Appendix 10

ESTIMATION OF THE POSSIBLE UNCERTAINTIES

Possible uncertainties in the estimation of the yearly dose received from drinking environmental (untreated) water in the Mooi River catchment will arise from analytical uncertainties, environmental variations, the applied uranium to dose correlation curve, the age dependant default intake values and the sampling frequency.

- The analytical uncertainty can be estimated from the uranium results obtained in the second phase study by both the radiochemical and ICP-MS analysis techniques. The correlations between the uranium concentration and the "all nuclide" dose described in paragraph 5 have been determined using the radiochemical uranium database. The same evaluation based on the ICP-MS uranium data showed the following correlations:
  - < 1 year old: [All nuclide dose] (mSv/a) = 0,00415 x [U] (µg/L) + 0,065 (R^2 = 0,922).
  - 12 - 17 year old: [All nuclide dose] (mSv/a) = 0,00273 x [U] (µg/L) + 0,024 (R^2 = 0,889).
  - Lifetime average: [All nuclide dose] (mSv/a) = 0,00124 x [U] (µg/L) + 0,017 (R^2 = 0,964).
- These data compare well with the correlation observed from the radiochemical uranium determination. The difference in the calculated dose based on radiochemical and ICP-MS analysis at a dose level of 75 µSv/a is about 2%, 4% and 1,5% for the respective age groups of < 1 year old, between 12 and 17 years old and the lifetime average evaluation. Table B provides the summed data on the linear regression and dose calculations.
- Environmental variations can be estimated from the standard deviation observed for the individual nuclide analyses in phase 1 and phase 2 of the study. Again the total yearly dose correlation has been calculated, now using the "upper" and "lower" bound regions of the analytical data (i.e. the average concentrations plus and minus one standard deviation respectively). The correlations were determined using both the Radiochemical and ICP-MS uranium data sets obtained in phase 2 of the study. Once more, both sets did not show substantial differences and accordingly the mean values were taken to evaluate the yearly fluctuation in the dose. The data for the critical groups (i.e. the < 1 year old followed by the age group between 12 and 17 years old) and the lifetime averages are shown in Table C. From this it may be observed that at around an estimated average yearly dose of 100 µSv/a the "upper" limits of the evaluated dose will not vary more than about 20%, 30% and 50% for the respective lifetime average evaluation and the age groups 12 to 17 years old and < 1 year old. This shows that the calculated yearly dose based on average yearly nuclide concentrations will provide a fair estimation of the radiological impact on the public.
- The applied uranium to dose correlation curve will show a slight variation if sampling sites would be randomly omitted from the regression calculations. This uncertainty will be less than 10% due to the high degree of correlation between the measured uranium concentration and the estimated yearly dose. Omission of sampling site 12 which dried up during the second phase of the survey, showing high nuclide concentrations during the first phase, will cause a difference of plus 6% in the calculated dose levels around 100 µSv/a, while the omission of the sampling site showing the highest average uranium concentration during the monitoring period will give a 3% negative deviation at about 100 µSv/a (see Table D). The expected uncertainty in the obtained correlation between the yearly dose and the uranium concentration for the Mooi River catchment will be less than 10%, provided statistically reliable average uranium data are obtained (e.g. through monthly monitoring).

- The age dependent default intake values are prone to a large uncertainty in the yearly dose evaluation. It should be emphasized that default intake rates are used in the dose calculations, i.e. assuming daily intake from the same source and assuming that the source is the only available source to the individuals concerned. Accordingly, at sites showing potentially elevated dose levels (e.g. above 100 µSv/a) due to default water

intake one should determine the actual yearly consumption from the source by the communities and/or individuals concerned.

- The influence of the sampling frequency on the calculated yearly dose can be estimated best from the uranium data obtained in phase 1 on the Mooi River catchment study. The average concentrations were calculated for the individual sites together with the four-weekly average, shifting the intervals by one week respectively. One would thus obtain the average concentrations for uranium at the following four intervals:

  Weeks 1, 5, 9, 13, 17, 21
  Weeks 2, 6, 10, 14, 18, 22
  Weeks 3, 7, 11, 15, 19, 23
  Weeks 4, 8, 12, 16, 20, 24

  Comparison of the minimum and maximum difference between these individual data and the average concentration observed over the entire sampling period provides an estimate of the possible over- or underestimation of the uranium concentration. In this model the sites not sampled at a particular date were regarded as not being accessible, although for dose calculations one should "dry" sites regard as having zero uranium concentration as they are not contributing to the yearly dose at that specific time. Table E shows the compiled data for phase 1 and the observed uranium ratio between phase 1 and phase 2. The following observations are made:

  - Four-weekly sampling compared to weekly sampling can over- or underestimate the yearly dose by a factor of up to 3. (Site 38 being discarded due to infrequent sampling).
  - The data obtained in the second phase can not clearly be related to seasonal influences. Sampling sites 35 and 36 show increased levels of uranium during the second semester not readily explained by sampling frequency variations. Sampling site 12 showed a decreased uranium content in the second phase of the study; this site dried up due to decreased/ceased input of waste water directly related to the gold mining activities.

Conclusions

- The correlations observed in paragraphs 5 and 8 between the uranium concentration (in µg/L) or the gross activity (in Bq/L) and the "all nuclide" yearly dose (in mSv/a) can be used for routine monitoring purposes of the Mooi River catchment area.
- The estimated uncertainty will be less than 10%.
- The proposed monitoring frequency is monthly for uranium and every six months for the full range of nuclides to evaluate whether the correlation is sustainable and to reduce the uncertainty due to sampling frequency.

References

(1) IAEA, Safety Series 115, Vienna, 1996.
(2) CNS, Document LG-1032, Centurion, 1997.

Table B: Yearly dose versus Uranium concentration for the 1997 Mooi River catchment survey

Average seasonal concentrations

Life-time Average

Regression Output: Rad Chem

Constant	**0.01665**
Std Err of Y Est	0.0130582
R Squared	**0.97028**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.00124**
Std Err of Coef.	3.469E-05

Regression Output: ICP-MS

Constant	**0.0174**
Std Err of Y Est	0.0142338
R Squared	**0.96403**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.00124**
Std Err of Coef.	3.85E-05

12 – 17 a

Regression Output: Rad Chem

Constant	**0.02023**
Std Err of Y Est	0.0548189
R Squared	**0.90147**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.002751**
Std Err of Coef.	0.0001456

Regression Output: ICP-MS

Constant	**0.02395**
Std Err of Y Est	0.0571486
R Squared	**0.8887**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.002728**
Std Err of Coef.	0.0001546

< 1 a

Regression Output: Rad Chem

Constant	**0.06324**
Std Err of Y Est	0.06663
R Squared	**0.93205**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.00409**
Std Err of Coef.	0.000177

Regression Output: ICP-MS

Constant	**0.06458**
Std Err of Y Est	0.071467
R Squared	**0.92188**
No. of Observations	41
Degrees of Freedom	39
X Coefficient(s)	**0.00415**
Std Err of Coef.	0.0001933

[U]	Yearly dose (mSv/a)			[U]	Yearly dose (mSv/a)			[U]	Yearly dose (mSv/a)		
(ug/L)	RadChem	ICP-MS	Ratio	(ug/L)	RadChem	ICP-MS	Ratio	(ug/L)	RadChem	ICP-MS	Ratio
5	0.023	0.024	0.967	5	0.034	0.038	0.904	5	0.084	0.085	0.981
25	0.048	0.049	0.981	25	0.089	0.092	0.966	25	0.166	0.168	0.984
50	0.079	0.080	0.986	50	0.158	0.160	0.984	50	0.268	0.272	0.985
75	0.109	0.111	0.989	75	0.227	0.229	0.991	75	0.370	0.376	0.986
100	0.140	0.142	0.990	100	0.295	0.297	0.995	100	0.473	0.479	0.986
125	0.171	0.173	0.991	125	0.364	0.365	0.998	125	0.575	0.583	0.986
150	0.202	0.204	0.991	150	0.433	0.433	1.000	150	0.677	0.687	0.987
175	0.233	0.235	0.992	175	0.502	0.501	1.001	175	0.780	0.790	0.987
200	0.264	0.266	0.992	200	0.570	0.569	1.002	200	0.882	0.894	0.987
225	0.295	0.297	0.992	225	0.639	0.638	1.002	225	0.984	0.998	0.987
250	0.326	0.329	0.993	250	0.708	0.706	1.003	250	1.087	1.101	0.987
275	0.357	0.360	0.993	275	0.777	0.774	1.004	275	1.189	1.205	0.987
300	0.388	0.391	0.993	300	0.846	0.842	1.004	300	1.291	1.309	0.987
325	0.419	0.422	0.993	325	0.914	0.910	1.004	325	1.394	1.412	0.987
350	0.450	0.453	0.993	350	0.983	0.979	1.005	350	1.496	1.516	0.987
375	0.481	0.484	0.993	375	1.052	1.047	1.005	375	1.599	1.620	0.987
400	0.512	0.515	0.993	400	1.121	1.115	1.005	400	1.701	1.723	0.987
425	0.543	0.546	0.993	425	1.189	1.183	1.005	425	1.803	1.827	0.987
450	0.574	0.577	0.994	450	1.258	1.251	1.005	450	1.906	1.931	0.987
475	0.605	0.609	0.994	475	1.327	1.320	1.006	475	2.008	2.034	0.987
500	0.636	0.640	0.994	500	1.396	1.388	1.006	500	2.110	2.138	0.987
525	0.667	0.671	0.994	525	1.465	1.456	1.006	525	2.213	2.242	0.987
550	0.698	0.702	0.994	550	1.533	1.524	1.006	550	2.315	2.345	0.987
575	0.728	0.733	0.994	575	1.602	1.592	1.006	575	2.417	2.449	0.987
600	0.759	0.764	0.994	600	1.671	1.661	1.006	600	2.520	2.553	0.987
625	0.790	0.795	0.994	625	1.740	1.729	1.006	625	2.622	2.656	0.987
650	0.821	0.826	0.994	650	1.808	1.797	1.006	650	2.724	2.760	0.987
675	0.852	0.858	0.994	675	1.877	1.865	1.006	675	2.827	2.864	0.987
700	0.883	0.889	0.994	700	1.946	1.933	1.007	700	2.929	2.967	0.987
725	0.914	0.920	0.994	725	2.015	2.001	1.007	725	3.032	3.071	0.987
750	0.945	0.951	0.994	750	2.083	2.070	1.007	750	3.134	3.175	0.987
775	0.976	0.982	0.994	775	2.152	2.138	1.007	775	3.236	3.278	0.987
800	1.007	1.013	0.994	800	2.221	2.206	1.007	800	3.339	3.382	0.987
825	1.038	1.044	0.994	825	2.290	2.274	1.007	825	3.441	3.486	0.987
850	1.069	1.075	0.994	850	2.359	2.342	1.007	850	3.543	3.589	0.987
875	1.100	1.106	0.994	875	2.427	2.411	1.007	875	3.646	3.693	0.987
900	1.131	1.138	0.994	900	2.496	2.479	1.007	900	3.748	3.797	0.987
925	1.162	1.169	0.994	925	2.565	2.547	1.007	925	3.850	3.900	0.987
950	1.193	1.200	0.994	950	2.634	2.615	1.007	950	3.953	4.004	0.987
975	1.224	1.231	0.994	975	2.702	2.683	1.007	975	4.055	4.108	0.987
1000	1.255	1.262	0.994	1000	2.771	2.752	1.007	1000	4.157	4.211	0.987

Table C: Evaluation of the Upper, Average and Lower Uranium concentration to estimate seasonal variations

Life-time Average						12 - 17 a						< 1 a					
[U]	Yearly dose (mSv/a)					[U]	Yearly dose (mSv/a)					[U]	Yearly dose (mSv/a)				
(ug/L)	Upper	Average	Lower	U/A Ratio	A/L Ratio	(ug/L)	Upper	Average	Lower	U/A Ratio	A/L Ratio	(ug/L)	Upper	Average	Lower	U/A Ratio	A/L Ratio
5	0.036	0.023	0.005	1.53	4.41	5	0.062	0.036	0.011	1.72	3.37	5	0.152	0.085	0.005	1.79	17.77
25	0.063	0.048	0.027	1.31	1.75	25	0.122	0.091	0.052	1.35	1.76	25	0.247	0.167	0.069	1.48	2.42
50	0.097	0.079	0.055	1.23	1.43	50	0.197	0.159	0.103	1.24	1.55	50	0.367	0.270	0.149	1.36	1.81
75	0.132	0.110	0.083	1.20	1.33	75	0.273	0.228	0.154	1.20	1.48	75	0.487	0.373	0.230	1.31	1.62
100	0.166	0.141	0.111	1.18	1.28	100	0.348	0.296	0.205	1.18	1.44	100	0.607	0.476	0.310	1.27	1.54
125	0.200	0.172	0.138	1.16	1.24	125	0.423	0.365	0.256	1.16	1.42	125	0.726	0.579	0.390	1.25	1.48
150	0.235	0.203	0.166	1.15	1.22	150	0.499	0.433	0.307	1.15	1.41	150	0.846	0.682	0.471	1.24	1.45
175	0.269	0.234	0.194	1.15	1.21	175	0.574	0.501	0.359	1.15	1.40	175	0.966	0.785	0.551	1.23	1.42
200	0.303	0.265	0.222	1.14	1.20	200	0.650	0.570	0.410	1.14	1.39	200	1.086	0.888	0.631	1.22	1.41
225	0.338	0.296	0.249	1.14	1.19	225	0.725	0.638	0.461	1.14	1.39	225	1.205	0.991	0.712	1.22	1.39
250	0.372	0.327	0.277	1.14	1.18	250	0.800	0.707	0.512	1.13	1.38	250	1.325	1.094	0.792	1.21	1.38
275	0.406	0.358	0.305	1.13	1.18	275	0.876	0.775	0.563	1.13	1.38	275	1.445	1.197	0.872	1.21	1.37
300	0.441	0.389	0.333	1.13	1.17	300	0.951	0.844	0.614	1.13	1.37	300	1.565	1.300	0.953	1.20	1.36
325	0.475	0.420	0.360	1.13	1.17	325	1.026	0.912	0.666	1.13	1.37	325	1.684	1.403	1.033	1.20	1.36
350	0.509	0.451	0.388	1.13	1.16	350	1.102	0.981	0.717	1.12	1.37	350	1.804	1.506	1.113	1.20	1.35
375	0.544	0.483	0.416	1.13	1.16	375	1.177	1.049	0.768	1.12	1.37	375	1.924	1.609	1.194	1.20	1.35
400	0.578	0.514	0.444	1.13	1.16	400	1.253	1.118	0.819	1.12	1.36	400	2.044	1.712	1.274	1.19	1.34
425	0.612	0.545	0.471	1.12	1.16	425	1.328	1.186	0.870	1.12	1.36	425	2.163	1.815	1.354	1.19	1.34
450	0.646	0.576	0.499	1.12	1.15	450	1.403	1.255	0.922	1.12	1.36	450	2.283	1.918	1.434	1.19	1.34
475	0.681	0.607	0.527	1.12	1.15	475	1.479	1.323	0.973	1.12	1.36	475	2.403	2.021	1.515	1.19	1.33
500	0.715	0.638	0.555	1.12	1.15	500	1.554	1.392	1.024	1.12	1.36	500	2.523	2.124	1.595	1.19	1.33
525	0.749	0.669	0.582	1.12	1.15	525	1.629	1.460	1.075	1.12	1.36	525	2.642	2.227	1.675	1.19	1.33
550	0.784	0.700	0.610	1.12	1.15	550	1.705	1.529	1.126	1.12	1.36	550	2.762	2.330	1.756	1.19	1.33
575	0.818	0.731	0.638	1.12	1.15	575	1.780	1.597	1.177	1.11	1.36	575	2.882	2.433	1.836	1.18	1.33
600	0.852	0.762	0.666	1.12	1.14	600	1.856	1.666	1.229	1.11	1.36	600	3.002	2.536	1.916	1.18	1.32
625	0.887	0.793	0.693	1.12	1.14	625	1.931	1.734	1.280	1.11	1.36	625	3.121	2.639	1.997	1.18	1.32
650	0.921	0.824	0.721	1.12	1.14	650	2.006	1.803	1.331	1.11	1.35	650	3.241	2.742	2.077	1.18	1.32
675	0.955	0.855	0.749	1.12	1.14	675	2.082	1.871	1.382	1.11	1.35	675	3.361	2.845	2.157	1.18	1.32
700	0.990	0.886	0.776	1.12	1.14	700	2.157	1.940	1.433	1.11	1.35	700	3.481	2.948	2.238	1.18	1.32
725	1.024	0.917	0.804	1.12	1.14	725	2.232	2.008	1.484	1.11	1.35	725	3.600	3.051	2.318	1.18	1.32
750	1.058	0.948	0.832	1.12	1.14	750	2.308	2.077	1.536	1.11	1.35	750	3.720	3.154	2.398	1.18	1.32
775	1.093	0.979	0.860	1.12	1.14	775	2.383	2.145	1.587	1.11	1.35	775	3.840	3.257	2.479	1.18	1.31
800	1.127	1.010	0.887	1.12	1.14	800	2.459	2.214	1.638	1.11	1.35	800	3.960	3.360	2.559	1.18	1.31
825	1.161	1.041	0.915	1.12	1.14	825	2.534	2.282	1.689	1.11	1.35	825	4.079	3.463	2.639	1.18	1.31
850	1.196	1.072	0.943	1.12	1.14	850	2.609	2.350	1.740	1.11	1.35	850	4.199	3.566	2.720	1.18	1.31
875	1.230	1.103	0.971	1.11	1.14	875	2.685	2.419	1.791	1.11	1.35	875	4.319	3.669	2.800	1.18	1.31
900	1.264	1.134	0.998	1.11	1.14	900	2.760	2.487	1.843	1.11	1.35	900	4.439	3.772	2.880	1.18	1.31
925	1.298	1.165	1.026	1.11	1.14	925	2.836	2.556	1.894	1.11	1.35	925	4.558	3.875	2.961	1.18	1.31
950	1.333	1.196	1.054	1.11	1.14	950	2.911	2.624	1.945	1.11	1.35	950	4.678	3.978	3.041	1.18	1.31
975	1.367	1.227	1.082	1.11	1.13	975	2.986	2.693	1.996	1.11	1.35	975	4.798	4.081	3.121	1.18	1.31
1000	1.401	1.258	1.109	1.11	1.13	1000	3.062	2.761	2.047	1.11	1.35	1000	4.918	4.184	3.202	1.18	1.31

Table D: Uncertainty in the yearly dose versus uranium concentration

[U] (ug/L)	Yearly dose (mSv/a) Based on Radiochemical uranium data			Ratio	
	All points	All except DWAF 12	All except DWAF 7a	All vs 12 exemption	All vs 7a exemption
5	0.023	0.024	0.022	0.94	1.02
25	0.048	0.047	0.048	1.01	0.99
50	0.079	0.075	0.080	1.04	0.98
75	0.109	0.103	0.112	1.06	0.97
100	0.140	0.132	0.145	1.07	0.97
125	0.171	0.160	0.177	1.07	0.97
150	0.202	0.188	0.209	1.07	0.97
175	0.233	0.217	0.241	1.08	0.97
200	0.264	0.245	0.273	1.08	0.97
225	0.295	0.273	0.306	1.08	0.97
250	0.326	0.301	0.338	1.08	0.97
275	0.357	0.330	0.370	1.08	0.97
300	0.388	0.358	0.402	1.08	0.97
325	0.419	0.386	0.434	1.09	0.96
350	0.450	0.414	0.466	1.09	0.96
375	0.481	0.443	0.499	1.09	0.96
400	0.512	0.471	0.531	1.09	0.96
425	0.543	0.499	0.563	1.09	0.96
450	0.574	0.527	0.595	1.09	0.96
475	0.605	0.556	0.627	1.09	0.96
500	0.636	0.584	0.659	1.09	0.96
525	0.667	0.612	0.692	1.09	0.96
550	0.698	0.640	0.724	1.09	0.96
575	0.728	0.669	0.756	1.09	0.96
600	0.759	0.697	0.788	1.09	0.96
625	0.790	0.725	0.820	1.09	0.96
650	0.821	0.753	0.853	1.09	0.96
675	0.852	0.782	0.885	1.09	0.96
700	0.883	0.810	0.917	1.09	0.96
725	0.914	0.838	0.949	1.09	0.96
750	0.945	0.866	0.981	1.09	0.96
775	0.976	0.895	1.013	1.09	0.96
800	1.007	0.923	1.046	1.09	0.96
825	1.038	0.951	1.078	1.09	0.96
850	1.069	0.979	1.110	1.09	0.96
875	1.100	1.008	1.142	1.09	0.96
900	1.131	1.036	1.174	1.09	0.96
925	1.162	1.064	1.206	1.09	0.96
950	1.193	1.092	1.239	1.09	0.96
975	1.224	1.121	1.271	1.09	0.96
1000	1.255	1.149	1.303	1.09	0.96

Table E: Sampling frequency influence

Variation between weekly and 4-weekly sampling

Sample		Average [U] (ug/L)	Dose Underestimate Min deviation	Dose Overestimate Max deviation	Ph1/Ph2 [U] Ratio	Inverse Min
38		9.31	0.04	2.63	0.90	23.69
28		1.26	0.32	3.59	0.90	3.11
33		1.06	0.38	2.55	0.90	2.66
15		114.00	0.46	1.31	0.90	2.17
22		5.06	0.49	1.58	0.90	2.04
13		18.78	0.50	2.27	0.90	2.02
29		**0.94**	**0.50**	**1.77**	**1.42**	**2.00**
18		3.99	0.53	1.39	0.90	1.90
34		**0.78**	**0.55**	**2.41**	**1.40**	**1.81**
37		**48.33**	**0.57**	**1.35**	**1.24**	**1.76**
32		0.96	0.59	2.18	0.90	1.71
14		**2.88**	**0.62**	**1.76**	**0.42**	**1.61**
11		84.07	0.63	1.59	0.90	1.58
26		0.63	0.64	2.37	0.90	1.55
27		**0.92**	**0.64**	**1.74**	**0.85**	**1.55**
7		**128.56**	**0.66**	**1.24**	**0.69**	**1.51**
25		0.62	0.67	2.56	0.90	1.49
16		**21.01**	**0.69**	**2.38**	**0.68**	**1.44**
36		**12.80**	**0.71**	**1.73**	**2.29**	**1.41**
23		**18.91**	**0.73**	**1.21**	**0.94**	**1.37**
30		**0.53**	**0.74**	**1.44**	**0.94**	**1.34**
6	a	3.19	0.75	1.25	0.90	1.33
10		23.24	0.75	1.26	0.90	1.32
39		22.01	0.77	1.40	0.90	1.30
8		58.77	0.77	1.36	0.90	1.30
24		0.52	0.79	1.52	0.90	1.26
35		**1.55**	**0.81**	**1.30**	**2.02**	**1.23**
7	a	**214.71**	**0.84**	**1.22**	**0.87**	**1.18**
20		0.57	0.85	1.23	0.90	1.18
6		**3.14**	**0.85**	**1.19**	**0.62**	**1.17**
5		**31.38**	**0.85**	**1.18**	**0.87**	**1.17**
12		**243.42**	**0.88**	**1.36**	**0.35**	**1.13**
2		20.50	0.88	1.23	0.90	1.13
3		**36.18**	**0.91**	**1.06**	**0.93**	**1.10**
21		7.33	0.91	1.16	0.90	1.10
1		156.54	0.93	1.09	0.90	1.07
31		0.42	0.94	1.13	0.90	1.07
19		2.96	0.94	1.19	0.90	1.06
9		**73.39**	**0.95**	**1.05**	**0.90**	**1.05**
17		48.85	0.99	1.60	0.90	1.01
4		38.28	0.99	1.02	0.90	1.01

* Data printed in bold are measured, others are estimated from the "global" mean