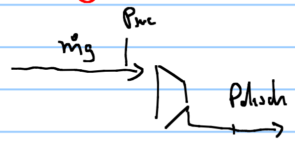
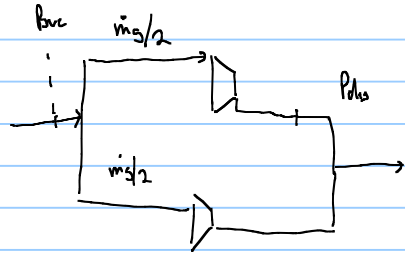
Comment when planning compressors in parallell.

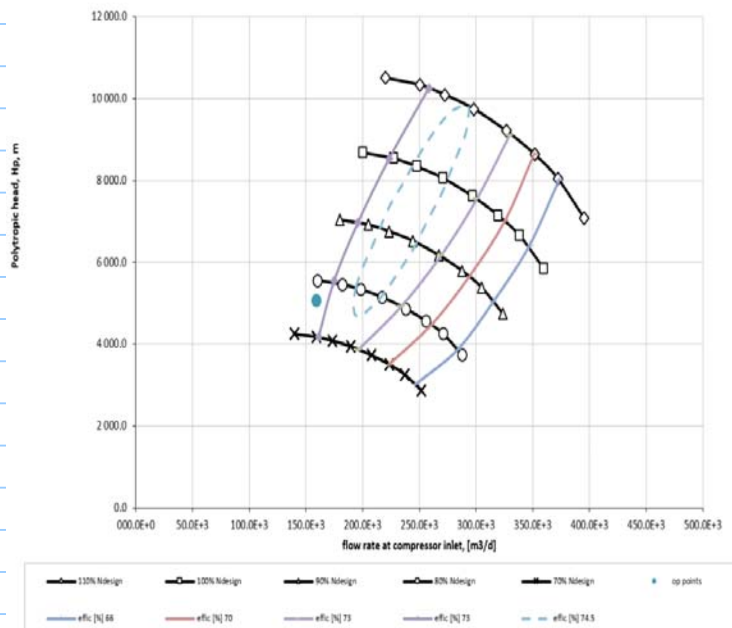


P_1

$$\underline{P} = \frac{H_p \cdot g \cdot \dot{m}}{\eta_p \cdot \eta_m}$$



$\underline{P}$ per compressor is $\underline{P}_1/2$ because the mass flow was halved. BUT in reality η_p changes with $\dot{m}$ because q_{actual} at compressor inlet is reduced



DT inlet cooler	Tsuc	rp	deltap	np -eff	n	Tdis	DT outlet cooler	Tin_pipeline	zsuc
[C]	[C]	[-]	[bar]	[-]	[-]	[C]	[C]	[C]	
47	20	1.71	32.6	0.73	1.46	73.9	0	73.9	0.916
0	67	1.18	11.9	0.7	1.49	85.9	0	85.9	0.935
0	67	1.39	22.0	0.7	1.49	105.7	0	105.7	0.944
0	67	1.74	33.4	0.7	1.49	134.8	0	134.8	0.954
0	67	2.53	47.5	0.7	1.49	188.3	0	188.3	0.967
0	67	#VALUE!	#VALUE!	0.7	1.49	#VALUE!	0	#VALUE!	#VALUE!
0	67	#VALUE!	#VALUE!	0.7	1.49	#VALUE!	0	#VALUE!	#VALUE!
0	67	#VALUE!	#VALUE!	0.7	1.49	#VALUE!	0	#VALUE!	#VALUE!

for 1st year of compression
$\Delta p_{choke} = 30$ bara
$\Delta T_{cooler} = 17\,°C$

k	1.30
Polytropic effic	0.7
Mech. Effic	0.95

Tin, K	298.15
Zin	0.98
Mw	28.97

zdisc	Bg @suc	qg_local	Hp	m	Power	Hp test	qact test	qact test single comp
	[m^3/Sm^3]	[m^3/d]	[m]	[kg/s]	[MW]	[m]	[m^3/d]	[m^3/d]
0.933	2.05E-02	409.9E+3	8366.0	155.7E+0	18.43	5064.5	318899.1772	159449.5886
0.942	1.68E-02	335.2E+3	2851.9	155.7E+0	6.55	1487.9	242119.9827	121059.9913
0.955	1.99E-02	398.4E+3	5924.7	155.7E+0	13.61	3091.0	287755.5395	143877.7697
0.970	2.52E-02	504.1E+3	10505.5	155.7E+0	24.13	5480.9	364116.1919	182058.096
0.988	3.72E-02	743.8E+3	19107.5	155.7E+0	43.89	9968.8	537247.0699	268623.535
#VALUE!	#VALUE!	#VALUE!	#VALUE!	155.7E+0	#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!	155.7E+0	#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!	155.7E+0	#VALUE!	#VALUE!	#VALUE!	#VALUE!

lets estimate cooler duty

$$\dot{Q} = \dot{m}(h_{in} - h_{out})$$

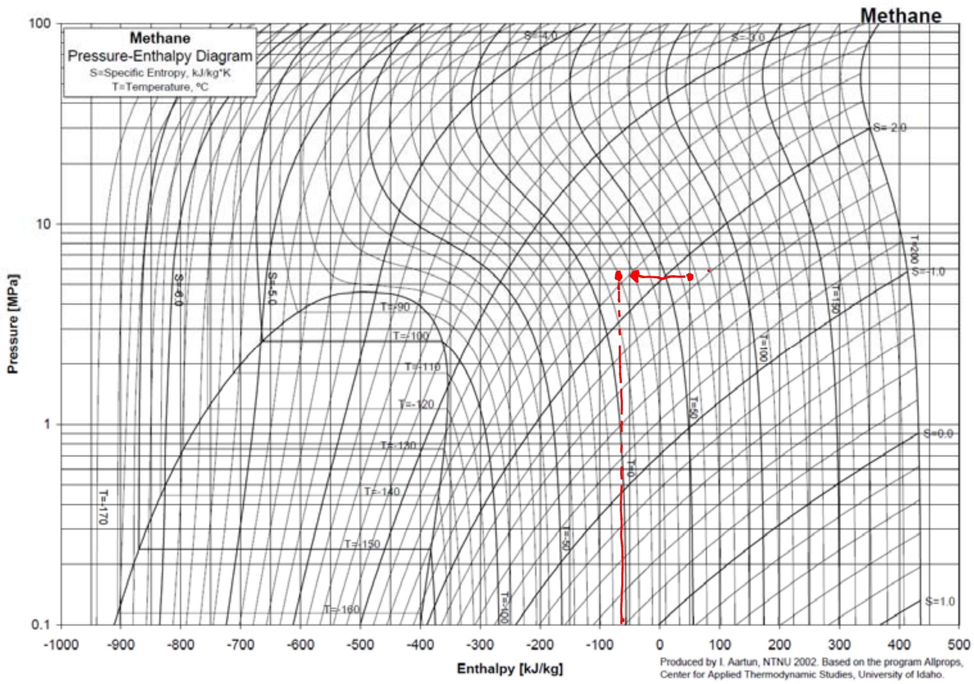
$$\dot{Q} = 155\,\mathrm{kg/s}\,(50-(-60)) = 155 \cdot 110000$$

$= 17$ MW

required cooling duty in year "1" of compression must be bigger than Åsgard's

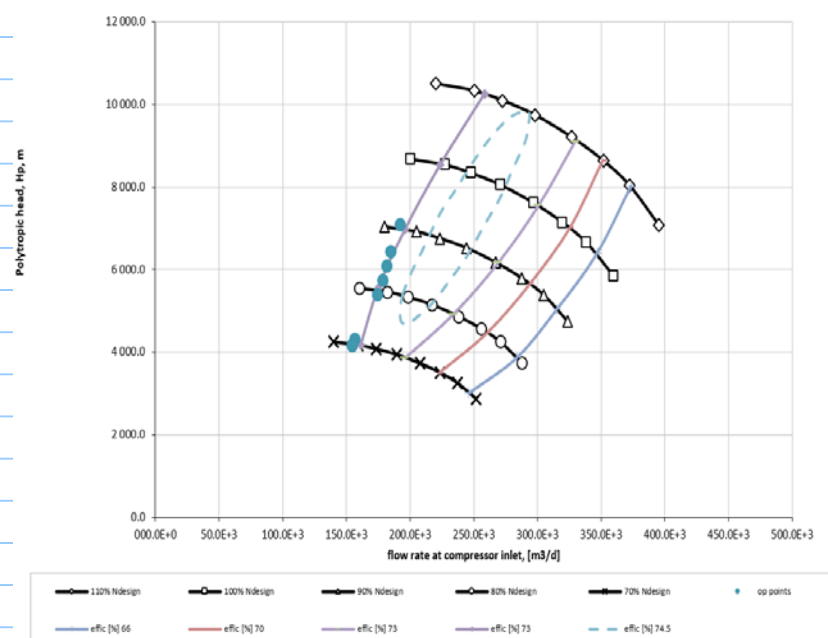
Cooler inlet
$T = 67°C$
$p = 4.6$ MPa

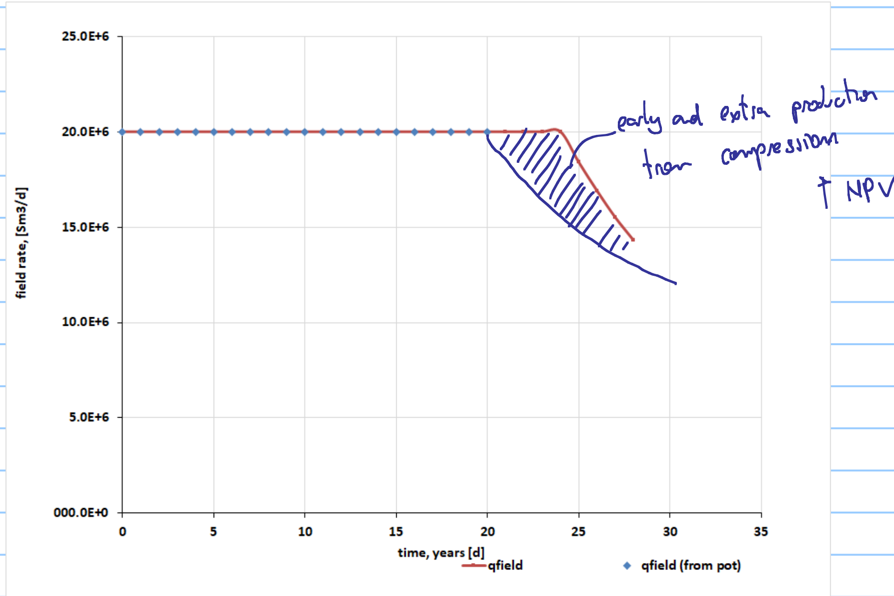
$h_{in} \approx 50$ kJ/kg
$h_{out} = -60$ kJ/kg
$T_{out} = 20°C$
$p_{out} = p_{in} = 4.6$ MPa



the inlet cooler seems to have a too high duty (17) compared to Aasgard (11 MW).
two options:
- make bigger / more efficient cooler $$$
- ΔTcooler must be reduced ~> more power is required, Tout will be higher

ΔTcooler of 20°C still works!





How to deal and quantify uncertainty in field development

for example in our Snøhvit case

↳ G, N , $q_g = C_R \left(P_R^2 - P_{wf}^2\right)^n$

uptime 90 - 100%

$$\left(\frac{\text{nr day producing in year}}{365}\right)$$

↳ cause additional OPEX

↳ cut in production → cut in Revenue

input variables used in engineering studies in FD are highly uncertain

$\phi_{min} \le \phi \le \phi_{max}$ and affect the value of KPIs that are used to discriminate and select development alternatives.

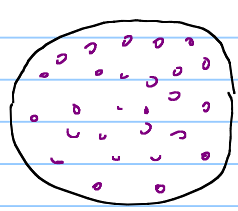
$$T_{RR} = N_{pu} = \frac{\overbrace{V_R \cdot \phi \cdot N_{tg} \cdot S_o}^{\text{volume of oil at local reservoir condition}}}{B_o}$$ total recoverable reserves

deterministic calculation: all input is known

$V_R \; \{V_{Rmin} - V_{Rmax}\}$

probabilistic calculation: input is uncertain

ϕ



number sample	ϕ
–	–
–	–
–	–
–	–
–	–

→ discrete frequency analysis

create bins

min Φ_1 (0.15)

— 0.175

Φ_2 (0.20)

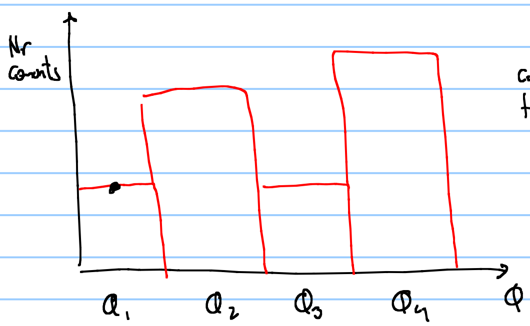
Φ_3 (0.25)

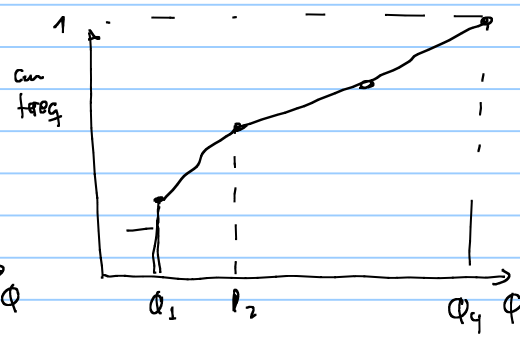
max Φ_4 (0.30)

if $\Phi_i = 0.18$

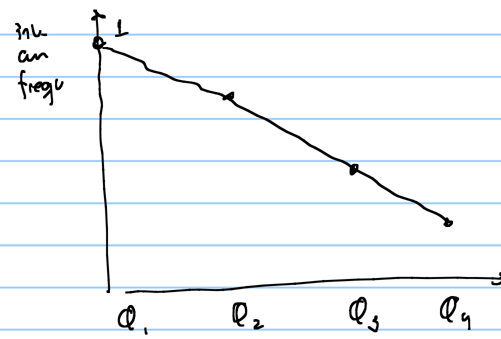
$\Phi_1 \le \Phi_i \le \Phi_2$

if $\Phi_i < \frac{(\Phi_2 - \Phi_1)}{2} + \Phi_1$ → counted as part of Φ_1





bin	Nr counts	rel. frequency	cum frequency	inv. cum frequency
Φ_1	x	x/N	x/N	$(x+w+z+y)/N \rightarrow 1$
Φ_2	y	y/N	$y/N + x/N$	$(w+z+y)/N$
Φ_3	z	z/N	$y/N + x/N + z/N$	$(w+z)/N$
Φ_4	w	w/N	$\frac{x+y+z+w}{N}$	w/N
	N			



how to do frequency analysis in excel:

E7 {=FREQUENCY(A2:A20;D7:D11)}

	A	B	C	D	E	F	G
1	Variable			min	1		
2	10			max	10		
3	7			Nr bins	5		
4	2			delta	2.25		
5	6						
6	1			bins	nr counts		
7	8			1	4		
8	1			3.25	4		
9	7			5.5	1		
10	3			7.75	3		
11	9			10	7		
12	1						
13	4						
14	8						
15	2						
16	8						
17	1						
18	9						
19	3						
20	10						

to create bins:
- find max
- find min
- define Nr bins
- calculate $delta = \frac{(max - min)}{(Nr\ bins - 1)}$

compute each bin

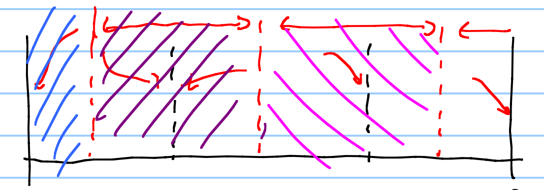
$bin^i = bin^{i-1} + delta$

starting from $bin^0 = min$

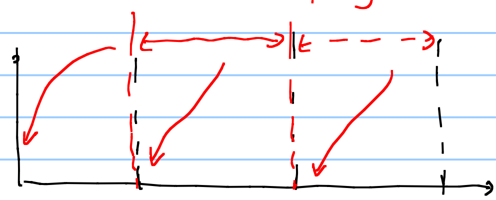
to apply frequency function:

ctrl + shift + enter (in sequence and leave it pressed)

selecting bins must take into account
- nr data points



be careful how the frequency is accounted for



Courtesy of "Peng Li"

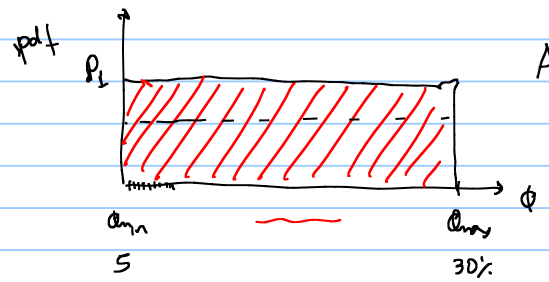
what happens if there are no measurements?

frequency ~> probability

rel frequency ~> pdf probability density function

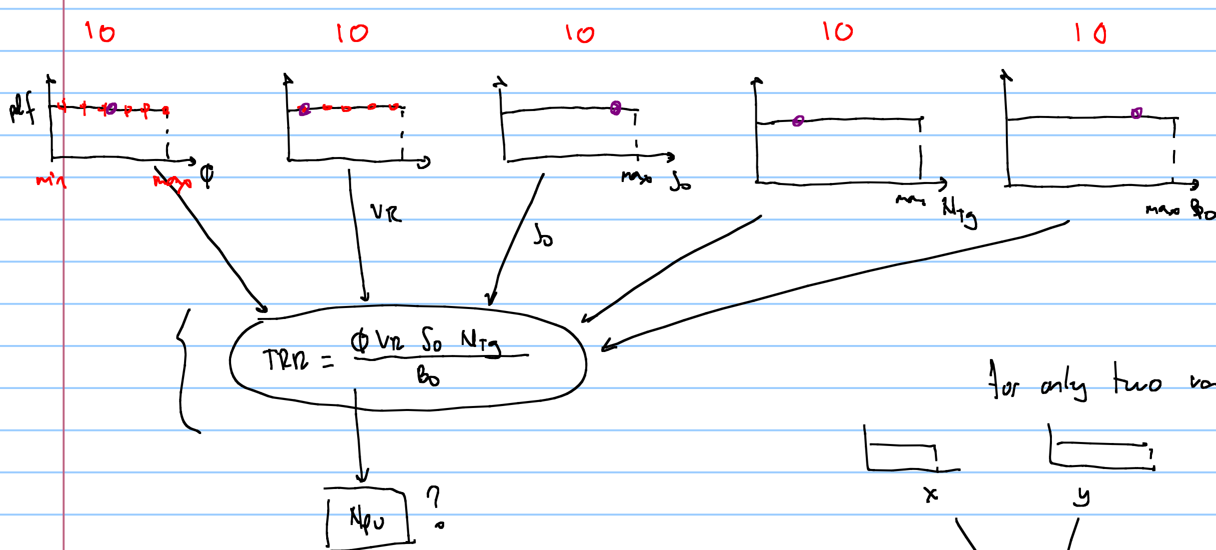
cum frequency plot ~> cdf cumulative distribution function

poor boy, no data pdf ϕ continuous probability

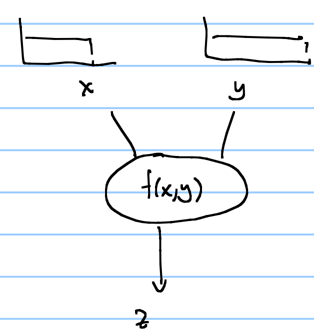


$$A_{rea} = (\phi_{max} - \phi_{min}) \cdot P_1 = 1$$

$$P_1 = \frac{1}{(\phi_{max} - \phi_{min})}$$



for only two variables:

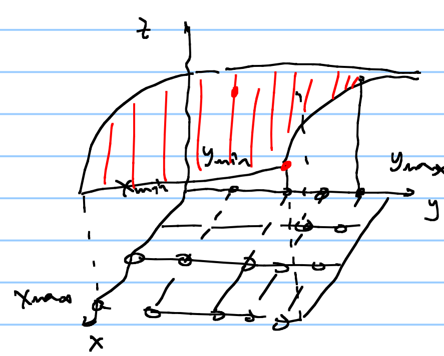


$10^5 \cdot 10\,min = 1E06\ min$

69,4 days

uniform sampling requires

$10 \times 10 \times 10 \times 10 \times 10 = 10^5$ simulations



for many variables we use "sampling methods" evaluate many combinations of (x_i, y_i) and the do a frequency analysis on the results

x	y	z
x_1	y_1	$z_{1,1}$
x_1	y_2	$z_{1,2}$

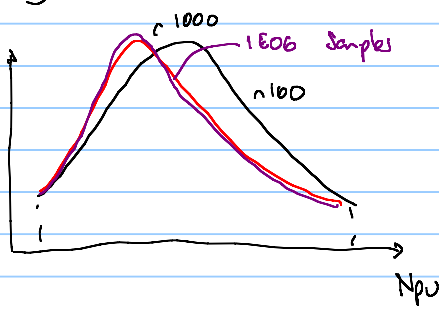
Monte Carlo sampling

1: take a random value of the variable in the interval for each variable

2: Compute the output variable → record result

3: repeat 1–2 many times

4: frequency analysis of results



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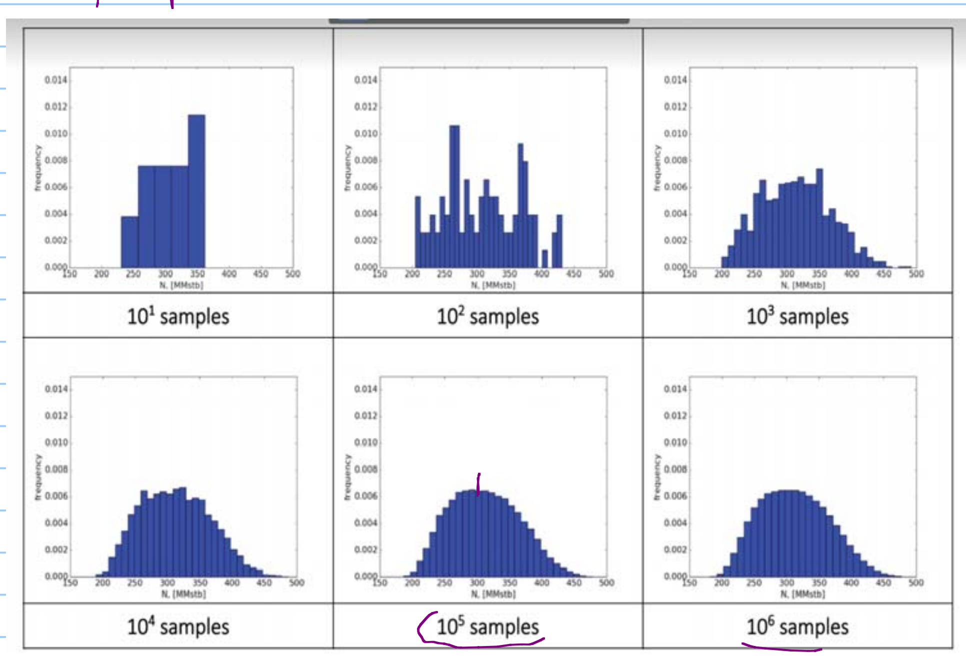


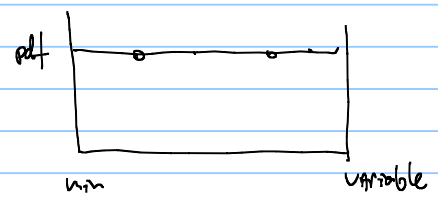
number of required iterations (page 113)

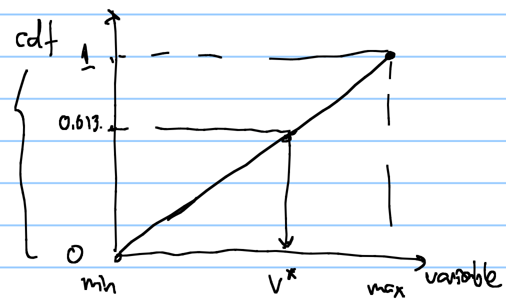
```
Function x_uniform(a, b)
    'value of the variable x for a uniform distribution
    'a is the minimum value of x
    'b is the maximum value of x
    'U is the random number
    Application.Volatile (True)
    U = Rnd()
    x_uniform = a + (b - a) * U
End Function
```

```
Function x_Triangular(a, b, c)
    'value of the variable x for a Triangular distribution
    'a is the minimum value of x
    'b is the maximum value of x
    'c is the mode value of x
    'U is the the random number
    Application.Volatile (True)
    U = Rnd()
    F_c = (c - a) / (b - a)
     If F_c > U Then
       x_Triangular = a + Sqr((b - a) * (c - a) * U)
     Else
        x_Triangular = b - Sqr((b - a) * (b - c) * (1 - U))
     End If
End Function
```

```
Function Npu(Bo, Fr, RV, Por, Ntg, So)
'total recoverable reserves, in stb or Sm3
'por porosity, fraction
'Ntg Net to gross, fraction
'So oil saturation, fraction
'Bo oil formation volume factor, (m3/Sm3 or bbl/stb)
'Fr ultimate recovery factor, fraction
Npu = RV * Por * Ntg * So * Ntg / Bo
End Function
```

Sampling is made on cdf





$$Var = min + \frac{(max - min)}{(1 - 0)}(rand - 0)$$