post and core build-ups replaced with amalgam during the current-week – the week dentists filled out the questionnaire – by 878 responding dentists were 411, 1,333, 883, 541, and 38, respectively. Based on the numbers of weeks a dentist reported working annually and the numbers of various types of restorations the dentist placed during the current-week, we computed that the 878 dentists will place 19,050 amalgams, 61,642 amalgams, 40,598 amalgams, 24,737 amalgams, and 788 amalgams as 1-, 2-, 3-,  $\geq$  4, surfaced and post and core build-ups in previously restored teeth in 2002, respectively. We then estimated that all Ontario dentists will place 150,055 amalgams, 485,502 amalgams, 319,750 amalgams, 194,796 amalgams, and 13,553 amalgams as 1-, 2-, 3-,  $\geq$  4, surfaced and post and core build-ups previously restored teeth in 2002, respectively.

Table 3 Summary of the mean (standard deviation) and total numbers of amalgams placed in previously restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surfaces restored	Mean *(SD) and Total numbers of restorations						
	Placed by 878 dentists						†Estimates for all dentists
	Weekly			Annually			
	Mean	SD	Total	Mean	SD	Total	Total
1-surfaced amalgams	0.47	1.75	411	21.70	81.41	19,050	150,055
2-surfaced amalgams	1.52	5.58	1,333	70.21	261.93	61,642	485,502
3-surfaced amalgam	1.01	3.51	883	46.24	164.11	40,598	319,750
4-surfaced amalgams	0.62	2.60	541	28.17	119.53	24,737	194,796
Core build-up amalgams	0.04	0.32	38	1.96	15.06	788	13,553

\* Standard Deviation

† Annual estimates

Table 4 Summary of the weight (Kg) of amalgams placed annually in previously restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surface restored	Based on the mean and 95% confidence limits of the weight of a restoration	Total quantity of amalgams placed in previously un-restored teeth		
		By 878 dentists weekly	By 878 dentists annually	Annual estimates for all dentists
1-surfaced amalgam restorations	Upper 95% confidence limit	0.17 Kg	7.81 Kg	61.51 Kg
	Mean	0.13 Kg	5.90 Kg	46.47 Kg
	Lower 95% confidence limit	0.08 Kg	3.81 Kg	30.01 Kg
2-surfaced amalgam restorations	Upper 95% confidence limit	1.04 Kg	48.08 Kg	378.67 Kg
	Mean	0.89 Kg	41.30 Kg	352.27 Kg
	Lower 95% confidence limit	0.75 Kg	34.52 Kg	271.87 Kg
3-surfaced amalgam restorations	Upper 95% confidence limit	1.15 Kg	52.78 Kg	415.69 Kg
	Mean	1.01 Kg	46.28 Kg	364.49 Kg
	Lower 95% confidence limit	0.86 Kg	39.38 Kg	310.15 Kg
≥4-surfaced amalgam restorations	Upper 95% confidence limit	1.11 Kg	50.96 Kg	401.35 Kg
	Mean	0.99 Kg	45.27 Kg	356.54 Kg
	Lower 95% confidence limit	0.86 Kg	39.33 Kg	309.76 Kg
Core amalgam restorations	Upper 95% confidence limit	0.08 Kg	3.55 Kg	27.96 Kg
	Mean	0.07 Kg	3.15 Kg	24.81 Kg
	Lower 95% confidence limit	0.06 Kg	2.74 Kg	21.58 Kg
Total for 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	3.55 Kg	163.18 Kg	1,285.18 Kg
	Mean	3.09 Kg	141.91 Kg	1,117.66 Kg
	Lower 95% confidence limit	2.60 Kg	119.78 Kg	943.37 Kg
Total weight of mercury incorporated into new 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	1.78 Kg	81.59 Kg	642.59 Kg
	Mean	1.54 Kg	70.96 Kg	558.83 Kg
	Lower 95% confidence limit	1.80 Kg	59.89 Kg	471.68 Kg





Table 4 presents the summary of the weights of amalgam used to replace old restorations. As seen in Table 4, the computed total (95% confidence limits) weight of 1-, 2-, 3-,  $\geq$  4-surfaced amalgam restorations and core amalgam build-ups placed in previously restored teeth by the 878 dentists annually were 5.90 Kg (7.81 Kg; 3.81 Kg), 41.30 Kg (48.08 Kg; 34.52 Kg), 46.28 Kg (52.78 Kg; 39.38 Kg), 45.27 Kg (50.96 Kg; 39.33 Kg) and 3.15 (3.55 Kg; 2.74 Kg), respectively. We estimated that the total (95% confidence limits) weight of amalgam placed as 1-, 2-, 3-,  $\geq$  4-surfaced amalgam restorations and core amalgam build-ups in previously restored teeth during 2002 by all Ontario dentists are 46.47 Kg (61.51 Kg; 30.01 Kg), 352.27 Kg (378.67 Kg; 271.87 Kg), 364.49 Kg (415.69 Kg; 310.15 Kg), 356.54 Kg (401.35 Kg; 309.76 Kg), and 24.81 Kg (27.96 Kg; 21.58 Kg), respectively. Overall, we estimated that the total weight of amalgam placed in previously restored teeth by dentists was 1,117.66 Kg and the 95% confidence interval is from a low of 953.37 Kg to a high of 1,285.18 Kg. Based on these findings, we estimate that the weight of mercury incorporated daily into new amalgams in previously restored teeth is 221.41 mg/dentist/day; there is a 95% chance that the actual weight of mercury used by each dentist ranged from a high of 254.49 mg/dentist/day to a low of 188.86 mg/dentist/day. Compared to the placement of amalgam in previously un-restored teeth, dentists used more amalgams to restore cavities that had restorations in them previously.

### **Removal of amalgams from teeth previously restored with amalgam**

The weekly and projected annual numbers of various types of amalgam restorations removed from previously restored tooth surfaces by dentists are presented in Table 5. During the current-week, the 878 responding dentists removed 1,471 amalgams, 3,172 amalgams, 2,195 amalgams, 930 amalgams, and 57 amalgams from 1-, 2-, 3-,  $\geq$  4, surfaced restorations and post and core build-ups from previously restored teeth, respectively. Based on the number of weeks a dentist reported working annually and the numbers of various types of restorations removed by the dentist during the current-week, we computed that the 878 dentists will remove 68,088 amalgams, 146,799 amalgams, 101,809 amalgams, 43,193 amalgams, and 2,634 amalgams from 1-, 2-, 3-,  $\geq$  4, surfaced restorations and post and core build-ups previously restored with amalgam in 2002, respectively. Therefore, all Ontario dentists will remove 536,258 amalgams, 1,156,188 amalgams, 801,864 amalgams, 340,149 amalgams, and 20,745 amalgams from 1-, 2-, 3-,  $\geq$  4, surfaced restorations and post and core build-ups previously restored with amalgam in 2002, respectively.

Results of the weight of amalgam removed from teeth that had previously been restored with amalgam are presented in Table 6. As seen in the table, for a one week period 878 dentists removed 6.89 Kg of amalgam from 1-, 2-, 3-,  $\geq$  4, surfaced restorations and post and core build-ups that had previously been restored with amalgam; there was a 95% chance that the weight could vary from a low of 5.77 Kg to a high of 7.96 Kg. Based on the results obtained in this study we estimated that Ontario dentists would remove 2,515.47 Kg of amalgam from teeth previously restored with amalgam in 2002. However, there was a 95% chance that the weight of the amalgam could vary from a high of 2,907.53 Kg to a low of 2,106.32 Kg. Assuming a composition of 50% by weight

mercury, the total weight of mercury in the amalgam removed from teeth that had previously been restored with amalgam in 2002 will be 1,257.74 Kg with a 95% chance that the weight could vary from a high of 1,453.76 Kg to a low of 1,053.16 Kg. Therefore each of the 6915 Ontario dentists would remove amalgam containing 498.32 mg of mercury daily from teeth that had previously been restored with amalgam and the 95% confidence interval could range from 575.68 mg/dentist/day to 417.26 mg/dentist/day.

Table 5 Summary of the mean (standard deviation) and total numbers of amalgams removed from previously restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surfaces restored	Mean *(SD) and Total numbers of restorations						
	Placed by 878 dentists						†Estimates for all dentists
	Weekly			Annually			
	Mean	SD	Total	Mean	SD	Total	Total
1-surfaced amalgams	1.68	4.25	1,471	77.55	194.75	68,088	536,258
2-surfaced amalgams	3.61	7.88	3,172	167.20	365.84	146,799	1,156,188
3-surfaced amalgam	2.50	5.12	2,195	115.96	240.82	101,809	801,864
4-surfaced amalgams	1.06	2.58	930	49.19	121.58	43,193	340,149
Core build-up amalgams	0.65	0.53	57	3.00	24.40	2,634	20,745

\* *Standard Deviation*

† *Annual estimates*

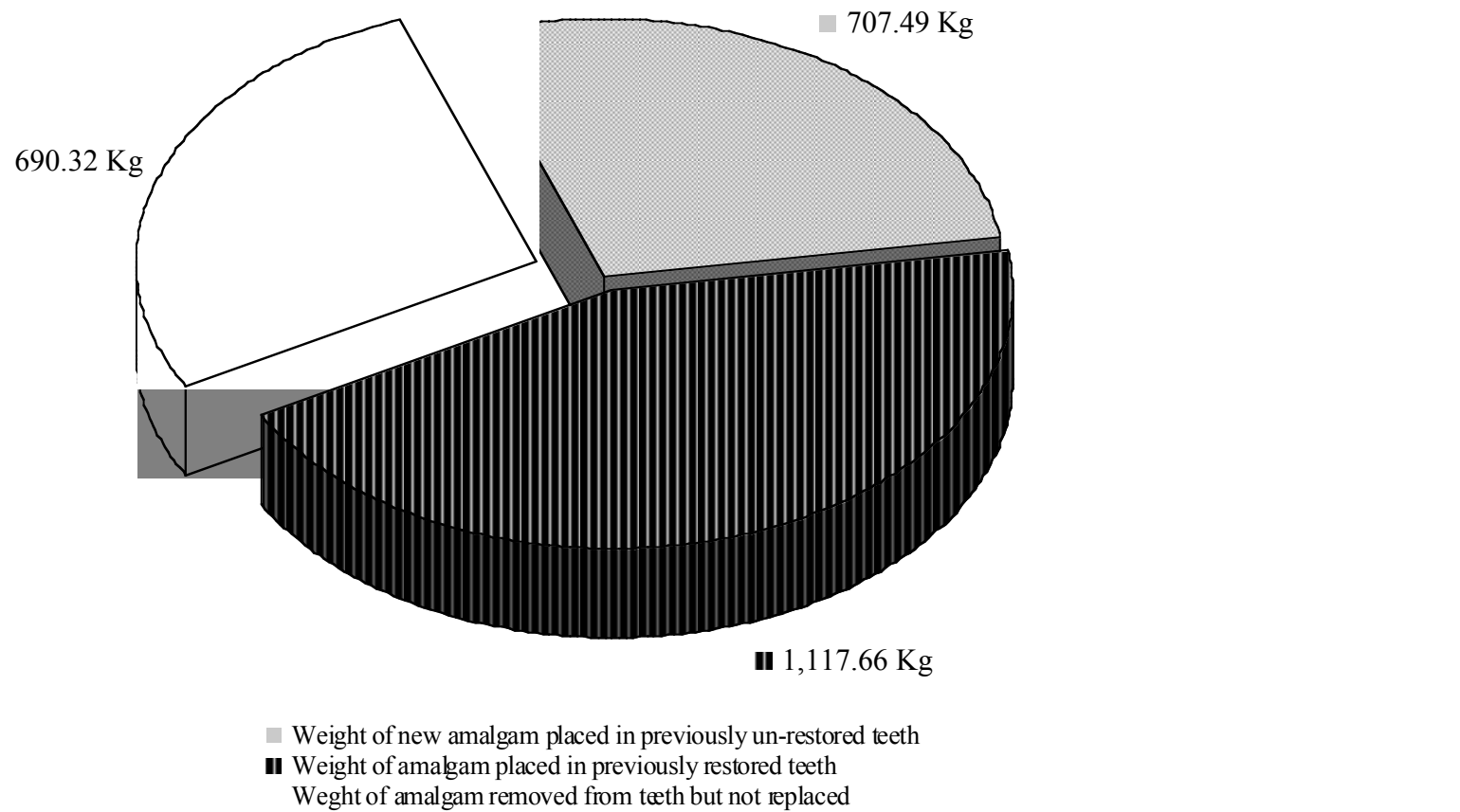
### **The negative balance in the weight of amalgams placed and removed**

As seen in Table 6, we have estimated that dentists would remove 2,515.47 Kg of amalgam from the teeth of Ontarians in 2002. However, examination of Table 4 shows that less than half of the weight of amalgam removed (44.4% or 1,117.66 Kg) was replaced with amalgam; other restorative materials would have been used to restore the cavities from which the amalgam restorations were removed. Additionally, Table 2 shows that 707.49 Kg of amalgam was placed as new restorations in previously un-restored teeth. As a result, in total more amalgam was removed from teeth than was placed in all new amalgam restorations combined. A negative balance of 690.32 Kg of amalgam is estimated for the flux (weight placed in teeth compared to the weight removed) of amalgam in the teeth of Ontarians in 2002 (Figure 1). The most loss in weight of 356.62 Kg occurred in 3-surfaced restorations; as well, the highest proportionate loss of 39% occurred in 3-surfaced restorations. The proportionate loss in 2-surfaced restorations was 30% (Figure 2).

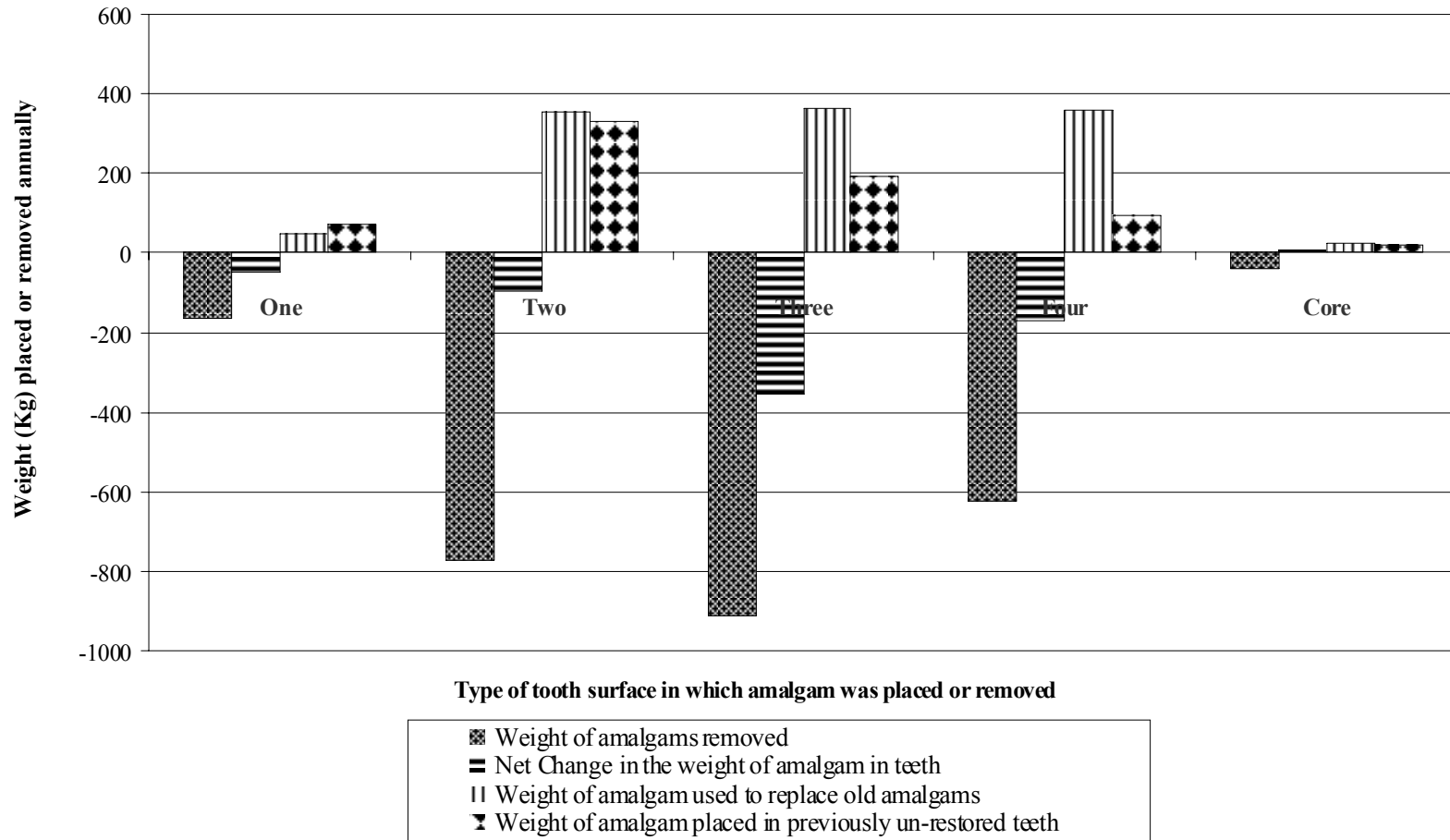
Table 6 Summary of the weight (Kg) of amalgams removed annually from previously restored teeth by 878 dentists and estimates for all Ontario dentists

Type of surface restored	Based on the mean and 95% confidence limits of the weight of a restoration	Total quantity of amalgams placed in previously un-restored teeth		
		By 878 dentists weekly	By 878 dentists annually	Annual estimates for all dentists
1-surfaced amalgam restorations	Upper 95% confidence limit	0.60 Kg	27.92 Kg	219.89 Kg
	Mean	0.46 Kg	21.11 Kg	166.26 Kg
	Lower 95% confidence limit	0.29 Kg	13.62 Kg	107.27 Kg
2-surfaced amalgam restorations	Upper 95% confidence limit	2.47 Kg	114.50 Kg	901.78 Kg
	Mean	2.12 Kg	98.36 Kg	774.67 Kg
	Lower 95% confidence limit	1.78 Kg	82.21 Kg	647.47 Kg
3-surfaced amalgam restorations	Upper 95% confidence limit	2.85 Kg	132.35 Kg	1,042.37 Kg
	Mean	2.50 Kg	116.06 Kg	914.07 Kg
	Lower 95% confidence limit	2.13 Kg	98.75 Kg	777.74 Kg
≥4-surfaced amalgam restorations	Upper 95% confidence limit	1.92 Kg	88.98 Kg	700.79 Kg
	Mean	1.70 Kg	79.04 Kg	622.51 Kg
	Lower 95% confidence limit	1.48 Kg	68.68 Kg	540.91 Kg
Core amalgam restorations	Upper 95% confidence limit	0.12 Kg	5.43 Kg	42.76 Kg
	Mean	0.10 Kg	4.82 Kg	37.96 Kg
	Lower 95% confidence limit	0.09 Kg	4.19 Kg	33.00 Kg
Total for 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	7.96 Kg	369.17 Kg	2,907.53 Kg
	Mean	6.89 Kg	319.39 Kg	2,515.47 Kg
	Lower 95% confidence limit	5.77 Kg	267.44 Kg	2,106.32 Kg
Total weight of mercury incorporated into new 1-, 2-, 3-, ≥4-amalgams and core build-up amalgams	Upper 95% confidence limit	3.98 Kg	184.58 Kg	1,453.76 Kg
	Mean	3.44 Kg	159.70 Kg	1,257.74 Kg
	Lower 95% confidence limit	2.88 Kg	133.72 Kg	1,053.16 Kg

**Figure 1**  
**Net change in the 2,515.47 Kg of amalgam removed from teeth by Ontario dentists in 2002**



**Figure 2**  
**Annual estimated flux of of the weight (kg) of amalgam placed and removed in tooth surfaces by Ontario Dentists**



## **Estimated annual release of mercury bound in amalgam particles**

The amount of mercury required for the preparation of dental amalgam varies among different name brands, but is close to 50% by weight. It is reasonable to assume that, on the average, dental amalgam contains 50% by weight of mercury.<sup>6</sup> Figure 3 depicts the estimated weights of mercury that would be contained in amalgam wastes released in 2002 by Ontario dentists based on current amalgam practice patterns; i.e., number of working weeks in a year, the numbers and types of amalgam restorations removed as well as current reported use of an amalgam separator. Less than one-quarter of the dentists who responded to the survey reported using an amalgam separator; of this group 7 who reported using a separator neither placed nor removed amalgam during the week the current week, i.e. the week that they completed the questionnaire. The weight of amalgam wastes produced as a result of removing old amalgams by the 878 dentists and projected estimates for all Ontario dentists are presented in Table 7. Had no separator been used, Ontario dentists would collectively have produced 1,509.27 Kg of amalgam or 754.64 Kg of mercury in 2002. The 95% confidence intervals for the weights of amalgam and mercury contained in the waste resulting from the removal of old amalgams are 1,744.54 Kg to 1,263.81 Kg and 872.27 Kg and 631.90 Kg, respectively.

Table 7 Summary of the weight (Kg) of amalgams released to local sewers when amalgam wastes are discharged either directly or through a separator annually by 878 dentists and estimates for all Ontario dentists

<b>Released based on compliance with the use of separator</b>	<b>Total (95% CI) weight of amalgam released</b>		
	<b>Upper 95% CI</b>	<b>Total</b>	<b>Lower 95% CI</b>
<b><u>878 dentist weekly</u></b>			
• 0% separator use compliance	4.78 Kg	4.13 Kg	3.46 Kg
• Current compliance (22%)	3.64 Kg	3.15 Kg	2.64 Kg
• 100% separator use compliance	0.05 Kg	0.04 Kg	0.04 Kg
<b><u>878 dentists annually</u></b>			
• 0% separator use compliance	221.50 Kg	191.63 Kg	160.47 Kg
• Current compliance (22%)	169.28 Kg	146.43 Kg	122.58 Kg
• 100% separator use compliance	2.44 Kg	2.10 Kg	1.76 Kg
<b><u>Estimate for all dentists</u></b>			
• 0% separator use compliance	1,744.54 Kg	1,509.27 Kg	1,263.81 Kg
• Current compliance (22%)	1,333.19 Kg	1,153.24 Kg	965.40 Kg
• 100% separator use compliance	19.19 Kg	16.60 Kg	13.90 Kg

Table 8 Summary of the numbers and 95% confidence intervals of amalgams placed or removed from previously restored teeth annually by 878 dentists and estimates for all Ontario dentists

Type of surface restored		Estimated total numbers (95% CI) of amalgams placed or removed annually		
		Placed in previously un-restored teeth	Placed in previously restored teeth	Removal from teeth previously restored with amalgam
<b>1-surfaced amalgam restorations</b>	Upper Limit	273,212	184,838	619,515
	Total	225,982	150,056	536,258
	Lower limit	178,752	115,273	453,002
<b>2-surfaced amalgam restorations</b>	Upper Limit	587,429	597,456	1,312,536
	Total	490,688	485,502	1,218,423
	Lower limit	393,948	373,548	999,840
<b>3-surfaced amalgam restorations</b>	Upper Limit	214,088	389,868	904,759
	Total	169,279	319,750	801,863
	Lower limit	124,470	249,632	698,968
<b>≥4-surfaced amalgam restorations</b>	Upper Limit	73,506	245,897	392,080
	Total	52,613	194,796	340,149
	Lower limit	31,740	143,694	288,217
<b>Core amalgam restorations</b>	Upper Limit	17,564	19,984	31,187
	Total	10,580	13,553	20,745
	Lower limit	3,596	7,122	10,303



Because, overall, 22% (195/878) of dentists use separators, the current estimated total (95% confidence interval) weight of amalgam particles that enter wastewater, and the mercury contained therein is 1,153.24 Kg (1,339.19 to 965.40 Kg) and 576.62 Kg (669.60 to 482.70 Kg), respectively. Therefore, the estimated total (95% confidence interval) daily production of mercury contained in the amalgam particles lost to wastewater in 2002 by Ontario dentists is 228.46 (265.30; 191.24) mg/dentist/daily.

### **Sensitivity analysis of the quantity of amalgam placed and removed**

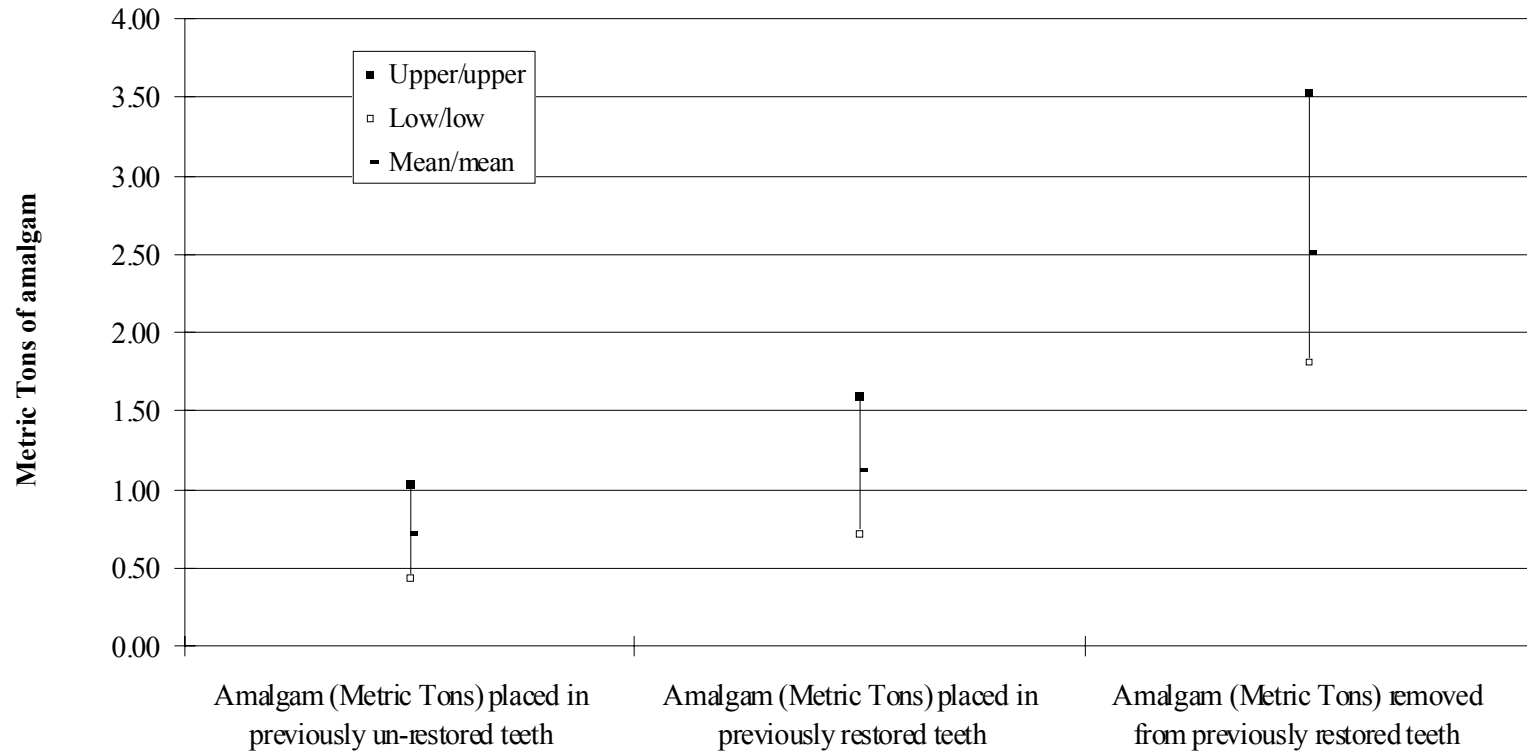
As seen in Tables 2, 4, and 6, we have computed the weight of new amalgams placed or removed by dentists by allowing only the weight of each type (1-, 2-, 3-,  $\geq$  4- surfaced amalgam restorations and core build-ups) of amalgam to vary within 95% confidence limits. However, there are many factors that can vary. For example, total numbers of restorations placed or removed annually is a statistically random variable. Tables 1, 3, and 5 show the means and standard deviations for the numbers of 1-, 2-, 3-,  $\geq$  4 surfaced and post and core build-ups amalgam restorations placed or removed annually by the 878 respondents. Based on our findings, we have computed 95% confidence intervals for the estimated total numbers of amalgams placed or removed annually. Table 8 shows the results of the computation. Based on the 95% confidence intervals of the sum of the numbers and the respective weights of 1-, 2-, 3-,  $\geq$  4- surfaced amalgam restorations and core amalgam build-ups, we have created nine scenarios for the annual weight of amalgam placed or removed by Ontario dentists. The results of the nine possible scenarios are presented in Table 9.

For example, if the estimate of the weight and number of amalgams placed were based on the lower confidence limits for both variables, then 433.28 Kg of new amalgam would be placed in previously un-restored teeth, 714.18 Kg of amalgam would be placed in previously restored teeth and 1,803.16 Kg of amalgam would be removed from teeth previously restored with amalgam by Ontario dentist during the year 2002. On the other hand, using the upper confidence limits for both variables result in the placement of 1,036.13 Kg of new amalgam in previously un-restored teeth, 1,596.34 Kg in previously restored teeth and the removal of 3,325.90 Kg of amalgam from teeth previously restored with amalgam. Figure 3 shows the mid (derived from using the mean weights and numbers of restorations placed or removed), upper (derived from using the upper 95% confidence limits of the weights and numbers of restorations placed or removed) and lower estimates (derived from using the lower 95% confidence limits of the weights and numbers of restorations placed or removed) of the weights of amalgam placed and removed, based on this scenario, by Ontario dentists in 2002.

Table 9 Sensitivity analysis of the estimates of the weight (Kg) of amalgam placed or removed annually by all Ontario dentists in 2002

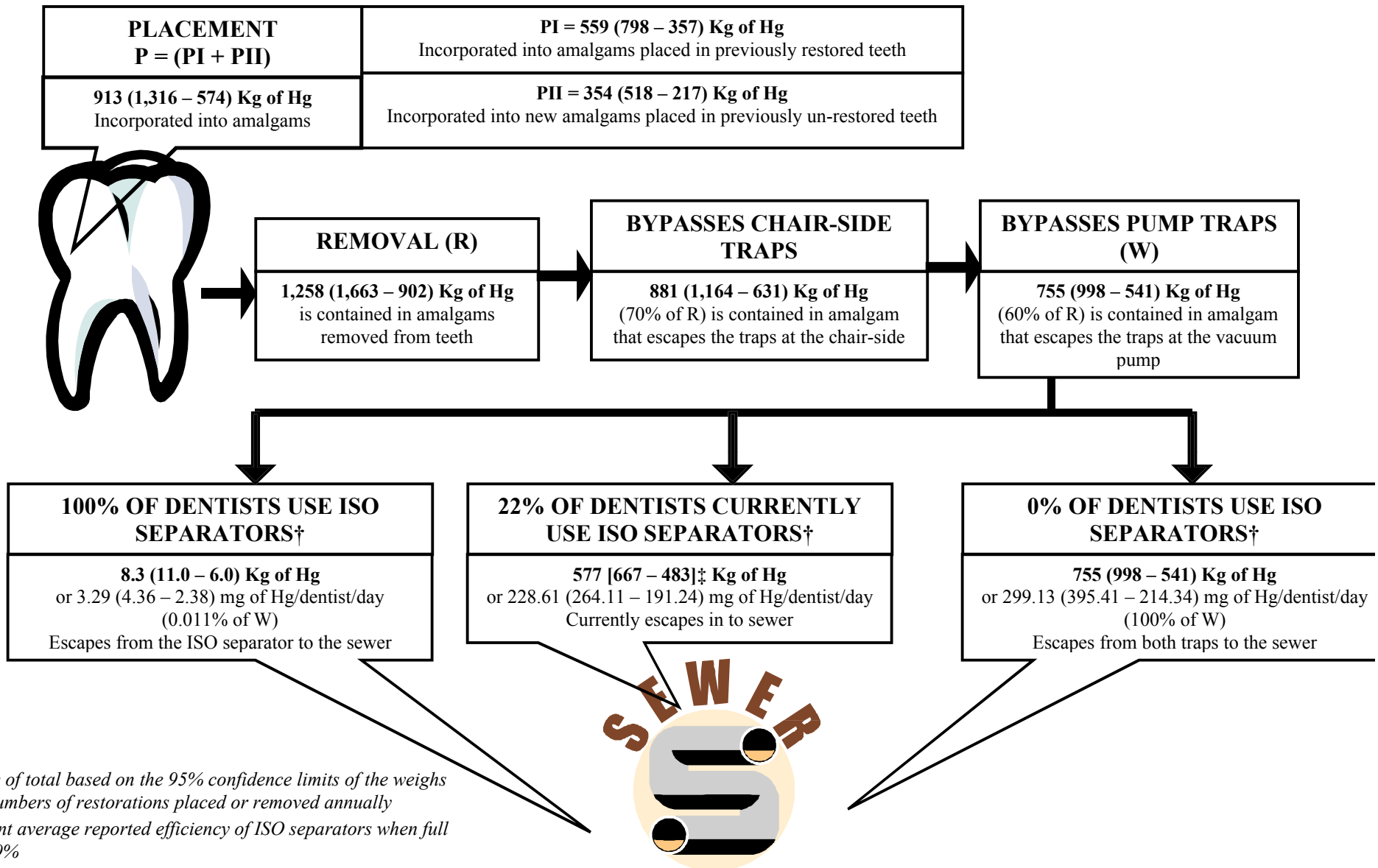
<b>Estimates based on the total (95% CI) numbers of 1-, 2-, 3-, ≥ 4- surfaced amalgam restorations and core amalgam build-ups placed or removed annually</b>	<b>Estimates based of the weight (95% CI) of 1-, 2-, 3-, ≥ 4- surfaced amalgams and core amalgam build-ups</b>		
	Upper 95% CI	Mean	Lower 95% CI
<b><u>Placement in previously un-restored teeth</u></b>			
• Upper 95% confidence limit	<b>1,036.13 Kg</b>	888.99 Kg	736.07 Kg
• Mean	825.63 Kg	707.44 Kg	584.66 Kg
• Lower 95% confidence limit	615.17 Kg	525.92 Kg	<b>433.28 Kg</b>
<b><u>Placement in previously restored teeth</u></b>			
• Upper 95% confidence limit	<b>1,596.34 Kg</b>	1,388.61 Kg	1,172.46 Kg
• Mean	1,284.85 Kg	1,117.40 Kg	943.16 Kg
• Lower 95% confidence limit	973.83 Kg	846.58 Kg	<b>714.18 Kg</b>
<b><u>Removal from teeth previously restored with amalgam</u></b>			
• Upper 95% confidence limit	<b>3,325.90 Kg</b>	2,877.45 Kg	2,409.53 Kg
• Mean	2,907.56 Kg	2,515.45 Kg	2,106.34 Kg
• Lower 95% confidence limit	2,489.22 Kg	2,153.44 Kg	<b>1,803.16 Kg</b>

**Figure 3.**  
**Sensitivity analysis of the weight (Metric Tons) of amalgam placed or removed by Ontario dentists**  
**in 2002**



**Estimates based on the 95% confidence limits of the weights of restorations and the numbers of restorations placed or removed in 2002**

**Figure 4**  
**Annual quantity \*(range) of mercury incorporated into new amalgams and released to sewer from the removal of old amalgams**



*Range of total based on the 95% confidence limits of the weights and numbers of restorations placed or removed annually  
 Current average reported efficiency of ISO separators when full is 98.9%*

*Range based only on the 95% confidence limits of the weights of restorations removed annually*

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