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STRATIFIED RANDOM SAMPLING PLANS DESIGNED TO ASSIST IN THE DETERMINATION OF RADON AND RADON DAUGHTER CONCENTRATIONS IN UNDERGROUND URANIUM MINE ATMOSPHERES

by

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A B S T R A C T

This report is limited to a description of sampling strategies for the monitoring of deleterious agents present in uranium mine air in underground and surface mining areas. These methods are designed to prevent overexposure of uranium miners to ionizing radiation to the lining of the respiratory system from radon and radon daughters and whole body exposure to external gamma radiation.

Underground uranium miners may also be exposed to silica dust, diesel exhaust gases (carbon monoxide, oxides of nitrogen and aldehydes).

One of the important contributions of this report is the detailed description of stratified random sampling monitoring methodology for obtaining baseline data to be used as a reference for subsequent compliance assessment.

R É S U M É

Le présent rapport ne comporte qu'une description des stratégies d'échantillonnage relatif à la détection d'éléments délétères dans l'air des mines d'uranium, souterraines et en surface. Ces méthodes sont destinées à empêcher que les mineurs d'uranium soient surexposés d'une part aux rayonnements ionisants provenant du radon et de ses produits de filiation et qui affectent la membrane des poumons et, d'autre part, que tout le corps soit exposé aux rayons gamma.

Les mineurs d'uranium qui travaillent sous terre risquent également d'être exposés à la poussière de silice, aux gaz d'échappement des moteurs diésels (monoxyde de carbone, oxydes d'azote et aldéhydes).

La description détaillée des composantes de la méthode de surveillance des échantillons pris au hasard afin d'obtenir des données de base devant servir de référence aux évaluations subséquentes de la conformité constitue l'un des plus importants apports du présent rapport.

PREFACE

This report is supplementary to the Atomic Energy Control Board report [1] released during April 1980 and published in part in the December 1980 issue of the Canadian Mining and Metallurgical Bulletin. It contains comprehensive statistical analysis of data obtained during investigations of personal dosimeters in underground uranium mines in Canada. Chapter 13 "Stratified Random Sampling of Mine Locations" very briefly suggests the subject matter of this report.

It is essentially the quality of the atmosphere [2] in underground uranium mines that is of primary importance to those exposed to radon, radon daughters, harmful dust and gases from diesel engines. Although ventilation control of the volume of clean air is an essential prerequisite, it is most important that provision be made for unbiased periodic sampling of all underground locations.

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INTRODUCTION

In order to reduce the risk of carcinoma of the lung resulting from the inhalation of radon and radon daughters, it is important that an evaluation be made of location - occupation - time cumulative exposures of underground uranium miners.

There is a need to obtain unbiased exposure measurements that are representative of employee exposure. This requires the design of the statistical sampling plans required to adequately monitor these locations so that each of these location - occupation - time periods will have equal opportunity of being sampled.

This report is written specifically for those interested in the implementation of various alternative random sampling plans designed to ensure a cumulative exposure as far below the dose limits of 4 WLM per year or 2 WLM per quarter as is reasonably achievable, economic and social factors being taken into account.

Precise predictions of the level of quartz in dust and radon daughter concentrations (27) is dependent on the assumption that mine ventilation will not be periodically interrupted. For instance, in a mine producing 2, 509, 833 tons of uranium ore during 1980 at 1.87 per cent U_3O_8 per ton (3) and assuming 90 to 100 cubic meters per second of air ventilation per 1000 tons of ore broken per day (14), the ventilation velocity in the mine is appreciable. Interruptions of mine ventilation must, therefore, be classified as "unusual occurrences" which, generally, cannot be predicted. Stratified random sampling procedures will ensure that each of these occurrences will have equal probability of being included in an unbiased location - time sampling strata.

The object of this report is to present recognized statistical procedures designed to ensure an unbiased sampling strategy. Stratified random sampling is particularly applicable first to establish baseline data for each location followed by periodic grab sampling of these locations. Because of the large number of mine locations involved and the variation in the operable duration of each of these locations, it is well known in the uranium mining industry and by the regulatory authorities, that to ensure compliance a random sampling regimen is required. To accomplish this goal the report contains a practical example of methods recommended to improve random sampling procedures in a Canadian uranium mine.

The report makes reference only to statistical random sampling of environmental atmospheric data. Choice of the instrument used for sampling and the instrument error calculations are not included.

The examples presented are designed to describe methods of obtaining simplified random samples of "location - occupation - time" for underground workers in a uranium mine. Since these are finite sampled populations or populations of known size, the number of items in the population from which the sample is to be selected is always known. Furthermore, the size of the sample required from this population is also known. Selecting a random sample from a finite population will ensure that each possible sample and each item in the population has an equal opportunity of being included in the sample selected. This is an important prerequisite for a statistically acceptable random sampling procedure.

Finally, examples are presented to illustrate the method of calculating the 95 per cent confidence limits, from full shift data, as an aid to establishing baseline data for each location.

Instructions for the Use of Random Number Tables.

The detailed instructions for the use of all of the available tables of random numbers are not identical, see Appendix A. This may result, initially, in some confusion and frustration. For this reason three different well known references have been selected to exemplify the instructions required for each of these tables of random numbers. These references and the tables therein may in turn refer to another source from which the simplified tables presented were originally obtained, viz, Natrella (5) making reference to the Rand Corporation.(6)

Repeated use of the same portion of any random number table is illegitimate and does not satisy the intent of randomness when selecting a sample. The excerpts from random sample tables used in this report are for the purposes of illustration only. The random numbers presented in Example 2 may, however, be used in any actual random sample problem.

Some tables of random numbers are printed in pairs, 22, 62, 84 etc. These may be read in rows or columns. Other tables may be read diagonally as well as in rows or columns. One of the tables presented and referenced in this paper is designed to read individual, paired or three-digit numbers in sequence in columns only. (Appendix A - Example 4.)

Full Period Sampling

As an example, suppose fifteen (15) personal samplers numbered 1 to 15 are to be assigned to underground uranium mine workers for full shift periods.

Since the workers selected will be located in the same locations (beats) for a period of one month the observations will be indicative of exposure experiences to be used to develop baseline data for these locations.

The instrument to instrument calibration and acceptable error variance is recognized by assigning random numbers to these fifteen (15) instruments as follows:-

Instrument Number	Random Number Series	Instruments are to be Assigned to-:
1	10	Staff
2	6	
3	3	
4	14	Stoping
5	2	
6	11	
7	5	Development
8	1	
9	4	
10	7	Hoisting and Haulage
11	13	
12	8	
13	15	Construction and Maintenance
14	9	
15	12	

An estimate of the work force to whom these instruments may be allocated is presented in Table 1.

Table I

UNDERGROUND WORK FORCE ESTIMATE
IN A URANIUM MINE
IN CANADA

STAFF	Underground Superintendent	1
	Captains	3
	Shift Bosses	10
	Geologists	6
	Engineers	9
	Ventilation	3
	Safety	2
		34
STOPING	Miner Leaders	30
	Miners	50
	Miners Helpers	20
	Fillmen	6
	Training	5
		111
DEVELOPMENT	Miners Headings	6
	Miners Raising	6
		12
HOISTING & HAULAGE	Motormen	16
	Mucking Machine Men	15
	Skip Tenders	6
	Hoistmen	3
		40
CONSTRUCTION & MAINTENANCE	Clean up & Powder	4
	Timbermen	12
	Trackmen	9
	Pipe Fitters	5
	Machine Doctors	2
	Tool Crib	2
	Dry	3
	Bit Sharpeners	3
	Mechanics	15
	Electricians	6
		61
	TOTAL	258

Judgement or Grab Sampling Regimen.

It is desirable from time and motion study considerations to perform grab sampling in a single specified underground working level or location during a particular shift. This will avoid the necessity of having to proceed from one level to another during the same shift period.

The random sampling times for grab samples during a particular shift have been derived in detail in Appendix A Example 1.

A further detailed discussion of stratified random sampling of mine locations is presented in Appendix A Example 8.

Confidence Limits - Atmospheric Radon Daughter Observations.

The definition and method of calculating the confidence limits for the population mean are presented in Appendix B.

The results of calculations of the confidence limits obtained for location-days and location-occupation are presented in Tables 2, 3 and 4.

TABLE 2

ATMOSPHERIC RADON DAUGHER OBSERVATIONS

OBTAINED IN A SASKATCHEWAN URANIUM MINE DURING 1977-78

Working Level x 100

LOCATION - DAY		n	$\overline{X}$	s	$s_{\bar{x}}$	t df=n-1 P=0.975	$ts_{\bar{x}}$	CONFIDENCE LIMITS 95 Per Cent
Stope 107630	1	13	22.92	7.32	2.03	2.179	4.42	18.5 - 27.34
	2	13	20.69	3.88	1.08	2.179	2.35	18.33 - 23.04
	3	13	23.92	5.72	1.59	2.179	3.46	20.46 - 27.28
	4	11	14.00	2.41	0.73	2.228	1.63	12.37 - 15.63
	5	11	34.45	10.05	3.03	2.228	6.75	27.70 - 41.20
Stope 240914	1	13	7.62	1.45	0.40	2.179	0.87	6.75 - 8.49
	2	13	5.39	2.10	0.38	2.179	0.83	4.56 - 6.66
	3	13	5.23	2.56	0.71	2.179	1.55	3.68 - 6.78
	4	13	6.31	2.02	0.56	2.179	1.22	5.09 - 7.53
	5	12	22.50	7.34	2.12	2.280	4.83	17.67 - 27.33
	6	13	3.31	1.65	0.46	2.179	1.00	2.31 - 4.31
	7	13	4.31	1.93	0.54	2.179	1.18	3.13 - 5.47
	8	13	4.38	1.94	0.54	2.179	1.18	3.20 - 5.56
	9	13	4.15	1.95	0.54	2.179	1.18	2.97 - 5.33
	10	13	8.07	3.57	0.99	2.179	2.16	5.91 - 10.23

TABLE 3

ATMOSPHERIC RADON DAUGHTER OBSERVATIONS

OBTAINED IN AN ONTARIO URANIUM MINE

JUNE TO AUGUST, 1976

Working Level x 1000

Date 1976	Location-Occupation	n	$\bar{x}$	s	$s_{\bar{x}}$	t d.f=n-1 P=0.975	$ts_{\bar{x}}$	Confidence Limits 95 Per Cent
Jun 1	AST-SL	15	78	16	4.13	2.145	8.86	69.14 - 86.68
2		15	101	53	13.68	2.145	29.34	71.66 - 130.34
3		16	53	11	2.75	2.131	5.86	47.14 - 58.86
4		12	57	10	2.89	2.201	6.36	50.64 - 63.36
7	BST-SL	16	349	74	18.5	2.131	39.42	309.58 - 388.42
8		18	272	104	24.5	2.110	51.72	220.28 - 323.72
9		17	271	80	19.4	2.120	41.13	229.87 - 312.13
10		21	329	49	10.69	2.086	22.31	306.69 - 351.31
11		12	347	50	14.43	2.201	31.76	315.24 - 378.76
14	CST-SL	23	220	36	7.51	2.074	15.58	204.42 - 235.58
15		19	258	62	14.22	2.101	29.88	228.12 - 287.88
16		25	252	51	10.20	2.064	21.05	230.95 - 273.05
17		22	188	42	8.95	2.080	18.65	169.38 - 206.62
18		20	265	56	12.52	2.093	26.21	238.79 - 291.21
21	DST-SL	14	74	11	2.94	2.160	6.35	67.65 - 80.35
22		16	132	102	25.50	2.131	54.34	77.66 - 186.34
23		13	99	26	7.21	2.179	15.71	83.29 - 114.71
24		16	121	24	6.00	2.131	12.79	108.21 - 133.79
25		14	103	67	17.91	2.160	38.68	64.32 - 141.68
28	EST-SL	12	1193	184	53.12	2.201	116.91	1076.09 - 1309.91
29		17	899	116	28.13	2.120	59.64	839.36 - 958.64
30		12	868	316	91.22	2.201	200.78	667.22 - 1068.78
Jul 1		9	563	158	52.67	2.306	121.45	441.55 - 684.45
5	FST-SL	3	380	52	30.02	4.303	129.19	250.81 - 509.19
6		13	398	77	21.36	2.179	46.54	351.46 - 444.54
7		11	447	122	36.78	2.228	81.96	365.04 - 528.96
8		16	353	75	18.75	2.131	39.96	313.04 - 292.96
9		7	364	45	17.00	2.447	41.62	322.38 - 405.62
12	GST-TS	23	905	136	28.36	2.074	58.81	846.19 - 963.81
13		21	120	31	6.76	2.086	14.11	105.89 - 134.11
14		21	730	188	41.04	2.086	85.62	644.38 - 815.62
15		21	161	26	5.67	2.086	11.84	149.16 - 172.84
16		3	433	21	12.12	4.303	52.17	380.83 - 485.17

Date 1976	Location-Occupation	n	$\bar{x}$	s	$s_{\bar{x}}$	t d.f=n-1 P=0.975	$ts_{\bar{x}}$	Confidence Limits 95 Per Cent
Jul 19	ADR-DH	5	488	66	29.52	2.776	81.94	406.06 - 569.94
20		22	649	342	72.91	2.080	151.66	497.34 - 800.66
21		26	613	251	49.23	2.060	101.40	511.60 - 714.40
22		25	630	112	22.40	2.064	46.23	583.77 - 676.23
23		25	368	96	19.20	2.064	39.62	328.38 - 407.68
26	HST-MS	16	493	55	13.75	2.131	29.30	463.7 - 522.3
27		3	640	212	122.40	4.303	526.70	113.3 - 1166.70
28		18	584	173	40.78	2.110	86.04	497.96 - 670.04
29		14	456	52	13.90	2.160	30.02	425.98 - 486.02
30		23	439	116	24.19	2.074	50.17	388.83 - 489.17
Aug 3	JST-BS	4	198	56	28.00	3.182	89.10	108.9 - 287.10
4		24	215	61	12.45	2.069	25.76	189.24 - 240.76
5		21	283	60	13.09	2.086	27.31	255.69 - 310.31
6		20	185	60	13.42	2.093	28.08	156.92 - 213.08
10	KST-TS	21	297	127	27.71	2.086	57.81	239.19 - 354.81
11		23	321	96	20.02	2.074	41.52	279.48 - 362.52
12		23	163	55	11.46	2.074	23.79	139.21 - 186.79
13		9	150	50	16.67	2.074	34.56	115.44 - 184.56

ST - Stope
DR - Drift
SL - Slusher
TS - Top Stope
DH - Drift Heading
MS - Middle Stope
BS - Bottom Stope

TABLE 4

ATMOSPHERIC RADON DAUGHTER OBSERVATIONS OBTAINED IN AN ONTARIO URANIUM MINE, MAY TO OCTOBER, 1977

Working Level x 1000

Location-Occupation-Day			n	$\bar{x}$	s	$s_{\bar{x}}$	t d.f=n-1 P=0.975	$ts_{\bar{x}}$	Confidence Limits 95 Per Cent	
ST	A-SL	7	14	76	29	7.75	2.160	16.74	59.26 -	92.74
		8	14	71	33	8.82	2.160	19.05	51.95 -	90.05
		9	16	49	15	3.75	2.131	7.99	41.01 -	56.99
		15	16	43	20	5.00	2.131	10.66	32.34 -	53.66
		16	15	55	27	6.98	2.145	14.97	40.03 -	69.97
		17	15	30	9	2.32	2.145	4.98	25.02 -	34.98
		18	17	58	33	8.00	2.120	16.97	41.03 -	74.97
		19	15	32	9	2.33	2.145	4.99	27.01 -	36.99
ST	B-SL	6	18	228	87	20.51	2.110	43.27	184.73 -	271.27
		7	17	213	52	12.61	2.120	26.74	186.26 -	239.74
		8	13	223	46	12.76	2.179	27.80	195.2 -	250.80
		9	17	399	337	81.73	2.120	173.27	225.73 -	572-27
		10	13	389	29	8.04	2.179	17.53	371.47 -	406.53
		15	18	221	67	15.79	2.110	33.32	187.68 -	254.32
		16	19	240	81	18.58	2.101	39.04	200.98 -	279.04
		17	18	182	33	7.78	2.110	16.04	165.59 -	198.41
		18	3	133	6	3.46	2.571	8.90	124.1 -	141.96
		19	13	169	37	10.26	2.179	22.36	146.64 -	191.36
ST	C-SL	1	18	47	17	4.00	2.110	8.45	38.55 -	55.45
		2	17	28	10	2.42	2.120	5.14	22.86 -	33.14
		9	15	44	16	4.13	2.145	8.86	35.14 -	52.86
		11	14	22	4	1.07	2.160	2.31	19.69 -	24.31
ST	D-SL	1	15	46	7	1.83	2.145	3.92	42.08 -	49.92
ST	E-SL	1	16	122	27	6.75	2.131	14.38	107.62 -	136.38
		2	17	71	18	4.36	2.120	9.26	61.74 -	80.26
		3	18	91	18	4.24	2.110	8.95	82.05 -	99.95
		5	18	98	19	4.48	2.110	9.45	88.55 -	107.45
		10	18	120	74	17.44	2.110	36.80	83.20 -	156.80
		11	17	77	17	4.12	2.120	8.74	68.26 -	85.74
		12	18	86	18	4.24	2.116	8.98	77.02 -	94.98
ST	F-SL	1	15	91	26	6.71	2.145	14.39	78.6 -	105.40
ST	G-SL	1	14	191	55	14.70	2.160	31.75	159.25 -	222.75
ST	J-SL	1	16	15	7	1.75	2.131	3.72	11.28 -	18.72
ST	K-SL	1	18	237	58	13.67	2.110	28.85	208.15 -	265.85

Location-Occupation-Day			n	$\bar{x}$	s	$s_{\bar{x}}$	t d.f=n-1 P=0.975	$ts_{\bar{x}}$	Confidence Limits 95 Per Cent
ST_1	A-DL	1	15	55	16	4.13	2.145	8.86	46.14 - 63.86
		2	18	141	135	31.82	2.110	67.14	73.86 - 208.14
		3	17	92	43	10.43	2.120	22.11	69.89 - 114.11
		4	18	76	28	6.60	2.110	13.92	62.08 - 89.92
		5	17	87	33	8.00	2.120	16.97	70.03 - 103.97
		10	17	63	18	4.37	2.120	9.26	53.74 - 72.26
		11	12	67	14	4.04	2.179	8.80	58.20 - 75.80
		12	16	125	29	7.25	2.131	15.45	109.55 - 140.45
		13	17	85	29	7.03	2.120	14.91	70.09 - 99.91
		14	14	121	31	8.29	2.160	17.89	103.11 - 138.89
ST_1	B-DL	2	13	338	41	11.37	2.179	24.78	313.22 - 362.78
		3	18	357	49	11.55	2.110	24.37	332.63 - 381.37
		4	16	308	29	7.25	2.131	15.45	292.55 - 323.45
		5	18	284	46	10.84	2.110	22.88	261.12 - 306.88
		12	17	254	32	7.76	2.120	16.45	237.55 - 270.45
		13	17	238	31	7.51	2.120	15.94	222.06 - 253.94
		14	16	218	32	8.00	2.131	17.05	200.95 - 235.05
		20	18	245	60	14.14	2.110	29.84	215.16 - 274.84
		21	12	294	67	19.34	2.179	42.14	251.86 - 336.14
		22	16	282	22	5.50	2.131	11.72	270.28 - 293.72
		23	15	233	48	12.39	2.145	26.58	206.42 - 259.58
		24	12	288	18	5.20	2.110	10.96	277.04 - 298.96
ST	C-DL	4	16	44	11	2.75	2.131	5.86	38.14 - 49.86
		5	16	30	17	4.25	2.131	9.06	20.94 - 39.06
		6	14	59	12	3.21	2.160	6.93	52.07 - 65.93
		7	15	79	45	11.62	2.145	24.94	54.06 - 103.94
		8	16	64	9	2.25	2.131	4.79	59.21 - 68.79
		10	11	55	8	2.41	2.228	5.37	49.63 - 60.37
		12	17	56	12	2.91	2.120	6.17	49.83 - 62.17
		13	17	74	9	2.18	2.120	4.63	69.37 - 78.63
		14	16	41	9	2.25	2.131	4.79	36.21 - 45.80
		15	16	44	10	2.50	2.131	5.33	38.67 - 49.33
		16	16	61	11	2.75	2.131	5.86	55.14 - 66.86
ST	E-DL	4	17	113	16	4.00	2.120	8.48	104.52 - 121.48
		6	19	215	32	7.34	2.101	15.42	199.58 - 230.42
		7	19	170	35	8.02	2.101	16.87	153.13 - 186.87
		8	18	234	55	12.96	2.110	27.35	206.65 - 261.35
		9	18	150	47	11.07	2.110	23.37	126.63 - 173.37
ST	G-DL	2	16	224	34	8.50	2.131	18.11	205.89 - 242.11
		3	17	198	31	7.52	2.120	15.94	182.06 - 213.94
		4	12	217	25	7.22	2.201	15.88	201.12 - 232.88
		5	16	201	67	16.75	2.131	35.69	165.31 - 236.69
		6	16	271	47	11.75	2.131	25.04	245.69 - 296.04
		7	16	172	28	7.00	2.131	14.91	157.09 - 186.92
		8	14	244	69	18.44	2.160	39.83	204.17 - 283.83

Location-Occupation-Day			n	$\bar{x}$	s	$s_{\bar{x}}$	t d.f=n-1 P=0.975	$ts_{\bar{x}}$	Confidence Limits 95 Per Cent
ST	H-DL	1	16	303	48	12.00	2.131	25.57	277.43 - 328.57
		2	16	346	64	16.00	2.131	34.09	311.91 - 380.09
		3	15	349	64	16.52	2.145	35.43	313.57 - 384.43
		4	16	354	54	13.50	2.131	28.76	325.24 - 382.76
ST	K-DL	4	11	240	47	14.17	2.228	31.57	208.63 - 271.57
ST	K-WA	2	17	262	67	16.25	2.120	34.45	227.55 - 296.45
		3	16	282	91	22.75	2.131	48.48	233.52 - 330.48
RA	A-MU	1	15	274	232	59.90	2.145	128.49	145.51 - 402.49
		2	18	132	97	22.86	2.110	48.24	
		3	18	141	135	31.82	2.110	67.14	73.86 - 208.14
RA	A-DL	4	16	76	18	4.50	2.131	9.59	66.41 - 85.59
		5	7	76	22	8.31	2.447	20.35	55.65 - 96.35
		6	16	91	22	5.50	2.131	11.72	79.28 - 102.72
		7	17	117	31	7.52	2.120	15.94	101.06 - 132.94
		8	16	233	217	54.25	2.131	115.60	117.4 - 346.60
		9	18	204	180	42.43	2.110	89.52	114.49 - 293.52
		10	18	118	7	1.65	2.110	3.48	114.52 - 121.48

APPENDIX - A

Instructions for the Use of Random Numbers

This Appendix presents easy-to-follow procedures for entering recognized but different random sampling tables available in the several referenced text books and publications*. Using these methods will simplify the derivation and calculation of desired random numbers to be associated with sampling times, locations and mine worker occupations.

* References: 5,6,8,9,10,11,12,13,14,21.

Example 1

Stratification of Shift Sampling Times.

For an eight hour shift period and a sampling time of 10 minutes n will have a total value of,

n = 6 x 8 = 48 consecutive sampling intervals per shift.

A random sample may then be selected from the 48 possible sampling intervals chosen from Table 7.

Number the 48 sampling intervals,

1,2,3,4,.................48.

For an 8 hour shift

Sampling Interval		Time
1		8.00 --- 8.10 AM
2		8.10 --- 8.20 AM
3		8.20 --- 8.30 AM
4		8.20 --- 8.40 AM
5		8.40 --- 8.50 AM
.		.
.	(Lunch - 12.00-12.30)	.
.		.
46		3.30 --- 3.40 PM
47		3.40 --- 3.50 PM
48		3.50 --- 4.00 PM

Typical Random Number Table

03	18	68	47	41
(a) 97	9	74	64	5
16	23	27	14	32
12	52	00	39	17
55	37	29	24	3
16	70	16	33	
84	56	11	65	
63	99	35	75	
33	16	38	18	
57	37	(a) 31	28	

(a) Subjective number choice
e.g. Social Insurance Number (SIN).

Should one wish to select six random samples, first select a number in the above table using a subjective decision such as the last two numbers in a Social Insurance Number.

Then the ten-minute sampling periods are identified in Table 7 as follows:

Period	Time Intervals
16	10.30 - 10.40 AM
12	9.50 - 10.00 AM
33	1.20 - 1.30 PM
18	10.50 - 11.00 AM
9	9.20 - 9.30 AM
23	11.30 - 11.40 PM

Sequential Time Intervals for ten minute sampling periods from Table 7

Period	Time
9	9.20 - 9.30 AM
12	9.50 - 10.00 AM
16	10.30 - 10.40 AM
18	10.50 - 11.00 AM
23	11.30 - 11.40 AM
33	1.20 - 1.30 PM

Table 5

Judgement or Grab Sampling

Charts

Ten Minute Periods

CONSECUTIVE SHIFT TIME HOURS	10	20	30	40	50	60
1	1	2	3	4	5	6
2	7	8	9	10	11	12
3	13	14	15	16	17	18
4	19	20	21	22	23	24
5	25	26	27	28	29	30
6	31	32	33	34	35	36
7	37	38	39	40	41	42
8	43	44	45	46	47	48

Example - 1A

Sampling Period 20 minutes for six sampling periods.

Period	Time
14-	12.20 - 12.40 AM
24-	3.40 - 4.00 PM
18-	1.40 - 2.00 PM
5-	9.20 - 9.40 AM
17-	1.20 - 1.40 PM
13-	12.00 - 12.20 PM

Sequential Sampling Period.

Period	Time
5	9.20 - 9.40 AM
13	12.00 - 12.20 AM
14	12.20 - 12.40 AM
17	1.20 - 1.40 PM
18	1.40 - 2.00 PM
24	3.40 - 4.00 PM

Table 6

Judgement or Grab Sampling

Charts

Twenty Minute Periods

CONSECUTIVE SHIFT TIME HOURS		10	20	40	60
	1	1	2	3	4
	2	**(5)**	6	7	8
	3	9	10	11	12
	4	**(13)**	**(14)**	15	16
	5	**(17)**	**(18)**	19	20
	6	21	22	23	**(24)**
	7	25	26	27	28
	8	29	30	31	32

For graphical presentation of partial shift and full shift sampling see Figures 1 and 2.

Sampling time as a percent of full shift exposure time is presented in Table 8.

Table 7

Sequence Number - Sampling Periods

Minutes			Shift Time
10	15	20	
			8.00 - 8.05
1			8.05 - 8.10
	1		8.10 - 8.15
2		1	8.15 - 8.20
			8.20 - 8.25
3	2		8.25 - 8.30
			8.30 - 8.35
4		2	8.35 - 8.40
	3		8.40 - 8.45
5			8.45 - 8.50
			8.50 - 8.55
6	4	3	8.55 - 9.00
			9.00 - 9.05
7			9.05 - 9.10
	5		9.10 - 9.15
8		4	9.15 - 9.20
			9.20 - 9.25
9	6		9.25 - 9.30
			9.30 - 9.35
10		5	9.35 - 9.40
	7		9.40 - 9.45
11			9.45 - 9.50
			9.50 - 9.55
12	8	6	9.55 - 10.00
			10.00 - 10.05
13			10.05 - 10.10
	9		10.10 - 10.15
14		7	10.15 - 10.20
			10.20 - 10.25
15	10		10.25 - 10.30
			10.30 - 10.35
16		8	10.35 - 10.40
	11		10.40 - 10.45
17			10.45 - 10.50
			10.50 - 10.55
18	12	9	10.55 - 11.00
			11.00 - 11.05
19			11.05 - 11.10
	13		11.10 - 11.15
20		10	11.15 - 11.20

Minutes: 10	Minutes: 15	Minutes: 20	Shift Time
			11.20 - 11.25
21	14		11.25 - 11.30
			11.30 - 11.35
22		11	11.35 - 11.40
	15		11.40 - 11.45
23			11.45 - 11.50
			11.50 - 11.55
24	16	12	11.55 - 12.00
			12.00 - 12.05
25			12.05 - 12.10
	17		12.10 - 12.15
26		13	12.15 - 12.20
			12.20 - 12.25
27	18		12.25 - 12.30
			12.30 - 12.35
28		14	12.35 - 12.40
	19		12.40 - 12.45
29			12.45 - 12.50
			12.50 - 12.55
30	20	15	12.55 - 1.00
			1.00 - 1.05
31			1.05 - 1.10
	21		1.10 - 1.15
32		16	1.15 - 1.20
			1.20 - 1.25
33	22		1.25 - 1.30
			1.30 - 1.35
34		17	1.35 - 1.40
	23		1.40 - 1.45
35			1.45 - 1.50
			1.50 - 1.55
36	24	18	1.55 - 2.00
			2.00 - 2.05
37			2.05 - 2.10
	25		2.10 - 2.15
38		19	2.15 - 2.20
			2.20 - 2.25
39	26		2.25 - 2.30
			2.30 - 2.35
40		20	2.35 - 2.40
	27		2.40 - 2.45
41			2.45 - 2.50
			2.50 - 2.55
42	28	21	2.55 - 3.00
			3.00 - 3.05
43			3.05 - 3.10
	29		3.10 - 3.15
44		22	3.15 - 3.20
			3.20 - 3.25
45	30		3.25 - 3.30

Minutes 10	Minutes 15	Minutes 20	Shift Time
			3.30 - 3.35
46		23	3.35 - 3.40
	31		3.40 - 3.45
47			3.45 - 3.50
			3.50 - 3.55
48	32	24	3.55 - 4.00

Figure 1

Full Shift Consecutive

Sampling Chart

Ten Minute Periods

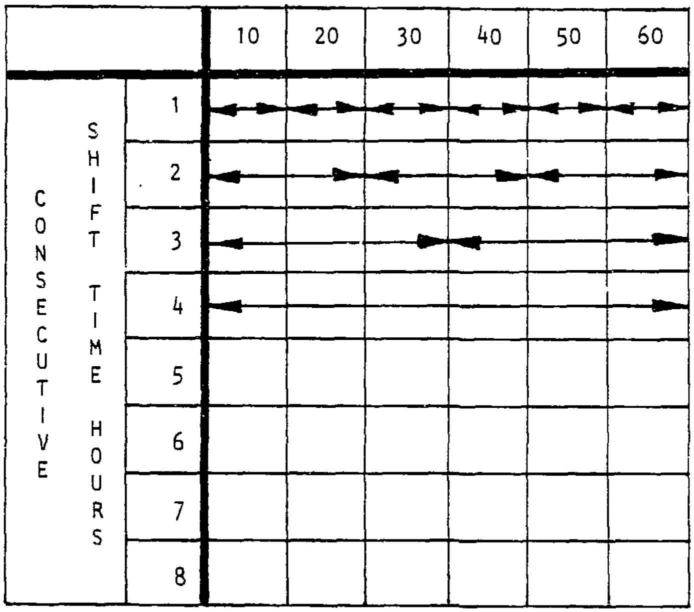


Figure 2

Partial Shift Consecutive Sampling Chart

Ten Minute Periods

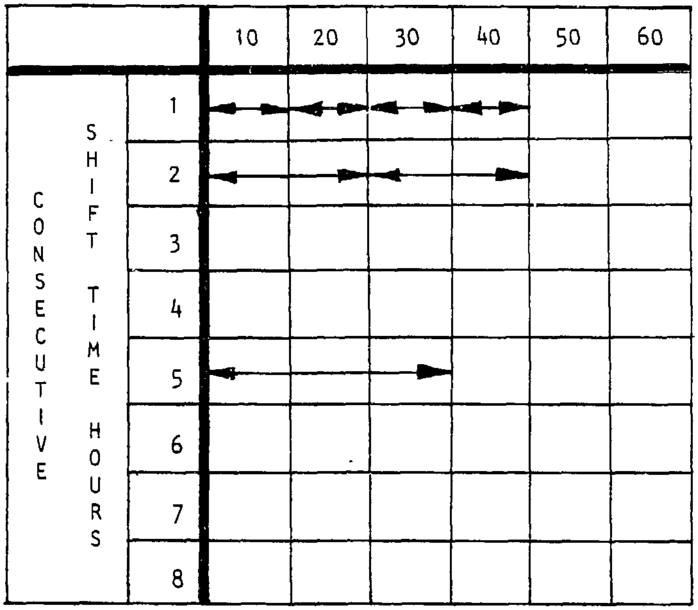


Table 8

Sampling Time as a Percent of Full Shift Exposure Time

Sampling Time Minutes	Percent of the Shift Exposure Time
5	1.0
10	2.0
15	3.1
20	4.2
25	5.2
30	6.3
35	7.3
40	8.3
45	9.4
50	10.4
55	11.5
60	12.5

- 8 hour shift x 60 = 480 minutes

10 minute sample $= \frac{10}{480} \times 100 = 2.0\%$

Example 2

Instructions for Using a Pocket Calculator Random Number Generator.

These programs generate sequences of uniformly distributed random numbers. The user chooses a "seed" number. That is any number generally between zero and 20,000 and within the limits of the random number series to be generated. The number 50 or 75 may be chosen for a random number sequence between 1 and 100. The lower limit A would then be 1 and the upper limit B, 100.

The user instructions for the TI - 58C or the TI - 59 are relatively simple to follow:-

Step	Procedure	Enter	Press	Display
1	Select Program	-	2nd Pgm15	-
2	Initialize	-	2nd E'	0
3	Enter Random Number Seed	50	E	50
4	Enter Lower Limit	1	A	1
5	Enter Upper Limit	100	B	100
6	Generate Random Numbers. Repeat as needed.	-	C -	93
			C -	20
			C -	99

See Tables 9, 10 and 11.

Table 9

Table of Random Numbers Generated Using the Texas Instrument Programmable 58C or the 59 Calculator.

Series - 1.

93	84	64	35	48	93	28	12	98	77
20	91	60	61	80	30	13	52	44	15
99	51	29	83	38	5	74	18	33	94
50	48	100	53	100	57	75	56	87	11
13	44	83	93	7	81	72	46	48	30
93	76	70	22	55	98	26	1	79	40
55	16	81	36	57	25	95	83	31	54
17	14	18	74	88	39	97	45	78	87
78	97	39	84	41	25	51	6	43	34
8	4	13	61	3	26	58	74	52	44

Series - 2.

74	3	71	25	16	33	97	69	98	84
55	90	86	88	60	61	39	58	44	46
49	27	12	74	84	83	12	27	97	5
48	31	70	17	30	97	26	21	81	82
1	45	10	9	6	33	36	39	88	54
77	71	32	47	43	24	97	92	48	30
74	97	69	12	77	19	100	51	11	70
58	21	7	26	73	61	29	23	35	4
22	91	100	19	55	23	32	6	60	48
36	13	61	43	18	24	43	24	13	92

Uniform Distribution
Lower Limit - 1.0
Upper Limit - 100.0
Master Library Module ML-15
Reference Guide page 52

Table 10

Three hundred random numbers in the range 1 to 100.

1- 73	26-19	51-52	76-27
2- 19	27-75	52-51	77-15
3- 85	28-11	53-93	78-93
4- 89	29-62	54-38	79-57
5- 15	30- 9	55-72	80-28
6- 8	31-98	56-16	81-77
7- 19	32-49	57-94	82-37
8- 59	33-87	58-78	83- 2
9- 7	34-38	59-76	84-41
10- 38	35-91	60-94	85-82
11- 39	36-60	61-31	86-41
12- 86	37- 7	62-90	87-12
13- 81	38-84	63-95	88-26
14- 52	39-20	64-39	89-16
15- 13	40-34	65-17	90-53
16- 92	41-62	66-94	91-21
17- 98	42-82	67-91	92-60
18- 52	43- 1	68-55	93-23
19- 37	44-84	69- 6	94-79
20-100	45- 3	70- 8	95-30
21- 38	46-69	71-53	96-24
22- 91	47- 8	72-43	97-16
23- 36	48-10	73-25	98-73
24- 97	49-18	74-47	99-19
25- 36	50-80	75-39	100-85

1-25	26-50	51-75	76-100
39	96	2	79
31	45	4	43
49	59	67	81
75	17	14	53
77	82	91	68
86	26	89	23
13	90	23	43
90	36	82	79
83	29	13	28
32	33	47	21
16	56	56	28
29	96	50	50
39	7	70	69
9	96	77	60
18	58	44	99
31	20	34	54
89	70	22	81
18	98	42	89
54	7	27	14
13	18	8	81
95	37	47	49
33	35	35	61
71	57	41	1
2	78	21	45
31	73	38	56

1-25	26-50	51-75	76-100
51	33	40	64
42	99	6	5
18	33	9	38
68	27	28	4
87	64	95	11
12	91	61	89
60	15	16	62
2	37	2	52
54	33	66	18
95	45	73	70
63	27	57	84
53	63	10	91
30	29	73	79
15	68	41	80
7	96	95	12
88	92	48	69
34	32	55	98
85	31	94	11
37	99	73	28
88	40	16	59
4	44	39	81
1	30	49	20
74	74	71	41
78	25	21	57
72	32	27	72

Table 11

Three hundred and fifty random numbers in the range 1 to 120.

1-25	26-50	51-75	76-100	101-125	126-150	151-175
49	69	91	105	25	24	95
99	13	119	93	78	33	54
49	80	89	95	16	98	49
14	100	117	90	51	65	36
31	47	99	4	85	53	27
19	113	30	23	63	67	27
64	71	58	30	38	93	54
25	17	16	105	68	17	120
72	102	8	109	2	110	30
27	16	118	110	86	119	36
95	97	58	99	66	21	64
36	26	59	116	45	50	101
29	42	56	17	20	119	93
19	65	114	95	31	21	114
106	32	87	61	56	117	93
26	60	60	36	4	83	38
95	9	86	110	25	9	43
53	111	63	87	11	54	81
9	20	51	116	108	31	86
114	55	68	2	20	12	121
118	61	93	87	74	98	112
26	80	79	49	7	44	114
28	121	79	42	74	68	24
25	29	26	38	22	39	96
48	10	40	56	120	37	96

176-200	201-225	226-250	250-275	276-300	301-325	326-350
8	46	64	25	98	16	104
46	110	52	52	105	9	10
47	72	30	44	26	10	43
104	9	57	68	98	96	94
98	102	47	28	88	19	109
63	24	33	19	79	112	64
16	41	18	88	24	111	63
111	75	113	23	8	33	110
118	99	69	103	87	3	33
62	1	34	107	47	21	79
45	102	93	18	13	73	105
121	4	45	9	19	49	68
46	84	2	23	46	83	76
110	10	92	71	8	81	89
43	12	114	102	13	94	34
118	22	37	88	112	114	96
43	97	109	27	48	83	90
23	63	115	54	100	111	83
91	62	47	95	101	103	56
14	113	20	11	82	6	100
74	46	114	55	42	62	69
11	87	110	104	67	55	109
118	19	66	31	76	115	49
59	114	7	90	59	27	45
106	94	9	67	119	75	92

Example 3

Computer Generated Random Numbers

This list of 500 random numbers may be used to design a statistical random sampling plan, Table 12.

Table 12

Listed below are 500 random numbers from 1 to 500.

148	469	125	142	131
301	325	228	63	21
30	42	265	406	309
110	199	165	322	106
222	113	393	116	102
155	466	17	227	160
103	208	310	198	93
39	137	207	412	402
260	185	475	345	494
284	72	484	268	43
201	392	97	164	237
100	435	287	184	269
308	99	214	459	386
211	496	339	483	387
2	236	127	240	180
467	74	337	400	36
6	389	347	115	422
188	55	401	234	305
264	417	1	456	67
368	182	232	31	474
316	122	376	404	144
246	146	369	112	451
187	340	216	394	272
16	326	92	348	59
46	202	210	277	298
399	132	409	24	212
50	372	391	84	37
217	472	317	464	447
448	138	49	438	225
437	41	385	480	383
89	235	307	450	98
47	196	258	279	161
388	80	126	421	428
82	87	157	203	487
478	363	33	254	120
403	318	169	141	273
114	140	94	28	143
365	25	218	204	303
159	370	333	449	9
34	290	477	433	263
83	338	244	439	3
158	444	359	171	382
411	413	341	485	375
15	431	342	366	68

367	295	407	334	492
288	443	381	396	195
378	351	229	23	315
371	384	311	119	442
312	174	440	154	170
352	490	8	362	287
280	418	107	424	57
242	357	332	278	81
200	105	88	320	145
471	291	327	434	147
266	230	498	364	95
139	7	292	45	294
118	108	85	38	379
27	330	462	493	189
245	79	86	247	255
319	489	256	194	153
479	128	221	205	121
64	70	104	239	457
390	432	172	293	69
193	249	238	133	446
168	445	408	289	156
60	231	473	73	135
335	276	415	453	54
65	283	4	22	206
75	26	123	130	405
420	219	323	425	374
51	377	324	61	10
259	111	436	329	12
250	151	96	176	331
321	91	461	397	350
349	48	152	20	56
52	66	476	470	162
302	117	460	452	224
90	358	499	441	62
306	44	35	19	71
213	414	167	248	197
465	300	270	243	285
454	491	190	241	495
353	109	486	175	32
223	166	354	192	233
124	77	11	360	179
373	58	343	267	181
281	500	53	134	173
209	380	314	150	356
346	298	226	416	430
395	253	18	286	427
163	497	129	177	419
299	423	271	215	262
251	183	186	76	136
328	220	29	13	336
344	410	275	178	78
429	458	274	426	149
257	482	463	304	361
468	282	313	261	14
481	40	191	252	488
5	455	101		355

Example 4

Some tables of random numbers are arranged as shown in Table 13. An example is Snedecor (7). Although the random numbers are listed in rows and columns, the number sequences are read vertically.

Starting Point

The starting point for drawing numbers from the random number table is the next number following the finish of the previous use of the table.

The first time the table is used one should use the last digit of a telephone number or a Social Insurance Number (SIN) to find a "random" starting point. For example if this digit is 4, start selecting random numbers in Table 13 column 00 at row 02. The starting point is number 33.

Random Number Sequences

Suppose there are 45 locations to assign a random number sequence. The numbers of interest are clearly those two digit numbers starting with zero and those two digit numbers starting with 4 whose second entry is five or less. Thus, the procedure is to read down the random number column in pairs of digits. For example, in Table 13 in column 00 and row 02 read 33 34 08 49 34 19 87 40 02 68 03 88 .... to the end of column 00. Then read 21 51 92 55 73 49 .... in column 01.

In Table 14 the first three columns in Table 13 have been repeated to further exemplify the vertical combination of digits to form these two digit random numbers.

The 00 column has been repeated as 94, 33, 34, 08 .... and the 01 column is also identified as 21, 51, 92, 55 ....

The starting point 33 has also been identified in Table 14.

Table 13

Hypothetical Random Numbers Sequence Mechanism Method.

COLUMNS

ROWS	00-04
00	92350
01	41035
02	35552
03	31355
04	39908
05	42080
06	05422
07	85205
08	47348
09	93654
10	34971
11	49106
12	14645
13	91511
14	82558
15	71255
16	47625
17	05250
18	06004
19	27850
20	66986
21	88048
22	08075
23	39318
24	86847
25	82042

Table 14

Random Numbers Obtained From Columns 00, 01 and 02 in Table 13.

		COLUMNS					
		00		01		02	
(Last Digit in SIN) (Starting Point)		9 4	94	2 1	21	3 0	30
		3 3	33	5 1	51	5 3	53
		3 4	34	9 2	92	9 0	90
	ROWS	0 8	08	5 5	55	4 2	42
		4 9	49	7 3	73	3 6	36
		3 4	34	4 9	49	9 1	91
		1 9	19	4 1	41	6 5	65

SIN - Social Insurance Number

Example 5

Another familiar table of random five digit numbers, illustrated in Table 15 is referenced in Beyer.(8)

Select Sixteen Random Numbers 1 to 16.

The problem of selecting 16 random digits begins with the identification of the first two digits from a SIN reference. In this case 07, followed by recording 50 numbers from columns 1 to 4.

The sixteen numbers are obtained by copying those numbers in sequence less than 17 and the remainder are obtained by dividing numbers greater than 16 by 20. This method will conserve the number of random numbers required for each shift obviating the necessity for recording a large number of paired digits.

In the example presented, for instance, the second number chosen in the series is 49 or 2x20+9 or 9 and the third 66 or 3x20+6 or 6.

Table 15

Hypothetical Random Numbers - Paired Row Column Sequence Method.

Row / Column		1	2	3	4	5	6	7 →
1	(7)	07198	38128	42919	30093	59832		
2	(9)	49564	40684	73956	60950	51261		
3	(6)	66869	90524	80098	90849	40724		
4		18988	88991	98691	70515	49897		
5	(11)	11966	18494	47044	36941	30747		
6		07810	38886	83658	94510	62081		
7		57648	25[illegible]24	96848	11021	4442		
8	(1)	21457	45869	10952	76789	96144		
9		98604	77824	54149	84109	26029		
10	(12)	32671	24749	16808	43799	23337		
11	(8)	88460	89322	02415	83952	43421		
12		78408	52442	81667	89638	59895		
13		68925	99447	92024	28307	54451		
14		39168	93814	66060	93645	96173		
15		31133	71419	51931	84380	84438		
16	(15)	55290	42845	23969	27334	94677		
17								
18								

↓ Sixteen Random Numbers

Row - Column	11	21	31	51	81	101	131	161	32	72
Random Sample	7	9	6	11	1	12	8	15	10	5

Row - Column	102	142	162	63	93	103
Random Sample	4	13	2	3	14	16

Selection of 50 random numbers from a table beginning with 07.

07 49 66 18 11 07 57 21 98 32 88

8 68 39 31 55 38 40 90 88 18

38 25 45 77 24 89 52 99 93 71

42 42 73 80 98 47 83 96 10 54 16

02 81 92 66 51 23 30 60

For a sample size of 16.

- Your SIN number is 412-726-207
  Start with the last number of your SIN - 07.
- For numbers greater than 16 divide by 20 and take the remainder. Delete the following:-
  - numbers greater than 16
  - repeated numbers
  - zero

Example 6

Statistical Random Sampling Grids.

Table 16 The Latin Square Grid.

This sampling procedure reduces the number of locations from 36 to 6 and may be designed for any practical number of locations, an important consideration, when the number of underground locations is relatively small.

The sampling sequence can be entered at random using either of the random number tables available.

For instance, the first series of samples will involve obtaining a 10-minute sample from Raise-A Table 16 then a 20 minute sample from Stope-A and so on. The second series of samples will be obtained from Stope A - 10 minute, Stope B 20 minute, Stope C - 30 minute, Raise B - 40 minutes, etc.

Alternatively 20-minute samples may be obtained from:-

Code	Location	Sampling Period
b-2	Stope-A	1 st.
c-3	Stope-B	2 nd.
d-4	Stope-C	3 rd.
e-5	Raise-B	4 th.
f-6	Stope-D	5 th.
a-1	Raise-A	6 th.

This table need not be altered. Random selection may be directed instead to 1 to 6 or six different random numbers assigned each day, week or month to these location identifications.

For a larger number of underground locations a grid similar to Table 17 may be used.

Table 16

Statistical Random Sampling Grid.

Sampling Sequence	Sample Duration - Minutes 10	20	30	40	50	60
1 st.	a1	b2	c3	d4	e5	f6
2 nd.	b2	c3	d4	e5	f6	a1
3 rd.	c3	d4	e5	f6	a1	b2
4 th.	d4	e5	f6	a1	b2	c3
5 th.	e5	f6	a1	b2	c3	d4
6 th.	f6	a1	b2	c3	d4	e5

Location Identification

a 1 - Raise A
b 2 - Stope A
c 3 - Stope B
d 4 - Stope C
e 5 - Raise B
f 6 - Stope D

Table 17

Statistical Random Sampling Grid.

Sampling Sequence	Sample Duration - Minutes 10	20	30	40
1 st.	17	24	19	7
2 nd.	2	8	6	23
3 rd.	22	9	14	3
4 th.	4	21	12	20
5 th.	1	18	10	5
6 th.	15	11	16	13

Location Identification

1-Raise A	5-	9-	13	17- Stope C	21-
2-Stope B	6-	10-	14	18-	22- Stope F
3-	7-	11-	15 Stope D	19-	23-
4-Stope E	8-	12-	16-	20-	24-

Example 7

Statistical Random Sampling Grid Sequential Selection and Alternate Sampling Periods.

Should it be desired to make a last-minute decision before travel to the locations of interest a grid similar to Figure 3 may be designed with alternative sampling times for randomly selected locations.

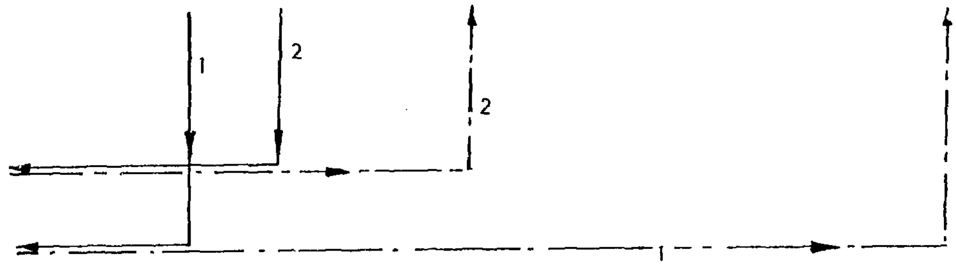
Figure 3

Statistical Random Sampling Grid.

Sample Location	
1	6
2	2
3	5
4	8
5	4
6	1
7	9
8	3
9	7
10	10

Sequential Selection and Sampling Periods

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
R-1	50	35	40	55	45	30	60	10	25	20 Minutes
R-2	7	5	6	9	8	4	10	1	3	2



(3) R- Random Number Sequence
R-1 Sample duration minutes
R-2 Number of 5 minute samples.

Note:

(1)- The first sample is to be taken in location 7. The sample duration is either 25 minutes or three 5 minute samples.

(2)- The second sample is to be taken in location 5. The sample duration is either 55 minutes or nine 5 minute samples.

Example 8

Stratified Random Sampling of a Large Number of Mine Locations.

The large number of individual mine locations and occupations which must be sampled during a working shift for a sufficient number of days to reveal the atmospheric radon daughter concentration in the mine presents the mine operator with a most difficult problem. There may be in excess of fifty mine locations to be sampled every half-hour for a period of eight hours a day for five to ten consecutive days.

This sampling frequency is an essential prerequisite to the calculation of a reliable exposure history for miners because the frequency and maximum working levels of unususal occurrences must be included in addition to that working level characteristic of the mine location of interest.

A stratified random sampling plan is suggested, the implementation of which will ensure, during each month, that each mine location and each shift period have equal opportunity of being selected.

The size of the sample and frequency of sampling must then be determined to satisfy regulatory authority requirements.

Random numbers are first assigned to the twelve months of the calendar year as follows:

Random Numbers

Assigned To Months

January	1	4
February	2	6
March	3	5
April	4	2
May	5	8
June	6	1
July	7	7
August	8	11
September	9	12
→ October	10	3
November	11	10
December	12	9

Based on a five-day week or a twenty-day month, one can assign numbers to the working days in the month.

Two examples of randomly chosen sets are presented as follows:

Random Numbers Assigned To Months
And To Working Days In A Month

Month	Working Day Set 1	Working Day Set 2
1	7	4
2	8	17
3	5	19
4	15	12
5	1	11
6	9	16
7	13	6
8	14	10
9	3	18
→ 10	→ 20	→ 2
11	4	5
12	17	14

The October sample is selected during the twentieth (20) or the second (2) working day.

Assignment Of Random Numbers To
Forty-Eight 30 Minute Intervals
During Three 8 Hour Shifts

Working Day	Half Hour	Shift	Working Day	Half Hour	Shift	Working Day	Half Hour	Shift
1	35	3	1	32	2	1	44	3
→ 2	27	2	→ 2	20	2	→ 2	37	3
3	30	2	3	11	1	3	14	1
4	10	1	4	9	1	4	46	3
5	2	1	5	17	1	5	8	1
6	38	3	6	1	1	6	45	3
7	7	1	7	31	2	7	42	3
8	29	2	8	16	1	8	12	1
9	47	3	9	43	3			
10	34	3	10	6	1			
11	19	2	11	4	1			
12	23	2	12	25	2			
13	5	1	13	3	1			
14	21	2	14	28	2			
15	18	2	15	41	3			
16	26	2	16	24	2			
17	40	3	17	36	3			
18	48	3	18	15	1			
19	33	2	19	39	3			
→ 20	22	2	→ 20	13	1			

Shift 1 - 8 a.m. - 4 p.m.
Shift 2 - 4 p.m. - 12 midnight
Shift 3 - midnight - 8 a.m.

During the twentieth (20) working day, the first (1) or second (2) shift may be sampled. During the second (2) working day the second (2) or third (3) shift may be sampled.

Stratification of stopes and other mine locations must be based on preliminary sampling to reveal those locations which may be grouped together by working level range. Stopes having a consistently high working level may necessitate an increased sampling frequency.

Random Numbers Assigned To

Mine Location Identification

Random Number	Strata	Location
1	1	Stope A
2	1	
3	1	
4	1	
5	1	
6	1	
7	1	
8	1	
9	1	
10	1	
11	1	
12	1	
13	2	Raise A
14	2	
15	2	
16	2	
17	2	
18	2	
19	2	
20	2	
21	2	
22	2	
23	2	
24	2	

APPENDIX - B

Instructions for the Calculation of the Confidence Limits for the Population Mean.

Baseline data was obtained in Canadian uranium mines during 1976 - 1978. (Tables 2, 3 and 4)

Confidence Limits

It sometimes troubles the experimenter, depending on which set of data is inspected, that the spread of the limits of the data may be large or small. The limits in some instances may, in fact, be quite large. The assurance can now be given that this is inherent in the nature of measurements by any method. The evidence of many trials as well as rigorous mathematical proof shows that based on the evidence of a single small set, independently and collectively at random, it is possible to make statements (inferences) relating the mean or average of the small set, to the average that would be obtained if a great many more measurements were made.

The solution to this problem for small samples $n \leqslant 30$ is a great landmark in the development of statistical methods. It was accomplished in 1908 by the English chemist W.S. Gossett who wrote under the name "Student".

It should be realized that a good small sample is better than a poor large sample and that a quite moderate amount of data submitted to efficient statistical evaluation often makes a much more convincing case.

When we calculate the confidence limits for the mean from the data obtained from a small sample what we are actually doing is to create a range minimum and maximum within which the population mean will lie 99, 95 or 90 per cent of the time. Now this mean is not the mean of our particular small sample but the average of all the means we would obtain if instead of just one sample we had hundreds of samples obtained in like manner.

For instance, let us say we have obtained thirty values from a particular location. The confidence limits we calculate at the 95 per cent confidence level will give us a minimum and maximum which will contain the average of hundreds of such means of observations should we have continued to obtain these averages over a period of months provided, of course, we obtained the sets of data under like circumstances.

Now, that is all the confidence limit tells us, and we should bear in mind that five means will lie outside this range at the 95% confidence level. Today we can calculate the 99.999 per cent confidence interval or, in this instance, one mean in 100,000 will lie outside the range. But, this range will be very much broader or wider.

If we adopt a 95 per cent level of confidence, the statement we can make about the average of the population of individual measurements is this:

The probability is approximately 0.95 that the average of the population of individual measurements is included between the 95 per cent confidence limits

$$\overline{X} \pm t_{0.975} \frac{s}{\sqrt{n}}$$

where $t_{0.975}$ depends on n, the sample size and degrees of freedom d.f = n-1. For instance the values of $t_{0.975}$ for n = 2, 5, 10, 20 and 30 are 12.706, 2.776, 2.262, 2.093 and 2.045 respectively. Other values may be found in Table 18.

The correct statistical interpretation of these 95 per cent confidence limits is this:

Suppose many random samples of size n are drawn and that the confidence limits,

$$\overline{X} \pm t_{0.975} \frac{s}{\sqrt{n}} \quad \text{are calculated}$$

for each sample, then in about 95 per cent of the samples it will be found that the confidence limits include the average of the population between them.

The precise form of this statement should be noted very carefully. It is widely misunderstood and misused. In particular, it should be observed that the statement does not mean that about 95 per cent of the individual measurements in the population will be included between the limits

$$\overline{X} \pm t_{0.975} \frac{s}{\sqrt{n}}$$

yet this is the interpretation often given to it.

Table 18

Percentile Values tp for Student's t - Distribution for p = 0.975 v = degrees of freedom, n - 1.

v	$t^*_{0.975}$	v	$t_{0.975}$
1	12.71	26	2.06
2	4.30	27	2.05
3	3.18	28	2.05
4	2.78	29	2.04
5	2.57	30	2.04
6	2.45		
7	2.36		
8	2.31		
9	2.26		
10	2.23		
11	2.20		
12	2.18		
13	2.16		
14	2.14		
15	2.13		
16	2.12		
17	2.11		
18	2.10		
19	2.09		
20	2.09		
21	2.08		
22	2.07		
23	2.07		
24	2.06		
25	2.06		

* Use the $t_{0.975}$ column in the t-distribution table to calulate the 95 per cent confidence limits.

Example

A sample obtained from Stope A, Slusher, on October 15, 1977 included 16 observations of radon daughter concentrations with an arithmetic mean $\overline{X} = \frac{\Sigma X_i}{n}$ = 0.043 working level (WL) and a standard deviation s = 0.020 WL.

The confidence interval (CI) is then,

$$CI = \overline{X} \pm t\, s_{\overline{x}}$$

$$= \overline{X} \pm t \frac{s}{\sqrt{n}}$$

Since $\overline{X}$ = 0.043
s = 0.020
n = 16
and t = 2.13 for n-1 or 15 degrees of freedom at the 0.975 probability level.

$$CI = 0.043 \pm 2.13 \frac{0.020}{\sqrt{16}}$$

$$= 0.043 \pm 2.13 \frac{0.020}{4}$$

$$= 0.043 \pm 2.13\,(0.005)$$

$$= 0.043 \pm 0.01065$$

$$= 0.03235 \text{ to } 0.05365$$

or 0.032 WL to 0.054 WL

Table 19

Calculation of Baseline Data

Stope A Slushing WL X 1000

Atmospheric Radon Concentrations

Date October 1977	n	$\overline{X}$	s	s^2
7	14	76	29	841
8	14	71	33	1089
9	16	49	15	225
15	16	43	20	400
16	15	55	27	729
17	15	30	9	81
18	17	58	33	1089
19	15	32	9	81

Assuming homogeniety of the variances, the grand mean is,

$$\bar{\bar{X}} = \frac{n_1 \bar{x}_1 + n_2 \bar{x} + \text{-----------} + n_k \bar{x}_k}{n_1 + n_2 + \text{------------} + n_k}$$

and the estimate of σ^2, s^2

where,

$$s^2 = \frac{(n_1-1)\, s_1{}^2 + (n_2-1)\, s_2^2 + \text{--------} + (n_x-1)\, s_k^2}{(n_1-1) + (n_2-1) + \text{-----------} + (n_x-1)}$$

then

$$\bar{\bar{X}} = \frac{14(76) + 14(71) + 16(49) + 16(43) + 15(55) + 15(30) + 17(58) + 15(32)}{14 + 14 + 16 + 16 + 15 + 15 + 17 + 15}$$

$$\bar{\bar{X}} = \frac{1064 + 994 + 784 + 688 + 825 + 450 + 986 + 480}{122}$$

$$\bar{\bar{X}} = \frac{6271}{122}$$

$= 51.4016,\quad 51.4$ (WL X 1000)

= or 0.051 WL

and s^2

$$= \frac{13 \times 841 + 13 \times 1089 + 15 \times 225 + 15 \times 400 + 14 \times 729 + 14 \times 81 + 16 \times 1089 + 14 \times 81}{13 + 13 + 15 + 15 + 14 + 14 + 16 + 14}$$

$$s^2 = \frac{10933 + 14157 + 3375 + 6000 + 10206 + 1134 + 17424 + 1134}{114}$$

$$s^2 = \frac{64362}{114}$$

$s^2 = 564.59$

$s = 23.76$ WL X 1000
or 0.024 WL

$\bar{\bar{X}} = 0.051$ WL, $s = 0.024$ WL.

This large value of the standard deviation relative to the mean value would indicate a variation in the confidence limits obtained for each day.

Confidence Limits

Date October 1977	95 Per Cent Confidence Limits
7	0.059 - 0.093
8	0.052 - 0.090
9	0.041 - 0.057
15	0.032 - 0.054
16	0.040 - 0.070
17	0.025 - 0.035
18	0.041 - 0.075
19	0.027 - 0.037

For the eight days observed the 95 per cent confidence limits range from 0.025 WL to 0.093 WL.

Although there is a wide range observed the results are considerably less than the 0.33 WL corresponding to 4 WLM per year.

One would expect, therefore, that periodic inspection of Stope A should result in an average value $\overline{X}$ within the range 0.025 WL and 0.093 WL.

APPENDIX C

Definitions

Applied Statistical Methods

Allocation, of a Sample

The way in which sample numbers are assigned to various parts of a population by the sampling plan; e.g. for a stratified population it may be decided to allocate the total sample number to the strata in proportion to the numbers of individuals in those strata.

Area Sampling

A method of sampling used when no complete frame of reference is available. The total area under investigation is divided into smaller sub-areas which are sampled at random by some restricted random process. Each of the chosen sub-areas are then fully inspected and may form a frame for further sampling.

Bias

Generally, an effect which deprives a statistical result of representativeness by systematically distorting it, as distinct from a random error which may distort on any one occasion but balances out on the average.

Biased Sample

A sample obtained by a biased sampling process, that is to say, a process which incorporates a systematic component of error, as distinct from random error which balances out on the average.

Confidence Limits [15]

The 95 per cent confidence interval or confidence limits:

That interval or range of values around an observed value which will in 95 per cent of the cases, include the expected value. The expected value is defined as the average of an infinite series of such determinations.

The 95 per cent confidence level:

This term is commonly used in establishing the probability of precision statements and means that there are 95 in 100 chances of being correct and 5 in 100 chances of being wrong in predicting that the expected precision (or expected value) will fall within the specified limits or range.

Judgement Sampling or Grab Sampling

Judgement sampling consists of removing a sample that is believed to be typical of the population. This procedure is entirely subjective and is often misleading. Never the less it is often used either because it is convenient or because the assumption is made that successive environmental samples if obtained sample has a fixed and determinate probability of selection. Ordinarily haphazard or seemingly purposless choice is generally insufficient to guarantee randomness when carried out by human beings and devices such as tables of random sampling numbers.

Population

In statistical usage the term population is applied to any finite or infinite collection of individuals.

Random

This word may be taken as representing a process of selection applied to a set of objects. The objects are said to be random if each one has an equal chance of being chosen.

Random Sampling

Random sampling is achieved if every location - occupation - time sub set of a population has equal chance of being selected. This is the most desireable sampling procedure because it involves few assumptions for the data analyses ensures an unbiased and an independent sample.

When a satisfactory sampling frame has been assigned to the units in the population (shift, time, location) a sequence of numbers can be assigned to them from a table of random numbers.

Random Order

An order of a set of objects when the ordering process is carried out in such a way that every possible order is equally probable.
Note: This may apply to locations or occupations in a uranium mine.

Random Sampling Numbers

Sets of numbers used for the drawing of random samples. They are usually compiled by a process involving a chance element and in their simplest form consist of a series of digits 0 to 9 occurring (so far as can be ascertained) at random with equal probability.

Sample

A part of a population or a subset from a set of units which is provided by some process or other usually by deliberate selection with the object of investigating the properties of the parent population.

Sampling Time

In practice the majority of samples taken are in the range of 3 to 5 minutes. Longer period sampling may be obtained for the purpose of establishing baseline data levels of exposure to radon, radon daughters, respirable dust and quartz in respirable dust.

Personal dosimetry may also be used to obtain samples for periods of 8 hours.

Systematic Sample, General

A sample which is obtained by some systematic method, as opposed to random choice; for example, sampling from a list by taking individuals at equally spaced intervals (called the sampling interval) or sampling from an area by determining a pattern of points on a map.

Systematic Sampling, in mines

In the case of systematic sampling every item in the population, location-occupation-time is assigned a unique number between 1 and N. While sampling this population one may decide to choose every 10th item (shift time period), starting with any one at random. If the first item chosen is the second 15 minute period then the 12th, 22nd, 32nd .... 15 minute periods will be sampled during the 8 hour shift in different locations. Although easy to administer this method is subject to bias.

Stratified Sample

A sample selected from a population which has been stratified, part of the sample coming from each stratum.

Stratification after Selection

It sometimes happens that the proportional numbers lying in certain strata are known but that it is possible to identify in advance the stratum to which a chosen number belongs. The sample selection then has to be made without reference to the strata e.g. by simple random sampling.

Stratification

The division of a population into parts known as strata; especially for the purpose of drawing a sample, an assigned proportion of the sample then being selected from each stratum. Note: A stratum may have reference to a mine location or occupation.

Statistics

Numerical data relating to an aggregate of individuals; the science of collecting, analysing and interpreting such data.

Radiation Monitoring

Air Monitoring

Collection and analysis of samples of air to determine the concentration of radioactive or other substances in air.

Aerosol

Fine particles of liquid or solid dispersed in air or other gases. (e.g. dusts, smoke, fumes.)

Attached Daughters

Radon daughters attached to aerosols. (Unattached daughters exist as free atoms or ions.)

Concentration

Amount of substance per unit volume; for example, the amount of radon and radon daughter products in a given volume of mine air. Radon daughter concentrations are expressed in terms of the "Working Level".

Daughter

A synonym for decay product. The new nuclide produced when a radioactive atom decays. For example, ^{218}Po is the daughter of the parent atom radon (Rn).

Inhalation

The drawing of air or other vapour into the lungs.

Occupational Exposure

Exposure to ionizing radiation during a person's occupation. Miners are occupationally exposed while at work.

Radiation Protection

Cumulative Exposure

Cumulative exposure of an individual to radioactive material in the atmosphere is defined as the sum of the products of the respective atmosphere concentrations and corresponding exposure times of the individual in all of his working locations divided by the total average working hours in a specified period.

then,

$$E = \frac{T_1 C_1 + T_2 C_2 + \ldots\ldots\ldots\ldots + T_n C_n}{170}$$

where,

E = cumulative exposure expressed in working level months.
$T_1.T_2,T_3$ = time in a working location, hours
C = Average concentration in a working location, expressed in working levels.
170 = total hours normally worked in one month.

Gamma Radiation

Electromagnetic radiation emitted in the process of nuclear transition or particle annihilation.

Radiation External (radiation protection)

Ionizing radiation reaching the body from sources outside the body.

Radon

The noble gas ^{222}Rn

Radon Daughters

The decay products of ^{222}Rn decay chain having short radioactive half-lives, namely:-

^{218}Po, ^{214}Pb, ^{214}Bi, and
^{214}Po (RaA, RaB, RaC, and RaC1)

Uranium

The mixture of ^{238}U, ^{235}U, and ^{234}U as they occur in nature.

Working Level (WL)

A special unit of radon daughter concentration in air. One working level is defined to be any combination of numbers of atoms of the first three decay products of Radon-222 in a letre of air such that the total α energy to complete decay to Radon D (Lead-210) is 1.3×10^5 MeV. For one year a concentration of 1.0 WL is equivalent to an exposure of 12 WLM or 1WL X 12 months. The regulatory limits for accumulated exposure are:

2 WLM in any 3 consecutive months

4 WLM in any 12 consecutive months

Working Level Hours

A special unit of cumulative exposure. The cumulative exposure in working level hours is the product of the time in hours and the radon daughter concentration in working levels.

Working Level Month

A special unit of cumulative exposure in which the hours worked is 170 hours (40 hours per week times 4 1/3 weeks per month).

APPENDIX - D

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