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Qualification of a precision pattern dispenser

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Abstract

The European Commission Joint Research Centre in Geel (JRC-Geel) is on a regular basis preparing radioactive sources. These sources can be used as calibration standards or reference sources in different applications, e.g. proficiency testing of laboratories monitoring radioactivity in the environment organized by JRC-Geel.

In order to automate the sample preparation process a precision pattern dispenser was designed to reproducibly dispense radioactive solutions. The set-up should be able to dispense pre-set amounts of stock solution in an automated and reproducible way in predefined positions or patterns. Correct dispensing should be ensured by defining the positions of ampoules or special source holders precisely. The set-up must also be able to dispense pre-set amount of liquid according to designed patterns on air filters having a maximum size of 60x60 cm. During all manipulations no evaporation of stock solution can be afforded in order not to compromise its concentration. The liquids to be handled are mainly acidic solutions so all parts must be resistant to the acidic environment. The number of instrument parts that come in contact with the radioactive solution must be kept to a minimum to limit the amount of radioactive waste and should be easily replaceable.

The precision pattern dispenser is composed of a commercially available sample handling unit that makes use of syringes to handle the liquid. This unit is coupled to an XYZ-table where e.g. air filters can be fixed on. A custom-made interface (protocol generator software) is used to design dispensing patterns on filters of different sizes and shapes. The combination of the filter and the pattern, called protocol, is sent to the software steering the sampling unit and the XYZ-table. The mass or volume to be dispensed and the position where it has to be dispensed is easily introducible and made visible in the protocol generator.

Qualification tests were conducted to evaluate the performance of the instrument and to assess the compliance with the requirements. The two most important parameters to be tested were trueness and precision. The maximum values according to the specifications were 2 % for trueness and 1 % for precision. Tests were performed by dispensing water into glass ampoules.

All other parameters described above were examined and found to be compliant with the specifications. The results of the tests demonstrate that the precision pattern dispenser can dispense liquid within the required specifications. The instrument can be used to spike air filters with an almost homogenous distribution of activity within a predefined area. The precision pattern dispenser makes it possible to prepare sources for different applications in a fast and accurate way.

1. Introduction

The European Commission Joint Research Centre (JRC) is on a regular basis preparing radioactive sources that are used as calibration standards or reference sources for different applications. It is also organising interlaboratory comparisons for laboratories monitoring radioactivity in the environment.

For these purposes samples have to be prepared in a reproducible way. In order to make this process more efficient and accurate an instrument to dispense radioactive solution, called precision pattern dispenser, was installed at the JRC-Geel.

In a first stage the basic requirements were specified. The most important requirement was that the instrument must be able to accurately dispense predefined amounts of radioactive solutions in an automated way at certain predefined positions. These known amounts can be dispensed on different sizes and shapes of blank filters or in ampoules or costum made source holders. In this current study the results of the performance tests of the instrument are presented.

1.1 General description of the instrument

A proposal was made by the company SampleQ [1] proposing a precision pattern dispenser. The precision pattern dispenser consists of two major parts, a commercially available liquid handling unit and a XYZ table. The liquid handling unit is steered by software and can dispense known amounts (introduced as volumes or masses) of liquids in objects that are suspended on the arm of the handling unit.

As one of the applications will also be the spiking of air filters, an XYZ table is coupled to the dispensing unit. On this table, air filters can be fixed. The dispensing unit can also dispense pre-set volumes of solution on predefined positions on the fixed air filters. The software in which the combination of positions and volumes, called patterns, can be designed, converts the patterns into a protocol that is steered to the dispensing robot and the XYZ table at the same time. The XYZ table is able to support filters of a maximum size of 60 by 60 cm. The software allows creating patterns within this area.

1.2 Details regarding the construction of the robot

The precision pattern dispenser is a modular instrument built by SampleQ, Belgium [1]. The core of the instrument is a liquid handling unit that is performing all dispensings. It is a commercially available automatic dispensing system PAL HTC-xt (CTC Analytics AG, Switzerland [2]).

Figure 1: Ampoules filling station of the automatic dispensing robot.

The dispensing system can dispense pre-set amounts of liquid in an automated and reproducible way. The liquids to be handled are mainly dilute acidic solutions of hydrochloric or nitric acid. The robot has a movable tower in which syringes of different volumes can be mounted. The movements of the tower containing the syringes, are executed in a smooth way to avoid any spillage of liquid to be dispensed during the movements.

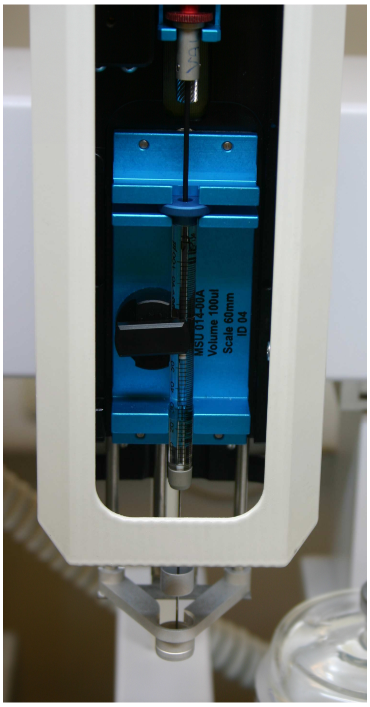

Figure 2: Syringe positioned inside the tower.

The volume of the mounted syringes can vary from 25 µL to 5 mL, in order to be able to dispense any random volume between 20 µL and 5 mL. The amount of liquid to be dispensed at once can be chosen within this volume range. The volume to be dispensed can be easily set in the Chronos software (LEAP Technologies, USA), which is controlling the movements of the tower and the syringe. The tower of the dispensing robot can also move over different modules that are suspended on the main horizontal arm. These items can include: solvent reservoirs (100 mL), waste and wash vials (20 mL), source trays in which different type of ampoules and other source holders can be mounted. In the current set-up 2 holders for the 3 solvent reservoirs having a volume of 100mL each can be suspended. In this way a maximum volume of 600 mL of solvent can be contained. All solvent containers used are closed with septa to prevent evaporation before, during and after dispensing. These septa can be easily replaced if deemed necessary.

Figure 3: Solvent reservoirs and wash and waste vials with closed septa.

The source trays are custom-made. They fit in the tray support which is suspended on the horizontal arm. In order to prevent them from changing their positions during the dispensing process the fitting of the support trays is made very tight. A chosen type of source holder can be placed in predefined positions in the source tray. The exact positions of all the items suspended on the arm, as well as the positions of the source holders in the source tray can be programmed in the PAL HTC-xt controller panel. In this controller a lot of other parameters influencing the dispensing process can be set, e.g. the speed of the arm, the ejection speed of the liquid, the aspiration speed of the liquid etc. Some of these settings are changed according to the syringe that is used.

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Figure 4: Custom-made tray for ampoules.

The Chronos software controls all the movements of the tower between the different items suspended on the arm as well as the movements of the plunger of the syringe it contains. The Chronos software can read in the settings from the controller. Some of the default settings set in the controller can still be adjusted in order to dispense the liquid in a smooth and accurate way.

During dispensing only the solvent and waste reservoirs and the syringes come in contact with the solution to be dispensed. All these items are resistant to acidic solutions. In this way only these parts need to be replaced if the solution to be dispensed is changed, keeping the amount of radioactive waste generated to a minimum. Another advantage of this method of dispensing is the minimisation of dead volume. Only the needle of the syringe contains a dead volume resulting in only a small amount of liquid waste generated.

The XYZ table serves as a movable platform to support and fix filters on which solution can be dispensed. In order to support the filters well, metallic strings are stretched over the whole area of the table every 5 cm. The filter can be fixed and stretched using metallic bars of different length, which in turn are clamped on the magnetic bars positioned on the outer side of the filter. The filter can be centred on the table using the marks on the bottom of the table. Under the metallic strings an adsorbing paper can be introduced to collect eventual spilling.

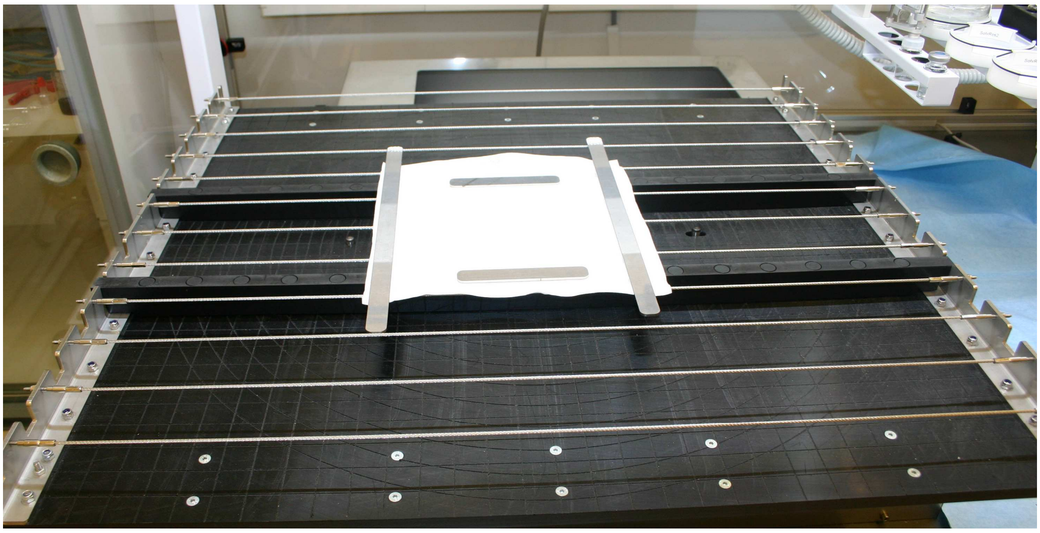

Figure 5: The XYZ-table.

The maximum deviation between the set position and the executed position of the dispensing is 2 mm in every direction. This is easily obtained by the set-up.

All manipulations are performed in such a way that the certified values of the standard solution are not compromised in any way and that no spillage or other forms of (cross-) contamination occur during the whole dispensing process.

The whole set up, i.e. the dispensing robot and the XYZ table, is placed in a protective Plexiglas enclosure. This protects the set-up from dust, but keeps it visible. The enclosure can be opened from the front so that all parts are accessible when items like syringes, liquid containers, source holders or filters need to be changed or when service is needed.

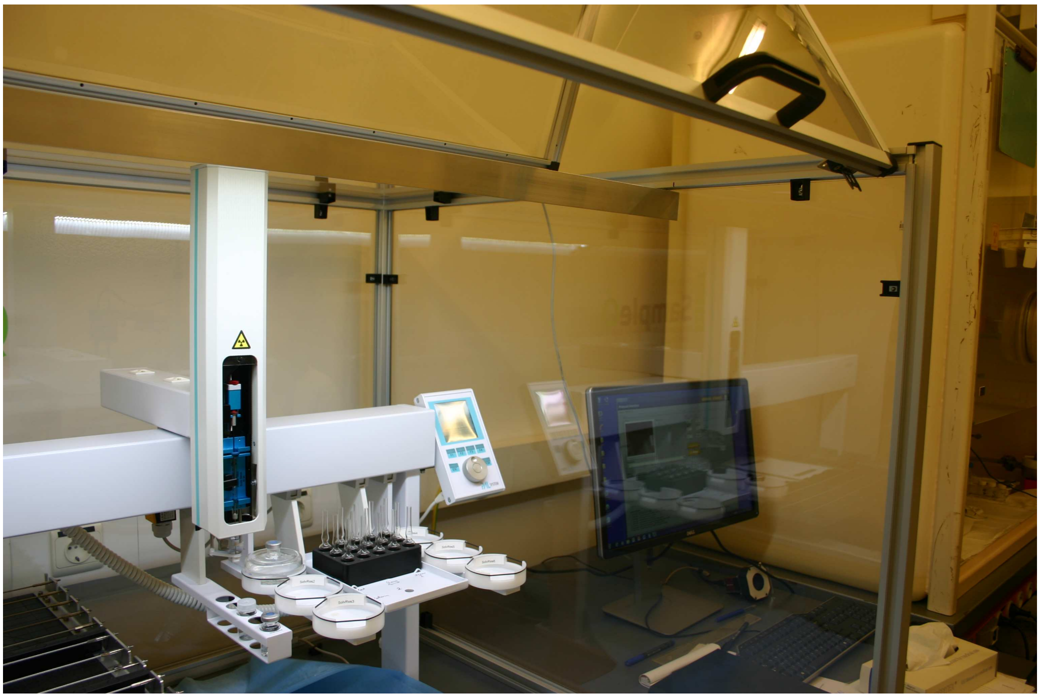

Figure 6: View on the opened plexiglass enclosure.

All relevant data of instrument settings – dispensing positions and volumes etc. – used during the dispensing are stored electronically and can be easily retrieved.

2. Qualification procedure

The properties described in the previous paragraph were the subject of the qualification. Two additional parameters were examined being the precision under repeatability conditions, hereafter called repeatability, and trueness – in this case the deviation of the actually dispensed amount of liquid from the pre-set amount programmed according to ISO 5725-1 [4]. For both criteria upper limits were set in the tender specifications. The repeatability for any random dispensed volume has to be better than 1 %, while trueness, the bias between the set volume and test results, has to be better than 2 %.

Both criteria were examined using syringes of 50, 100, 250, 500 µL and 1 and 5 mL. For each syringe, tests were carried out by dispensing 20, 40, 60 and 80 % of its total volume. For each volume the pre-set volume of water was dispensed 10 times into tarred 5 mL glass ampoules. After dispensing in these 10 ampoules, they were weighed again. The difference in mass gave the amount of liquid dispensed. This mass was corrected for buoyancy taking into account the laboratory temperature, humidity and air pressure. By dividing the calculated mass by the density of the water at the lab temperature (correction of 0.2%) [5], the dispensed volume was obtained. The trueness was calculated as the difference between the average volume obtained from the results of the 10 dispensings and the pre-set volume. The repeatability was calculated as a standard deviation of the 10 dispensed volumes.

2.1 Results of the qualification procedure

Dispensing of liquid into glass ampoules was tested. A new set of 10 ampoules of 5 mL was used each time. The ampoules were filled with water using six different syringes (50 µL to 5 mL). The amount of liquid was ranging from 20 µL to 4 mL. A summary of the results is displayed in Table 1 and details of the dispensing are given in Figures 7 to 29. The raw data are added in Annex 1.

All 23 tests resulted in a repeatability better than 1%, 22 of them even better than 0.5%. As the instrument will be used mainly under repeatability conditions, the results enhance the trust in the dispensing capabilities.

For the trueness assessment, 22 of 23 tests gave results better than 2%. Only the dispensing of 20 µL using a 100 µL syringe showed a value above 2%. This is probably due to the fact that this is close to the edge of the dynamic range of the syringe in combination with the small amount that has to be dispensed. If a dispense volume of 20µL with a trueness better than 2% is necessary, a 50 µL syringe can be used.

In general, the volume dispensed is lower than the set volume. To reduce the bias, one can calibrate the syringe with water and in the software a correction factor can be introduced. The correction factor can be applied to the volumes to be dispensed and should correct for the systematic bias.

Table 1: Summary of the qualification results

Syringe volume (µL)	Dispensed volume (µL)	Trueness (%)	repeatability (%)
50	20	1.11	0.45
	30	0.97	0.30
	40	0.61	0.18
100	20	3.33	0.88
	40	1.57	0.35
	60	1.32	0.21
	80	1.02	0.16
250	50	1.35	0.38
	100	0.64	0.08
	150	0.43	0.08
	200	0.35	0.05
500	100	0.92	0.12
	200	0.25	0.12
	300	0.22	0.19
	400	0.17	0.18
1000	200	0.55	0.05
	400	0.10	0.02
	600	0.03	0.02
	800	0.16	0.06
5000	1000	0.13	0.19
	2000	0.20	0.38
	3000	0.55	0.12
	4000	0.25	0.06

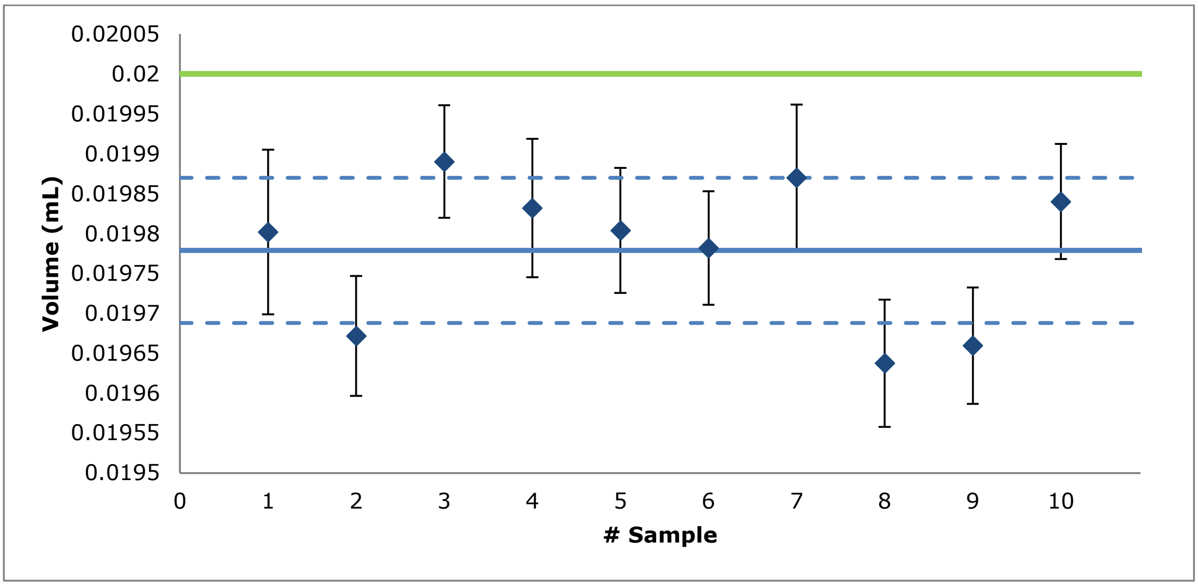

Figure 7: 20 µL dispensed using 50 µL syringe

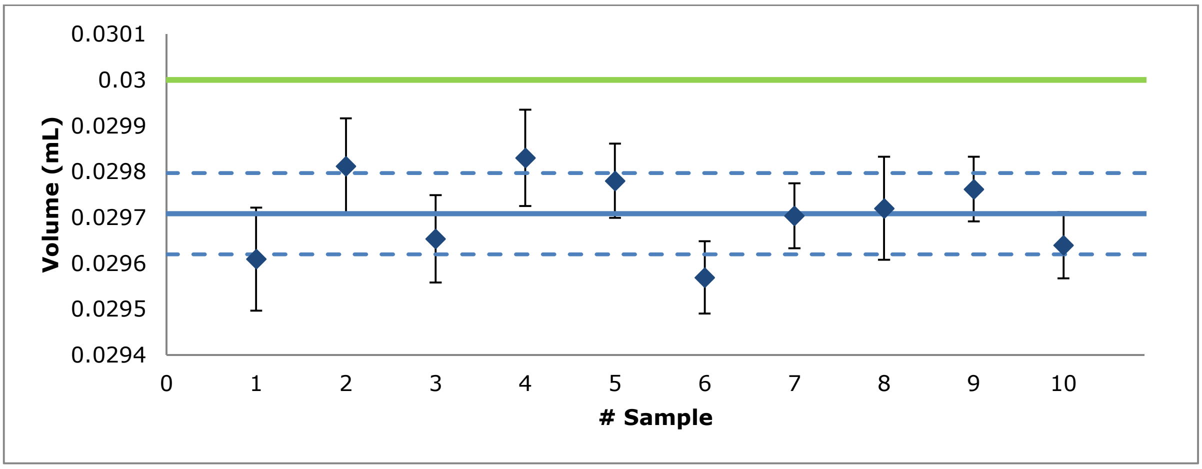

Figure 8: 30 µL dispensed using 50 µL syringe

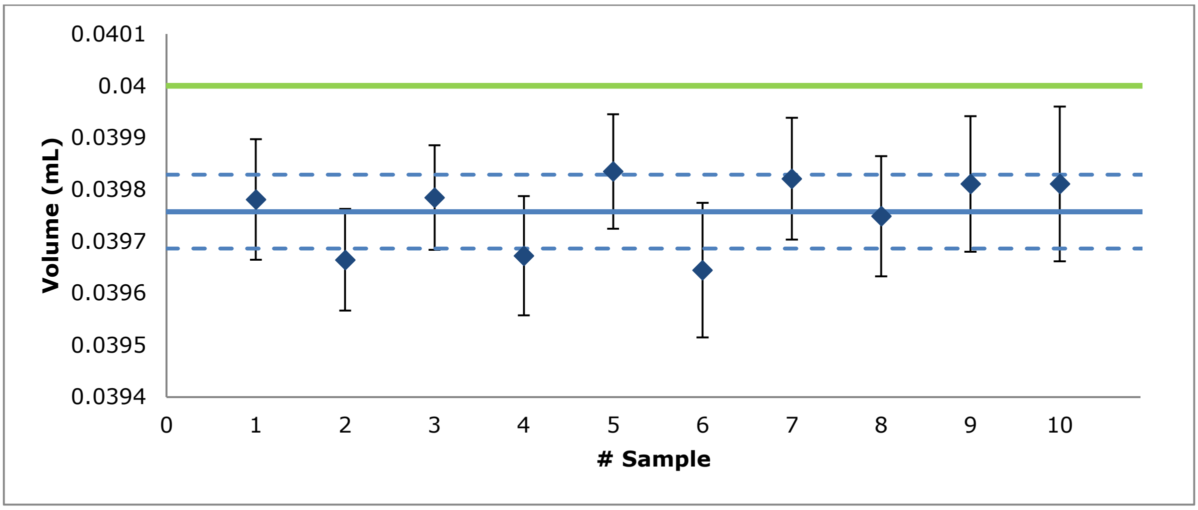

Figure 9: 40 µL dispensed using 50 µL syringe

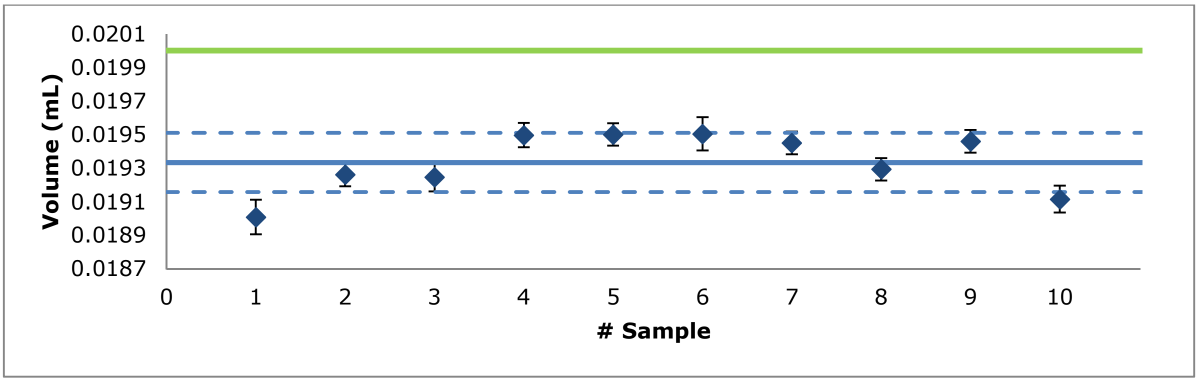

Figure 10: 20 μL dispensed using 100 μL syringe

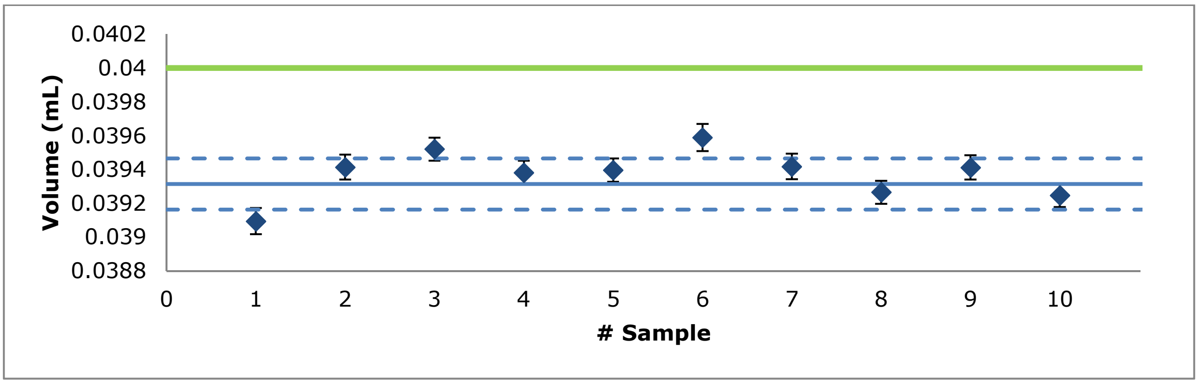

Figure 11: 40 μL dispensed using 100 μL syringe

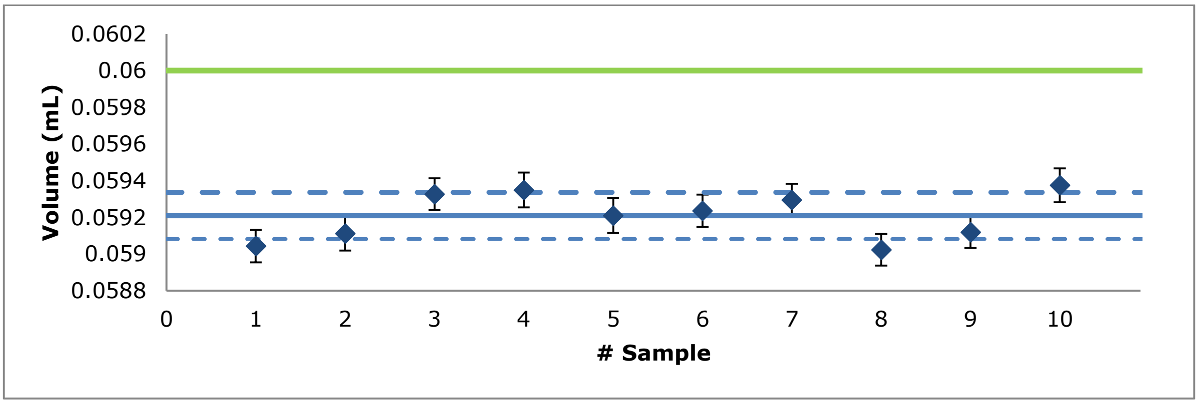

Figure 12: 60 μL dispensed using 100 μL syringe

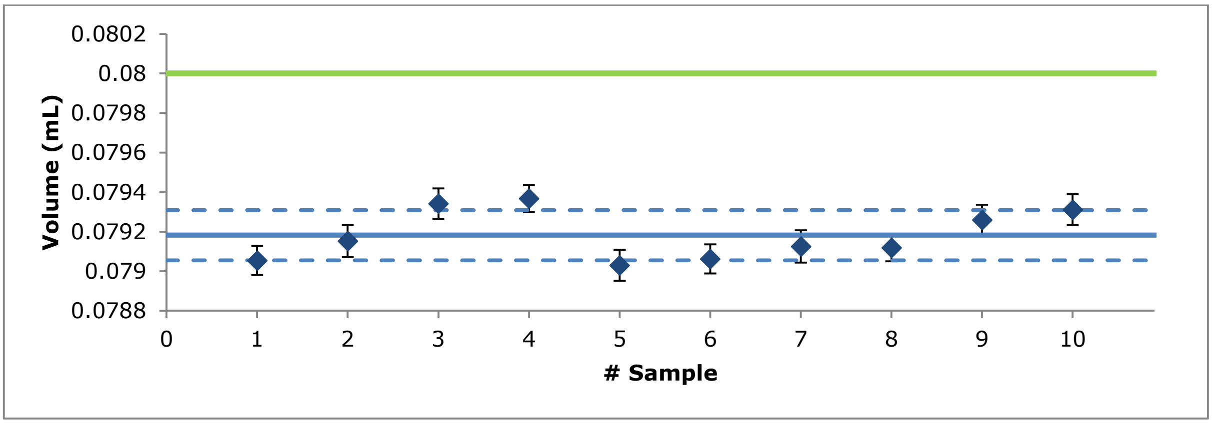

Figure 13: 80 μL dispensed using 100 μL syringe

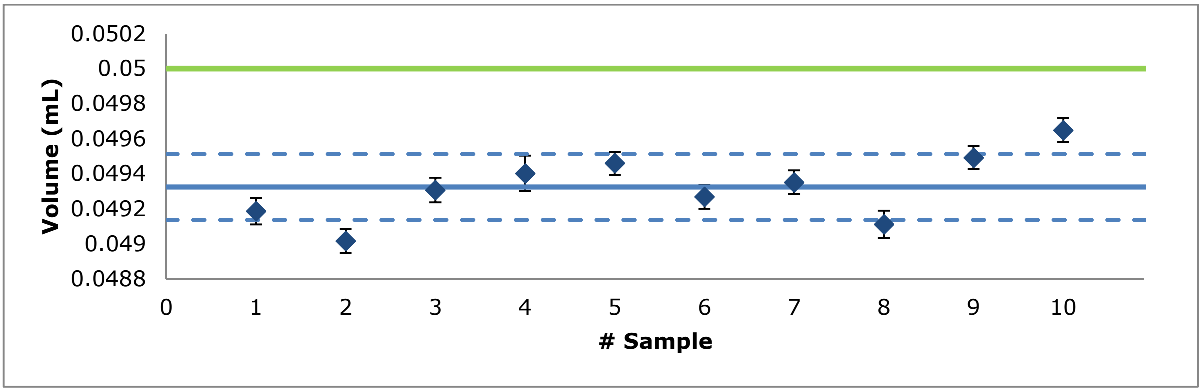

Figure 14: 50 µL dispensed using 250 µL syringe

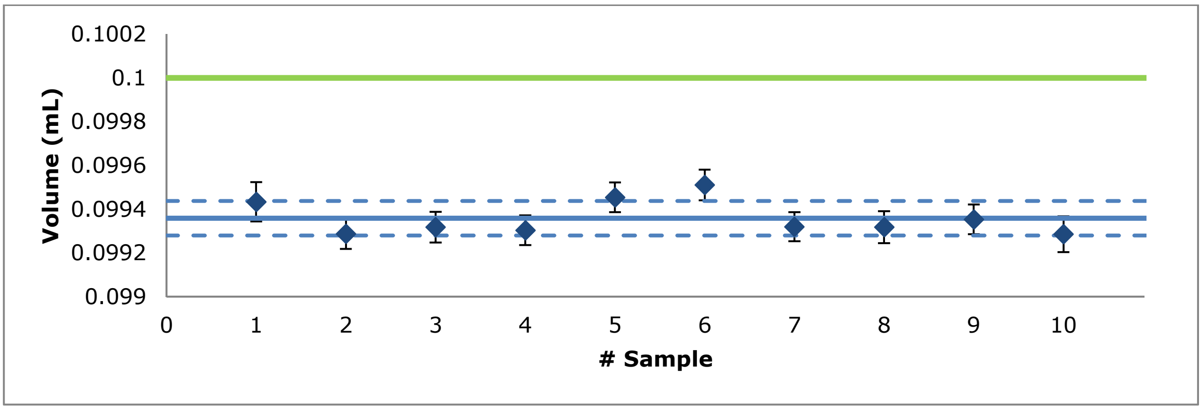

Figure 15: 100 µL dispensed using 250 µL syringe

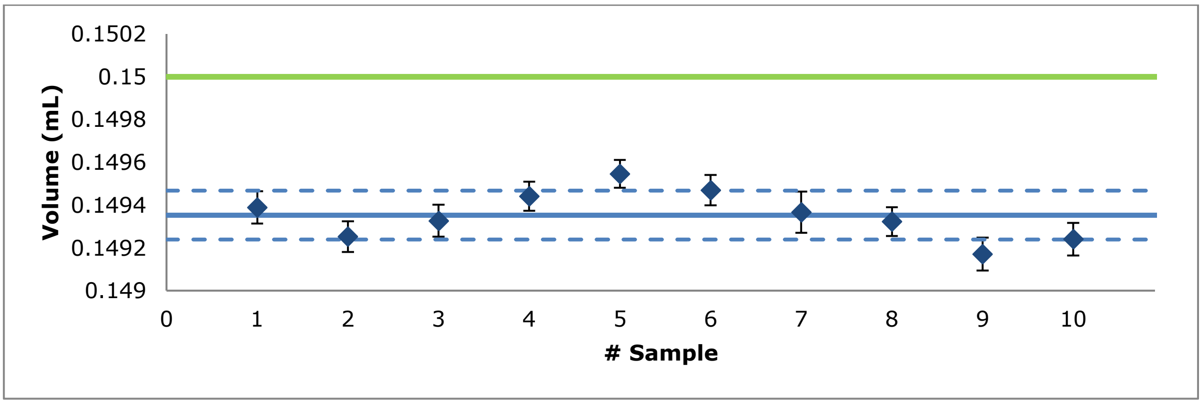

Figure 16: 150 µL dispensed using 250 µL syringe

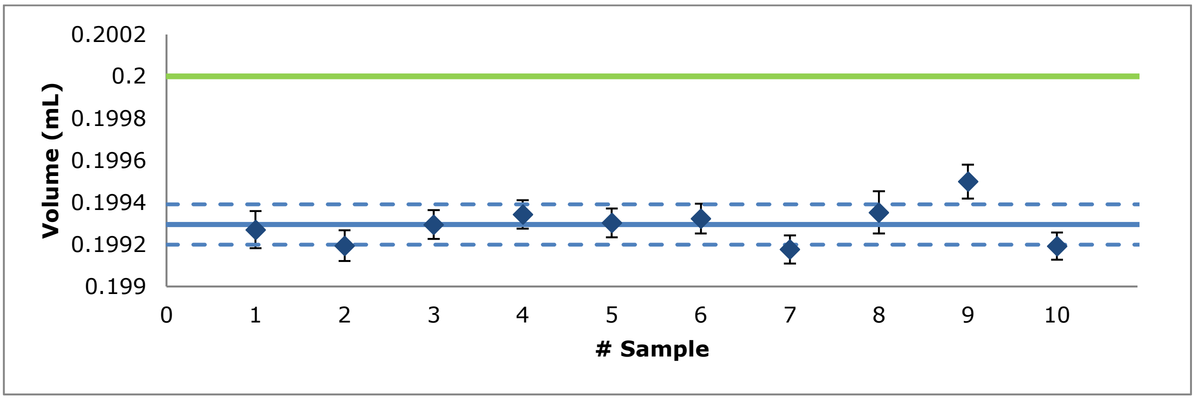

Figure 17: 200 µL dispensed using 250 µL syringe

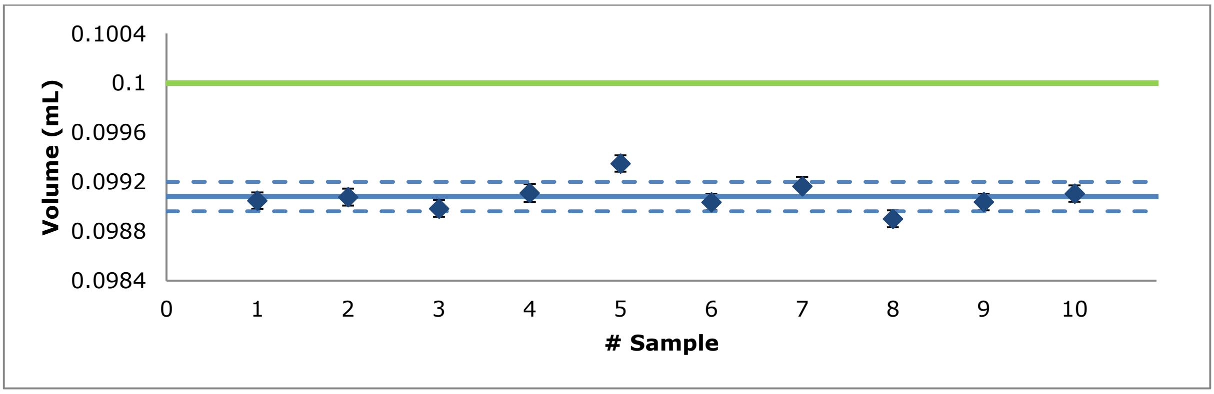

Figure 18: 100 µL dispensed using 500 µL syringe

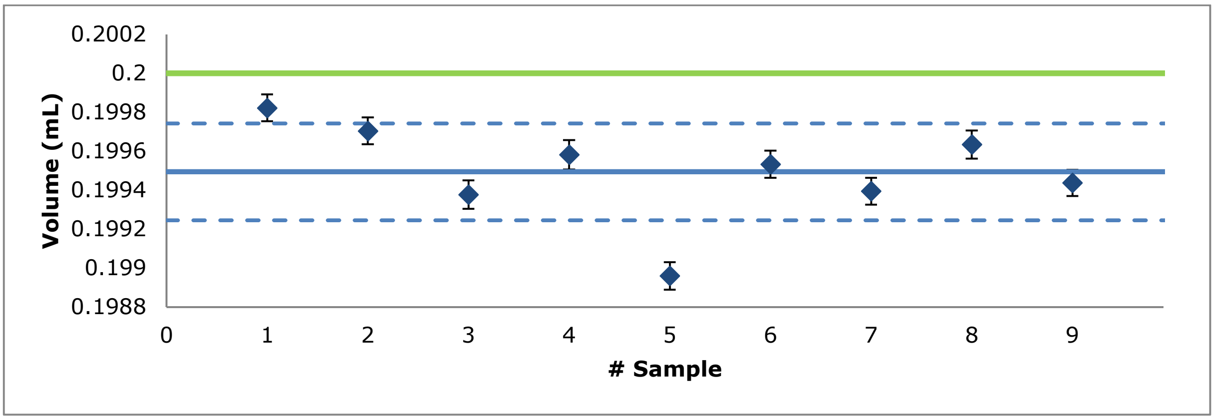

Figure 19: 200 µL dispensed using 500 µL syringe

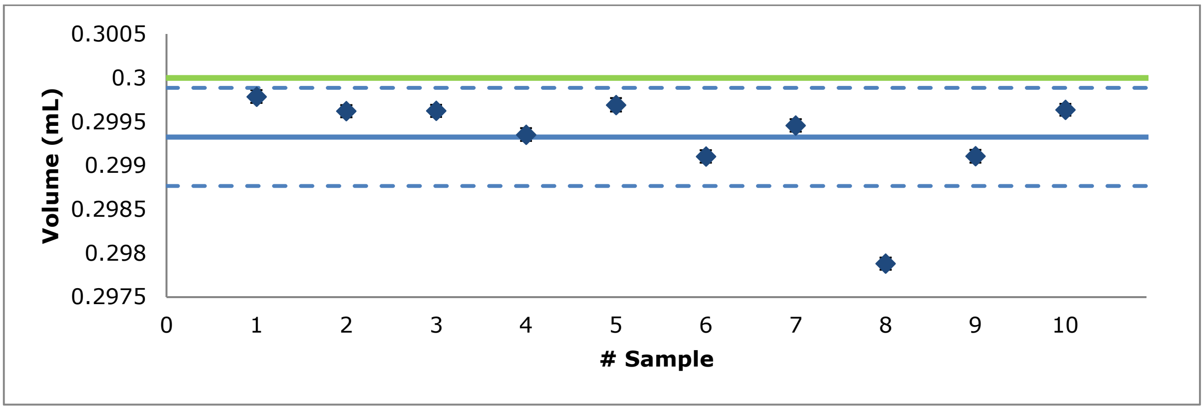

Figure 20: 300 µL dispensed using 500 µL syringe

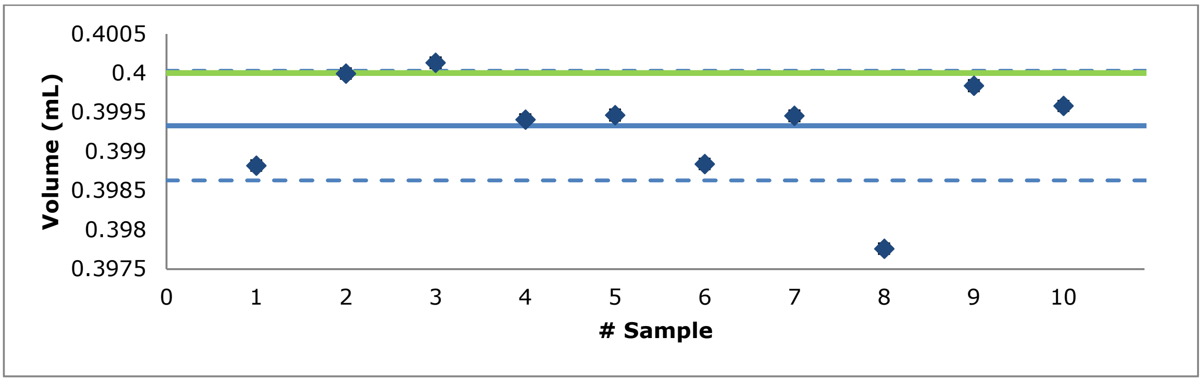

Figure 21: 400 µL dispensed using 500 µL syringe

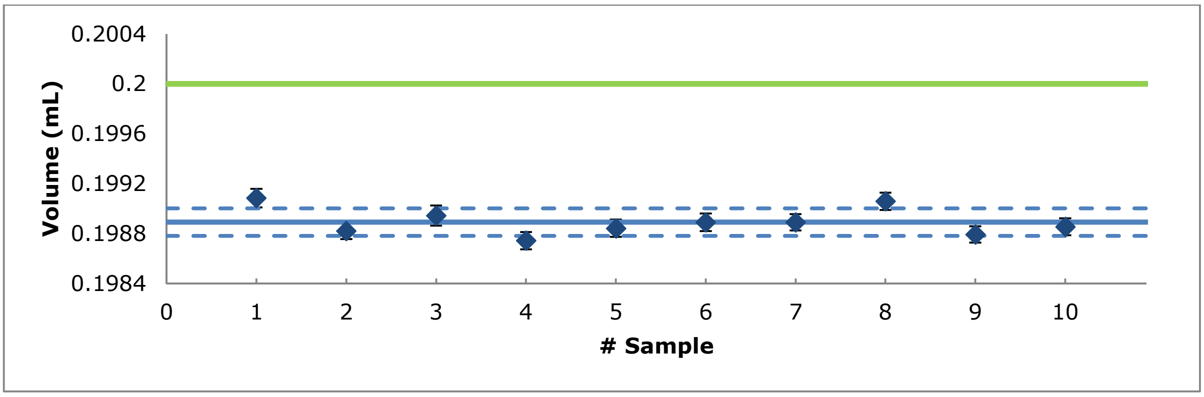

Figure 22: 200 µL dispensed using 1000 µL syringe

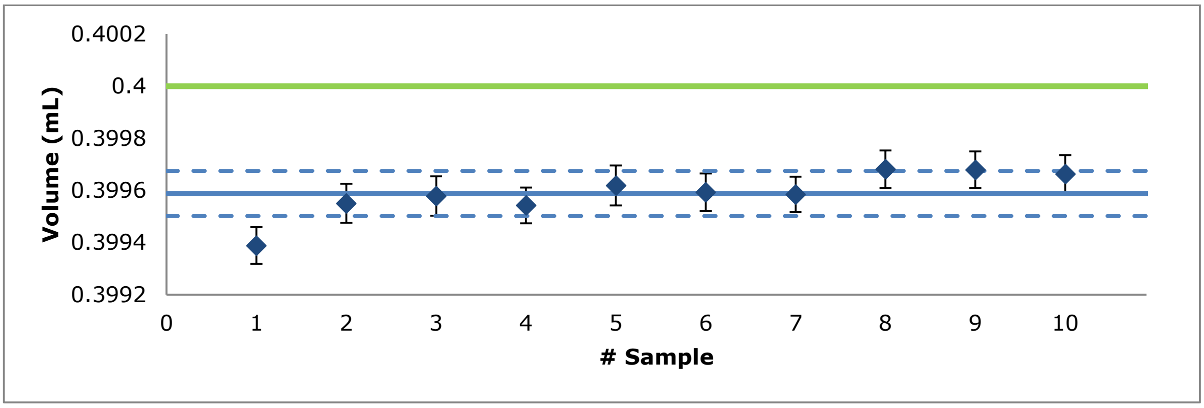

Figure 23: 400 µL dispensed using 1000 µL syringe

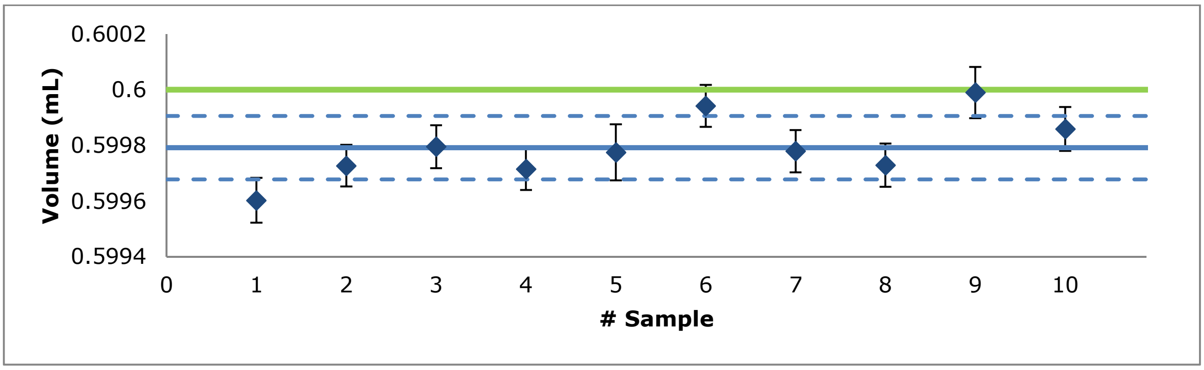

Figure 24. 600 µL dispensed using 1000 µL syringe

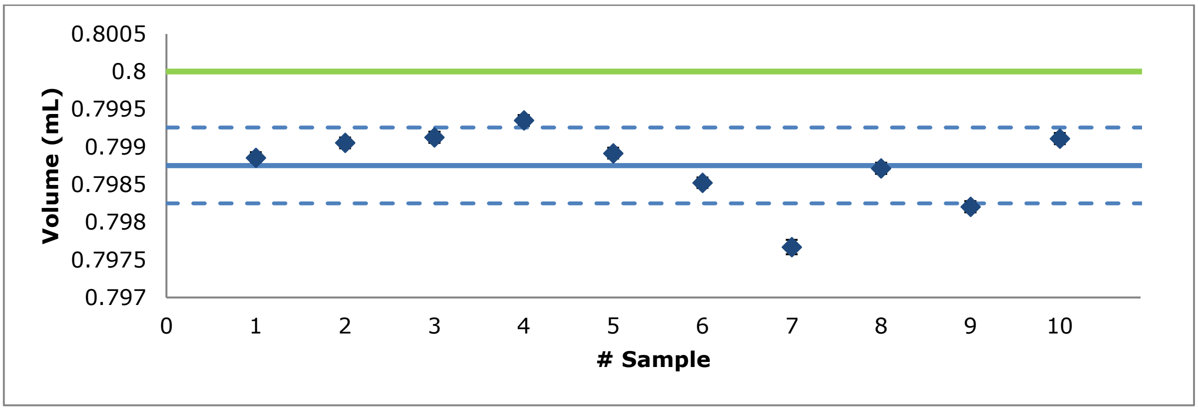

Figure 25: 800 µL dispensed using 1000 µL syringe

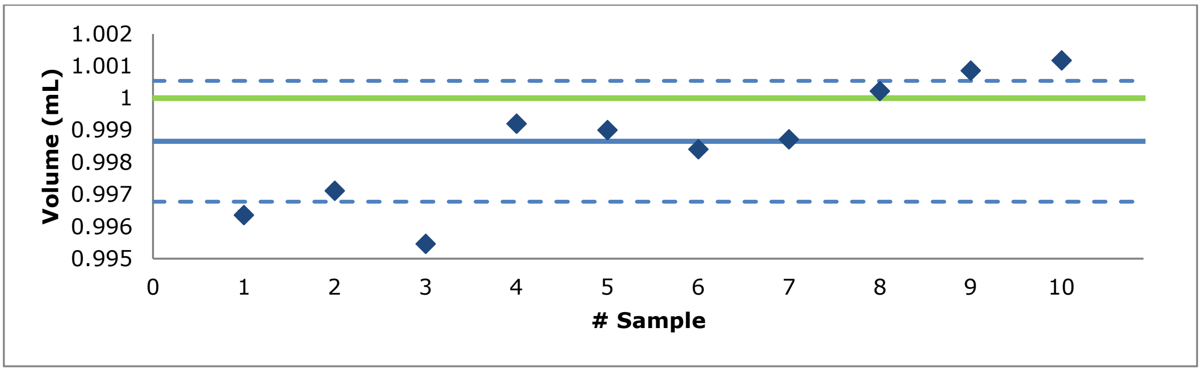

Figure 26: 1000 µL dispensed using 5000 µL syringe

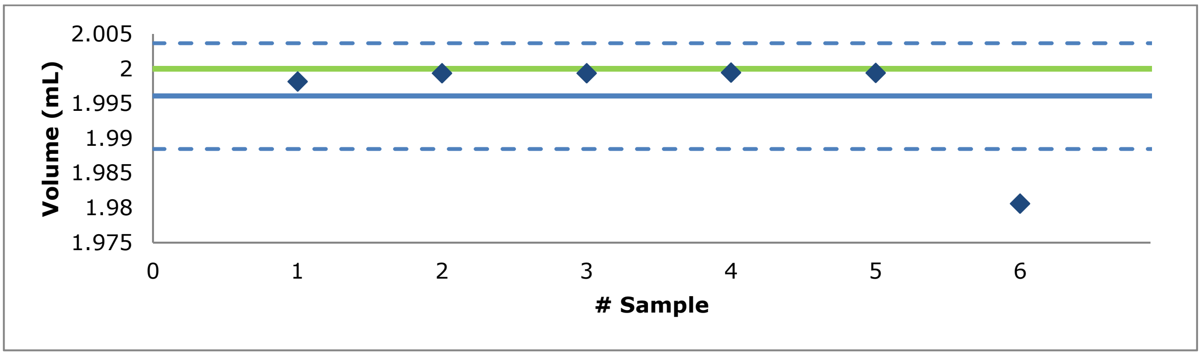

Figure 27: 2000 µL dispensed using 5000 µL syringe

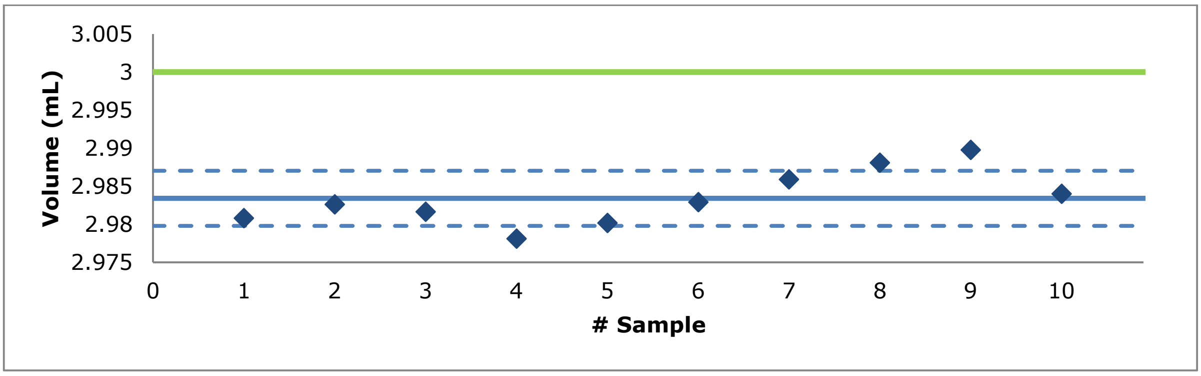

Figure 28: 3000 µL dispensed using 5000 µL s yringe

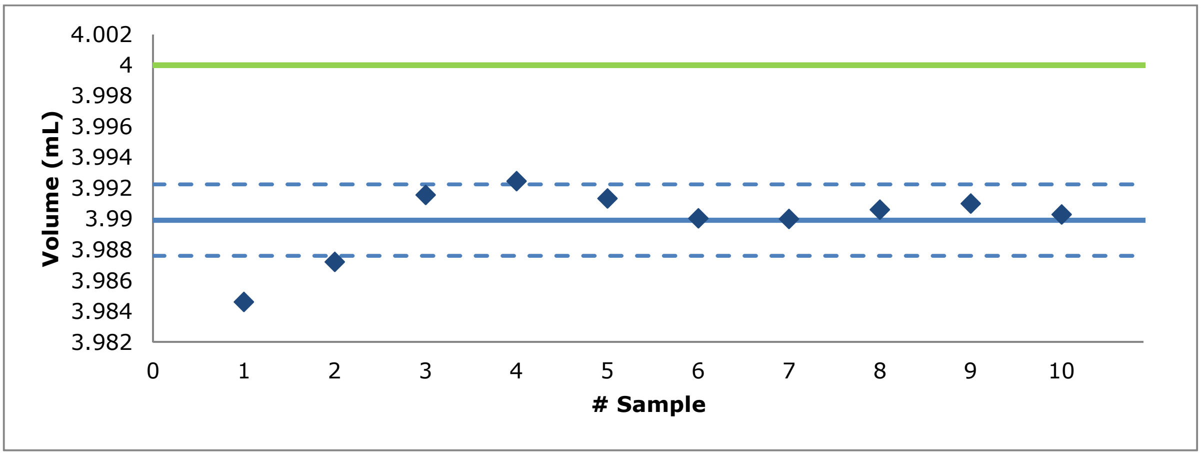

Figure 29: 4000 µL dispensed using 5000 µL syringe

2.2 Results for air filters preparation

In order to dispense liquid on a filter, dispensing patterns are designed in the custom-made software application called Protocol Generator (Flamac, Belgium [3]).

To enter the application one has to log in as an operator and has to select a folder in which all relevant data of the project will be stored.

In the software, a filter model can be created with a certain width and length (inserted as X-size and Y-size) for a rectangular filter and diameter for a circular filter. Also the thickness of the filter (inserted as filter support height) can be introduced. On these filters one has to define an active area smaller than the filter size in which a dispensing pattern can be created.

Two kinds of patterns, rectangular and circular, can be created independent of the shape of the filter. The pattern is a set of predefined positions where a chosen amount of liquid has to be dispensed by the device.

The software allows saving different sizes of filters together with their active area, the patterns to be dispensed and combination of filter and patterns. All these files created by the software are saved in a selected folder and can be read in at a later stage. Once a combination of a filter and a dispensing pattern (called protocol) is generated in the software, it can be sent to the Chronos software (controlling the dispensing robot) and the motor controlling the XYZ table in order to execute the dispensing according to the inserted protocol.

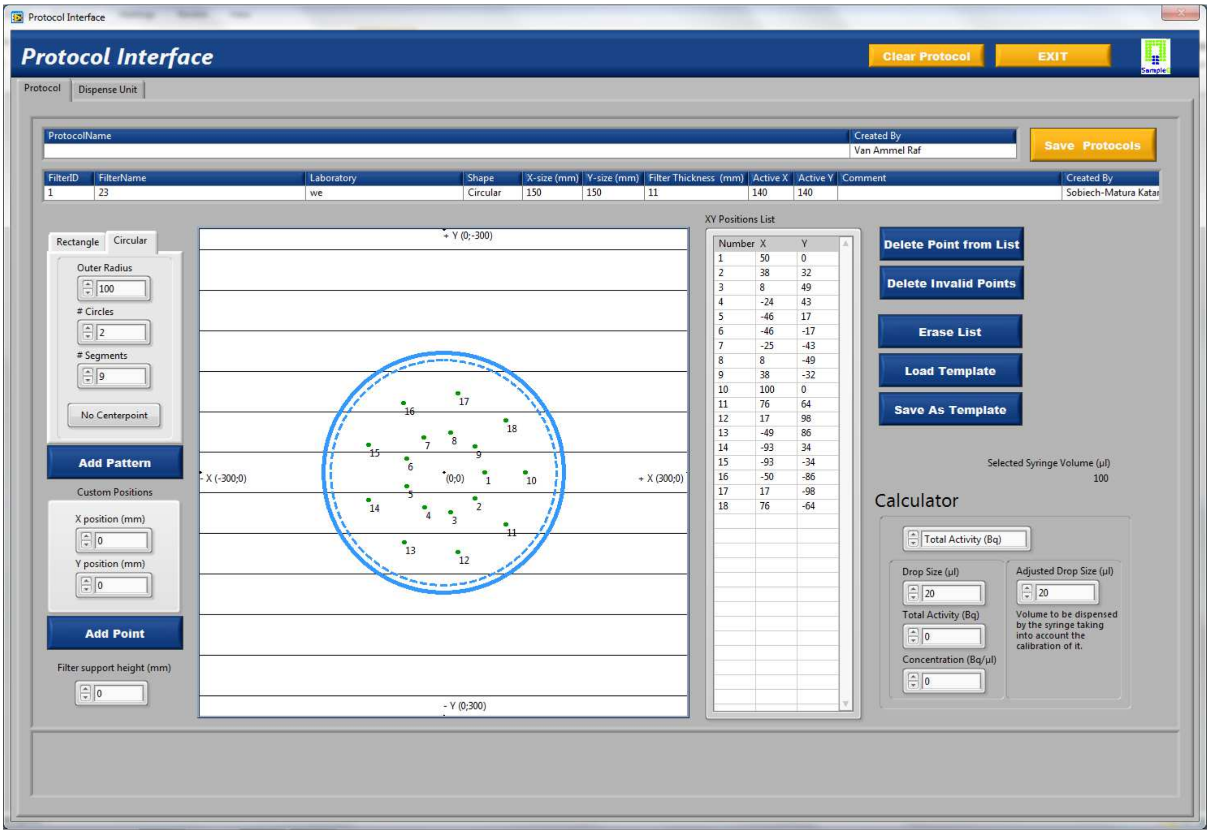

Figure 30: View of the protocol interface

3. Conclusion

For the purchase of a precision pattern dispenser the minimum requirements were laid down. The minimum requirements were met with the solution that was proposed by sampleQ. After installation the precision pattern dispenser tests were carried out to test the repeatability and trueness of the dispensing. The tests show that the instrument performed the dispensing within the target values set for both parameters. The precision pattern dispenser is qualified for use.

References

[1] SampleQ, Avenue J.E. Lenoir 2,B-1348 Louvain-la-Neuve, Belgium, http://www.sampleq.com/
[2] CTC Analytics AG,Industriestrasse 20, CH-4222 Zwingen, Switzerland, http://www.ctc.ch/
[3] Flamac a division of SIM, Technologiepark-Zwijnaarde 903, 9052 Gent, http://www.flamac.be/
[4] ISO 5725-1:1994(en): Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions
[5] Handbook of Chemistry and Physics, 53rd Edition, p. F4

List of abbreviations and definitions

JRC-Geel: European Commission Joint Research Centre in Geel

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Annex 1

Results of the ampoules weighing

Table 2: Results of dispensing with a 50 µL syringe: 20, 30 and 40 µL

# sample	Set Volume (mL)	Dispensed volume (mL)	Unc. (mL)	Deviation from the set value
1	0.02	0.019802	0.000085	0.99%
2	0.02	0.019672	0.000113	1.64%
3	0.02	0.019890	0.000087	0.55%
4	0.02	0.019832	0.000113	0.84%
5	0.02	0.019804	0.000099	0.98%
6	0.02	0.019782	0.000121	1.09%
7	0.02	0.019870	0.000102	0.65%
8	0.02	0.019637	0.000113	1.81%
9	0.02	0.019660	0.000098	1.70%
10	0.02	0.019840	0.000118	0.80%
Mean		0.019779		1.11%
Stdev		9.1E-05		0.45%
1	0.03	0.029610	0.000112	1.30%
2	0.03	0.029812	0.000104	0.63%
3	0.03	0.029654	0.000095	1.15%
4	0.03	0.029830	0.000105	0.57%
5	0.03	0.029780	0.000081	0.73%
6	0.03	0.029570	0.000079	1.43%
7	0.03	0.029704	0.000071	0.99%
8	0.03	0.029720	0.000112	0.93%
9	0.03	0.029762	0.000070	0.79%
10	0.03	0.029640	0.000072	1.20%
Mean		0.029708		0.97%
Stdev		8.9E-05		0.30%
1	0.04	0.039780	0.000116	0.55%
2	0.04	0.039664	0.000098	0.84%
3	0.04	0.039784	0.000101	0.54%
4	0.04	0.039672	0.000115	0.82%
5	0.04	0.039835	0.000111	0.41%
6	0.04	0.039644	0.000130	0.89%
7	0.04	0.039821	0.000118	0.45%
8	0.04	0.039748	0.000116	0.63%
9	0.04	0.039811	0.000131	0.47%
10	0.04	0.039811	0.000149	0.47%
Mean		0.039757		0.61%
Stdev		7.1E-05		0.18%

Table 3: Results of dispensing with a 100 µL syringe: 20, 40, 60 and 80 µL

# sample	Set Volume (mL)	Dispensed volume (mL)	Unc. (mL)	Deviation from the set value
1	0.02	0.019009	0.000103	4.95%
2	0.02	0.019262	0.000070	3.69%
3	0.02	0.019246	0.000084	3.77%
4	0.02	0.019497	0.000073	2.52%
5	0.02	0.019501	0.000067	2.50%
6	0.02	0.019505	0.000099	2.48%
7	0.02	0.019451	0.000068	2.75%
8	0.02	0.019294	0.000067	3.53%
9	0.02	0.019461	0.000068	2.70%
10	0.02	0.019116	0.000080	4.42%
Mean		0.019334		3.33%
Stdev		1.8E-04		0.88%
1	0.04	0.039094	0.000077	2.26%
2	0.04	0.039413	0.000074	1.47%
3	0.04	0.039520	0.000068	1.20%
4	0.04	0.039381	0.000069	1.55%
5	0.04	0.039395	0.000069	1.51%
6	0.04	0.039588	0.000080	1.03%
7	0.04	0.039417	0.000076	1.46%
8	0.04	0.039265	0.000068	1.84%
9	0.04	0.039411	0.000071	1.47%
10	0.04	0.039247	0.000070	1.88%
Mean		0.039373		1.57%
Stdev		1.4E-04		0.35%
1	0.06	0.058928	0.000089	1.59%
2	0.06	0.058996	0.000093	1.48%
3	0.06	0.059210	0.000087	1.12%
4	0.06	0.059232	0.000095	1.08%
5	0.06	0.059094	0.000095	1.31%
6	0.06	0.059120	0.000088	1.27%
7	0.06	0.059178	0.000088	1.17%
8	0.06	0.058908	0.000086	1.63%
9	0.06	0.059004	0.000087	1.47%
10	0.06	0.059258	0.000092	1.04%
Mean		0.059210		1.32%
Stdev		1.3E-04		0.21%
1	0.08	0.078899	0.000074	1.18%
2	0.08	0.078997	0.000082	1.06%
3	0.08	0.079185	0.000077	0.82%
4	0.08	0.079211	0.000069	0.79%
5	0.08	0.078875	0.000078	1.21%
6	0.08	0.078907	0.000073	1.17%
7	0.08	0.078969	0.000082	1.09%
8	0.08	0.078963	0.000069	1.10%
9	0.08	0.079103	0.000077	0.93%
10	0.08	0.079155	0.000077	0.86%
Mean		0.079183		1.02%
Stdev		1.3E-04		0.16%

Table 4: Results of dispensing with a 250 μL syringe: 50, 100, 150 and 200 μL

# sample	Set Volume (mL)	Dispensed volume (mL)	U (mL)	Deviation from the set value
1	0.05	0.049187	0.000076	1.63%
2	0.05	0.049016	0.000068	1.97%
3	0.05	0.049307	0.000071	1.39%
4	0.05	0.049401	0.000101	1.20%
5	0.05	0.049460	0.000066	1.08%
6	0.05	0.049269	0.000069	1.46%
7	0.05	0.049351	0.000068	1.30%
8	0.05	0.049110	0.000079	1.78%
9	0.05	0.049492	0.000066	1.02%
10	0.05	0.049648	0.000068	0.70%
Mean		0.049324		1.35%
Stdev		1.9E-04		0.38%
1	0.1	0.099435	0.000090	0.57%
2	0.1	0.099288	0.000069	0.71%
3	0.1	0.099318	0.000070	0.68%
4	0.1	0.099304	0.000067	0.70%
5	0.1	0.099455	0.000068	0.55%
6	0.1	0.099511	0.000070	0.49%
7	0.1	0.099320	0.000066	0.68%
8	0.1	0.099318	0.000073	0.68%
9	0.1	0.099354	0.000068	0.65%
10	0.1	0.099286	0.000081	0.71%
Mean		0.099359		0.64%
Stdev		7.9E-05		0.08%
1	0.15	0.149390	0.000075	0.41%
2	0.15	0.149253	0.000072	0.50%
3	0.15	0.149327	0.000075	0.45%
4	0.15	0.149442	0.000068	0.37%
5	0.15	0.149546	0.000065	0.30%
6	0.15	0.149470	0.000070	0.35%
7	0.15	0.149368	0.000096	0.42%
8	0.15	0.149323	0.000067	0.45%
9	0.15	0.149171	0.000077	0.55%
10	0.15	0.149241	0.000076	0.51%
Mean		0.149353		0.43%
Stdev		1.1E-04		0.08%
1	0.2	0.199270	0.000089	0.36%
2	0.2	0.199194	0.000073	0.40%
3	0.2	0.199294	0.000068	0.35%
4	0.2	0.199343	0.000068	0.33%
5	0.2	0.199302	0.000069	0.35%
6	0.2	0.199323	0.000071	0.34%
7	0.2	0.199176	0.000067	0.41%
8	0.2	0.199353	0.000101	0.32%
9	0.2	0.199499	0.000080	0.25%
10	0.2	0.199192	0.000065	0.40%
Mean		0.199295		0.35%
Stdev		9.6E-05		0.05%

Table 5: Results of dispensing with a 500 µL syringe: 100, 200, 300 and 400 µL

# sample	Set Volume (mL)	Dispensed volume (mL)	U (mL)	Deviation from the set value
1	0.1	0.099050	0.000067	0.95%
2	0.1	0.099078	0.000068	0.92%
3	0.1	0.098985	0.000067	1.01%
4	0.1	0.099110	0.000072	0.89%
5	0.1	0.099348	0.000066	0.65%
6	0.1	0.099035	0.000066	0.96%
7	0.1	0.099166	0.000077	0.83%
8	0.1	0.098901	0.000070	1.10%
9	0.1	0.099037	0.000067	0.96%
10	0.1	0.099106	0.000065	0.89%
Mean		0.099082		0.92%
Stdev		1.2E-04		0.12%
1	0.2	0.199822	0.000068	0.09%
2	0.2	0.199704	0.000069	0.15%
3	0.2	0.199377	0.000073	0.31%
4	0.2	0.199582	0.000075	0.21%
5	0.2	0.198960	0.000071	0.52%
6	0.2	0.199533	0.000070	0.23%
7	0.2	0.199395	0.000069	0.30%
8	0.2	0.199634	0.000073	0.18%
9	0.2	0.199437	0.000067	0.28%
Mean		0.199494		0.25%
Stdev		2.5E-04		0.12%
1	0.3	0.299787	0.000068	0.07%
2	0.3	0.299620	0.000067	0.13%
3	0.3	0.299624	0.000070	0.13%
4	0.3	0.299353	0.000068	0.22%
5	0.3	0.299692	0.000071	0.10%
6	0.3	0.299102	0.000067	0.30%
7	0.3	0.299458	0.000070	0.18%
8	0.3	0.297881	0.000067	0.71%
9	0.3	0.299106	0.000071	0.30%
10	0.3	0.299636	0.000066	0.12%
Mean		0.299326		0.22%
Stdev		5.6E-04		0.19%
1	0.4	0.398818	0.000065	0.30%
2	0.4	0.399994	0.000082	0.00%
3	0.4	0.400132	0.000068	-0.03%
4	0.4	0.399406	0.000067	0.15%
5	0.4	0.399464	0.000066	0.13%
6	0.4	0.398840	0.000066	0.29%
7	0.4	0.399454	0.000065	0.14%
8	0.4	0.397757	0.000086	0.56%
9	0.4	0.399839	0.000067	0.04%
10	0.4	0.399580	0.000078	0.10%
Mean		0.399328		0.17%
Stdev		7.0E-04		0.18%

Table 6: Results of dispensing with a 1000 µL syringe: 200, 400, 600 and 800 µL

# sample	Set Volume (mL)	Dispensed volume (mL)	U (mL)	Deviation from the set value
1	0.2	0.199086	0.000074	0.46%
2	0.2	0.198823	0.000067	0.59%
3	0.2	0.198945	0.000080	0.53%
4	0.2	0.198745	0.000069	0.63%
5	0.2	0.198843	0.000069	0.58%
6	0.2	0.198891	0.000071	0.55%
7	0.2	0.198891	0.000066	0.55%
8	0.2	0.199060	0.000070	0.47%
9	0.2	0.198795	0.000065	0.60%
10	0.2	0.198855	0.000067	0.57%
Mean		0.198893		0.55%
Stdev		1.1E-04		0.05%
1	0.4	0.399388	0.000070	0.15%
2	0.4	0.399550	0.000075	0.11%
3	0.4	0.399578	0.000076	0.11%
4	0.4	0.399542	0.000069	0.11%
5	0.4	0.399618	0.000077	0.10%
6	0.4	0.399592	0.000072	0.10%
7	0.4	0.399584	0.000069	0.10%
8	0.4	0.399681	0.000073	0.08%
9	0.4	0.399679	0.000070	0.08%
10	0.4	0.399663	0.000072	0.08%
Mean		0.399587485		0.10%
Stdev		8.6E-05		0.02%
1	0.6	0.599603	0.000081	0.07%
2	0.6	0.599727	0.000075	0.05%
3	0.6	0.599796	0.000077	0.03%
4	0.6	0.599715	0.000075	0.05%
5	0.6	0.599776	0.000101	0.04%
6	0.6	0.599942	0.000076	0.01%
7	0.6	0.599780	0.000076	0.04%
8	0.6	0.599729	0.000078	0.05%
9	0.6	0.599990	0.000092	0.00%
10	0.6	0.599860	0.000079	0.02%
Mean		0.599792		0.03%
Stdev		1.1E-04		0.02%
1	0.8	0.798858	1.997845	0.14%
2	0.8	0.799054	1.998242	0.12%
3	0.8	0.799128	1.998264	0.11%
4	0.8	0.799353	1.998696	0.08%
5	0.8	0.798917	1.998199	0.14%
6	0.8	0.798525	1.997375	0.18%
7	0.8	0.797670	1.995948	0.29%
8	0.8	0.798717	1.997936	0.16%
9	0.8	0.798205	1.996961	0.22%
10	0.8	0.799112	1.998329	0.11%
Mean		0.798754		0.16%
Stdev		5.0E-04		0.06%

Table 7: Results of dispensing with a 5000 µL syringe: 1000, 2000, 3000 and 4000 µL

# sample	Set Volume (mL)	Dispensed volume (mL)	U (mL)	Deviation from the set value
1	1	0.996359	0.000124	0.36%
2	1	0.997122	0.000071	0.29%
3	1	0.995462	0.000073	0.45%
4	1	0.999205	0.000072	0.08%
5	1	0.999005	0.000070	0.10%
6	1	0.998411	0.000097	0.16%
7	1	0.998722	0.000084	0.13%
8	1	1.000220	0.000078	-0.02%
9	1	1.000854	0.000076	-0.09%
10	1	1.001173	0.000072	-0.12%
Mean		0.998653		0.13%
Stdev		1.9E-03		0.19%
1	2	1.998192	0.000026	0.09%
2	2	1.999380	0.000026	0.03%
3	2	1.999396	0.000026	0.03%
4	2	1.999494	0.000028	0.03%
5	2	1.999452	0.000028	0.03%
Mean		1.996090		0.20%
Stdev		7.6E-03		0.38%
1	3	2.980831	0.000024	0.64%
2	3	2.982638	0.000023	0.58%
3	3	2.981697	0.000025	0.61%
4	3	2.978159	0.000025	0.73%
5	3	2.980186	0.000023	0.66%
6	3	2.982949	0.000030	0.57%
7	3	2.985927	0.000023	0.47%
8	3	2.988139	0.000023	0.40%
9	3	2.989800	0.000023	0.34%
10	3	2.984046	0.000023	0.53%
Mean		2.983437		0.55%
Stdev		3.6E-03		0.12%
1	4	3.984627	0.000023	0.38%
2	4	3.987231	0.000028	0.32%
3	4	3.991572	0.000023	0.21%
4	4	3.992467	0.000023	0.19%
5	4	3.991347	0.000023	0.22%
6	4	3.990057	0.000027	0.25%
7	4	3.990002	0.000024	0.25%
8	4	3.990607	0.000024	0.23%
9	4	3.991022	0.000037	0.22%
10	4	3.990314	0.000030	0.24%
Mean		3.989925		0.25%
Stdev		2.3E-03		0.06%

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