UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2011/2012

January 2012

KAA 501 – Quality Control In Chemistry
[Kawalan Mutu Dalam Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of TWENTY FIVE pages of printed material before you begin the examination.

Instructions:

Answer **FIVE** (5) questions. **Section A** is **COMPULSORY**. Answer **TWO** (2) questions from **Section B**. If a candidate answers more than five questions only the first five questions in the answer sheet will be graded.

Answer each question on a new page.

You may answer the questions either in Bahasa Malaysia or in English.

In the event of any discrepancies, the English version shall be used.

Appendices: AQL Sampling Table based on the Mil-STD-105D
Cumulative standard normal distribution (values of the probability ϕ corresponding to the value Z_ϕ of a standard normal random variable)
Plackett and Burman Design for 11 factors
Constants for the construction of control charts
Table of the Standard Normal Cumulative distribution Function $\Phi(z)$

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SECTION A

1. The following data concerns the thickness of nonmagnetic coatings of zinc. Two measurements are made on the same specimen. The first uses a method involving electron probe microanalyzer (EPMA) while another involves a scanning electron microscope-energy dispersive spectrometry (SEM-EDS).

Specimen	EPMA (μm)	SEM-EDS (μm)
1	105	116
2	120	132
3	85	104
4	181	139
5	115	114
6	127	129
7	630	720
8	155	174
9	250	312
10	310	338
11	443	465

i. Explain what is meant by a Type I error and Type II error.

ii. At the 0.05 level of significance, is there evidence of a difference in the average measurement of thin layer thickness using the two methods?

iii. What would be the results if the inappropriate t-test for two independent samples is used?

iv. Explain the difference between the results in (ii) and (iii)

(20 marks)

2. When checking large batches of goods, the following acceptance sampling plans are considered:

Plan 1: A sample of size 50 is inspected and the batch is accepted if three or fewer non-conforming items are found. Otherwise, the batch is rejected.

Plan 2: A sample of size 30 is inspected and the batch is accepted if zero or one non-conforming item is found. If three or more are found, the batch is rejected. If two non-conforming items are found, a further sample of size 30 is taken and the batch is accepted if a total of four or fewer (out of 60) non-conforming items are found. Otherwise, it is rejected.

(a) For each sampling plan, calculate the probability of accepting the batches containing 2, 5 and 10% non-conforming items. Sketch the operating characteristics of each plan.

(12 marks)

(b) For the second plan, evaluate the expected number of items inspected each time the plan is used when the proportion of non-conforming in the batch is 0.02 and 0.10.

(4 marks)

(c) Discuss the factors which need to be considered when deciding which of the two plans is to be used.

(4 marks)

(Given: The binomial formula $P(d \leq c) = \sum_{d=0}^{c} [n!/d!(n-d)!] p^d (1-p)^{n-d}$

3. The water supply resources for a town were routinely analyzed for lead content. Five water samples were drawn each day in a 20 day period. The lead content in ppb for each location sampled in one geographical area over a 20-day period is presented in the following table.

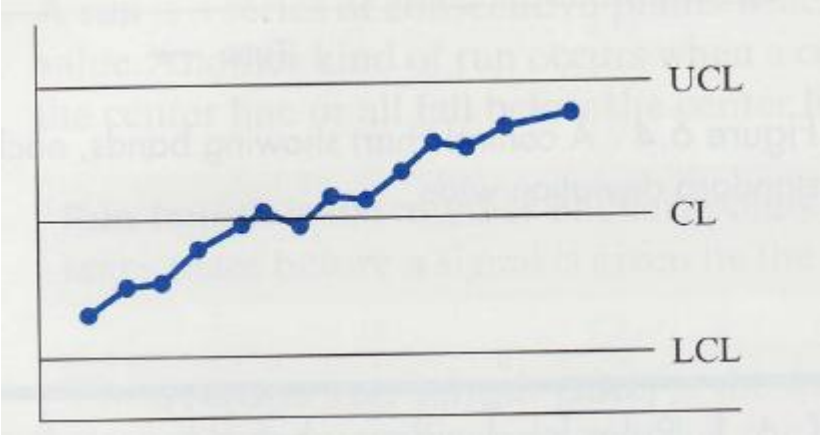
	Water Samples (ppb)							
Day	1	2	3	4	5	X-bar	R_i	S_i
1	13	8	2	5	8	7.2	11	4.09
2	0	6	1	9	15			
3	4	2	4	3	4	3.4	2	0.89
4	3	15	8	3	5	6.8	12	5.02
5	5	10	5	4	0	4.8	10	3.56
6	9	5	13	7	7	8.2	8	3.03
7	0	4	4	3	9			
8	9	3	0	6	0	3.6	9	3.91
9	14	0	0	5	3	4.4	14	5.77
10	3	9	5	0	2	3.8	9	3.42
11	5	8	0	7	8	5.6	8	3.36
12	3	2	2	7	4	3.6	5	2.07
13	5	11	14	8	3	8.2	11	4.44
14	13	5	5	12	7	8.4	8	3.85
15	7	0	1	0	6	2.8	7	3.42
16	12	7	10	4	13	9.2	9	3.70
17	9	4	4	8	9	6.8	5	2.59
18	6	1	1`	3	13	4.8	12	5.02
19	7	0	5	7	2	4.2	7	3.11
20	10	0	10	12	7	7.8	12	4.71

i. Fill up the blanks in the table.

ii. Produce an X-bar and R-bar charts.

iii. Comment on the stability of the analytical process.

iv. What will be your analysis of the analytical process if the following control chart was obtained instead?



(20 marks)

SECTION B

4. (a) In the tablet manufacture of a certain drug, the following process parameters from 20 samples of size n = 4 were observed. The target weight of the tablet was 65.5 mg with a tolerance of ± 1.25 mg. The process is stable with a mean of 65.6 mg and the UCL and LCL are 66.86 and 64.34 mg, respectively.

   i. What are the values of C_p and C_{pk} of the tablet manufacturing process?

   ii. Assuming that the output is normally distributed, what proportion of drug tablets can be expected to be non-conforming?

   iii. If the specifications were changed to 65.5 mg ± 2 percent of the target weight, what would be the values of C_p and C_{pk}.

   (10 marks)

   (b) For the use of chemicals and consumables, discuss the following aspects: grade, labeling, storage, safety and disposal.

   (10 marks)

5. (a) Differentiate the differences between the following method validation parameters:

   i. Specificity and selectivity

   ii. Reproducibility and repeatability

   iii. Limit of detection (LOD) and limit of quantification (LOQ)

   iv. Sensitivity and linearity

   (8 marks)

(b) The determination of 6 replicates of a standard solution of 2.0 ppm Cd in water using atomic absorption spectroscopy yielded the following results.

Sample	Values Observed (ppm)
1	1.6
2	1.7
3	1.9
4	1.7
5	1.9
6	1.7

i. Assess the precision and accuracy of the method.

ii. Determine the method detection limit (MDL) and limit of quantification (LOQ).

iii. Calculate the coefficient of variation for this method. Based on the modified Horwitz equation, provide the expected coefficient of variation (CV) for this method. Comment on the comparison between your calculated CV against the expected CV.

iv. Is this method fit for the purpose of determining Cd in water at the estimated concentration level of 0.05 ppm ? Justify your answer.

(12 marks)

6. (a) A HPLC method was described for the determination of phenantrene, a polyaromatic hydrocarbon (PAH) substance in water. The solution is a standard solution containing 125 mg L^{-1} of the PAH substance in acetonitrile. Chromatographic conditions: A 25 cm stainless steel - μBondapack C18 column and the mobile phase was a mixture of 1:1 water/acetonitrile. A flow rate of about 1.5 $mLmin^{-1}$ and ambient temperature was used. The UV detector set at wavelength 254 nm was used to detect the analyte. This method was selected for a robustness test in order to see the effect of variability within various parameters of the HPLC. The results of the robustness test are provided in the table below. Eight factors were selected from the operating procedure for examination in a Plackett-Burman design for 11 factors (N = 12). Therefore three dummy factor columns have to be included. The responses determined in this robustness test are the percent recoveries of phenantrene and are given in Table I while some of the calculated effect are given in Table II.

Table I

Experimental runs	**Recoveries (%)**
1	101.4
2	102.7
3	101.3
4	102.9
5	99.1
6	101.7
7	101.4
8	98.8
9	101.8
10	99.3
11	98.7
12	103.1
Mean	101.0
RSD	1.61

Table II

Factors	**Effects**
pH	0.000
Column	-0.300
Dum1	
Temp	-0.367
%B begin	-1.067
%B end	0.467
Dum2	
Flow	-0.300
Wavelength	
Buffer Conc.	1.100
Dum3	

i. Calculate the effects for Dum 1, Dum 2, Dum 3 and wavelength factors.

ii. Use half normal plot to identify factors that are not robust used in this method.

iii. Use the statistical method via estimation of standard error using dummy factors for identifying non-robust factors.

iv. Use the algorithm of Dong to determine the non robust factors

(14 marks)

(b) Plackett-Burman experimental design is a form of fractional factorial design. Define the following terms which relate to the experimental design.

i. Full factorial design

ii. Two level screening design

iii. Confounding effect

(6 marks)

7. (a) Outline the differences between X-bar control chart, exponentially weighted moving average chart (EWMA) and cumulative sum (CUSUM) control charts.

(6 marks)

(b) Briefly differentiate between ISO 17025 and ISO 9000. Outline the normal procedure and preparation for your laboratory to obtain ISO 17025 accreditation. Finally differentiate between accreditation and certification

(9 marks)

(c) An inter-laboratory study was carried out by 10 laboratories to determine Fe in palm oil and 50 determinations were carried out in total. The standard deviations (*s*) of the data obtained by each laboratory are as follows:

Lab	1	2	3	4	5	6	7	8	9	10
s	6.47	3.83	3.51	4.16	5.89	8.92	5.63	6.28	5.63	5.50

Use Cochran's test to determine whether laboratory 6 has failed the inter-laboratory test and could not be awarded the ISO17025 accreditation status.

(5 marks)

BAHAGIAN A

1. Data berikut merujuk kepada ketebalan saduran zink bukan magnetic. Dua pengukuran dilakukan ke atas setiap spesimen yang sama. Kaedah pertama melibatkan prob elektron penganalisis mikro (EPMA) manakala kaedah kedua

melibatkan mikroskop imbasan elektron-spektrometri sebaran tenaga (SEM-EDS).

Spesimen	EPMA (µm)	SEM-EDS (µm)
1	105	116
2	120	132
3	85	104
4	181	139
5	115	114
6	127	129
7	630	720
8	155	174
9	250	312
10	310	338
11	443	465

i. Jelaskan apa yang dimaksudkan dengan ralat Jenis I dan ralat Jenis II.

ii. Pada paras bernilai 0.05, apakah terdapat bukti terhadap perbezaan dalam purata pengukuran ketebalan lapisan nipis menggunakan kedua-dua kaedah ini?

iii. Apakah hasil yang akan diperolehi sekiranya ujian t untuk sampel tak bersandar yang digunakan ?

iv. Jelaskan perbezaan yang diperolehi di antara hasil daripada (i) dan (iii).

(20 markah)

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2. Apabila menyemak kelompok barang yang besar, rancangan pensampelan penerimaan yang berikut dipertimbangkan:

Rancangan 1: Sebanyak 50 item diperiksa dan kelompok itu diterima jika tidak melebihi tiga item yang tidak mematuhi ditemui. Sebaliknya, kelompok itu ditolak.

Rancangan 2: Sebanyak 30 item diperiksa dan kelompok itu diterima jika tidak melebihi satu item yang tidak mematuhi ditemui. Jika tiga atau lebih yang tidak mematuhi ditemui, kelompok itu ditolak. Jika dua item yang tidak mematuhi ditemui, sebanyak 30 item diperiksa lagi dan kelompok itu diterima jika tidak melebihi empat item (daripada sejumlah 60 item) yang tidak mematuhi ditemui. Sebaliknya, kelompok itu ditolak.

(a) Bagi setiap rancangan pensampelan, kirakan kebarangkalian untuk menerima kelompok yang mengandungi 2, 5 dan 10% item yang tidak mematuhi. Lakarkan lengkungan ciri-ciri pengoperasian bagi setiap rancangan.

(12 markah)

(b) Bagi rancangan yang kedua, nilaikan bilangan jangkaan item yang diperiksa setiap kali rancangan itu digunakan apabila bahagian item yang tidak mematuhi dalam kelompok adalah 0.02 dan 0.10.

(4 markah)

(c) Bincangkan faktor yang perlu dipertimbangkan ketika memilih rancangan yang digunakan.

(4 markah)

(Diberi: Formula binomial $P(d \le c) = \sum_{d=0}^{c} [n!/d!(n-d)!] p^d (1-p)^{n-d}$

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3. Sumber bekalan air untuk sebuah Bandar di analisis secara rutin untuk kandungan plumbum. Lima sampel air di ambil setiap hari bagi tempoh 20 hari. Kandungan plumbum dalam nilai bahagian per billion (ppb) bagi setiap lokasi yang disampel

dalam suatu kawasan geografi untuk tempoh 20 hari pertama di berikan di dalam jadual di bawah.

	Water Samples (ppb)							
Day	1	2	3	4	5	X-bar	R_i	S_i
1	13	8	2	5	8	7.2	11	4.09
2	0	6	1	9	15			
3	4	2	4	3	4	3.4	2	0.89
4	3	15	8	3	5	6.8	12	5.02
5	5	10	5	4	0	4.8	10	3.56
6	9	5	13	7	7	8.2	8	3.03
7	0	4	4	3	9			
8	9	3	0	6	0	3.6	9	3.91
9	14	0	0	5	3	4.4	14	5.77
10	3	9	5	0	2	3.8	9	3.42
11	5	8	0	7	8	5.6	8	3.36
12	3	2	2	7	4	3.6	5	2.07
13	5	11	14	8	3	8.2	11	4.44
14	13	5	5	12	7	8.4	8	3.85
15	7	0	1	0	6	2.8	7	3.42
16	12	7	10	4	13	9.2	9	3.70
17	9	4	4	8	9	6.8	5	2.59
18	6	1	1`	3	13	4.8	12	5.02
19	7	0	5	7	2	4.2	7	3.11
20	10	0	10	12	7	7.8	12	4.71

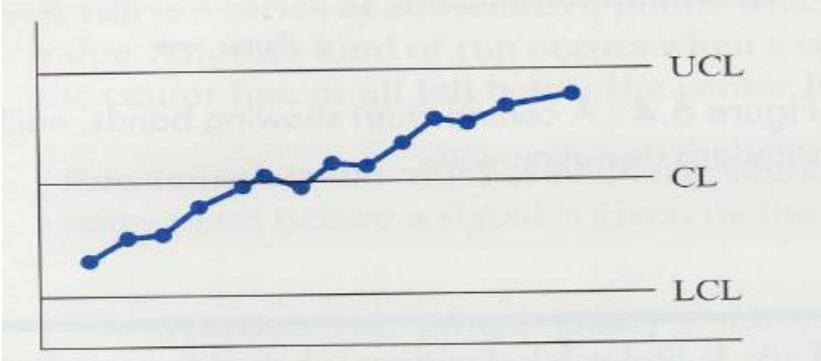
i. Isikan ruang kosong di dalam jadual di atas.

ii. Hasilkan carta-carta X-bar dan R-bar .

iii. Komen tentang kestabilan proses analisis ini.

…22/-

iv. Apakah analisis anda sekiranya proses analisis tersebut menghasilkan carta kawalan berikut ?



(20 markah)

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BAHAGIAN B

4. (a) Dalam pembuatan tablet bagi suatu ubat , parameter proses daripada 20 sampel bersaiz n=4 dipatuhi. Sasaran berat tablet ialah 65.5 mg dengan toleransi ± 1.25 mg. Proses ini di dapati stabil dengan nilai purata tablet ialah 65.6 mg dan nilai UCL dan LCL adalah masing-masing 66.86 and 64.34 mg .

i. Apakah nilai C_p dan C_{pk} bagi proses pembuatan tablet ini?

ii. Dengan menganggap keluaran mematuhi taburan normal, apakah nilai perkadaran tablet ubat yang dijangka tidak mematuhi spesifikasi?

iii. Sekiranya spesifikasi diubah kepada 65.5 mg ± 2 peratus berat sasaran, apakah nilai untuk C_p dan C_{pk} yang dijangkakan?

(10 markah)

(b) Bagi penggunaan bahan kimia, bincangkan aspek yang berikut: gred, pelabelan, penyimpangan, keselamatan dan pelupusan.

(10 markah)

5. (a) Bezakan parameter kaedah pengesahan dibawah

i. Spesifik dan selektiviti

ii. Kebolehulangan dan keterulangan

iii. Had pengesan (LOD) dan had pengkuantifan (LOQ)

iv Sensitiviti dan kelinearan

(8 markah)

…24/-

(b) Penentuan 6 replikat suatu larutan piawai 2.0 bahagian per million (ppm) Cd dalam air menggunakan spektroskopi penyerapan atom menghasilkan keputusan beikut.

Sampel	Nilai diperolehi (ppm)
1	1.6
2	1.7
3	1.9
4	1.7
5	1.9
6	1.7

i. Taksirkan kepersisan dan kejituan kaedah ini.

ii. Tentukan had pengesanan kaedah (MDL) dan had pengkuantifan (LOQ).

iii. Kira pekali variasi (CV) kaedah ini. Berdasarkan persamaan Horwitz terubahsuai, berikan nilai CV yang dijangkakan untuk kaedah ini. Komen ke atas perbandingan di antara CV yang anda kira dengan CV yang dijangkakan.

iv. Apakah kaedah ini sesuai untuk tujuan penentuan Cd dalam air yang dianggarkan mempunyai kandungan Cd pada paras 0.05 ppm? Justifikasikan jawapan anda.

(12 markah)

…25/-

6. (a) Satu kaedah HPLC telah diperikan untuk penentuan fenantrena , sejenis sebatian hidrokarbon poliaromatik (PAH) di dalam air. Untuk tujuan pengesahan, analasis ketegapan dilakukan. Larutan yang digunakan untuk ujian ketegapan ini ialaha larutan piawai yang mengandungi 125 mg L^{-1} sebatian PAH dalam asetonitril. Keadaan Kromatografi: Satu turus 25 cm stainless steel -µBondapack C18 dan fasa gerak ialah suatu campuran 1:1 air /asetonitril. Kadar aliran dipersekitaran 1.5 ml/min dan suhu ambient telah digunakan. Pengesan UV dengan jarak gelombang 254 nm telah digunakan untuk mengesan analit. Ujian ketegapan ini bertujuan untuk melihat kesan variasi ke atas beberapa parameter HPLC. Keputusan ujian ketegapan tersebut diberikan di dalam jadual-jadual dibawah. Lapan faktor telah dipilih daripada prosedur operasi untuk diuji menggunakan rekabentuk Plackett-Burman untuk 11 faktor (N = 12). Dengan itu terdapat tiga faktor dumi yang telah dimasukkan kedalam turus matriks. Gerakbalas yang ditentukan untuk ujian ketegapan ini adalah peratus pemulihan dan diberikan di dalam jadual A manakala sebahagian daripada kesan yang telah dikira diberikan dalam jadual b.

Experimental runs	**Recoveries (%)**
1	101.4
2	102.7
3	101.3
4	102.9
5	99.1
6	101.7
7	101.4
8	98.8
9	101.8
10	99.3
11	98.7
12	103.1
Mean	101.0
RSD	1.61

(a)

Factors	**Effects**
pH	0.000
Column	-0.300
Dum1	
Temp	-0.367
%B begin	-1.067
%B end	0.467
Dum2	
Flow	-0.300
Wavelength	
Buffer Conc.	1.100
Dum3	

(b)

i. Kira kesan untuk faktor-faktor Dumi1, Dumi 2, Dumi 3 dan jarak gelombang.

ii. Guna plot separuh normal untuk mengenalpasti faktor-faktor yang tidak tegap dalam kaedah ini.

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iii. Guna kaedah statistik melalui factor dumi untuk mencari ralat piawai bagi tujuan penalpastian factor tidak tegap.

iv. Guna kaedah algorithma Dong untuk menentukan faktor-faktor tak tegap.

(14 markah)

(b) Rekabentuk eksperimen Plackett-Burman adalah jenis rekabentuk faktor pechan . Definasikan sebutan-sebutan yang berkaitan dengan rekabentuk eksperimen dibawah:

i. Rekabentuk faktor penuh. Full factorial design

ii. Rekabentuk tapisan dua paras

iii. Kesan kekeliruan (confounding

(6 markah)

7. (a) Lakarkan perbezaan di antara carta kawalan X-bar, carta purata pemberat bergerak secara eksponen (EWMA) dan carta kawalan jumlah kumulatif (CUSUM).

(6 markah)

(b) Bezakan secara ringkas di antara ISO 17025 dan ISO 9000. Gariskan prosedur normal dalam persediaan makmal anda untuk memperolehi akreditasi ISO 17025. Akhir sekali, gariskan perbezaan di antara akreditasi dan pensijilan.

(9 markah)

(c) Satu kajian antara makmal telah dilakukan oleh 10 makmal untuk menentukan kandungan Fe dalam minyak kelapa sawit di mana sejumlah 50 penentuan telah dilakukan. Sisihan piawai (*s*) untuk data yang diperolehi setiap makmal diberikan seperti berikut:

makmal	1	2	3	4	5	6	7	8	9	10
s	6.47	3.83	3.51	4.16	5.89	8.92	5.63	6.28	5.63	5.50

Guna ujian Cochran untuk menentukan samada makmal 6 gagal dalam ujian antara makmal tersebut dan tidak boleh diberikan status akreditasi ISO 17025

(5 markah)

OooOOooo

APPENDIX

Useful Equations for the examination

$$M_j = \frac{0.6745(X_i - \tilde{\tilde{X}})}{MAD}$$

$$z_i = \frac{(x_i - \bar{x})}{s}$$

Where

$$s = \sqrt{\frac{\sum_{i-1}^{x}(x_i - \bar{x})^2}{n-1}}$$

$$s_{ai} = \sqrt{\frac{n\sum(x_i - \bar{x})^2(1-u_i^2)^4}{\left|(1-u_i^2)(1-5u_i^2)\right|}}$$

Where

$$u = \frac{x_i - \bar{x}}{9MAD}$$

$$R_{i+1} = \frac{\left|x^{(i)} - \bar{x}^{(i)}\right|}{s(i)}$$

$$Q\exp = Xq - Xn/w$$

$$t = \frac{|E_x|}{(SE)_e}$$

$$E_X = t_{critical}\text{multiply}(SEe)$$

$$(SE)_e\sqrt{\frac{s^2}{N/2} + \frac{s^2}{N/2}} = \sqrt{\frac{4S^2}{N}}$$

$$\sqrt{\left(\sum E^2{}_{error}/n_{error}\right)}$$

$$s_o = 1.5\text{median}|E_i|$$

$$S_1\sqrt{m^{-1}\sum E_i^2}$$

$$ME = t_{(1-\alpha/2,df)}S_1$$

$$E_X = \frac{\sum\gamma^{(+)}}{N/2} - \frac{\sum\gamma^{(-)}}{N/2}$$

$$SE = \sqrt{\frac{\sum E^2{}_{emr}}{n_{emr}}}$$

$$\sigma_m = \frac{\sigma}{\sqrt{N}}$$

$$CL = \bar{x} \pm \frac{ts}{\sqrt{N}}$$

$$C = \frac{X_{(2)} - X_{(1)}}{X_{(n-1)} - X_{(1)}}$$

$$C = \frac{X_{(n)} - X_{(n-1)}}{X_{(n)} - X_{(2)}}$$

$$G_1 = \frac{|\bar{x} - x_i|}{s}$$

$$G_2 = \frac{x_n - x_1}{s}$$

$$G_3 = 1 - \left(\frac{(n-3)xS^2_{n-2}}{(n-1)(s^2)}\right)$$

$$C_n = \frac{\text{Suspected}(S^2)}{\sum_{i=1}^{g} Si^2}$$

$$\bar{n} = \frac{\sum_{i-1}^{g} n_i}{\delta}$$

$$t_{obs} = \frac{\bar{x}_1 - \bar{x}_2}{S_{\bar{x}}}$$

$$SE_{pooled} = \sqrt{s^2_{pooled}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

$$s^2_{pooled} = \frac{SS_1 + SS_2}{n_1 + n_2 - 2}$$

$$t = \frac{\bar{d}}{\sqrt{s^2/n}}$$

	df	ss	ms
Bef Groups	$I-1$	$\sum ni(\bar{y}_{i\bullet} - \bar{y}_{\bullet\bullet})^2$	ss/df
With Group	$n^* - I$	$\sum\sum(y_{ij} - \bar{y}_{i\bullet})^2$	ss/df

$$\frac{\left|\bar{x}_1 - \bar{x}_2\right|}{\sqrt{MSW\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} > t_{\alpha/2}$$

$$b_1 = \frac{SP_{xy}}{SS_x}$$

$$S_{\Gamma lx} = \sqrt{\frac{SS_{resid}}{n-2}}$$

$$SE_{b1} = \sqrt{\frac{S^2_{y/x}}{SS_x}}$$

$$r = \frac{b_1 S_x}{S_\Gamma}, r^2 = \frac{SS_{resid}}{SS_y}$$

$$CV = 2^{(1-0.51ogc)}$$

$$S_1 = \sqrt{m^{-1}\sum E_1^2}$$

$$ME = t_{(1-\alpha/2,df)} \cdot S_1$$

$$\sigma_{\bar{x}} = \frac{A_2\bar{R}}{3} \qquad s = \sigma_{\bar{x}}\sqrt{n = \frac{\bar{R}}{d_2}}$$

$$CL = \bar{x} \pm 3\sigma x$$

$$Cp = \frac{USL - LCL}{6\sigma}$$

Upper percentage points of Cochran'S Test for homogeneity of Variance

df for $\hat{\sigma}_j^2$	α	k = number of variances										
		2	3	4	5	6	7	8	9	10	15	20
1	.05	.9985	.9669	.9065	.8412	.7808	.7271	.6798	.6385	.6020	.4709	.3894
	.01	.9999	.9933	.9676	.9279	.8828	.8376	.7945	.7544	.7175	.5747	.4799
2	.05	.9750	.8709	.7679	.6838	.6161	.5612	.5157	.4775	.4450	.3346	.2705
	.01	.9950	.9423	.8643	.7885	.7218	.6644	.6152	.5727	.5358	.4069	.3297
3	.05	.9392	.7977	.6841	.5981	.5321	.4800	.4377	.4027	.3733	.2758	.2205
	.01	.9794	.8831	.7814	.6957	.6258	.5685	.5209	.4810	.4469	.3317	.2654
4	.05	.9057	.7457	.6287	.5441	.4803	.4307	.3910	.3584	.3311	.2419	.1921
	.01	.9586	.8335	.7212	.6329	.5635	.5080	.4627	.4251	.3934	.2882	.2288
5	.05	.8772	.7071	.5895	.5065	.4447	.3974	.3595	.3286	.3029	.2195	.1735
	.01	.9373	.7933	.6761	.5875	.5195	.4659	.4226	.3870	.3572	.2593	.2048
6	.05	.8534	.6771	.5598	.4783	.4184	.3726	.3362	.3067	.2823	.2034	.1602
	.01	.9172	.7606	.6410	.5531	.4866	.4347	.3932	.3592	.3308	.2386	.1877
7	.05	.8332	.6530	.5365	.4564	.3980	.3535	.3185	.2901	.2666	.1911	.1501
	.01	.8988	.7335	.6129	.5259	.4608	.4105	.3704	.3378	.3106	.2228	.1748
8	.05	.8159	.6333	.5175	.4387	.3817	.3384	.3043	.2768	.2541	.1815	.1422
	.01	.8823	.7107	.5897	.5037	.4401	.3911	.3522	.3207	.2945	.2104	.1646
9	.05	.8010	.6167	.5017	.4241	.3682	.3259	.2926	.2659	.2439	.1736	.1357
	.01	.8674	.6912	.5702	.4854	.4229	.3751	.3373	.3067	.2813	.2002	.1567
16	.05	.7341	.5466	.4366	.3645	.3135	.2756	.2462	.2226	.2032	.1429	.1108
	.01	.7949	.6059	.4884	.4094	.3529	.3105	.2779	.2514	.2297	.1612	.1248
36	.05	.6602	.4748	.3720	.3066	.2612	.2278	.2022	.1820	.1655	.1144	.0879
	.01	.7067	.5153	.4057	.3351	.2858	.2494	.2214	.1992	.1811	.1251	.0960
144	.05	.5813	.4031	.3093	.2513	.2119	.1833	.1616	.1446	.1308	.0889	.0675
	.01	.6062	.4230	.3251	.2644	.2229	.1929	.1700	.1521	.1376	.0934	.0709

Reprinted from chapter 15 of *Techniques of Statistical Analysis*, edited by C. Eisenhart, M.W. Hastay, and W. A. Wallis, McGraw-Hill Book Company, 1947.

Critical values for Dixon's Test

n	Level of Significance α		
	0.10	0.05	0.01
3	0.886	0.941	0.988
4	0.679	0.765	0.889
5	0.557	0.642	0.780
6	0.482	0.560	0.698
7	0.434	0.507	0.637
8	0.479	0.554	0.683
9	0.441	0.512	0.635
10	0.409	0.477	0.597
11	0.517	0.576	0.679
12	0.490	0.546	0.642
13	0.467	0.521	0.615
14	0.492	0.546	0.641
15	0.472	0.525	0.616
16	0.454	0.507	0.595
17	0.438	0.490	0.577
18	0.424	0.475	0.561
19	0.412	0.462	0.547
20	0.401	0.450	0.535
21	0.391	0.440	0.524
22	0.382	0.430	0.514
23	0.374	0.421	0.505
24	0.367	0.413	0.497
25	0.360	0.406	0.489

…13/-

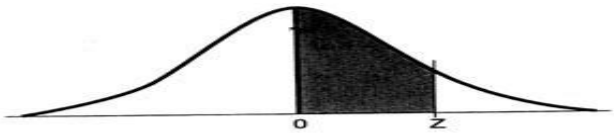
Grubbs' critical value table: For G1 only

N	0.1	0.075	0.05	0.025	0.01		N	0.1	0.075	0.05	0.025	0.01
3	1.15	1.15	1.15	1.15	1.15		53	0	0	2.981	3.151	999
4	1.42	1.44	1.46	1.48	1.49		54	0	0	2.988	3.158	999
5	1.6	1.64	1.67	1.71	1.75		55	0	0	2.995	3.165	999
6	1.73	1.77	1.82	1.89	1.94		56	0	0	3.002	3.172	999
7	1.83	1.88	1.94	2.02	2.1		57	0	0	3.009	3.179	999
8	1.91	1.96	2.03	2.13	2.22		58	0	0	3.016	3.186	999
9	1.98	2.04	2.11	2.21	2.32		59	0	0	3.023	3.193	999
10	2.03	2.1	2.18	2.29	2.41		60	0	0	3.03	3.2	999
11	2.09	2.14	2.23	2.36	2.48		61	0	0	3.036	3.206	999
12	2.13	2.2	2.29	2.41	2.55		62	0	0	3.042	3.212	999
13	2.17	2.24	2.33	2.46	2.61		63	0	0	3.048	3.218	999
14	2.21	2.28	2.37	2.51	2.66		64	0	0	3.054	3.224	999
15	2.25	2.32	2.41	2.55	2.71		65	0	0	3.06	3.23	999
16	2.28	2.35	2.44	2.59	2.75		66	0	0	3.066	3.236	999
17	2.31	2.38	2.47	2.62	2.79		67	0	0	3.072	3.242	999
18	2.34	2.41	2.5	2.65	2.82		68	0	0	3.078	3.248	999
19	2.36	2.44	2.53	2.68	2.85		69	0	0	3.084	3.254	999
20	2.38	2.46	2.56	2.71	2.88		70	0	0	3.09	3.26	999

Control Charts Factors

Sample Size	**For Averages**	**For Ranges**		**Standard Deviation**
n	**A_2**	**D_3**	**D_4**	**d_2**
2	1.88	0	3.29	1.13
3	1.02	0	2.58	1.69
4	.73	0	2.28	2.06
5	.58	0	2.11	2.33
6	.48	0	2.00	2.53
7	.42	0	1.92	2.70
8	.37	.14	1.87	2.85
9	.34	.18	1.82	2.97
10	.31	.31	1.78	3.08

…14/-



This table presents the area between the mean and the Z score . When Z=1.96, the shaded area is 0.4750.

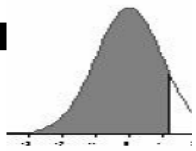
Areas Under the Standard Normal Curve

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2517	.2549
0.7	.2580	.2611	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4979	.4980	.4981
2.9	.4981	.4982	.4982	.4983	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.4987	.4987	.4987	.4988	.4988	.4989	.4989	.4989	.4990	.4990
3.1	.4990	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.4993	.4993	.4994	.4994	.4994	.4994	.4994	.4995	.4995	.4995
3.3	.4995	.4995	.4995	.4996	.4996	.4996	.4996	.4996	.4996	.4997
3.4	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4997	.4998
3.6	.4998	.4998	.4999	.4999	.4999	.4999	.4999	.4999	.4999	.4999
3.9	.5000									

Source: Adapted by permission from *Statistical Methods* by George W. Snedecor and William G. Cochran, sixth edition © 1967 by The Iowa State University Press, Ames, Iowa, p. 548.

…15/-

Student's t–distribution table



	p										
df	0.75	0.80	0.85	0.90	0.95	0.975	0.980	0.990	0.995	0.9975	0.9990
1	1.0000	1.3764	1.9626	3.0777	6.3137	12.706	15.895	31.821	63.656	127.32	318.29
2	0.8165	1.0607	1.3862	1.8856	2.9200	4.3027	4.8487	6.9645	9.9250	14.089	22.329
3	0.7649	0.9785	1.2498	1.6377	2.3534	3.1824	3.4819	4.5407	5.8408	7.4532	10.214
4	0.7407	0.9410	1.1896	1.5332	2.1318	2.7765	2.9985	3.7469	4.6041	5.5975	7.1729
5	0.7267	0.9195	1.1558	1.4759	2.0150	2.5706	2.7565	3.3649	4.0321	4.7733	5.8935
6	0.7176	0.9057	1.1342	1.4398	1.9432	2.4469	2.6122	3.1427	3.7074	4.3168	5.2075
7	0.7111	0.8960	1.1192	1.4149	1.8946	2.3646	2.5168	2.9979	3.4995	4.0294	4.7853
8	0.7064	0.8889	1.1081	1.3968	1.8595	2.3060	2.4490	2.8965	3.3554	3.8325	4.5008
9	0.7027	0.8834	1.0997	1.3830	1.8331	2.2622	2.3984	2.8214	3.2498	3.6896	4.2969
10	0.6998	0.8791	1.0931	1.3722	1.8125	2.2281	2.3593	2.7638	3.1693	3.5814	4.1437
11	0.6974	0.8755	1.0877	1.3634	1.7959	2.2010	2.3281	2.7181	3.1058	3.4966	4.0248
12	0.6955	0.8726	1.0832	1.3562	1.7823	2.1788	2.3027	2.6810	3.0545	3.4284	3.9296
13	0.6938	0.8702	1.0795	1.3502	1.7709	2.1604	2.2816	2.6503	3.0123	3.3725	3.8520
14	0.6924	0.8681	1.0763	1.3450	1.7613	2.1448	2.2638	2.6245	2.9768	3.3257	3.7874
15	0.6912	0.8662	1.0735	1.3406	1.7531	2.1315	2.2485	2.6025	2.9467	3.2860	3.7329
16	0.6901	0.8647	1.0711	1.3368	1.7459	2.1199	2.2354	2.5835	2.9208	3.2520	3.6861
17	0.6892	0.8633	1.0690	1.3334	1.7396	2.1098	2.2238	2.5669	2.8982	3.2224	3.6458
18	0.6884	0.8620	1.0672	1.3304	1.7341	2.1009	2.2137	2.5524	2.8784	3.1966	3.6105
19	0.6876	0.8610	1.0655	1.3277	1.7291	2.0930	2.2047	2.5395	2.8609	3.1737	3.5793
20	0.6870	0.8600	1.0640	1.3253	1.7247	2.0860	2.1967	2.5280	2.8453	3.1534	3.5518
21	0.6864	0.8591	1.0627	1.3232	1.7207	2.0796	2.1894	2.5176	2.8314	3.1352	3.5271
22	0.6858	0.8583	1.0614	1.3212	1.7171	2.0739	2.1829	2.5083	2.8188	3.1188	3.5050
23	0.6853	0.8575	1.0603	1.3195	1.7139	2.0687	2.1770	2.4999	2.8073	3.1040	3.4850
24	0.6848	0.8569	1.0593	1.3178	1.7109	2.0639	2.1715	2.4922	2.7970	3.0905	3.4668
25	0.6844	0.8562	1.0584	1.3163	1.7081	2.0595	2.1666	2.4851	2.7874	3.0782	3.4502

Critical Values of the F Distribution
($\alpha = .05$)

df within	df between										
	1	2	3	4	5	6	7	8	12	24	∞
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.68	4.53	4.37
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.00	3.84	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.57	3.41	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.28	3.12	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.07	2.90	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	2.91	2.74	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.79	2.61	2.41
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.69	2.51	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.60	2.42	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.53	2.35	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.48	2.29	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.42	2.24	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.38	2.19	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.34	2.15	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.31	2.11	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.28	2.08	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.25	2.05	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.23	2.03	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.20	2.01	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.18	1.98	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.16	1.96	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.15	1.95	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.13	1.93	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.12	1.91	1.66
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.10	1.90	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.09	1.89	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.00	1.79	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	1.92	1.70	1.39
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	1.88	1.65	1.33
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.85	1.63	1.28
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.83	1.61	1.26
∞	3.84	3.00	2.61	2.37	2.22	2.10	2.01	1.94	1.75	1.52	1.00

…16/-

Plackett-Burman Design For 11 Factors

Exp.	***Factors***											***Response***
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	
1	+	+	-	+	+	+	-	-	-	+	-	***y*1**
2	-	+	+	-	+	+	+	-	-	-	+	***y*2**
3	+	-	+	+	-	+	+	+	-	-	-	***y*3**
4	-	+	-	+	+	-	+	+	+	-	-	***y*4**
5	-	-	+	-	+	+	-	+	+	+	-	***y*5**
6	-	-	-	+	-	+	+	-	+	+	+	***y*6**
7	+	-	-	-	+	-	+	+	-	+	+	***y*7**
8	+	+	-	-	-	+	-	+	+	-	+	***y*8**
9	+	+	+	-	-	-	+	-	+	+	-	***y*9**
10	-	+	+	+	-	-	-	+	-	+	+	***y*10**
11	+	-	+	+	+	-	-	-	+	-	+	***y*11**
12	-	-	-	-	-	-	-	-	-	-	-	***y*12**

…17/-

Rankits to draw a half-normal plot for the most frequently used screening designs (effect "1" indicates the smallest effect)

Effect	**Design size**		
	***N*=8**	***N*=12**	***N*=16**
1	0.09	0.06	0.04
2	0.27	0.17	0.12
3	0.46	0.29	0.21
4	0.66	0.41	0.29
5	0.90	0.53	0.38
6	1.21	0.67	0.47
7	1.71	0.81	0.57
8		0.98	0.67
9		1.19	0.78
10		1.45	0.89
11		1.91	1.02
12			1.18
13			1.36
14			1.61
15			2.04