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APPENDIX A
COUNTING STATISTICS

A.1 Neutron Counting

Neutron counting follows a Poisson distribution, which estimates the variance in the count as

$$\sigma^2 = N \tag{A.1}$$

where N is the number of neutrons counted, Knoll(1979)

For a neutron counting measurement repeated K times from the same source for equal counting periods, the uncertainty in N can be expressed as the standard error of mean. The sample average N_x is as below (Knoll, 1979).

$$N_x = \sum_{i=1}^{K} \frac{N_i}{K} \tag{A.2}$$

The standard error of the mean is given by:

$$\varepsilon = \sqrt{\frac{N_x}{K}} \tag{A.3}$$

The percent error of the mean is:

$$\% \Delta N_x = \sqrt{\frac{100}{N_x K}} \tag{A.4}$$

For this work, each measurement was repeated ten times to ensure that the uncertainty or the standard error associated with all measurement was less than one percent.

A.2 Void Fraction Measurement

The neutron count rates can be converted to a linear representation of liquid volume fraction by following relationship:

$$\hat{\rho} = \frac{N(\rho) - N(0)}{N(1) - N(0)} \tag{A.5}$$

where $\hat{\rho}$ is the estimated liquid fraction. N(ρ), N(1) and N(0) are the scatterometer responses corresponding to respectively the test section with the actual liquid fraction, the test section full of liquid and test section full of vapor. There is a propagation error in the measurement of the liquid fraction since it is a function of many values. The propagation error can be expressed as follow.

$$\Delta\hat{\rho} = \frac{\partial\hat{\rho}}{\partial N(x)}\Delta N(x)^2 + \frac{\partial\hat{\rho}}{\partial N(0)}\Delta N(0)^2 + \frac{\partial\hat{\rho}}{\partial N(1)}\Delta N(1)^2 \tag{A.6}$$

Using a differential identity, the final form of the error can be stated as:

$$\Delta\hat{\rho} = \frac{\sqrt{(N(1)-N(0))^2\Delta N(x)^2 + (N(x)-N(1))^2\Delta N(0)^2 + (N(x)-N(0))^2\Delta N(1)^2}}{(N(1)-N(0))^2} \tag{A.7}$$

It should be noted however the counts N(0) and N(1), being reference counts, can be pre-determined so that they possess a low uncertainly. The count rate N(ρ) is usually measured on-line within a short period and tends to have a relatively large variance, in comparison to the reference measurements.

APENDIX B
THE DATA OF STATIC RESULTS

Table B.1 The count rate for 2 minutes of Lucite fraction of zero

Exp.	Count rate
1	1745
2	1733
3	1764
4	1721
5	1738
6	1736
7	1712
8	1704
9	1749
10	1711

mean	1731.30
%standard error	0.76
Variance	364.01
standard error	13.16

Table B.2 The count rate for 2 minutes of Lucite fraction of 0.086

exp.	count rate
1	1734
2	1723
3	1750
4	1698
5	1736
6	1752
7	1803
8	1763
9	1724
10	1758

mean	1853.70
%standard error	0.73
Variance	904.23
standard error	13.62

Table B.3 The count rate for 2 minutes of Lucite fraction of 0.173

Exp.	Count rate
1	1756
2	1737
3	1760
4	1760
5	1782
6	1751
7	1709
8	1726
9	1723
10	1770

mean	1747.40
%standard error	0.76
Variance	527.60
standard error	13.22

Table B.4 the count rate for 2 minutes of Lucite fraction of 0.259

Exp.	Count rate
1	1758
2	1739
3	1760
4	1721
5	1770
6	1769
7	1761
8	1803
9	1790
10	1768

mean	1763.90
%standard error	0.75
Variance	534.32
standard error	13.28

Table B.5 The count rate for 2 minutes of Lucite fraction of 0.345

Exp.	Count rate
1	1779
2	1770
3	1749
4	1731
5	1769
6	1758
7	1780
8	1765
9	1789
10	1800

mean	1769.00
%standard error	0.75
Variance	396.00
standard error	13.30

Table B.6 The count rate for 2 minutes of Lucite fraction of 0.432

Exp.	Count rate
1	1802
2	1788
3	1728
4	1803
5	1745
6	1806
7	1799
8	1747
9	1783
10	1774

mean	1777.50
%standard error	0.75
Variance	790.50
standard error	13.33

Table B.7 The count rate for 2 minutes of Lucite fraction of 0.518

Exp.	Count rate
1	1767
2	1844
3	1781
4	1857
5	1772
6	1779
7	1800
8	1793
9	1811
10	1782

mean	1798.60
%standard error	0.75
Variance	926.04
standard error	13.41

Table B.8 The count rate for 2 minutes of Lucite fraction of 0.604

Exp.	Count rate
1	1852
2	1799
3	1838
4	1825
5	1772
6	1853
7	1849
8	1789
9	1787
10	1835

mean	1819.90
%standard error	0.74
Variance	924.77
standard error	13.49

Table B.9 The count rate for 2 minutes of Lucite fraction of 1.00.

Exp.	Count rate
1	1815
2	1847
3	1883
4	1839
5	1887
6	1903
7	1860
8	1856
9	1831
10	1816

mean	1853.70
%standard error	0.73
Variance	904.23
standard error	13.62

APENDIX C

THE DATA OF DYNAMIC RESULTS

Table C.1 The count rates for 12 seconds at temperature 50°C and pressure 5 MPa

Exp.	Count rate
1	183754
2	179607
3	179644
4	178182
5	179106
6	177814
7	178851
8	179634
9	179821
10	179510

mean	179592.30
%standard error	0.07
Variance	2591195.79
standard error	134.01

Table C.2 The count rates for 12 seconds at temperature 100°C and pressure 5MPa

Exp.	Count rate
1	153214
2	167193
3	169014
4	169984
5	168361
6	163144
7	169618
8	168164
9	168318
10	171614

mean	166862.40
%standard error	0.08
Variance	27868684.04
standard error	129.18

Table C.3 The count rates for 12 seconds at temperature 150°C and pressure 5 MPa

Exp.	Count rate
1	146314
2	147028
3	146892
4	146462
5	147396
6	153831
7	151014
8	150312
9	147487
10	147918

mean	148465.40
%standard error	0.08
Variance	6031036.27
standard error	121.85

Table C.4 The count rates for 12 seconds at temperature 200°C and pressure 5 MPa

exp.	count rate
1	132544
2	134778
3	133906
4	132045
5	133862
6	133710
7	133449
8	133116
9	132172
10	132413

mean	133199.50
%standard error	0.09
Variance	799603.61
standard error	115.41

APPENDIX D
THE EXAMPLE OF INOUT AND OUTPUT FOR MCNP4C

```
c cell card
1 1 -0.78401 -1 -2 -3 imp:n=1 $ inside pipe
2 2 –8.2 1 -2 imp:n=1 $ pipe
3 0 3 imp:n=0 $ outside
4 0 2 -3 1 imp:n=1 $ source

c surface
1 cz 0.501 $ inside radius
2 cz 0.62546 $ outside radius
3 cz 3

c source
sdef pos=0 -1 0 erg=d1 dir=d2 vec=0 -1 0
sc1 energy spectrum cf252
sp1 -3 1.025 2.926
sb2 -31 1
c material
m1  1001 0.66667 8016 0.33333
m2  26000 1
c neutron
phys:n
c detecter
fc5 flux at a point in the void
f5:n 0 0 1 0
nps 10000000
```

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