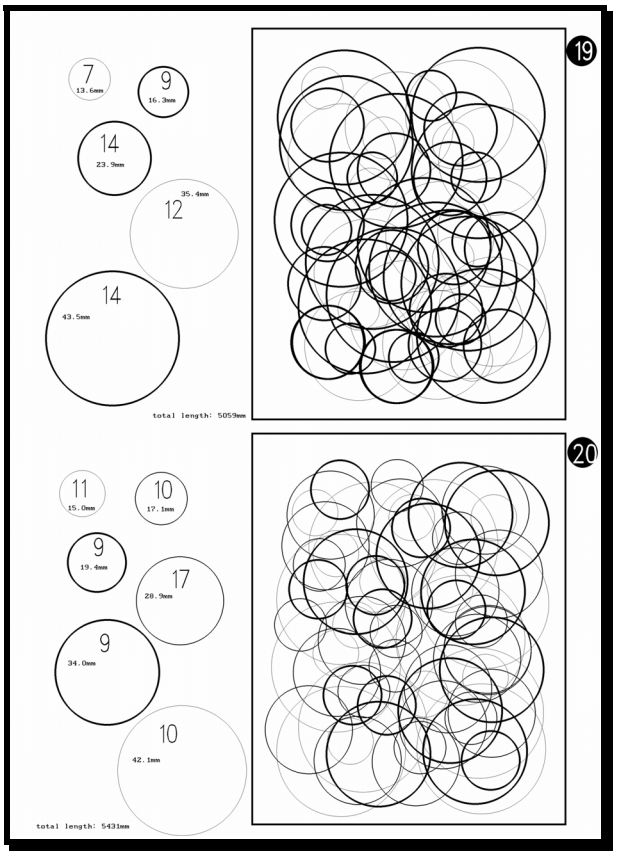
DELTA-T DEVICES

Delta-T SCAN



Reference Targets

Complete Test and Recalibration Kit Type CTS

WARNING

DO NOT LET THESE FILMS GET WET

OR THEY MAY SWELL AND LOSE THEIR ACCURACY

PROTECT FROM HUMIDITY, DIRT AND SCRATCHES.

Delta-T® SCAN Complete Test and Recalibration Reference Target Set Type CTS

Version 1
Document code CTS-UM-1
Nov 1993
Editor: Nick Webb

Delta-T Devices Ltd
128 Low Road
Burwell
Cambridge, CB5 OEJ
England

Telephone: (0638) 742922 (international +44 638 742922)
Fax: (0638) 743155 (international +44 638 743155)
Telex: 817670 ASABSE G

COPYRIGHT

CONTENTS

SET A_2

Envelope Number **Description**

1 Area and Perimeter test targets; scanner check target
2-11 Length test targets (note: the total length is the length of the circles within the rectangle excluding the frame!)
12 to 13 Thickness test targets
14 Particle size and Tip count test targets
15 Object count test targets
16 to 18 Shape test Targets

SET B

19 to 34 Root Length Test Targets (Codes DTS 1 to 16)

SET C

35 Root Target RT5 (3 rings, 400 mm x 0.5588 mm)
35 Root Target RT6 (negative of RT5)

Introduction

This ring binder contains three sets of reference targets on photographic film.

Calibration, and recalibration is not normally required for Delta-T SCAN when used with image files acquired from a flatbed or hand scanner. This is because the magnification is predetermined by the mechanical design of the scanner, and the choice of resolution is set by the scanning process. The only calibration required is to determine various coefficients for the root length algorithms, and that has already been done at the factory by Delta-T.

These targets are provided to let you test and check the performance of your scanner and the Delta-T SCAN image analysis algorithms.

For those that wish to experiment, provision is made in the Delta-T SCAN software for entering your own root length coefficients into a polynomial equation, but we imagine most customers will be satisfied with the calibration provided by Delta-T.

It is difficult to specify an industry standard set of target reference roots for testing software. For testing purposes, and to ensure conformance to specifications, it is only fair that the test target set be precisely. Therefore these targets are all solid black, with sharply defined edges. The root targets are circular, in order to reflect the requirements of the statistical assumptions in the root overlap correction algorithms. Real roots may not have these ideal properties, as assumed by the theoretical models underlying the algorithms, and so one should expect that the accuracy of real measurements on real roots is less than the ideal figures obtained on these test targets. We have endeavoured to emulate the appearance of real root samples through the use of randomly overlapping circles, and a range of thicknesses. In addition we have included two completely independent sets of test targets, Set A was generated by Kirchhof and Pendar, in Australia, and Set B was generated by Delta-T in England. The methods of generating and printing the two sets of targets were also different.

As described in Appendix 1A of the Delta-T Scan User Manual, Set A was printed in two different ways, which we shall call A_1 and A_2. Set A_1 was printed at 300 dpi onto paper in Australia and was used to test all the non root targets, and to calibrate and test the root algorithms, (reported in Appendix 1A of the Delta-T SCAN User Manual). As explained in that appendix, printer artefacts may have significantly affected the results. It is not possible for Delta-T to reproduce this original set for you, exact to the last microscopic black dot. Your photocopies (on paper) differ from the original test set A_1 due to two stages of reproduction and printing on different machines. Additional artefacts include the possibility of systematic errors in the magnification of the images caused by the photocopier, and differences in root target length due to the different fractal coastlines caused by the sputtered nature of ink deposition by the two printers.

Set A_2 is supplied here in the Reference Target ring binder. It was generated from the same DR HALO® raster scan image files as set A_1, but has been printed at 1200 dpi

onto photographic film by an industrial printed circuit board manufacturer (RAK). It does not exhibit a fractal coastline (at current resolution, i.e. up to 400 dpi) but is does exhibit the staircase effect characteristic of raster graphics. So the round circles are all made up of sections of straight line. If you compare these targets with the photocopied versions then you will observe that the staircase effect has been obscured by the printer and photocopier. In retrospect we like the jerkiness of these images because roots can tend to be made up of short straight sections also. In future upgrades of this product we will consider introducing targets which are more root-like in their architecture.

Set B was used to independently test the root length algorithms, as reported in Appendix 1B of the Delta-T Scan User Manual. This is the test set upon which the 3% accuracy specification is based. It is generated using a vector graphics
drawing software and printed at a resolution of greater than 5000 dpi using a printed circuit board photographic process. The lines appear smooth.

Set C comprises the target RT5 and its negative RT6 which derive from the Delta-T DIAS video based root analysis system (type RLS). These targets consist of three non-overlapping circles. RT5 was used as the repeating unit used in generating Set B. Set C has not been part of the test or specification programme for Delta-T SCAN. You may find RT5 useful for setting the scanner threshold as described in *Method 3, Use of a root target of known width or area*, in Chapter 10 of the Delta-T Scan User Manual.

The DIAS video-based image acquisition system is compatible with Delta-T SCAN, in so far as DIAS images can saved to a Tiff file and analyzed by Delta-T SCAN.
But the DIAS system does not have the resolution and field of view to acquire most of the Delta-T SCAN root length targets. You need a good flatbed scanner for this.

Sources of additional error in the measurement of real roots.

A maximum error of 9% was reported in Appendix 1A using the Harris Campbell method on targets about 40 cm long. At such short lengths it is possible that the theoretical requirements of uniform coverage, and random overlap, were not met by the targets. There errors are also in the direction expected by non-conformance with the theoretical expectations of the overlap correction, and of the fractal coastline artefacts in these targets. One weakness of the published 3% accuracy specification for root length (derived from target Set B) was that it was based on targets which did not explore the shorter end of the length range. Any future revisions to the root length test-targets will address this criticism.

To give an estimate for the additional, non system errors which may be generated by the use of real roots the only figures we currently have available are the performance specifications given for the Harris Campbell overlap correction in the DIAS Root Length System User Manual, where we quote as follows

"Coefficients of variation between 5% and 2% were typically found by Harris and Campbell (1987) for roots between 170 and 700 cm long. (Results obtained with the Delta-T Area Meter)

Root overlap can cause the Newman(Tennant/Head) equation to underestimate length by up to 90%.

The Harris Campbell correction can reduce this to typically less than 15%

A precise statement of the accuracy of the Harris Campbell overlap correction is not possible as it depends on the assumption that the roots are randomly oriented. In practice this may not be so."

The following pages are reproduced from the Delta-T SCAN User Manual, and are included here for completeness.

Extracts from the Delta-T Scan User Manual

Appendix 1. Results of Delta-T SCAN© Accuracy Tests

Appendix 1A contains the results of tests performed by G Kirchhof on the accuracy of Delta-T SCAN with a particular set of targets and a hand scanner. Photocopies of the targets are given in Appendix 9. Images were scanned using a LogiTech 256 grey scale hand scanner*. A brief comparison with other selected scanners is also given. Kirchhof interpreted some of these results as suggesting that accuracy of perimeter measurements may decrease at high resolutions. We now think this was a printer artefact. Close examination with a microscope show that the targets in Appendix 9 present a fractal "coastline". (Hidden under this is also a second artefact caused by the raster graphics method of generating the image files). Apart from this one criticism we think the user will find this test report helpful and so we have included it in its entirety. In particular it is an instructive and useful warning to alert the user to the possibility of fractal effect with real targets. Roots have root hairs, and mycorrhyzoidal fungii. Both can contribute to a fractal-coastline behaviour as resolution is increased. Soil scientists using the root length and perimeter algorithms to measure crack length should also be alert to this.

A second criticism of Appendix 1A is that the same targets were used for calibrating and testing the root length algorithms. In response we created an independent set of 16 root test targets (Set B, reference codes DTS 1-16) using vector graphics and PCB photographic film fabrication techniques. The results of these tests are presented in Appendix 1B. Our specification for root length accuracy is based on this test.

You can repeat these tests on the high quality photographic film copies of our test and calibration targets, which are available from Delta-T. But be warned you will need about 100 Megabytes of hard disk storage to scan all these targets!

A visual examination with a microscope should make these difference clear, that is, between the photocopied targets their equivalent high resolution film targets (Set A_2, at 1200 dpi) and with the vector-graphics test target (Set B, at better than 5000 dpi).

Appendix 1B. Results of Delta-T SCAN© Root Length Tests

An independent set of root length test targets (reference code DTS) was created to test the accuracy of the Delta-T SCAN generic calibration coefficients. The method used to generate these targets is given below. They do not suffer from the fractal coastline or raster graphics discontinuities associated with the original set used in Appendix 1A and portrayed in Appendix 9. Results are graphed in 2 and tabulated in 1. The Delta-T SCAN specification for accuracy of root length measurements is defined as the 95% confidence limits we obtained on testing the algorithms against these targets when scanned at 300 dpi (dots per inch).

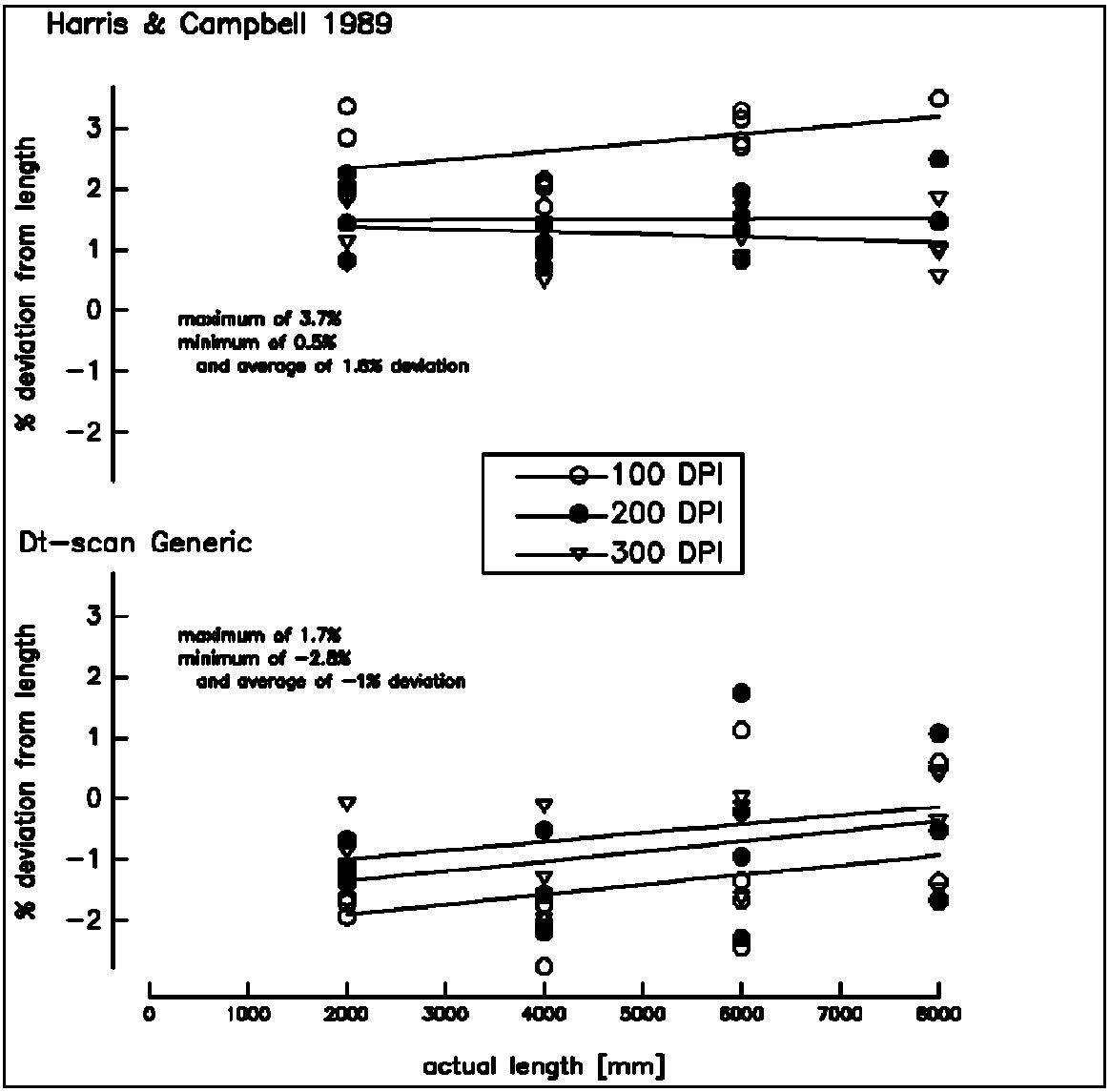


Figure 2 Graphs of % error vs root length in mm for targets DTS 1 to 16

These results showed that the length of overlapping roots can be measured to better than 3%, given perfect image quality. Of course, you must expect less than perfect image quality in reality, due to factors that the Delta-T SCAN software cannot control, such as there being sufficient contrast between the roots and the background.

Table I: Results of Root Length Tests.

Target type	resolution [DPI]	length measurement type	average deviation [%]	standard deviation	95% confidence interval (± 2 standard deviation)	minimum deviation [%]	maximum deviation [%]
Calibration targets from Appendix 9. Results from Appendix 1A	100, 200 & 400	DT-scan generic	0.2	1.71	-3.2 to +3.6	-3.5	+6.0
		Harris & Campbell (1989)	2.2	2.46	-2.7 to +7.1	**-5.2**	**+9.3**
Independent Test Targets DTS 1-16	100	Delta-T SCAN generic	-1.5	1.00	-3.5 to +0.5	-2.8	1.1
	200		-0.9	1.11	-3.1 to +1.3	-2.3	1.7
	300		-0.6	0.96	**-2.5 to +1.3**	-2.0	1.7
	100, 200 & 300		-1.0	1.07	-3.1 to +1.1	-2.8	1.7
	100	Harris & Campbell (1989)	2.7	0.64	+1.4 to +4.0	1.7	3.7
	200		1.5	0.56	+0.4 to +2.6	0.7	2.5
	300		1.3	0.51	**+0.3 to +2.3**	0.5	2.0
	100, 200 & 300		1.8	0.86	+0.1 to +3.5	0.5	3.7

Summary of Results Table for Test Target Set A

target #	thin lines (0.2mm)			medium lines (0.3mm)			thick lines (0.6mm)			percent length			total length [mm] *correct to ±1.3%*
	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	thin lines	medium lines	thick lines	
1	1	5.4	17							100	0	0	153
	1	14.2	45										
	1	29.1	91										
2							1	5.4	17	0	0	100	155
							1	14.4	45				
							1	29.6	93				
3	2	17.2	108				1	47.0	148	42	0	58	256
4	1	16.3	51	1	25.8	81	1	37.5	118	20	32	47	250
5	4	22.1	278							100	0	0	396
	5	7.5	118										
6							4	22.3	280	0	0	100	384
							5	6.6	104				
7	2	6.8	43				2	37.4	235	30	0	70	442
	2	14.3	90				3	7.8	74				

target #	thin lines (0.2mm)			medium lines (0.3mm)			thick lines (0.6mm)			percent length			total length [mm] *correct to ±1.3%*
	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	thin lines	medium lines	thick lines	
8	2	6.7	42	1	21.4	67	2	6.7	42	24	50	26	505
	2	12.8	80	2	29.2	183	1	29.0	91				
9	5	7.3	115							100	0	0	759
	5	18.7	294										
	2	55.7	350										
10							5	8.2	129	0	0	100	783
							5	19.2	302				
							2	56.0	352				
11	2	9.4	59				3	12.2	115	68	0	32	909
	3	26.2	247				2	28.7	180				
	2	49.0	308										
12	2	11.5	72	4	15.0	188	3	13.8	130	29	40	31	1,227
	4	22.4	281	3	32.3	304	2	40.1	252				
13	8	15.7	395							100	0	0	1,924
	7	23.6	519										

target #	thin lines (0.2mm)			medium lines (0.3mm)			thick lines (0.6mm)			percent length			total length [mm] *correct to ±1.3%*
	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	thin lines	medium lines	thick lines	
	8	40.2	1,010										
14							9	16.5	467	0	0	100	1,972
							8	27.0	679				
							6	43.8	826				
15	3	16.8	158				5	18.4	289	59	0	41	2,015
	5	22.8	358				3	23.2	219				
	6	35.5	669				3	34.2	322				
16	6	10.9	205	5	12.2	192	5	17.9	281	8	33	59	2,475
				7	28.0	616	8	47.0	1,181				
17	10	13.6	427							100	0	0	3,115
	16	21.7	1,091										
	11	46.2	1,597										
18							12	13.8	520	0	0	100	3,290
							14	22.6	994				
							12	47.1	1,776				

target #	thin lines (0.2mm)			medium lines (0.3mm)			thick lines (0.6mm)			percent length			total length [mm] *correct to ±1.3%*
	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	number of circles	diameter [mm]	length [mm]	thin lines	medium lines	thick lines	
19	7	13.6	299				9	16.3	461	32	0	68	5,059
	12	35.4	1,335				14	23.9	1,051				
							14	43.5	1,913				
20	11	15.0	518	10	17.1	537	9	19.4	549	34	38	28	5,431
	10	42.1	1,323	17	28.9	1,543	9	34.0	961				

)Summary Table for Target Set B

Number of 3-ring units	Total "Root" Length *	THICKNESS				UNITS
		0.005	0.011	0.022	0.044	inches
		0.127	0.2794	0.5588	1.1176	mm
5	2000 mm	*DTS-1*	*DTS-2*	*DTS-3*	*DTS-4*	*Target Codes*
10	4000 mm	*DTS-5*	*DTS-6*	*DTS-7*	*DTS-8*	
15	6000 mm	*DTS-9*	*DTS-10*	*DTS-11*	*DTS-12*	
20	8000 mm	*DTS-13*	*DTS-14*	*DTS-15*	*DTS-16*	

* Note: The total lengths given here are what you would measure if they were not overlapping. These targets test the root length algorithms ability to compensate for root overlap.

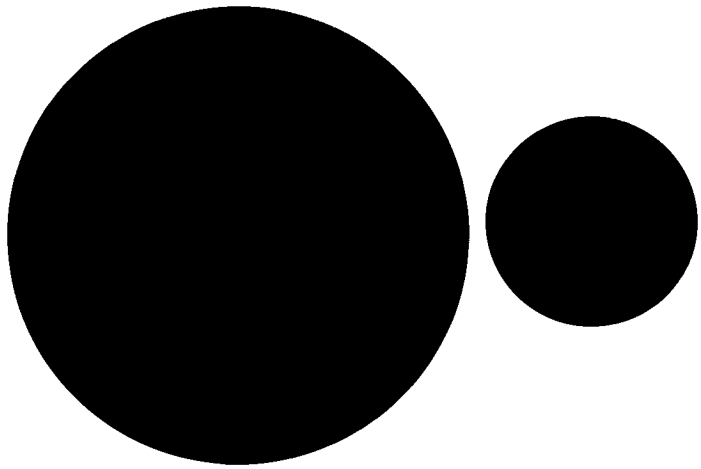
Summary Table for Target Set C

Number of 3-ring units	Total Length	Thickness mm	Target Code	Area mm^2	Background
1	400 mm	0.5588	RT5	223.4	Transparent
1	400 mm	0.5588	RT6	223.4	Black

Note : Non overlapping root targets, suitable for evaluating the Newman/Head/Tennant length algorithm, or for setting the threshold using the known thickness or area.

Area and Perimeter Test Targets

D = 60.5 mm
A = 2875 mm2
P = 190 mm

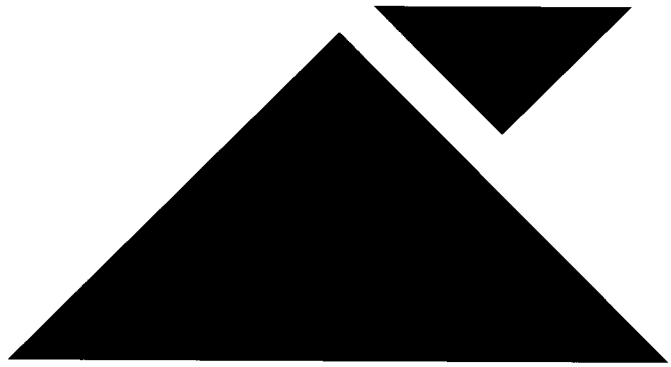


D = 27.7 mm
A = 603 mm2
P = 87 mm

x = 58.5 mm
y = 56.7 mm
A = 3317 mm2
P = 230 mm

x = 26.7 mm
y = 21.2 mm
A = 566 mm2
P = 96 mm

h = 43.6 mm
l = 86.9 mm
A = 1894 mm2
P = 210 mm



h = 16.9 mm
l = 33.8 mm
A = 286 mm2
P = 82 mm

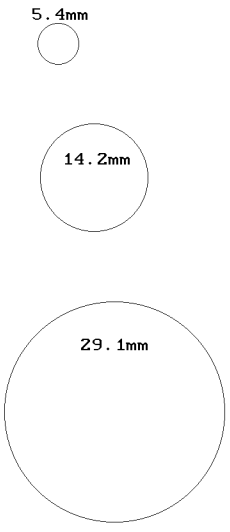
approximate DPI

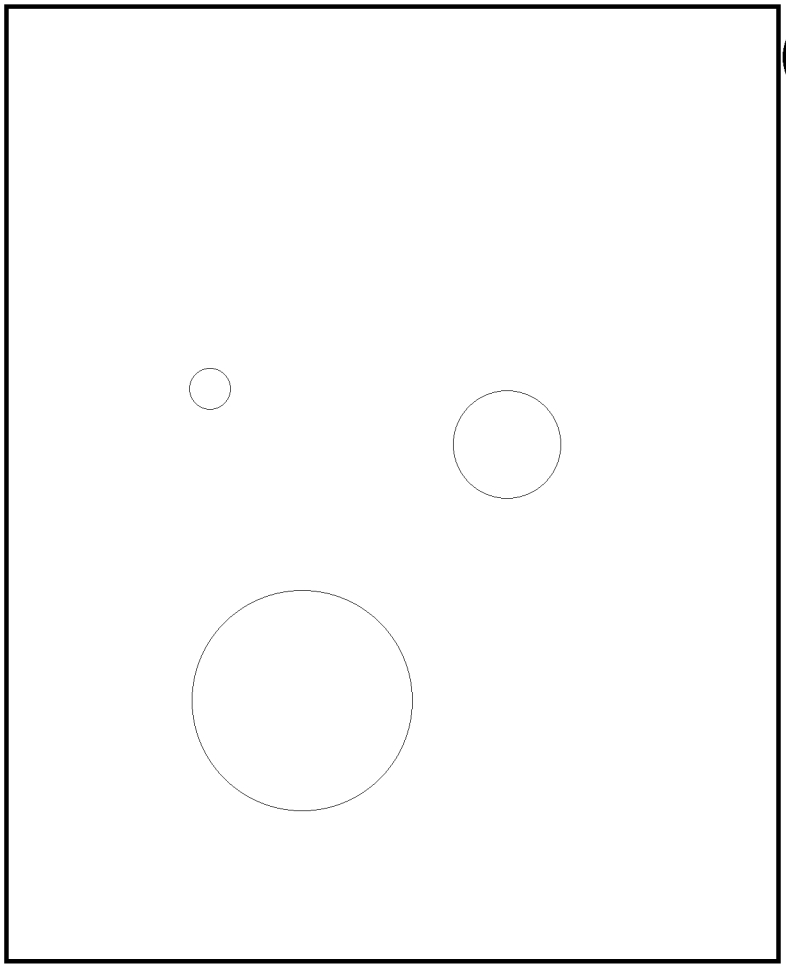
250 85 40 25

0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0

line thickness in [mm]

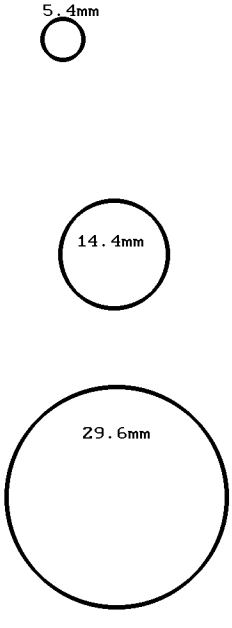
1

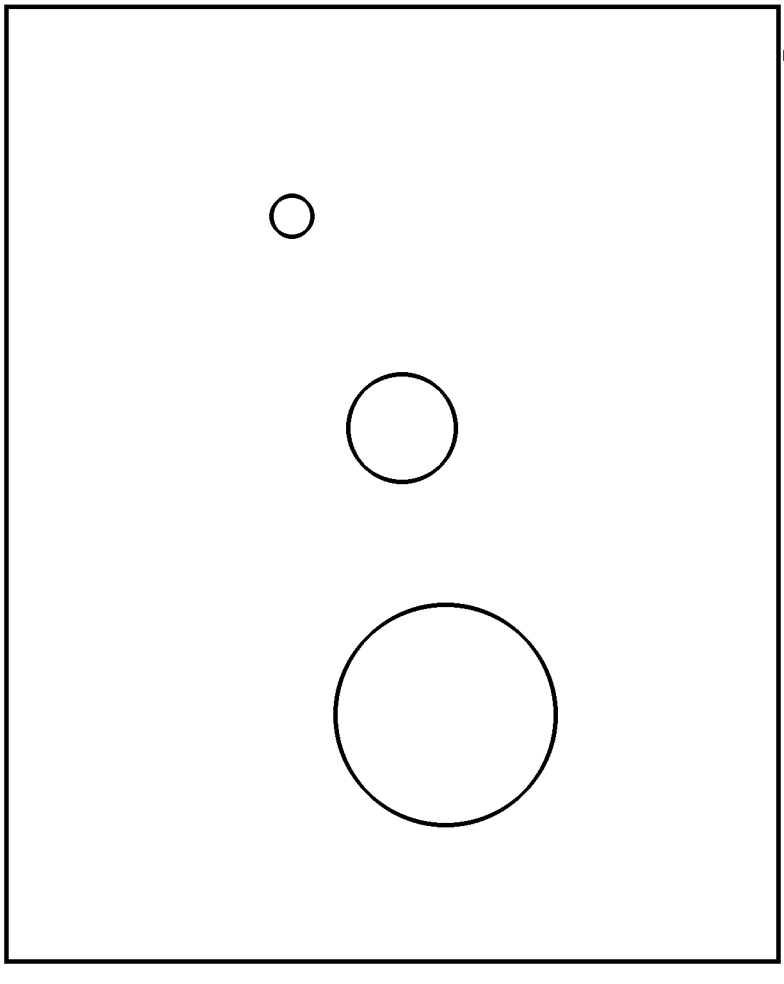




total length: 153mm

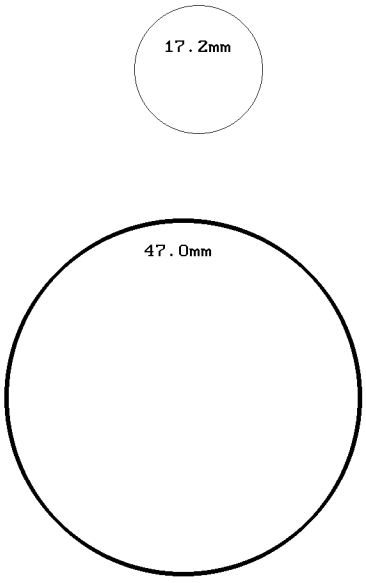
2

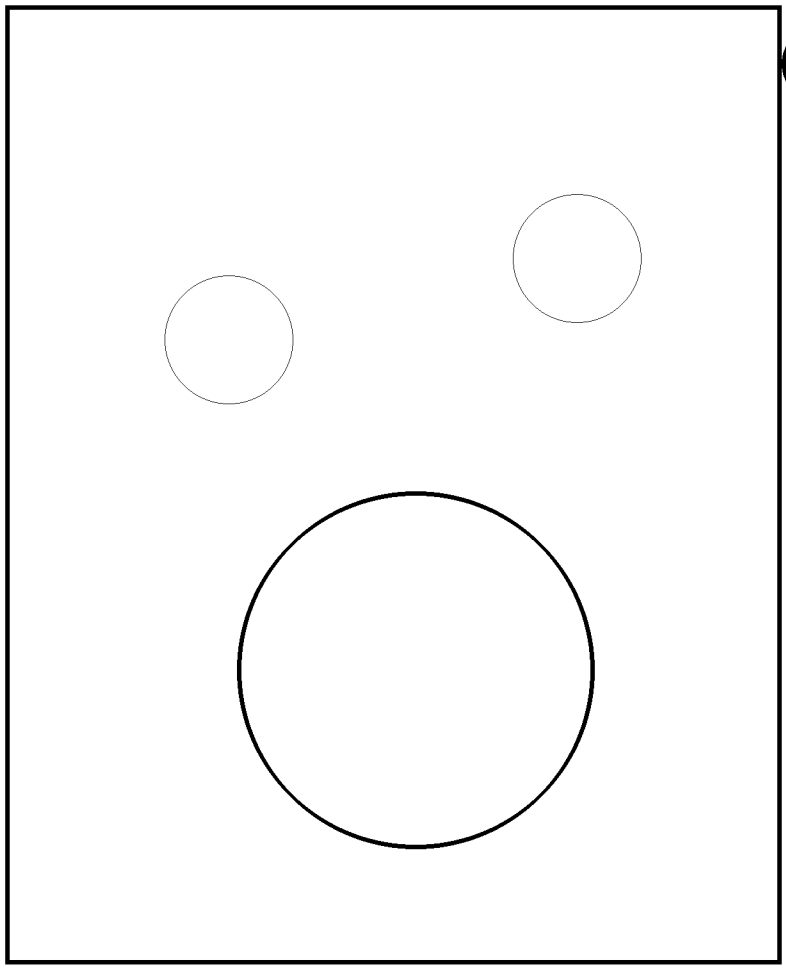




total length: 155mm

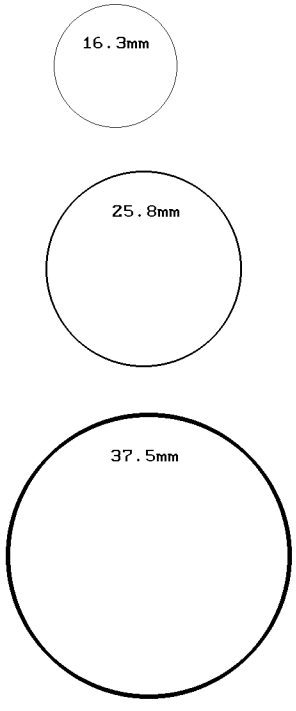
3

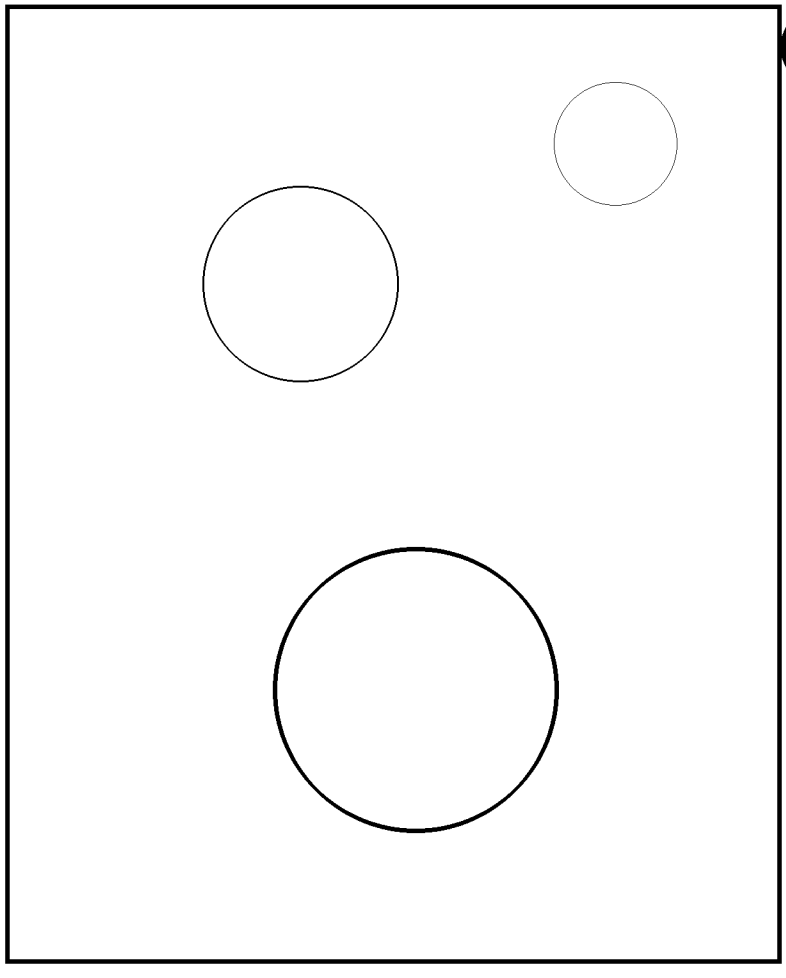




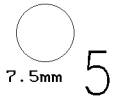
total length: 256mm

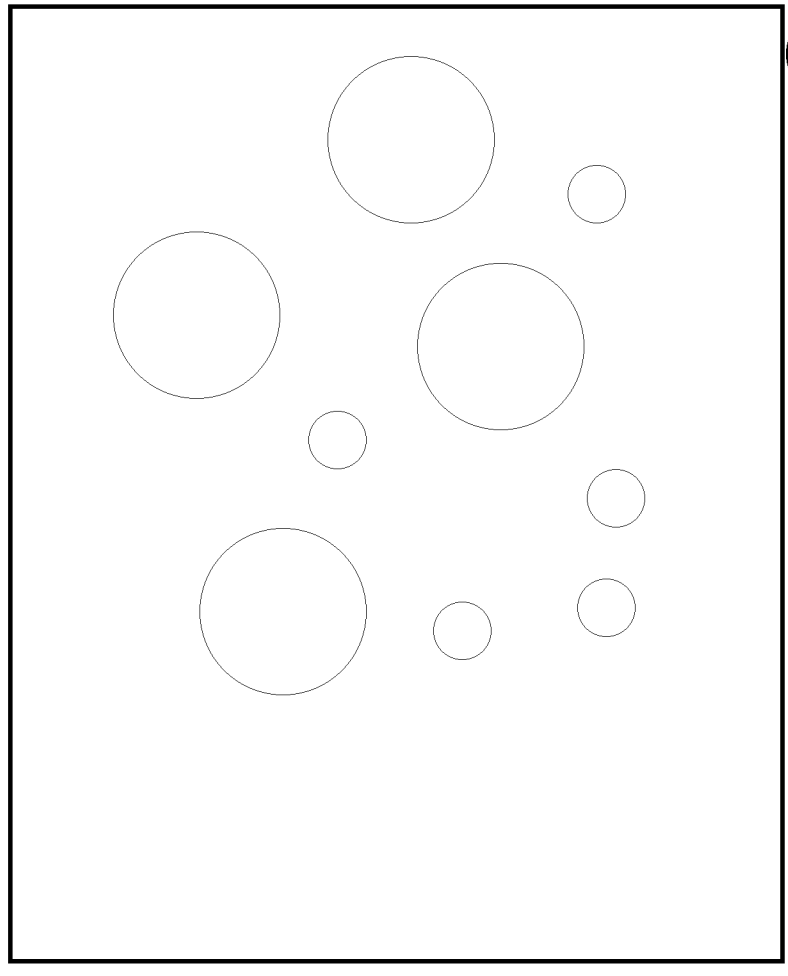
4



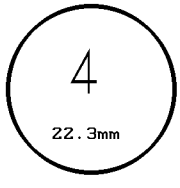


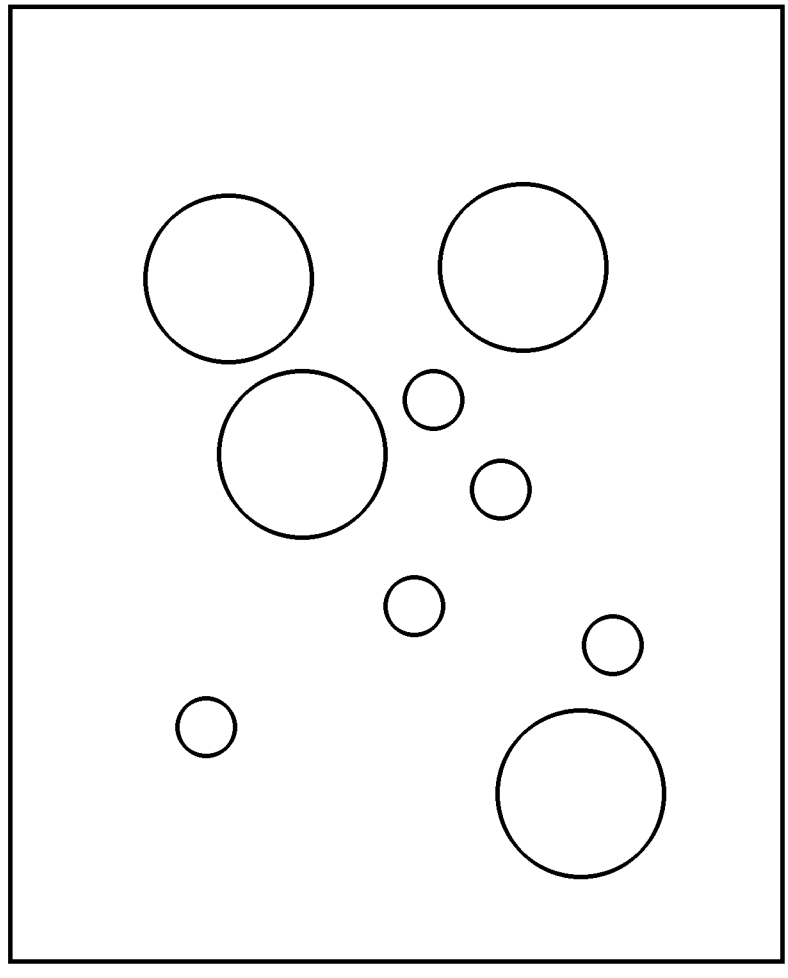
total length: 250mm





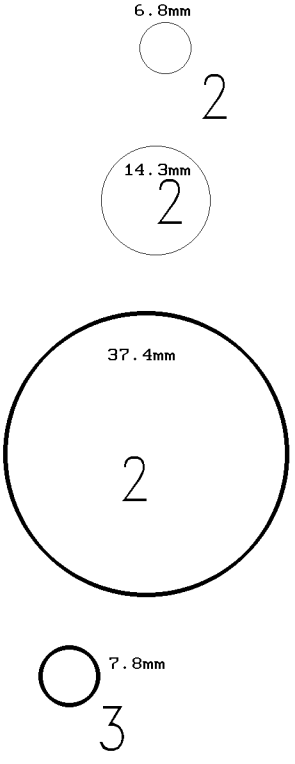
total length: 396mm

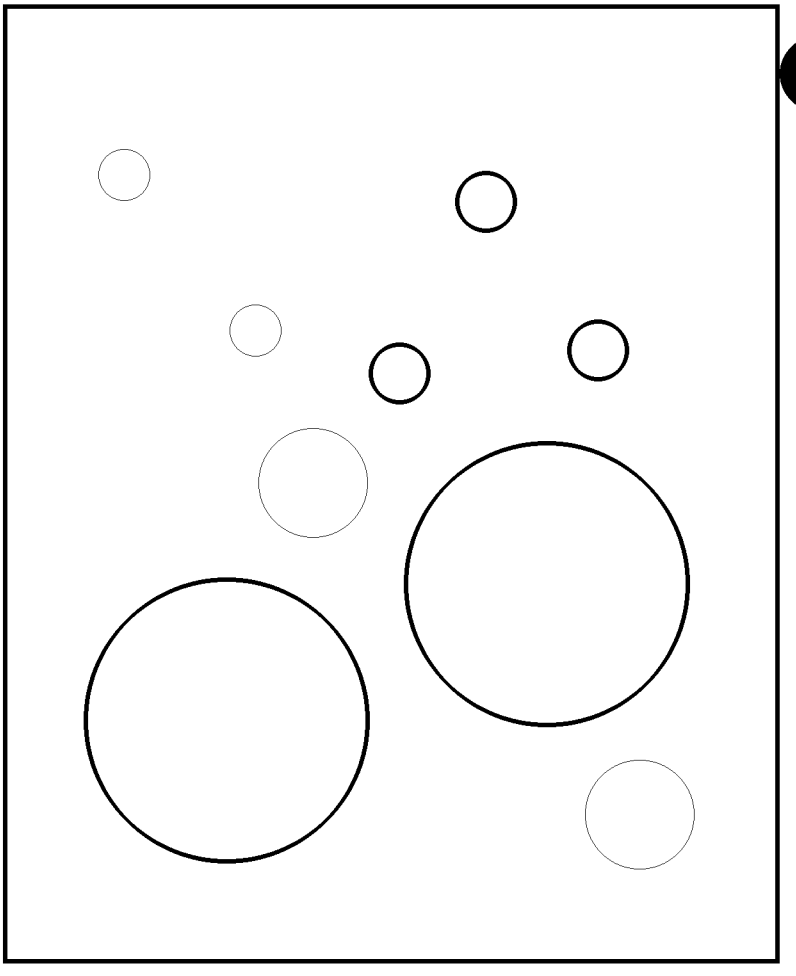




total length: 384mm

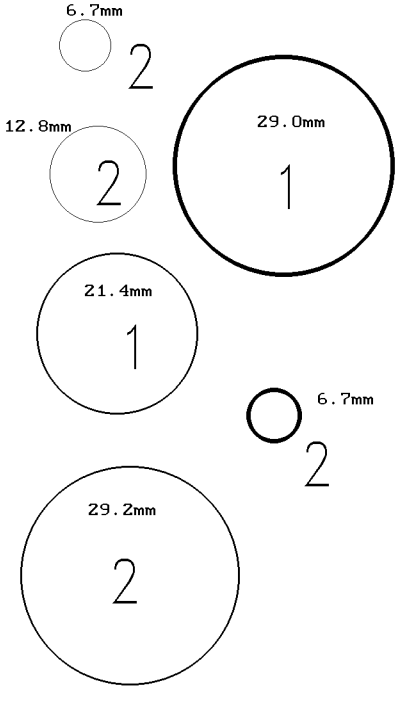
7

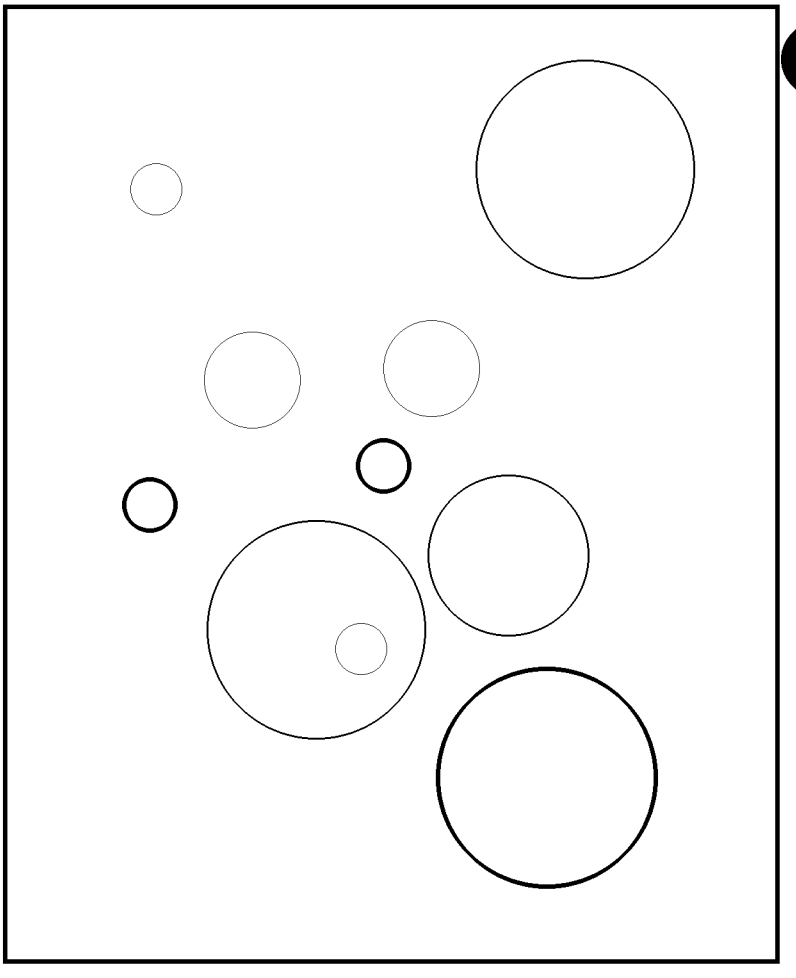




total length: 442mm

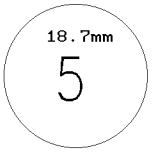
8

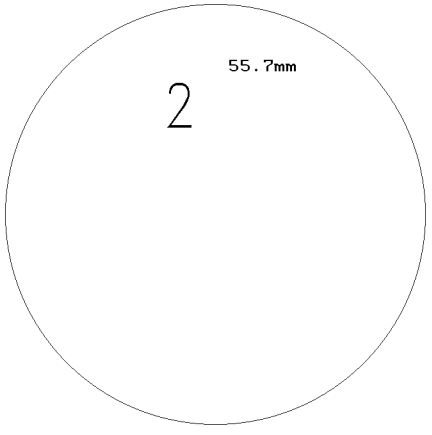




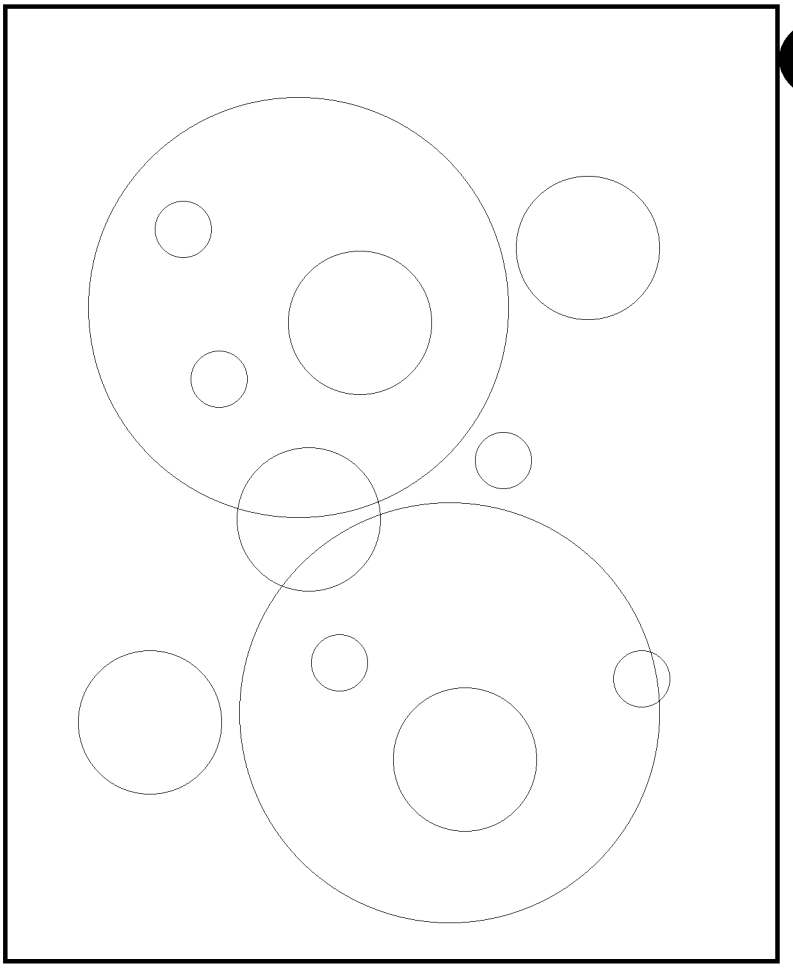
total length: 505mm

9

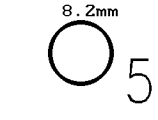


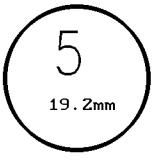


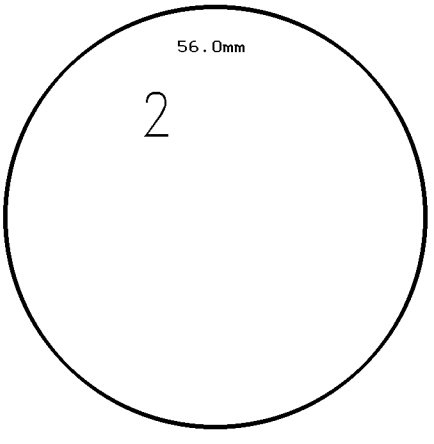
total length: 759mm



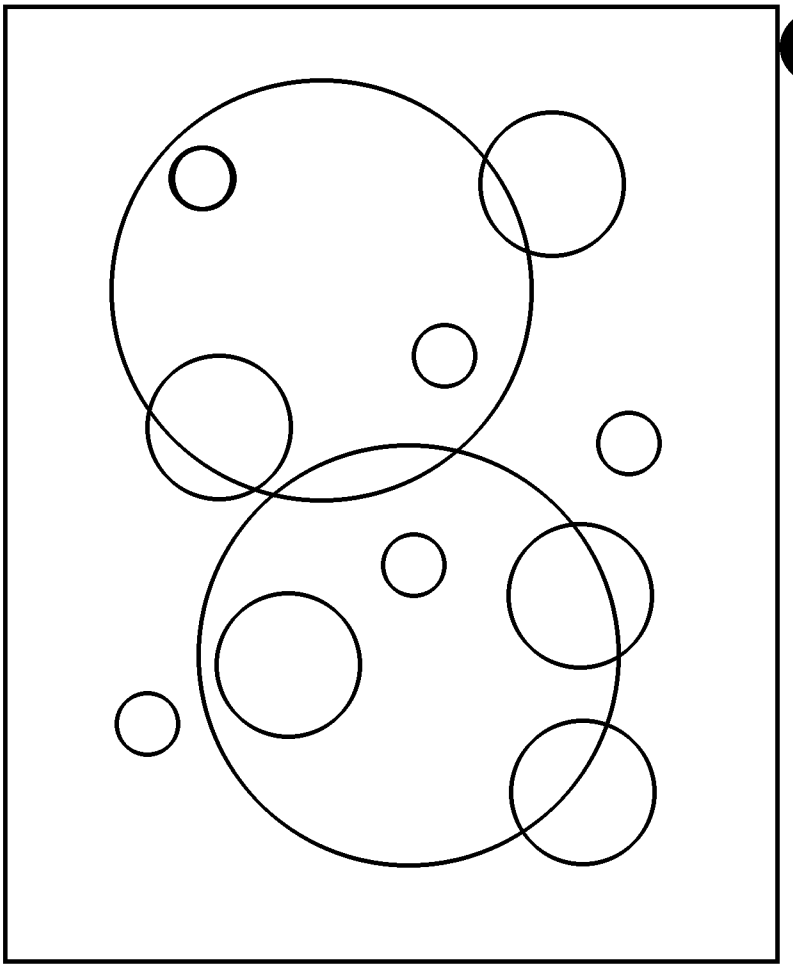
10

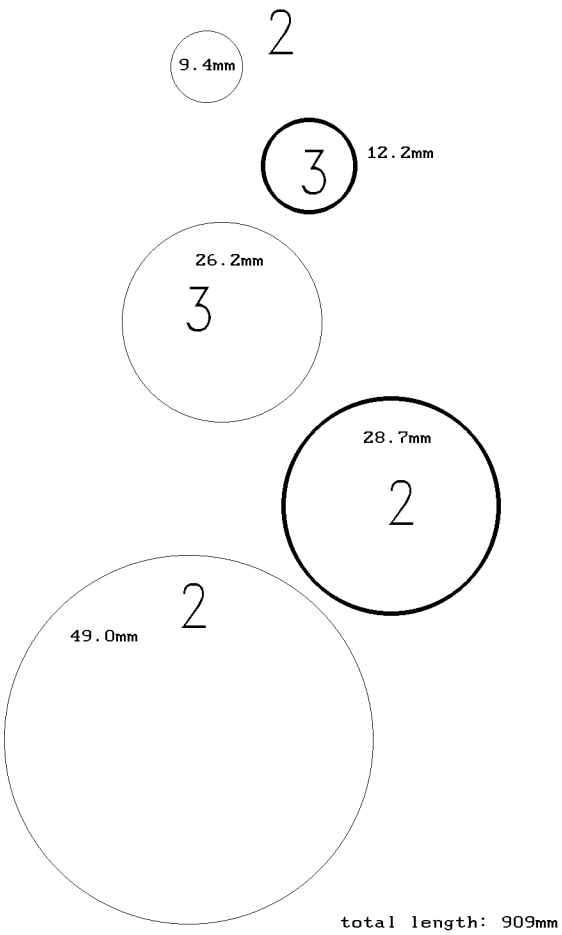






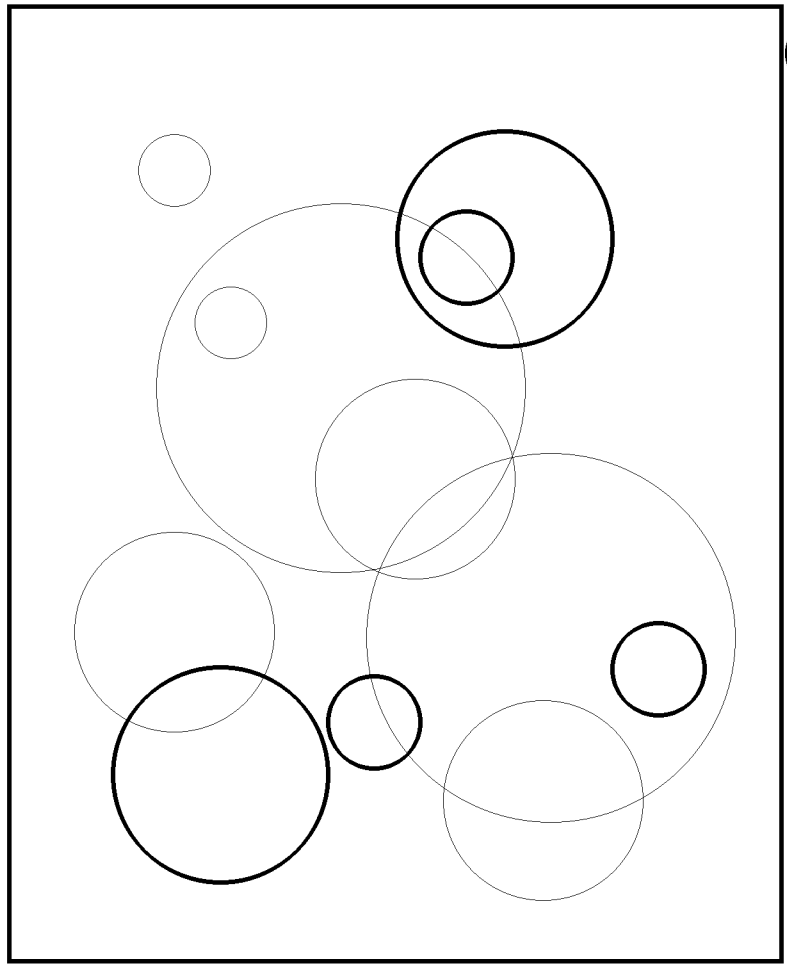
total length: 783mm

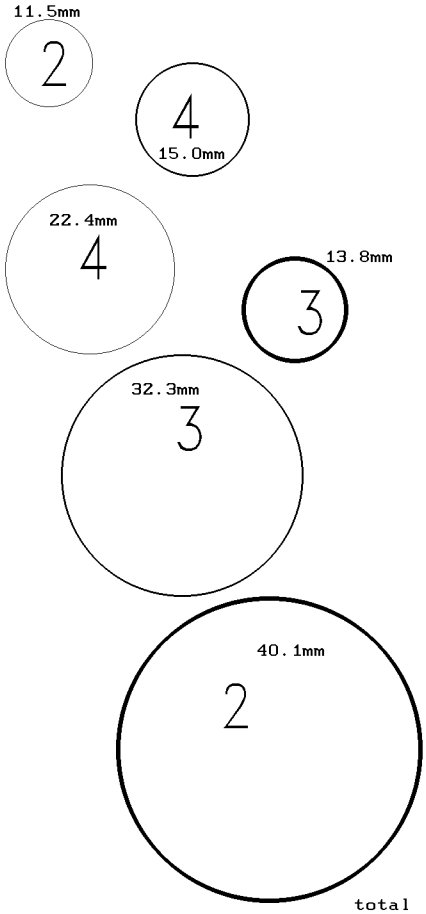




total length: 909mm

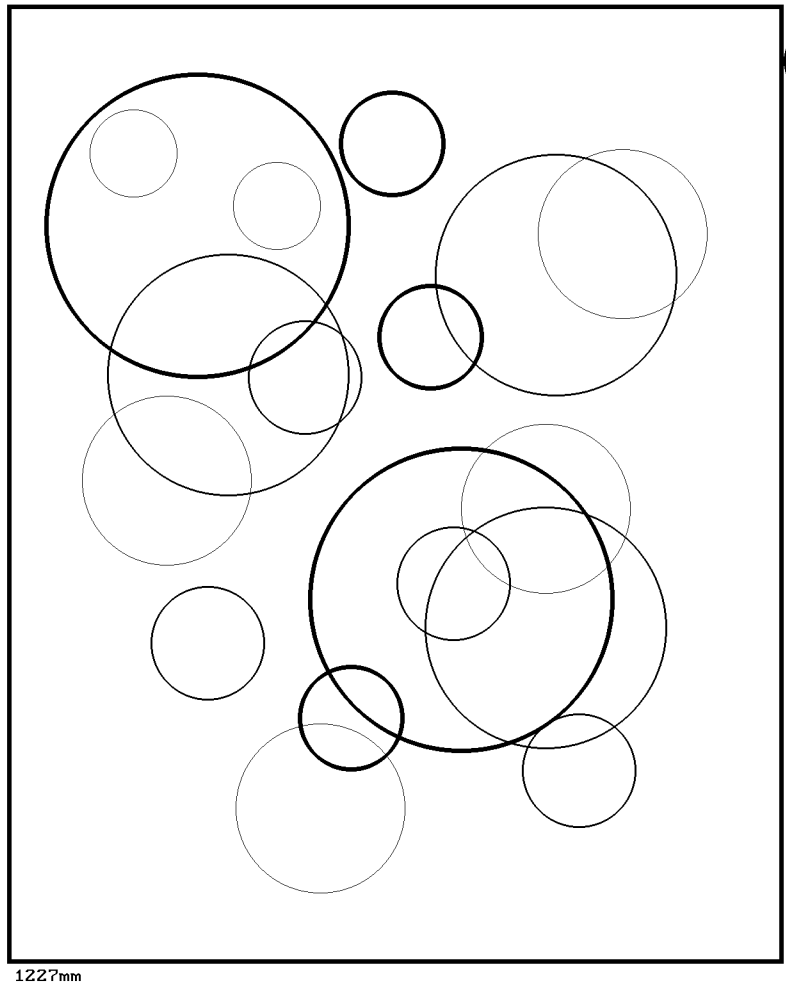
11



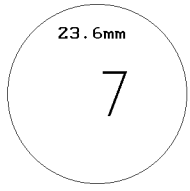


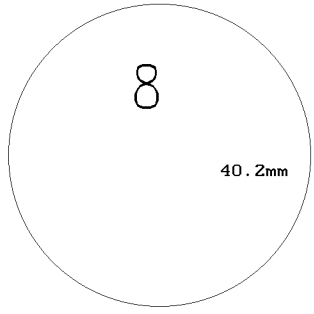
total length: 1227mm

12

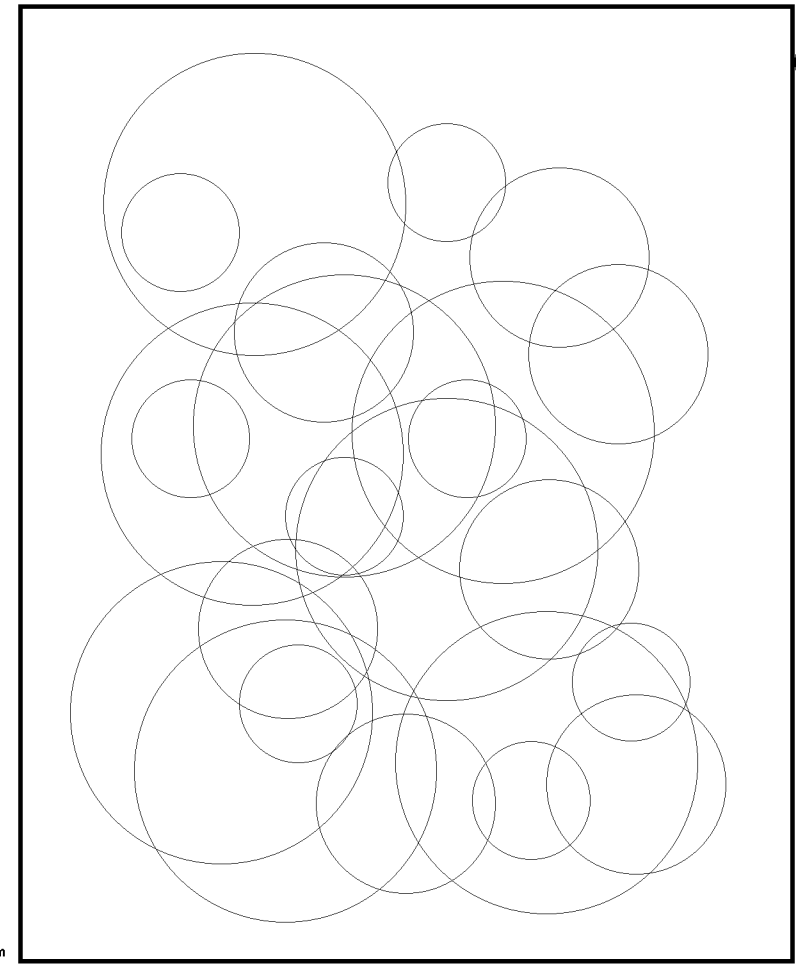


13

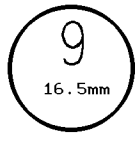


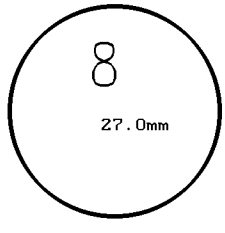


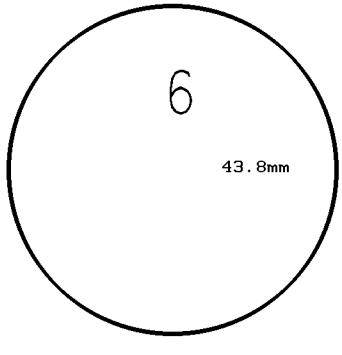
total length: 1924mm



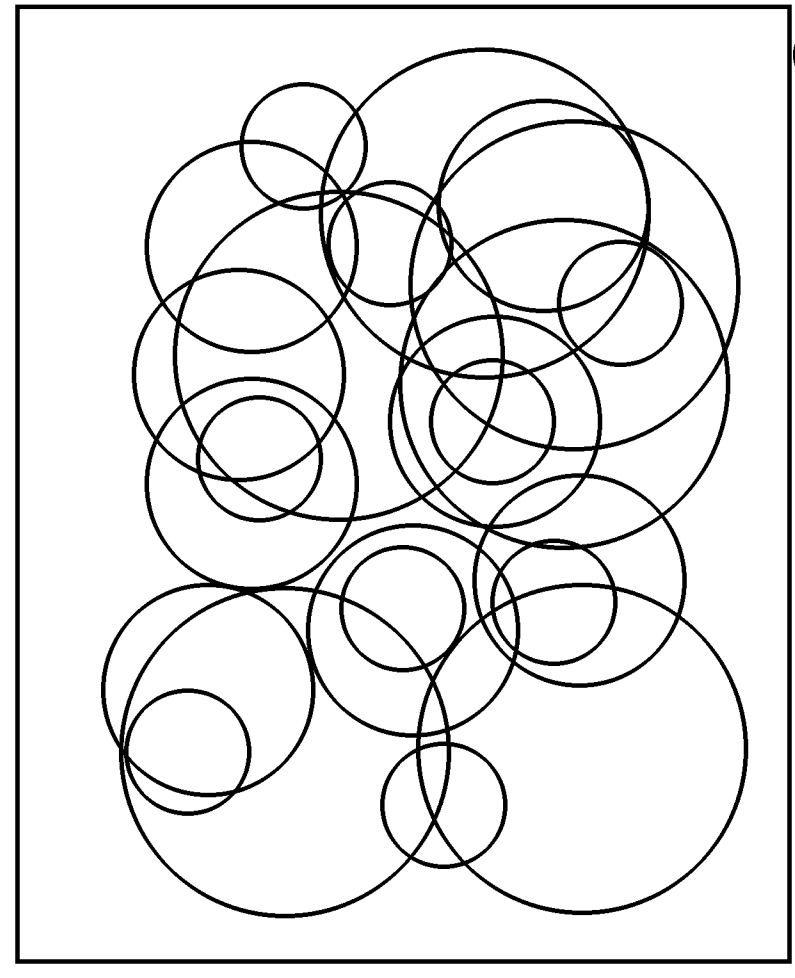
14

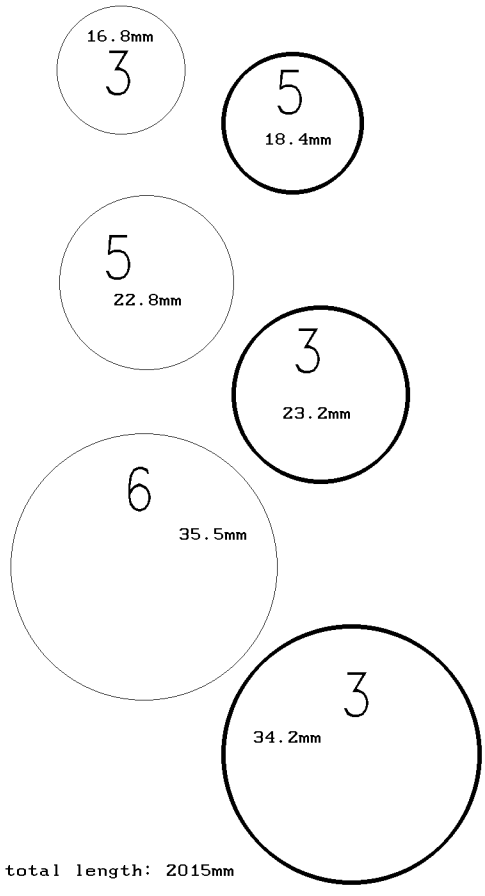






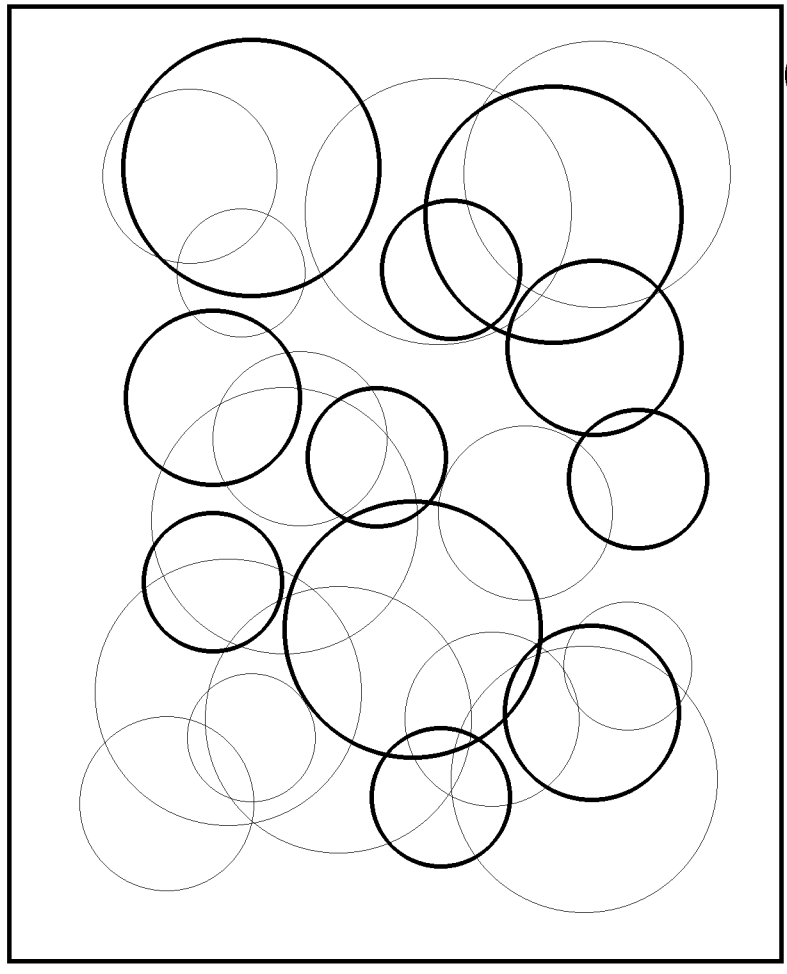
total length: 1972mm

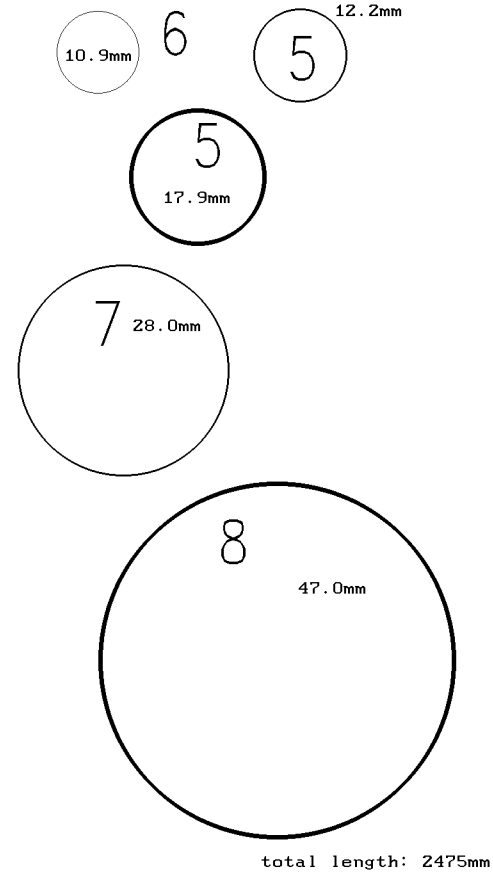




total length: 2015mm

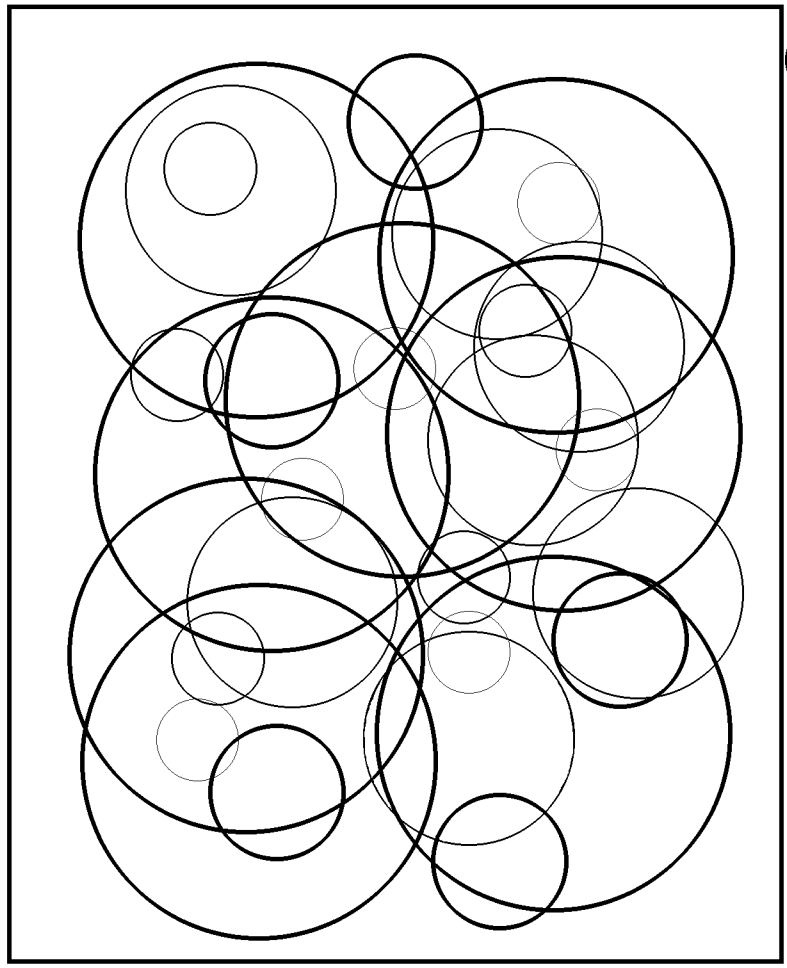
15



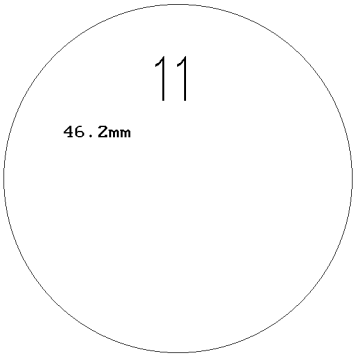


total length: 2475mm

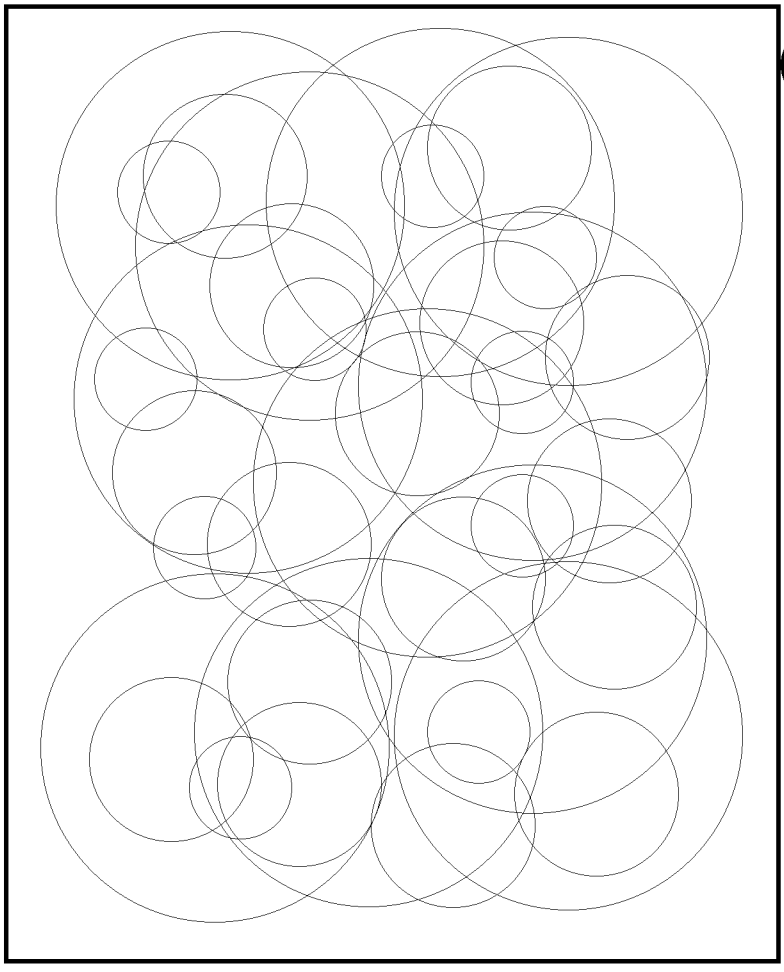
16



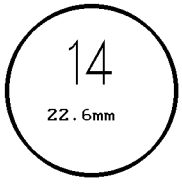
17

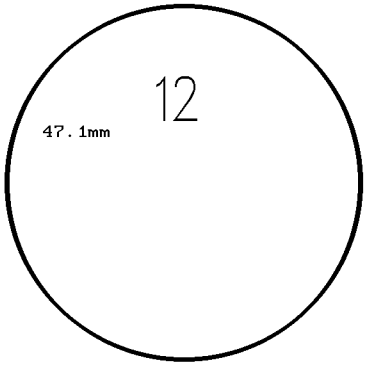


total length: 3115mm

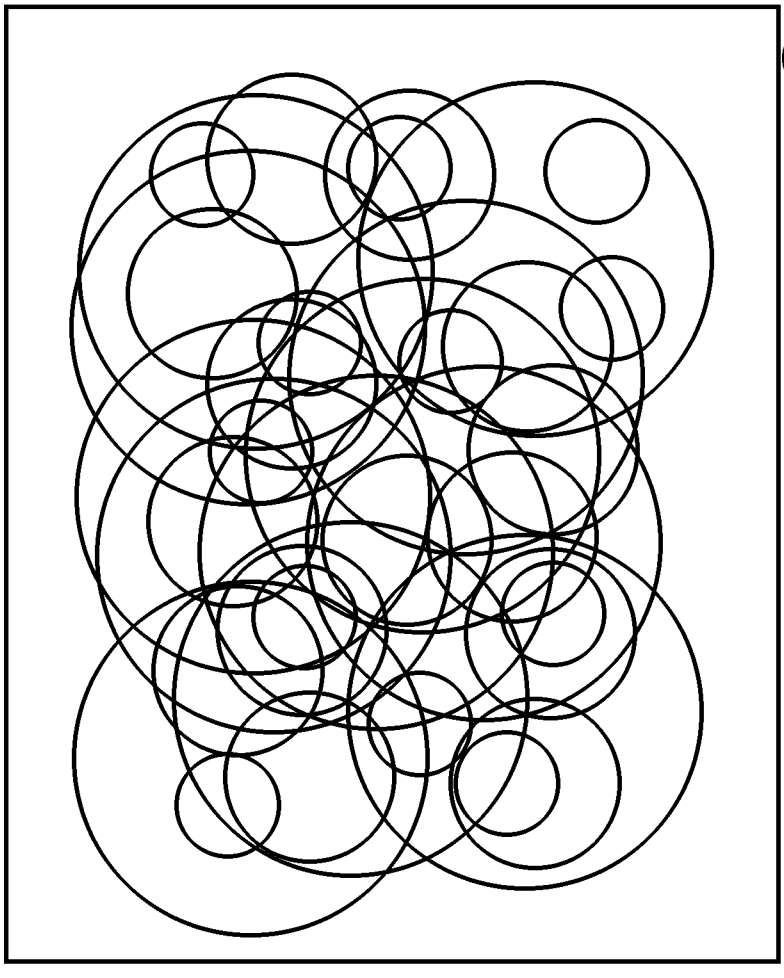


18

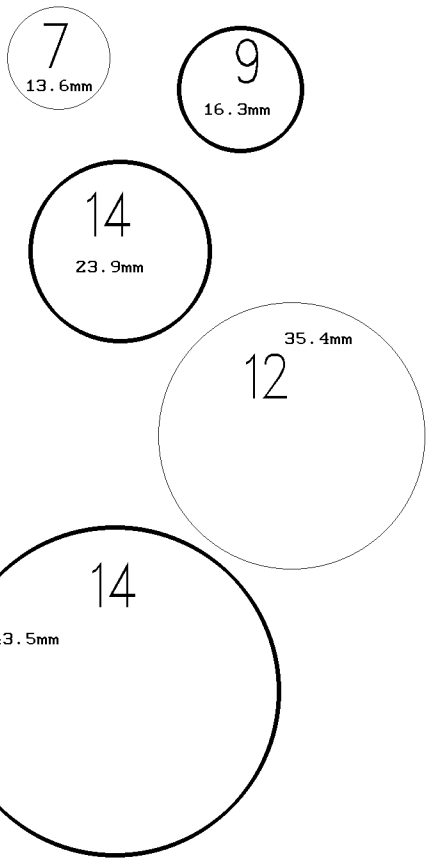




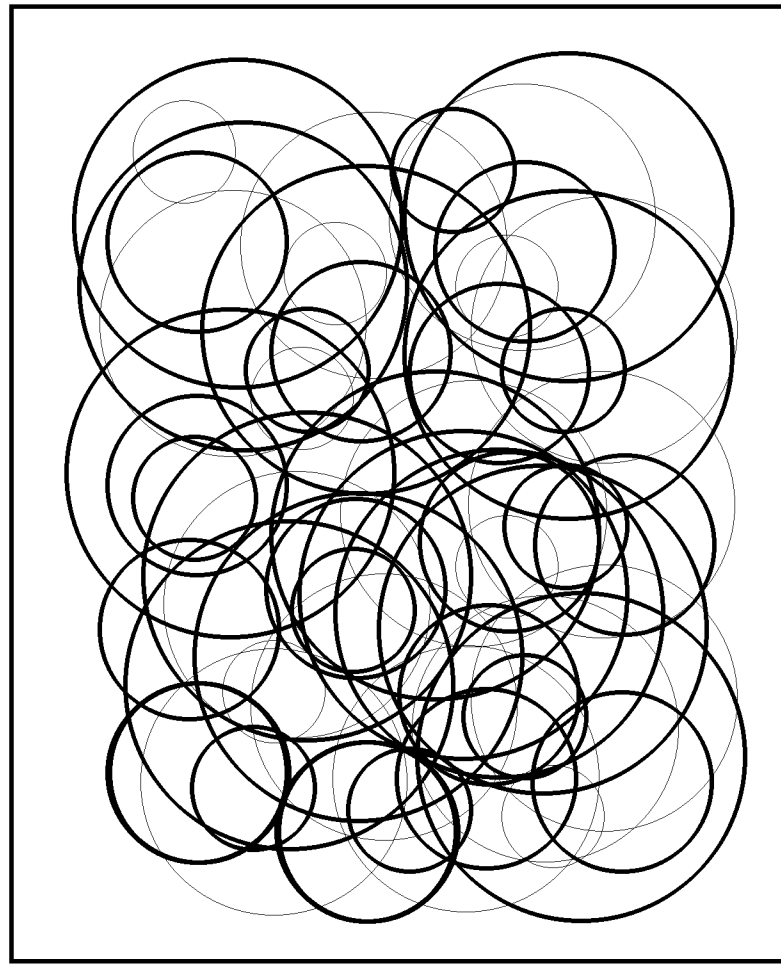
total length: 3290mm



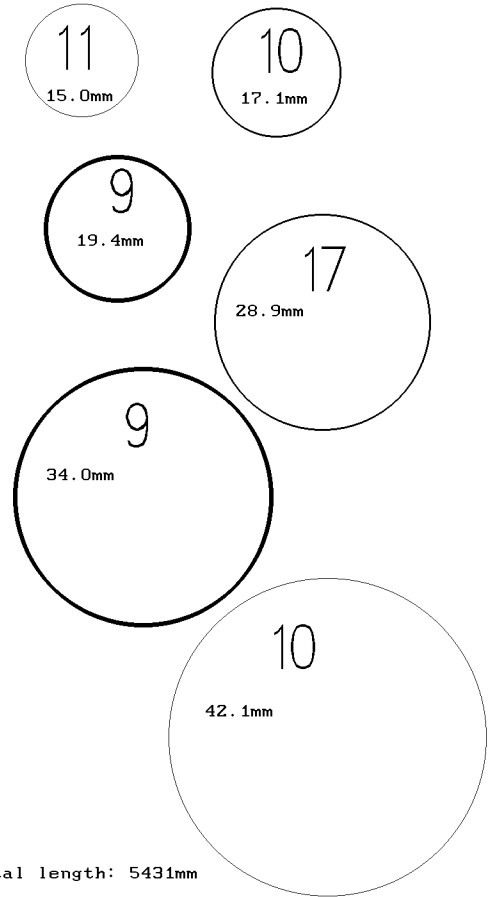
19



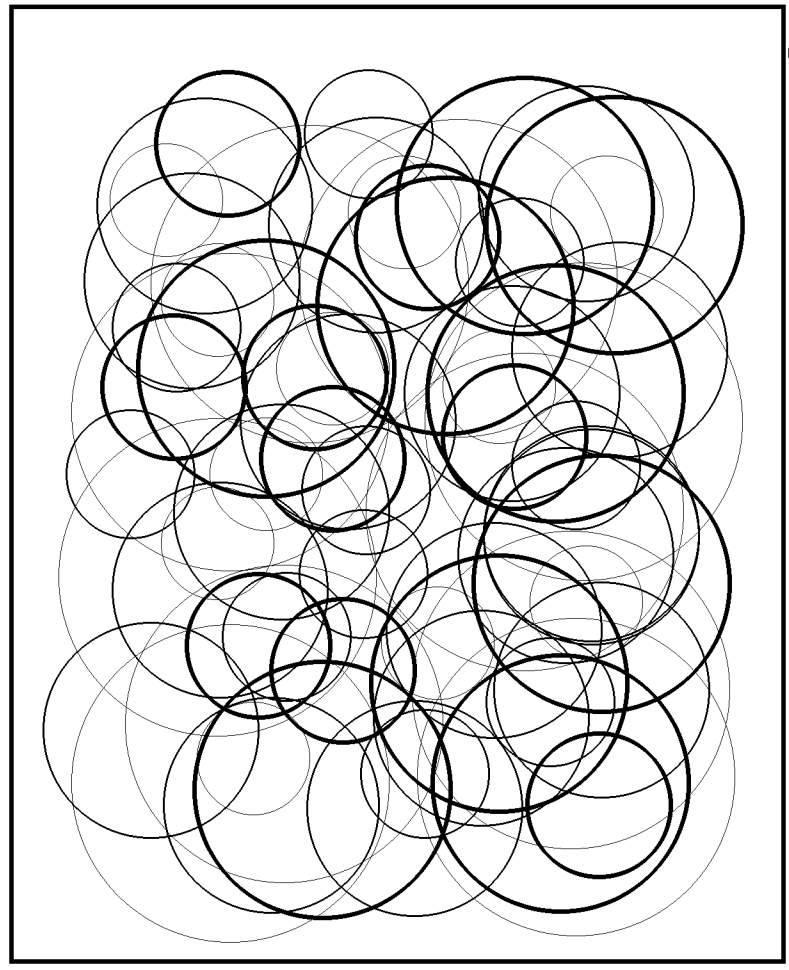
total length: 5059mm



20

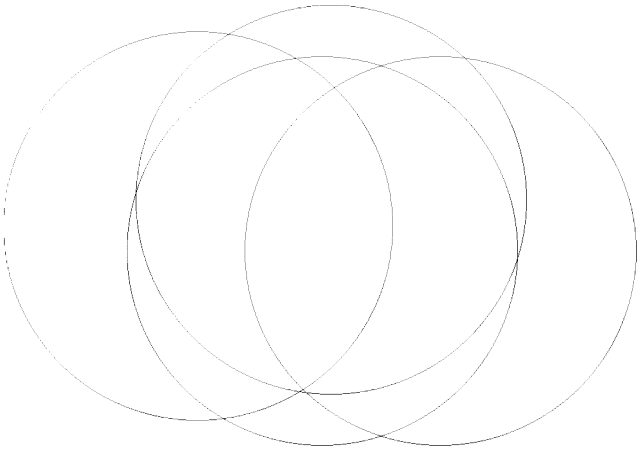


total length: 5431mm

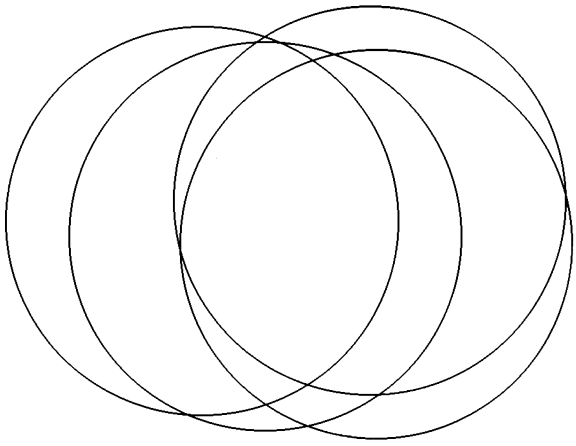


Thickness Test Targets

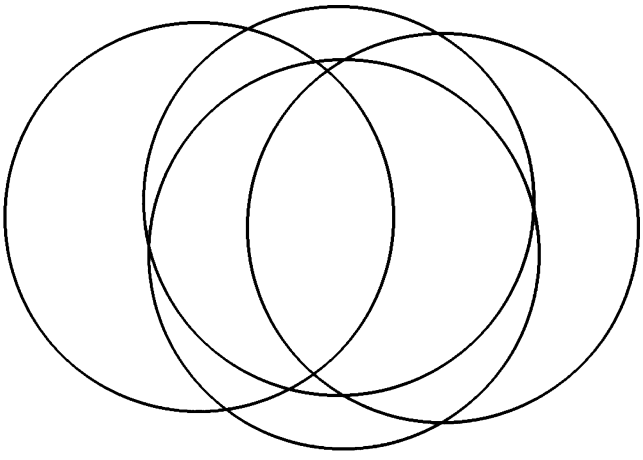
4 circles each, with equal line thickness



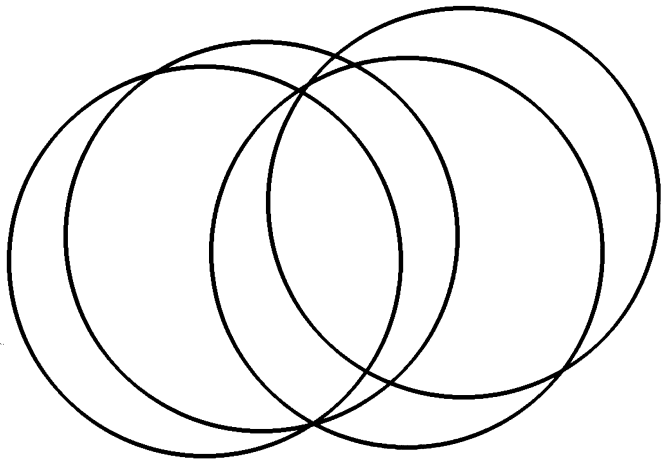
0.1 mm



0.25 mm

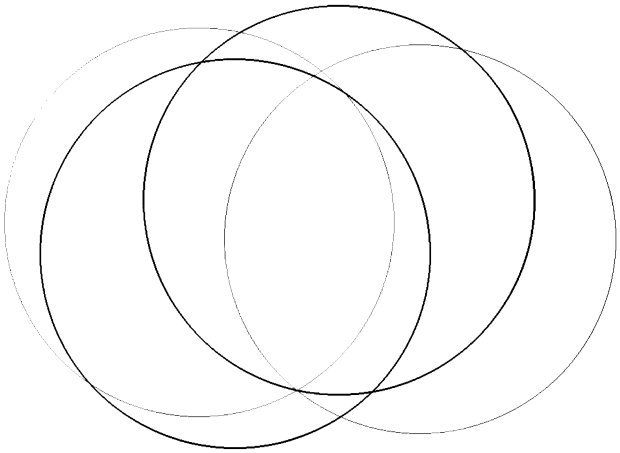


0.4 mm

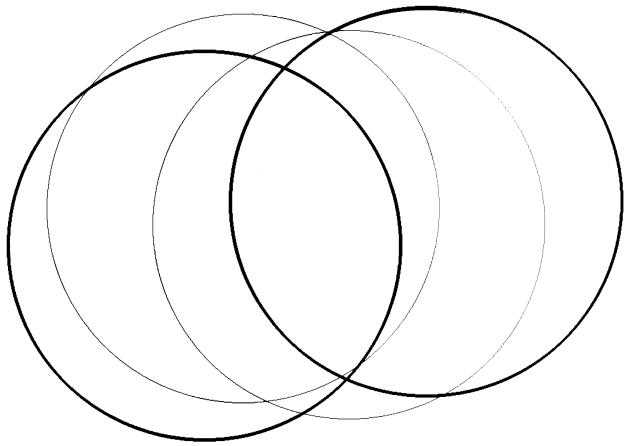


0.6 mm

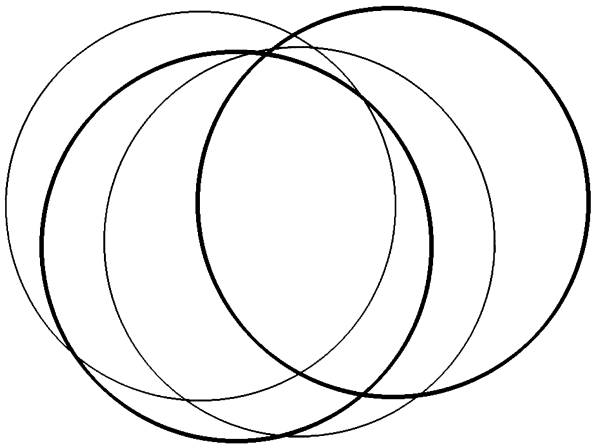
Thickness Test Targets
4 circles each, bimodal
and 4-modal line thicknesses



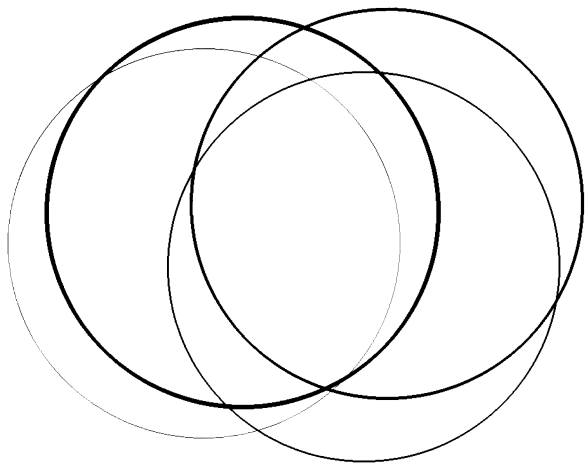
0.1 and 0.25 mm



0.1 and 0.4 mm



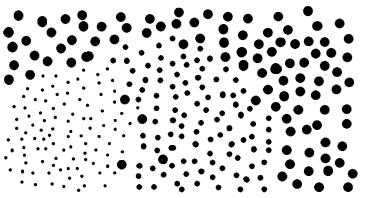
0.25 and 0.6 mm



0.1, 0.25, 0.4
and 0.6 mm

Particle Size Test Targets

100 small circles
0.45 mm diameter

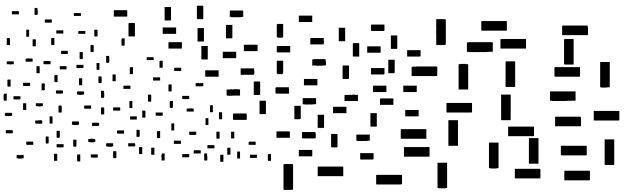


100 large circles
1.25 mm diameter

100 medium circles
0.75 mm diameter

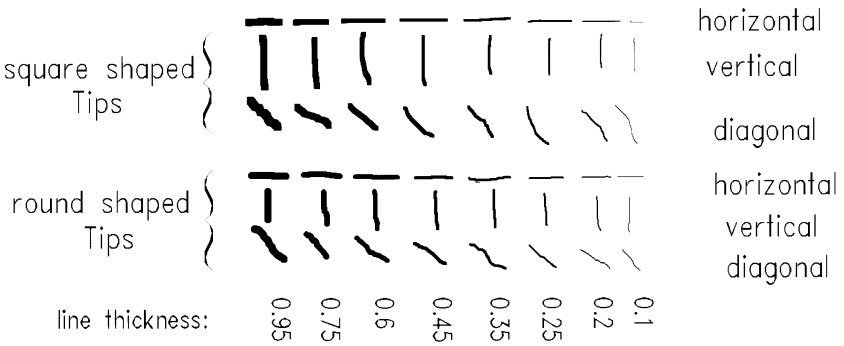
100 small rectangles
0.4 x 0.95 mm

50 medium rectangles
0.85 x 1.8 mm



30 large rectangles, 1.3 x 3.4 mm

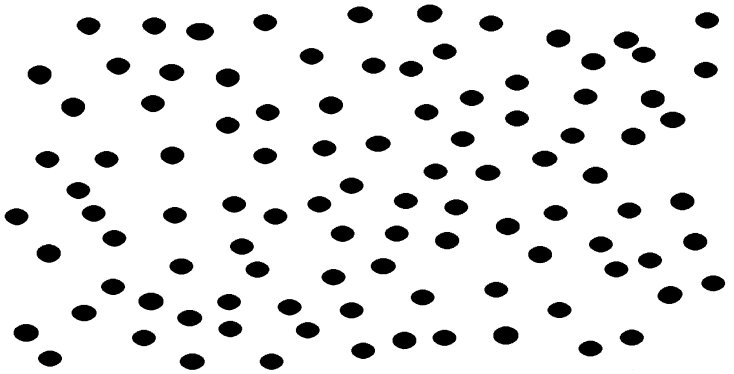
Tip Test Targets



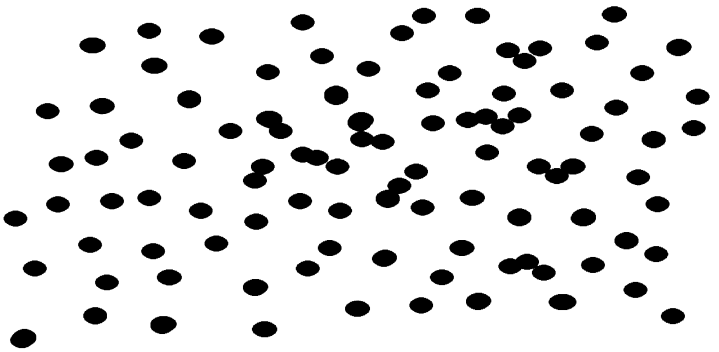
total number of tips: 96

Object Count Targets

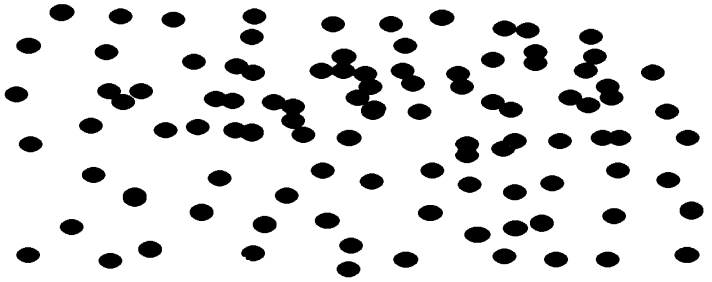
100 objects in each target



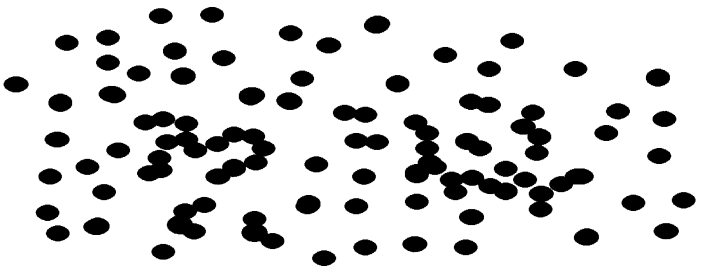
100 objects
not touchin



77 of 100 obje
not touching



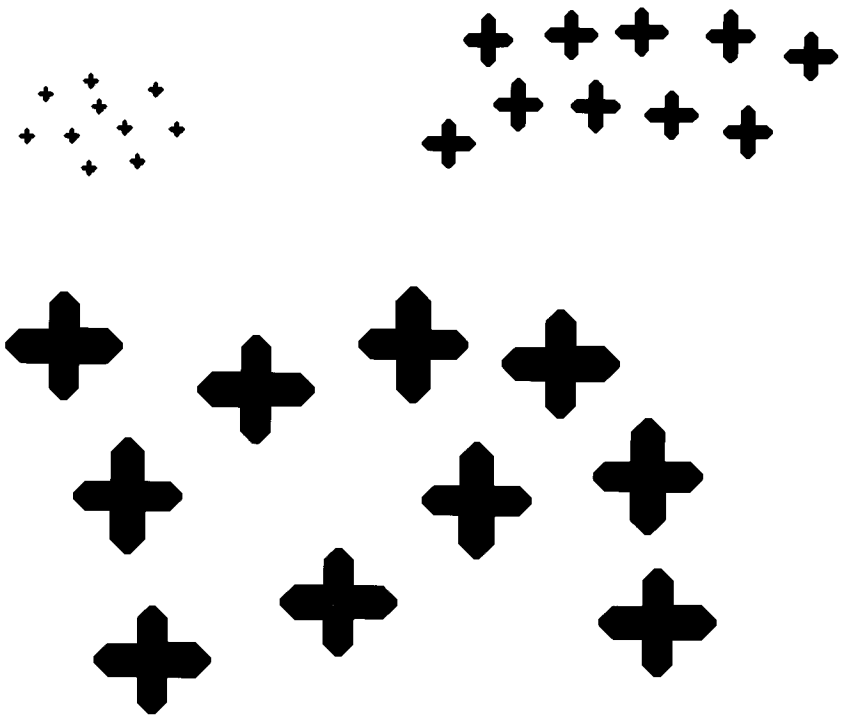
60 of 100 objects
not touching

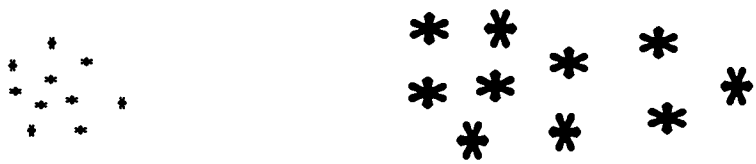


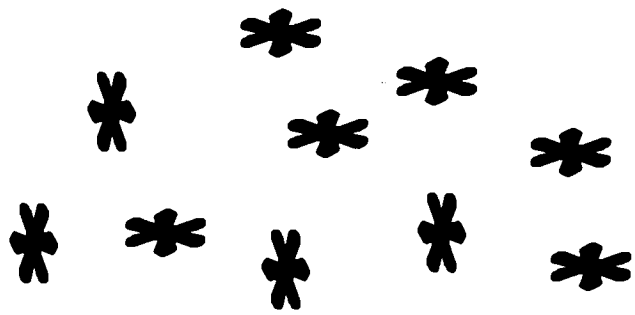
53 of 100 objects
not touching

39 of 100 obje
not touching

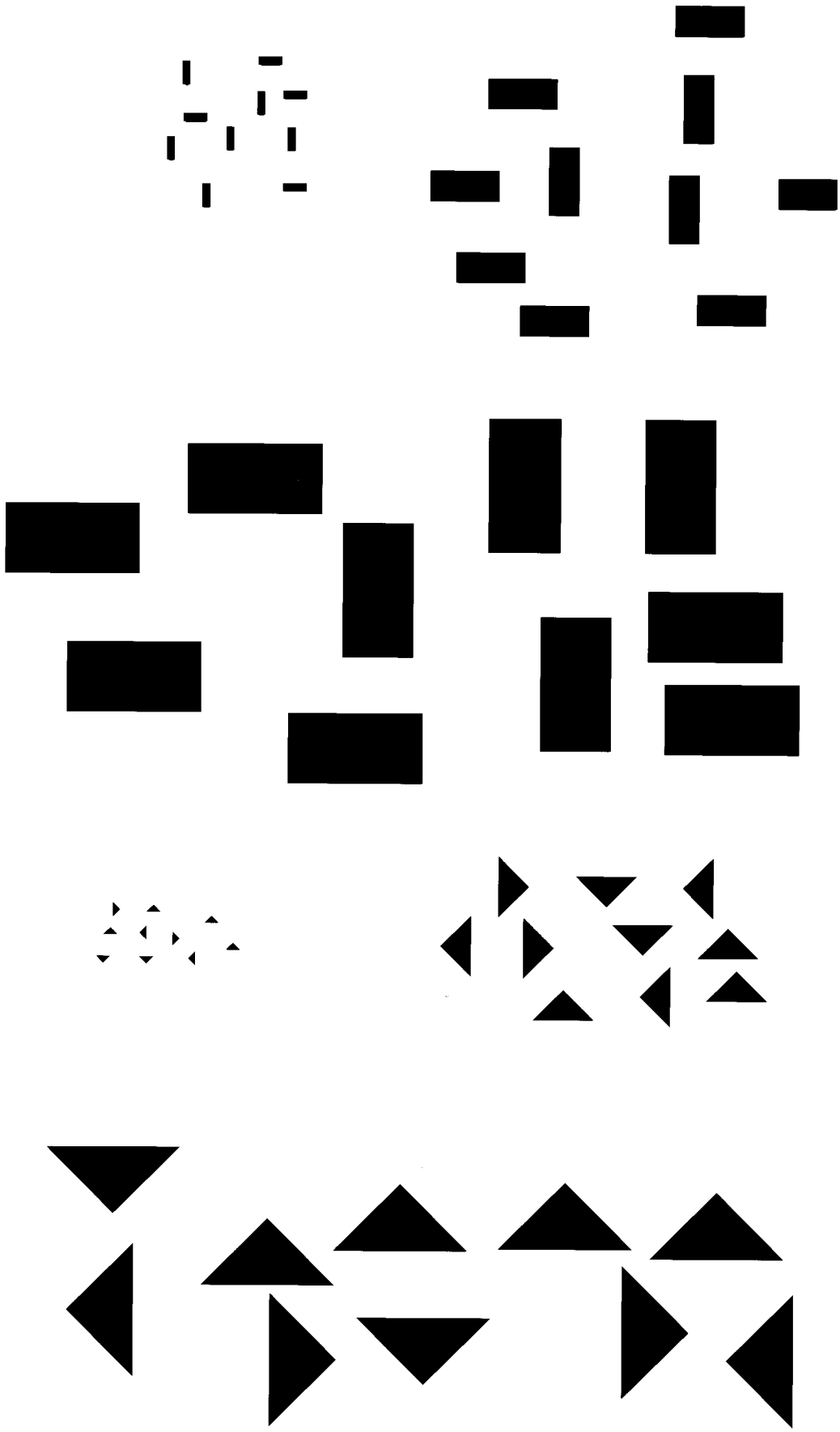
Shape Test Targets, irregular objects



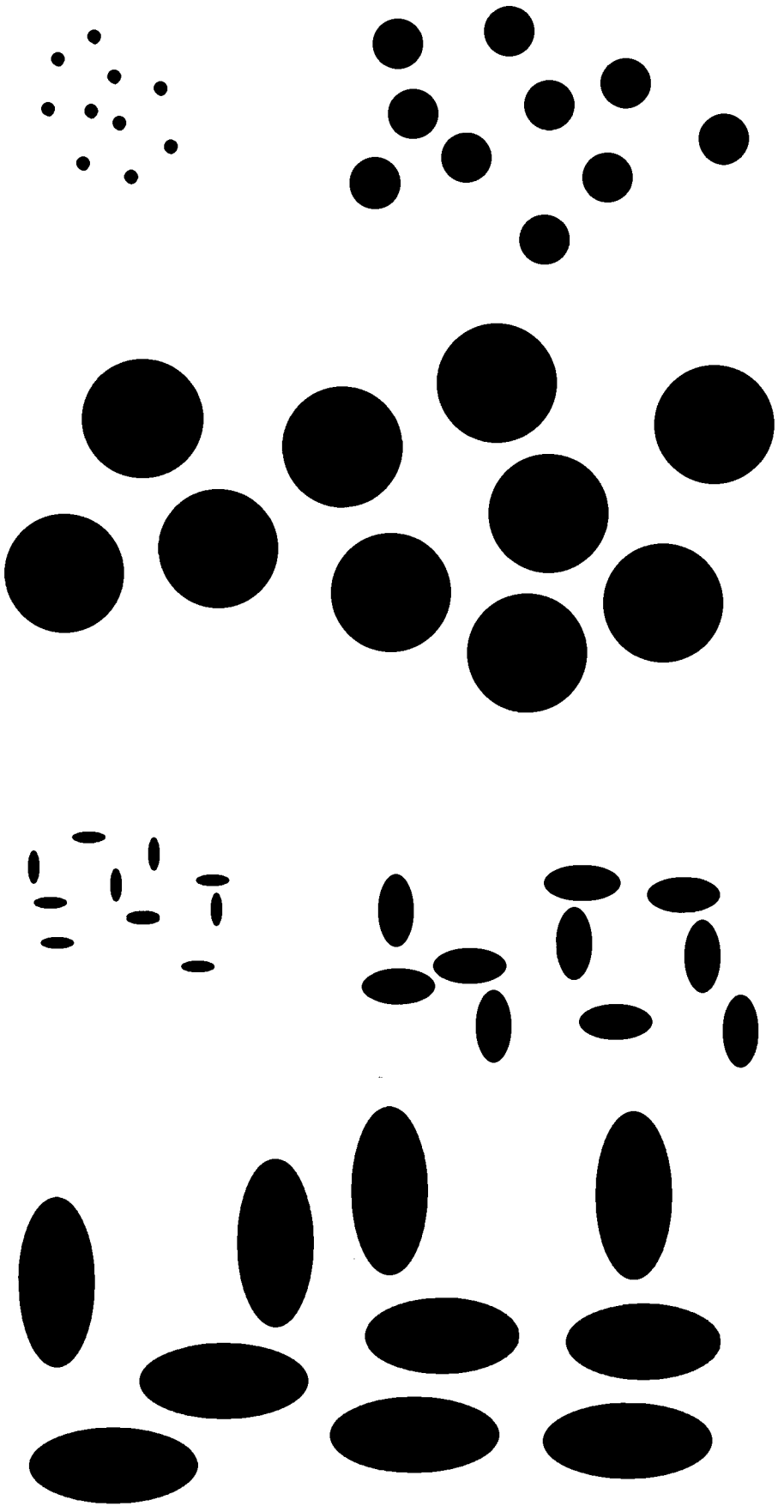




Shape Test Targets, angular objects



Shape Test Targets, rounded objects



TARGET SET B


DTS-1.pdf


DTS-2.pdf


DTS-3.pdf


DTS-4.pdf


DTS-5.pdf


DTS-6.pdf


DTS-7.pdf


DTS-8.pdf


DTS-9.pdf


DTS-10.pdf


DTS-11.pdf


DTS-12.pdf

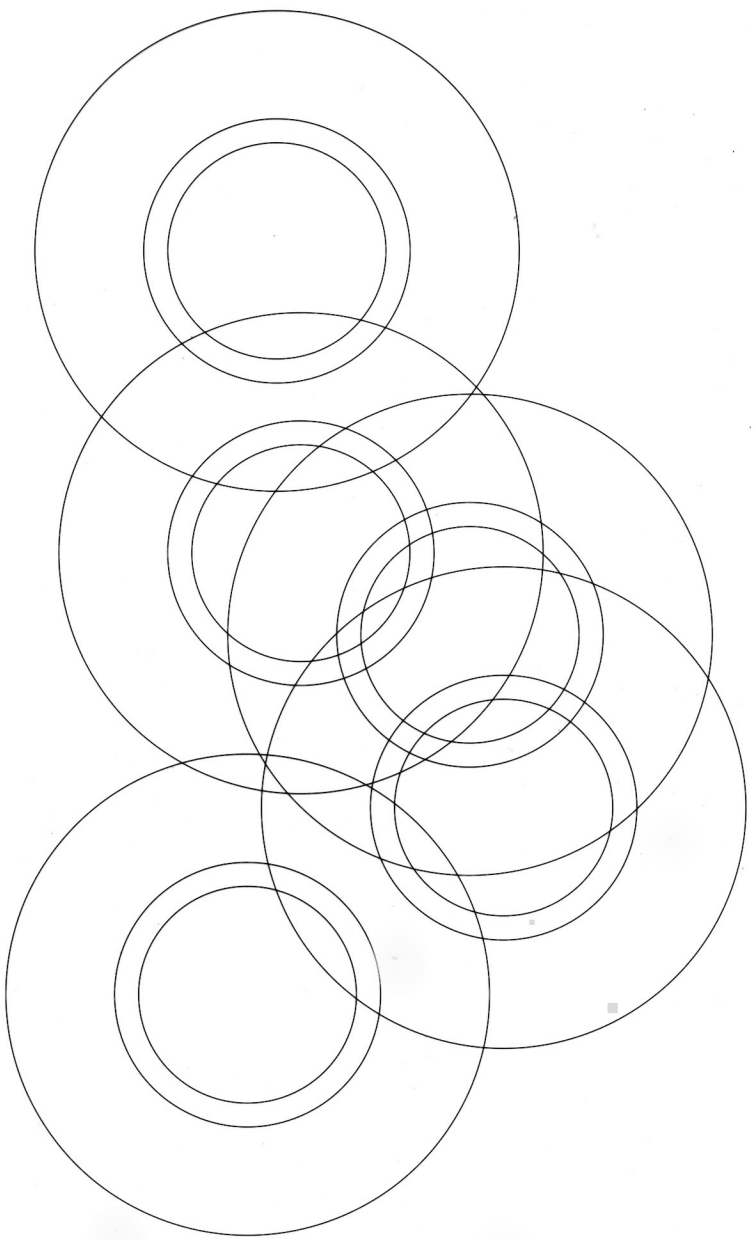

DTS-13.pdf


DTS-14.pdf

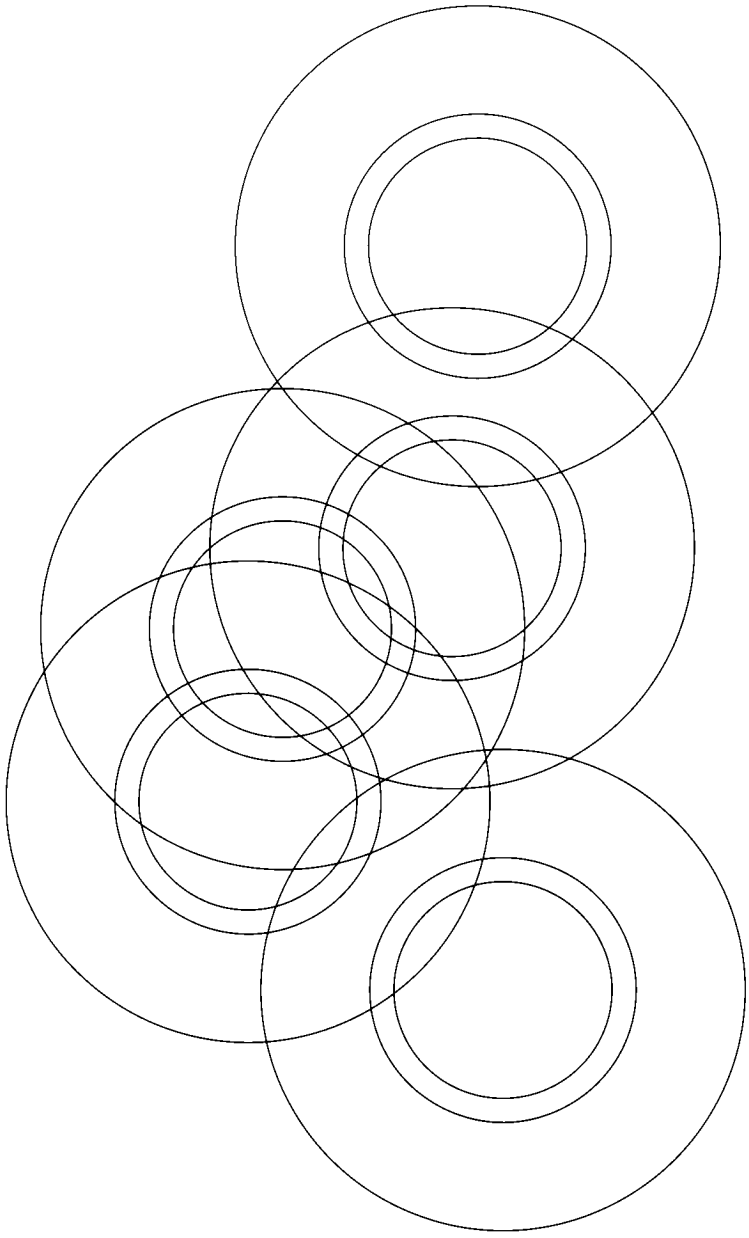

DTS-15.pdf


DTS-16.pdf

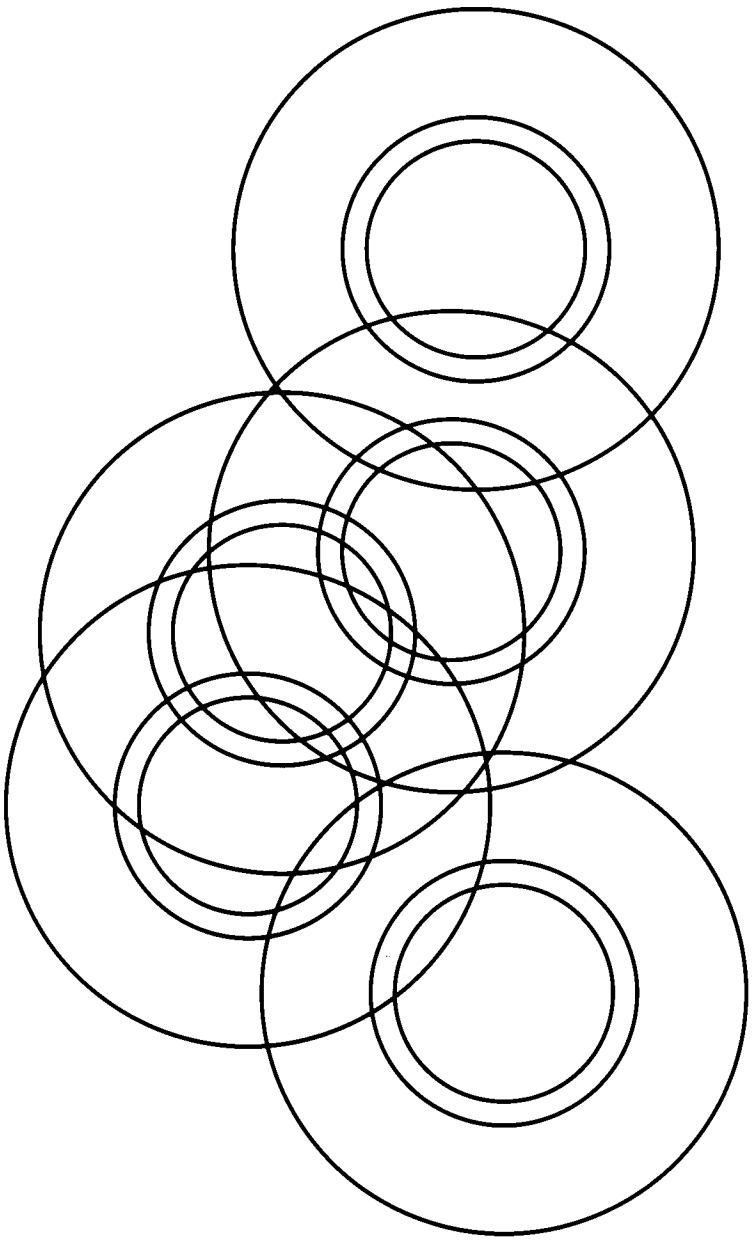
DTS-1 (copy)
2000 mm
0.127 mm



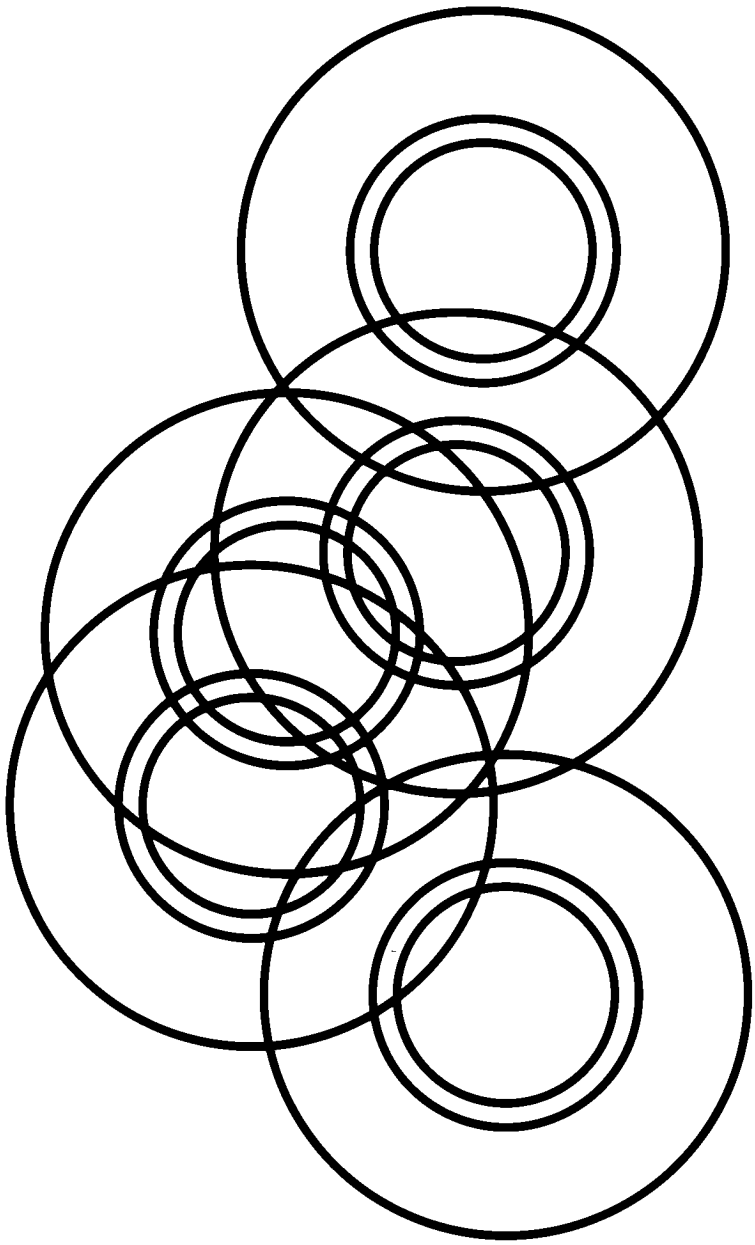
DTS-2 (copy)
2000 mm
0.2794 mm



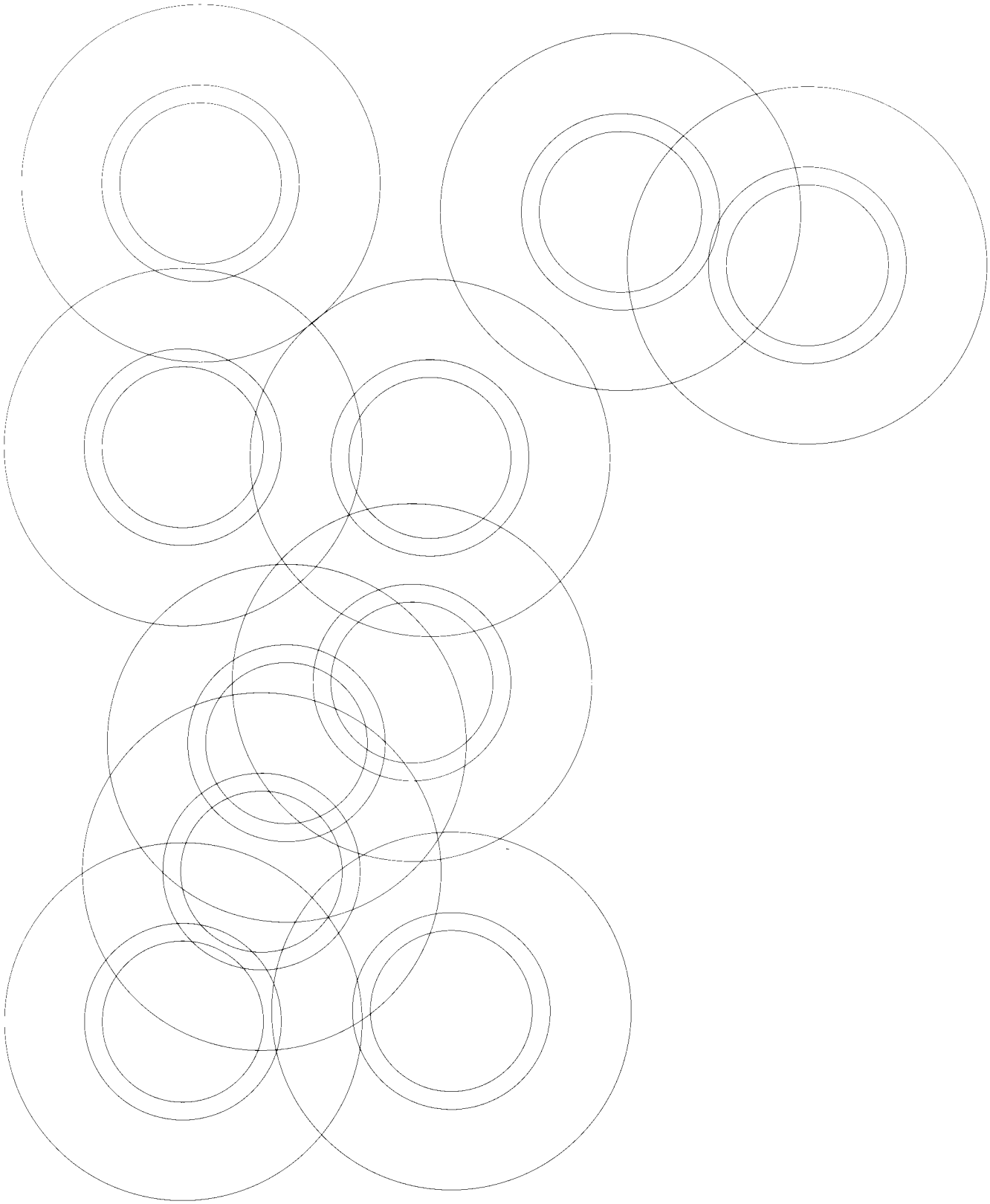
DTS-3 (copy)
2000 mm
0.5588 mm



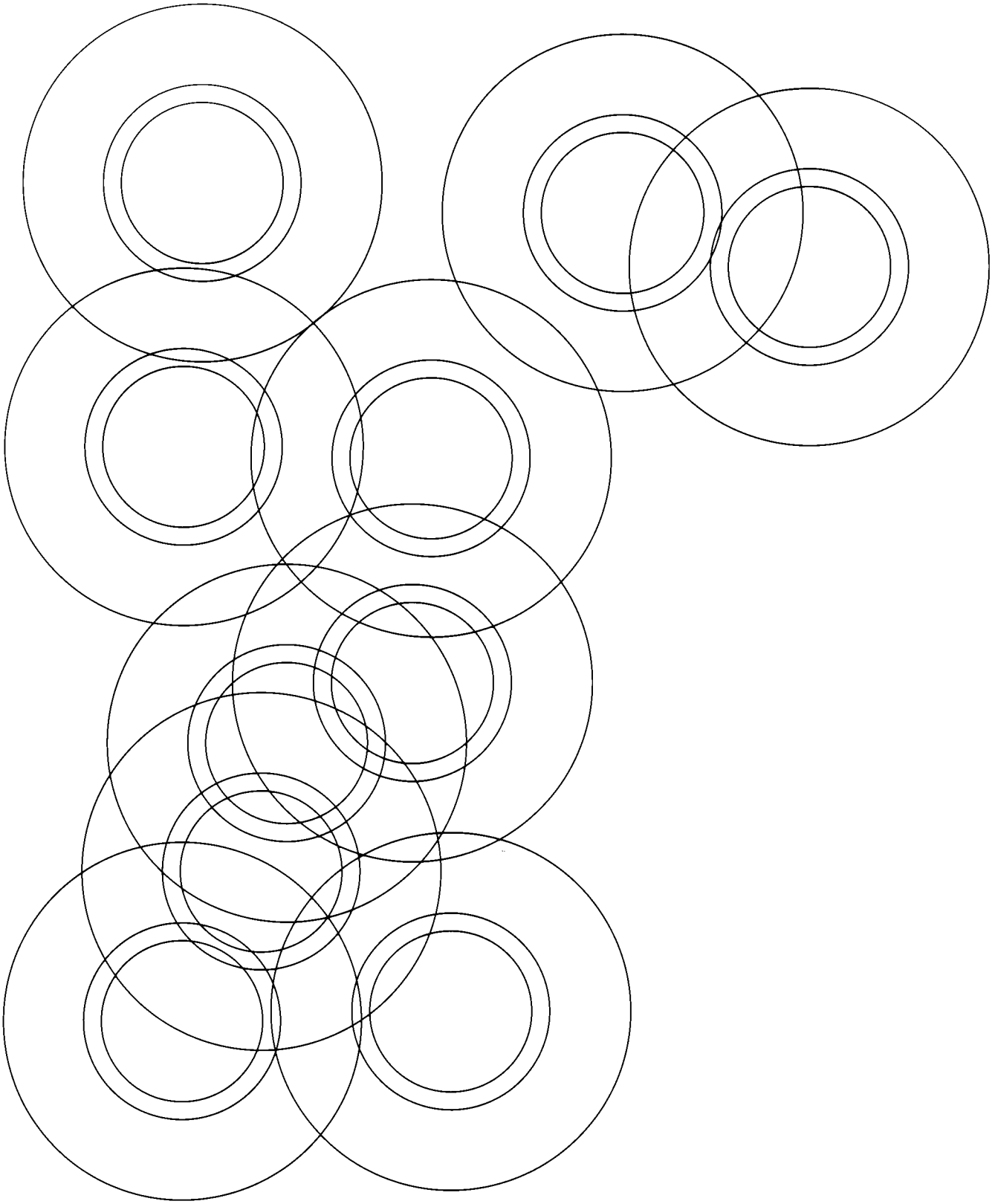
DTS-4 (copy)
2000 mm
0.5588 mm



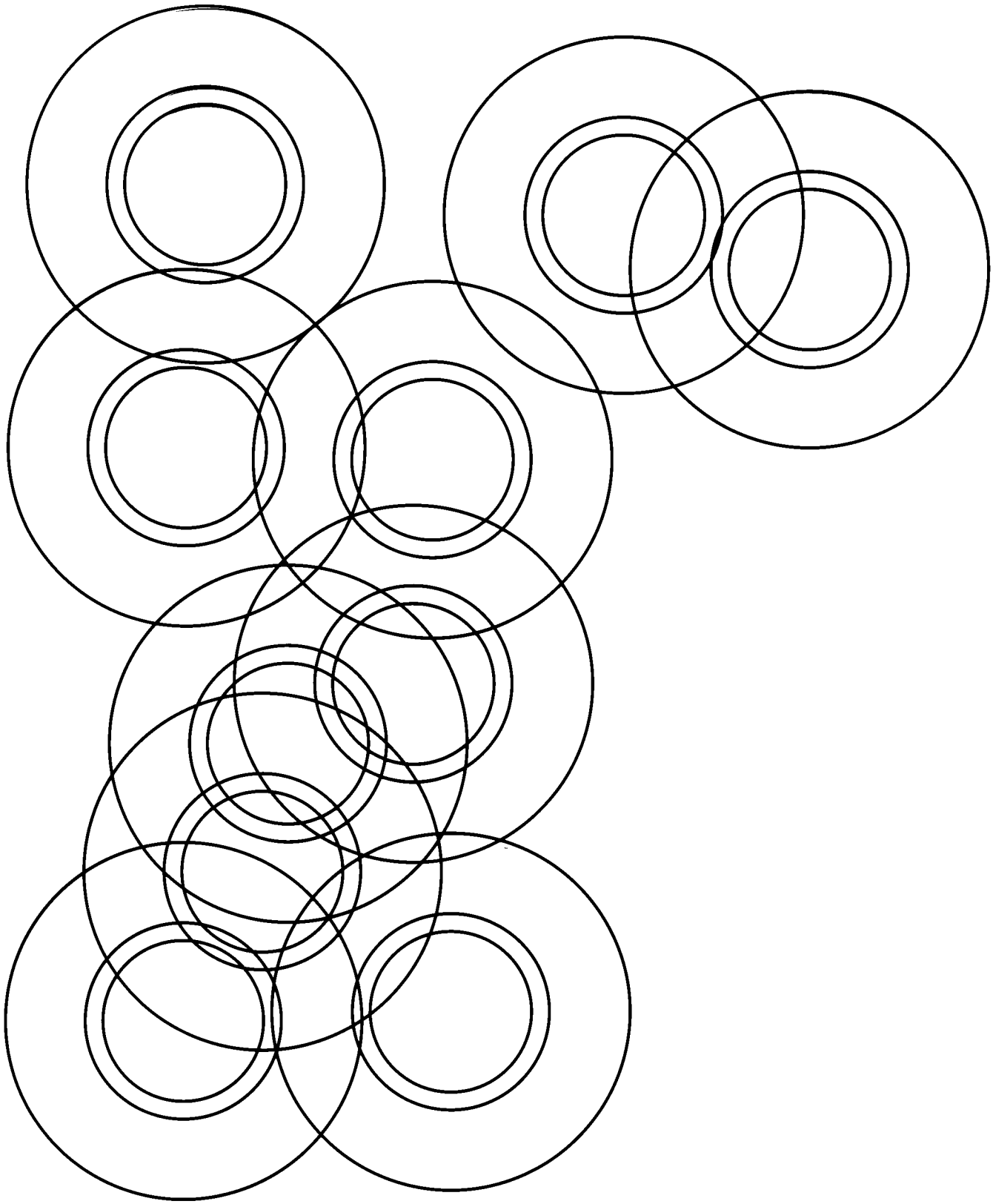
DTS-5 (copy)
4000 mm
0.127 mm



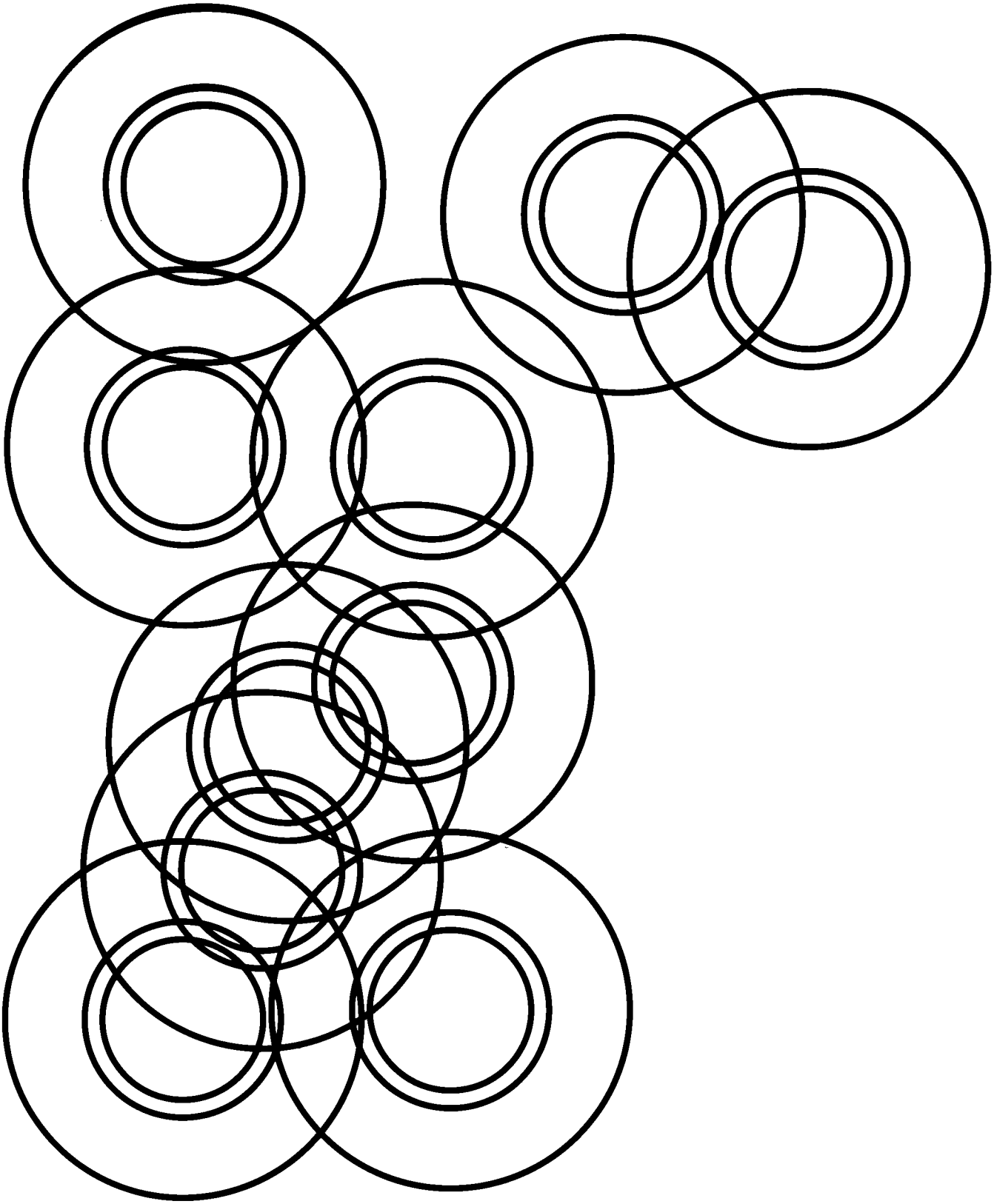
DTS-6
4000 mm
0.2794 mm



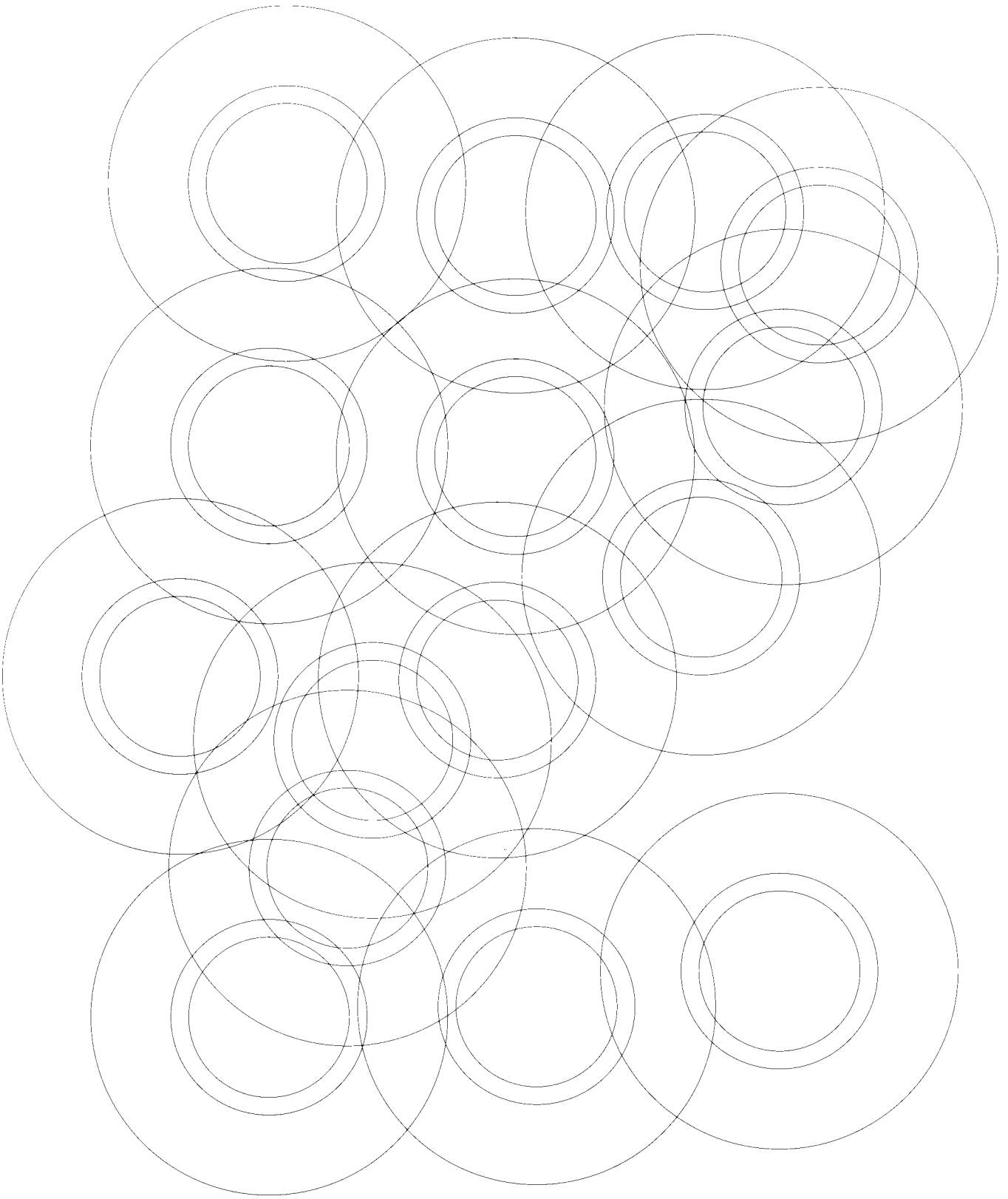
DTS-7 (copy)
4000 mm
0.5588 mm



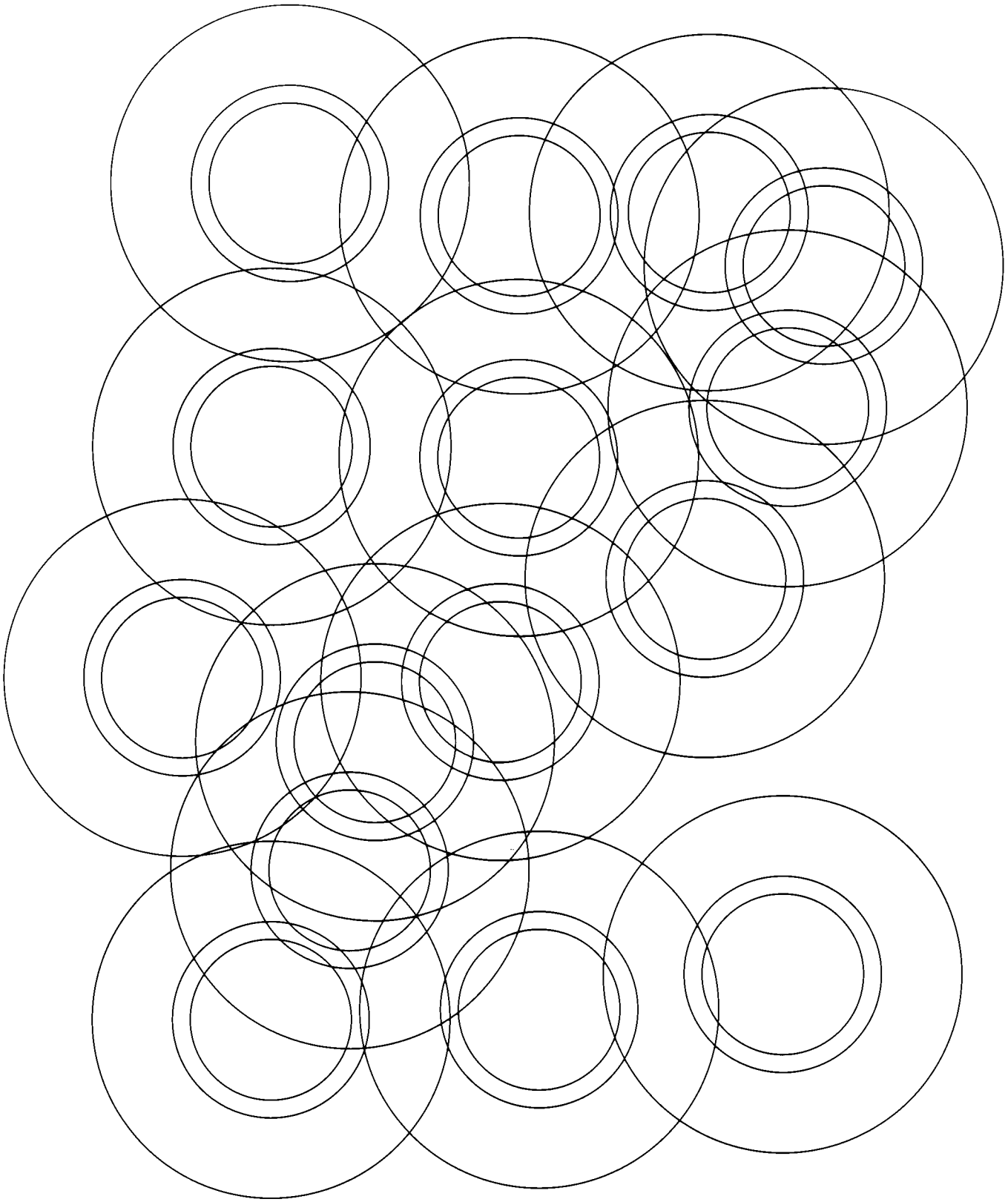
DTS-8 (copy)
4000 mm
1.1176 mm



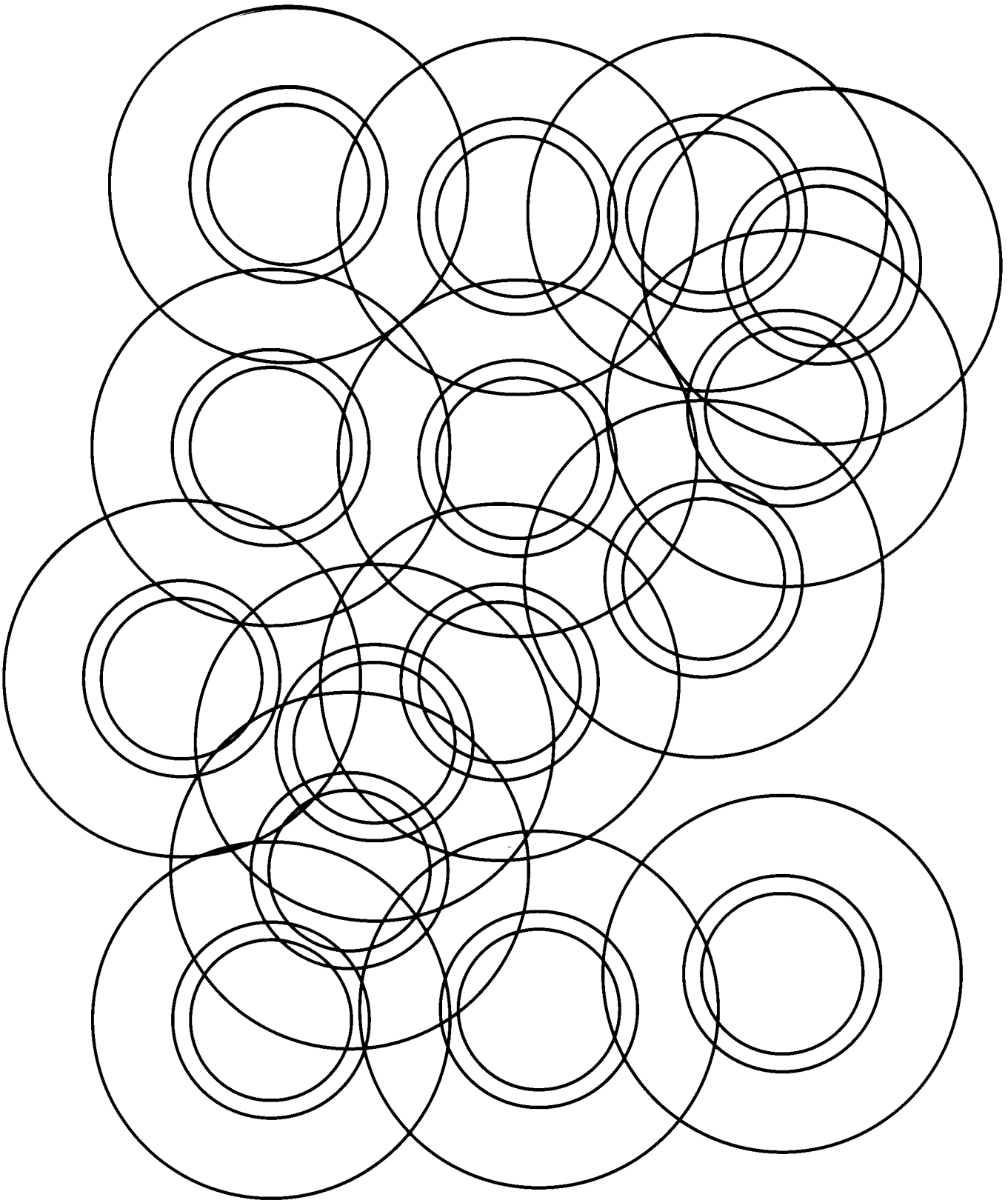
DTS-9 (copy)
6000 mm
0.127 mm



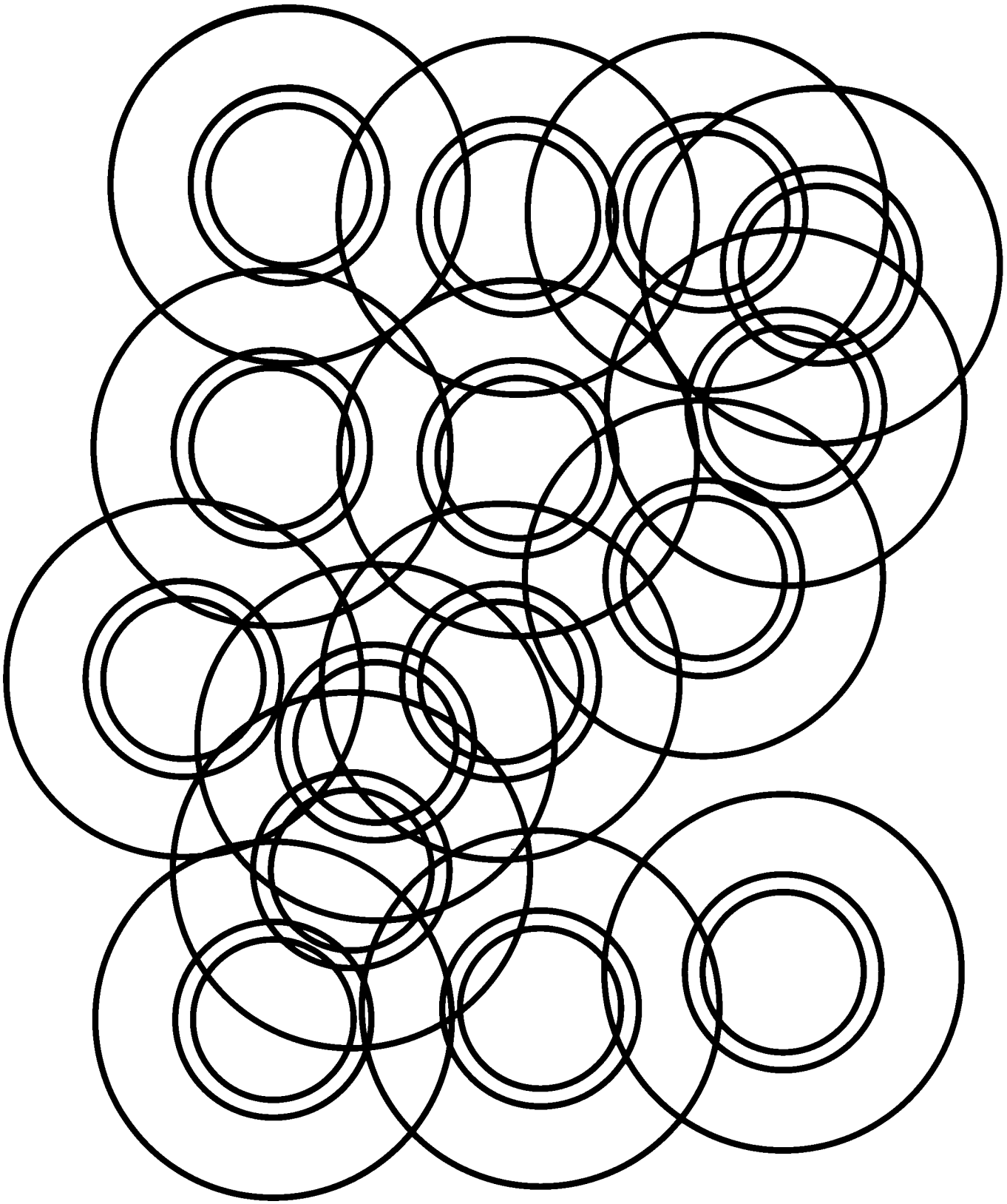
DTS-10
6000 mm
0.2794 mm

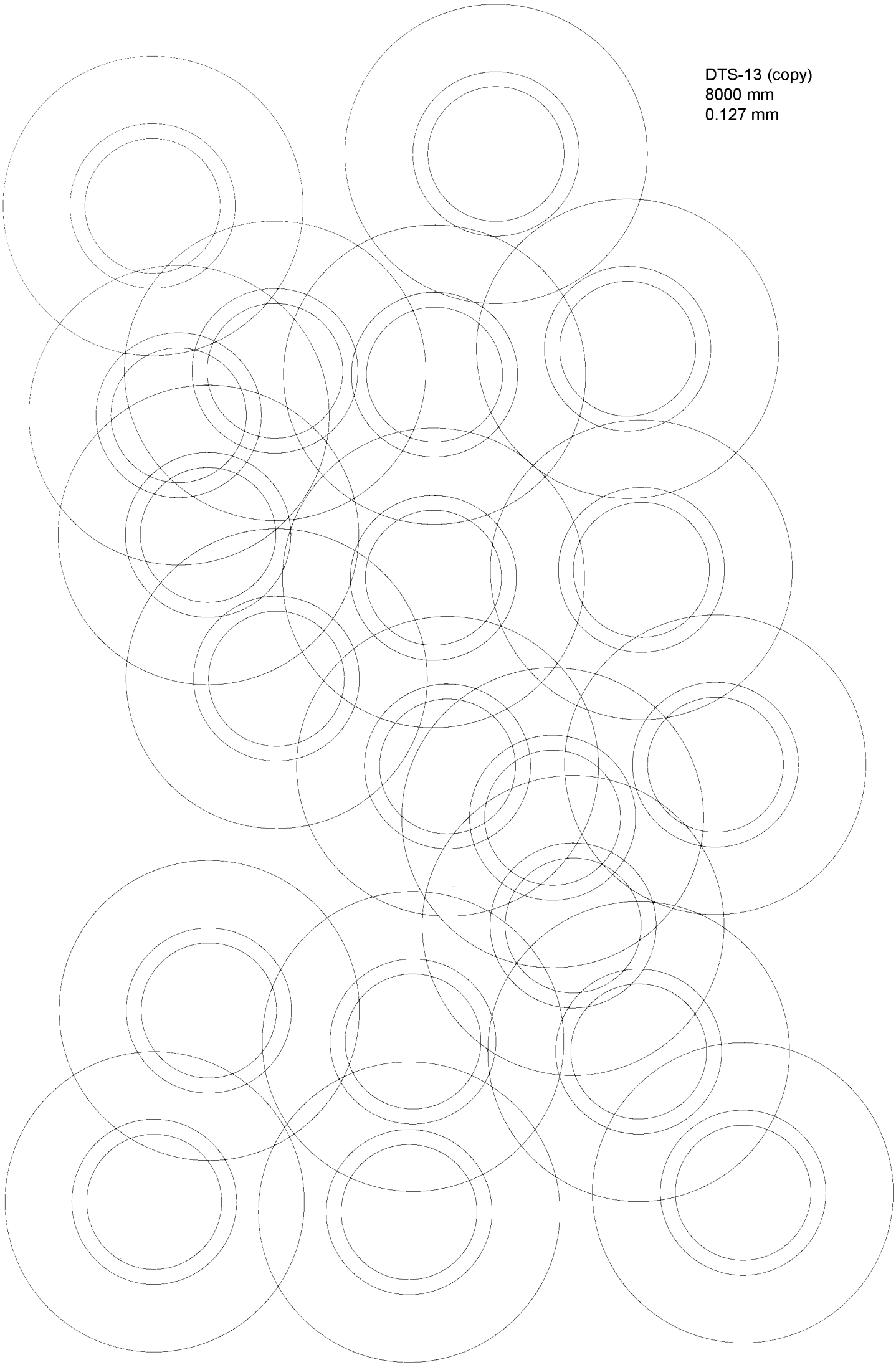


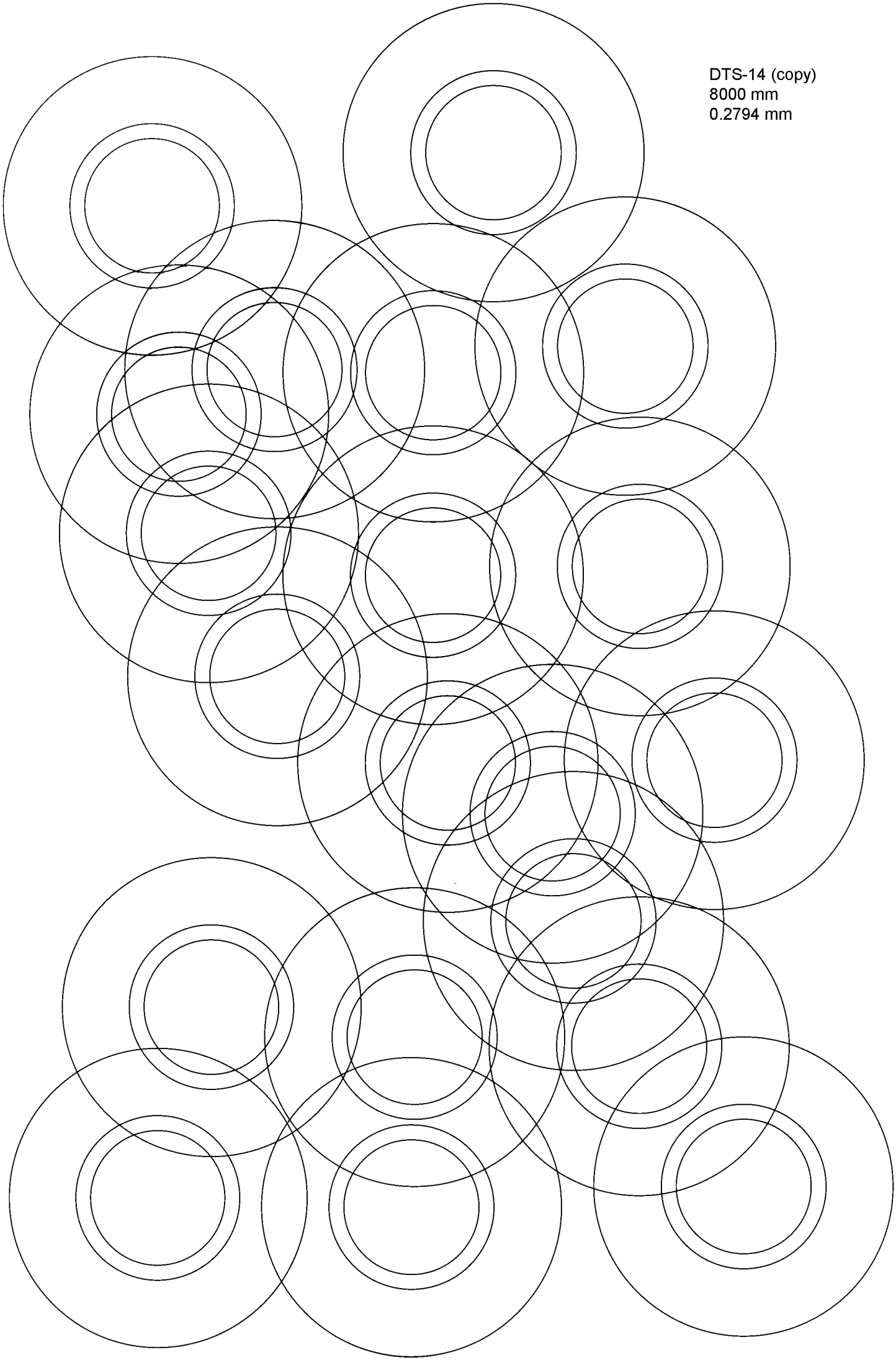
DTS-11 (copy)
6000 mm
0.5588 mm

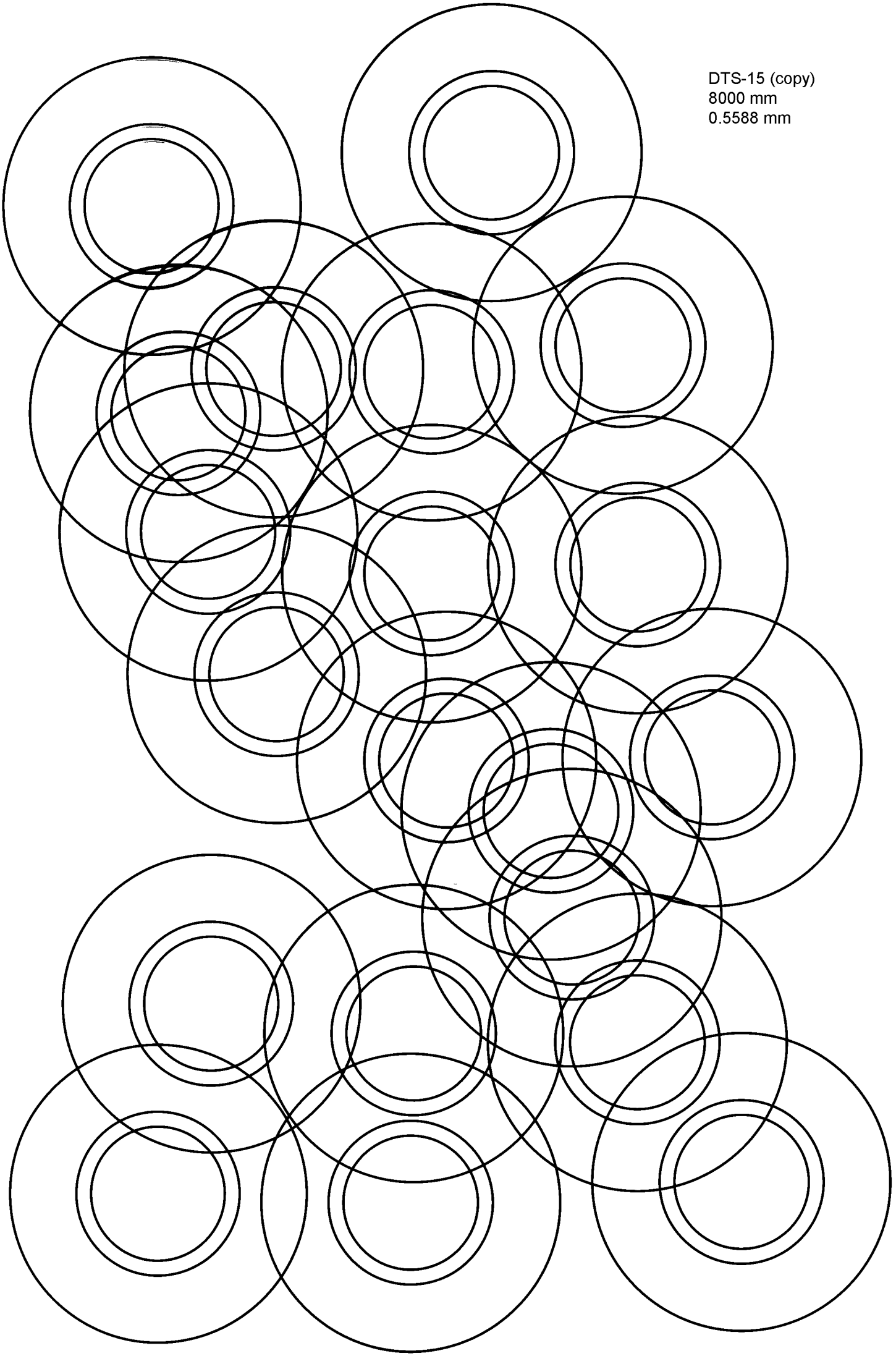


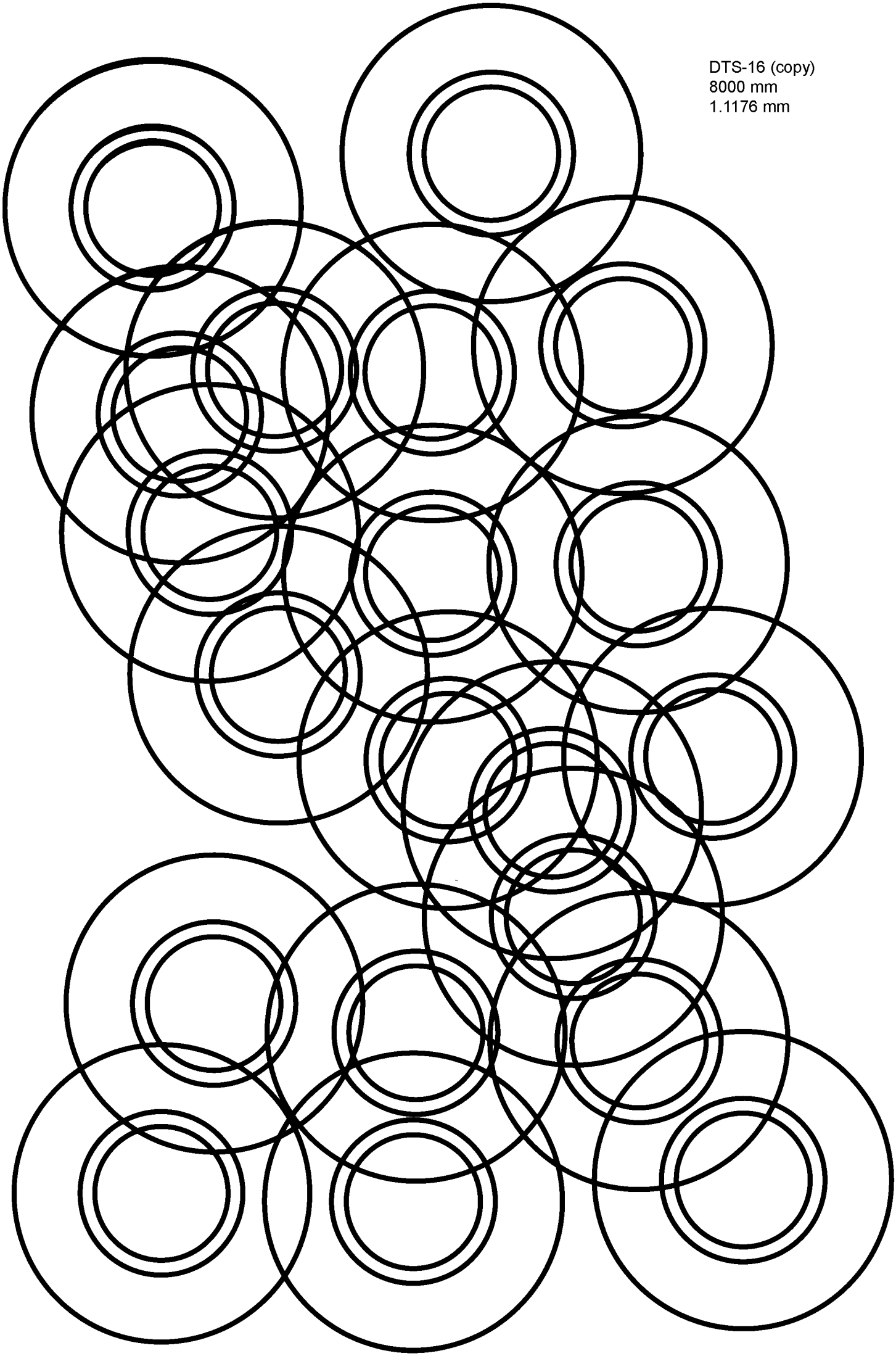
DTS-12 (copy)
6000 mm
1.1176 mm




DTS-13 (copy)
8000 mm
0.127 mm


DTS-14 (copy)
8000 mm
0.2794 mm


DTS-15 (copy)
8000 mm
0.5588 mm


DTS-16 (copy)
8000 mm
1.1176 mm

TARGET SET C

RTS.pdf

RTS (copy)
400 mm
0.5588 mm