ENCLOSURE 2
ATTACHMENT 1

SHINE MEDICAL TECHNOLOGIES, INC.

SHINE MEDICAL TECHNOLOGIES, INC. APPLICATION FOR CONSTRUCTION PERMIT RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

REPORT-TEC-01-15, REVISION 1
ESTIMATION OF UNCERTAINTY IN RADIOLYSIS GAS PRODUCTION IN THE TSV

12 pages follow

REPORT TITLE:	Estimation of Uncertainty in Radiolysis Gas Production in the TSV
REPORT NUMBER:	REPORT-TEC-01-15
REVISION NUMBER:	1

REVISION LOG

REVISION NUMBER	DESCRIPTION OF CHANGES	EFFECTIVE DATE OF REVISION
0	Original issue	9/19/14
1	Added Appendix A to discuss the change in uncertainty when only considering data points near the expected operating range of the TSV as well as discussion of measurement accuracy.	1/26/15

1 Overview

Water in aqueous solutions is subject to radiolysis by fission products and other fast charged particles such as protons and electrons. This report describes the methods used to estimate the uncertainty in the radiolytic gas production rate in the TSV.

2 Methods

The amounts of different radiolytic chemicals produced depend on the linear energy transfer (LET) to the solution from fission recoils or other charged particles. Figure 1 shows that low LET radiation such as fast electrons creates the largest yields of H, whereas high LET fission products, like those present in the SHINE system, create larger amounts of H_2 from the decomposition of water molecules rather than the creation of free radicals H and OH. [1]

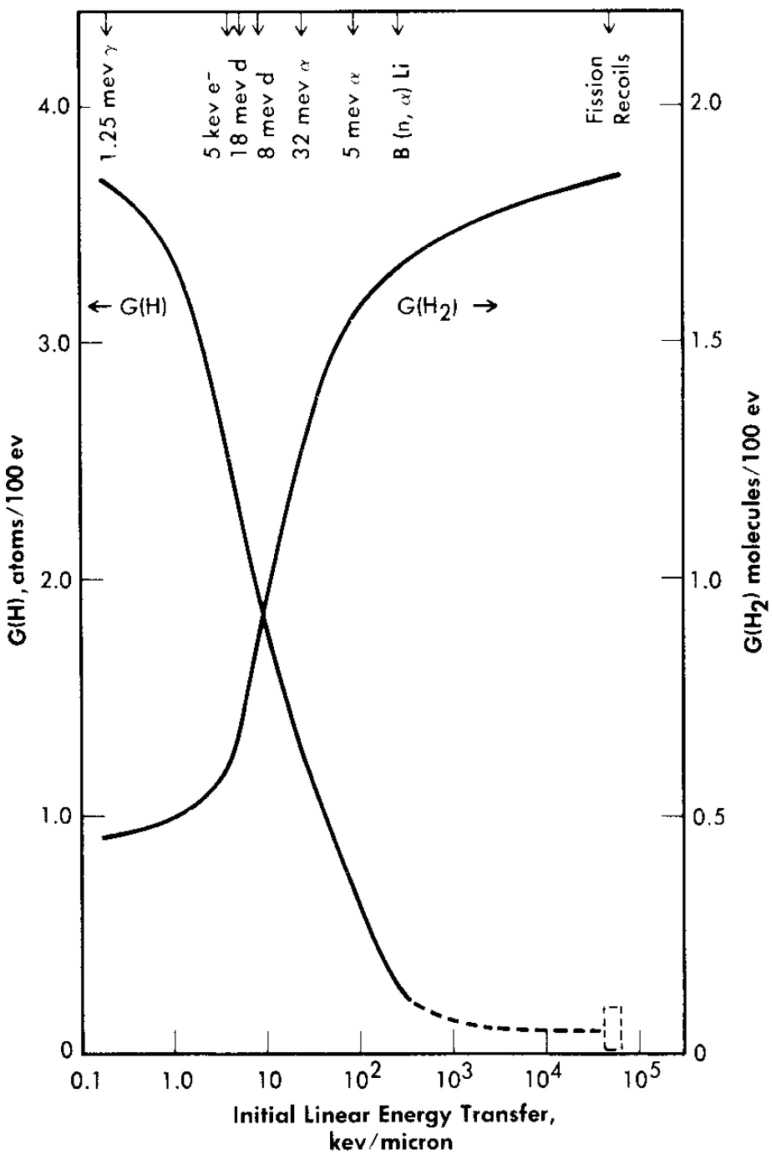

Figure 1: G(H) and G(H_2), production rates as a function of LET

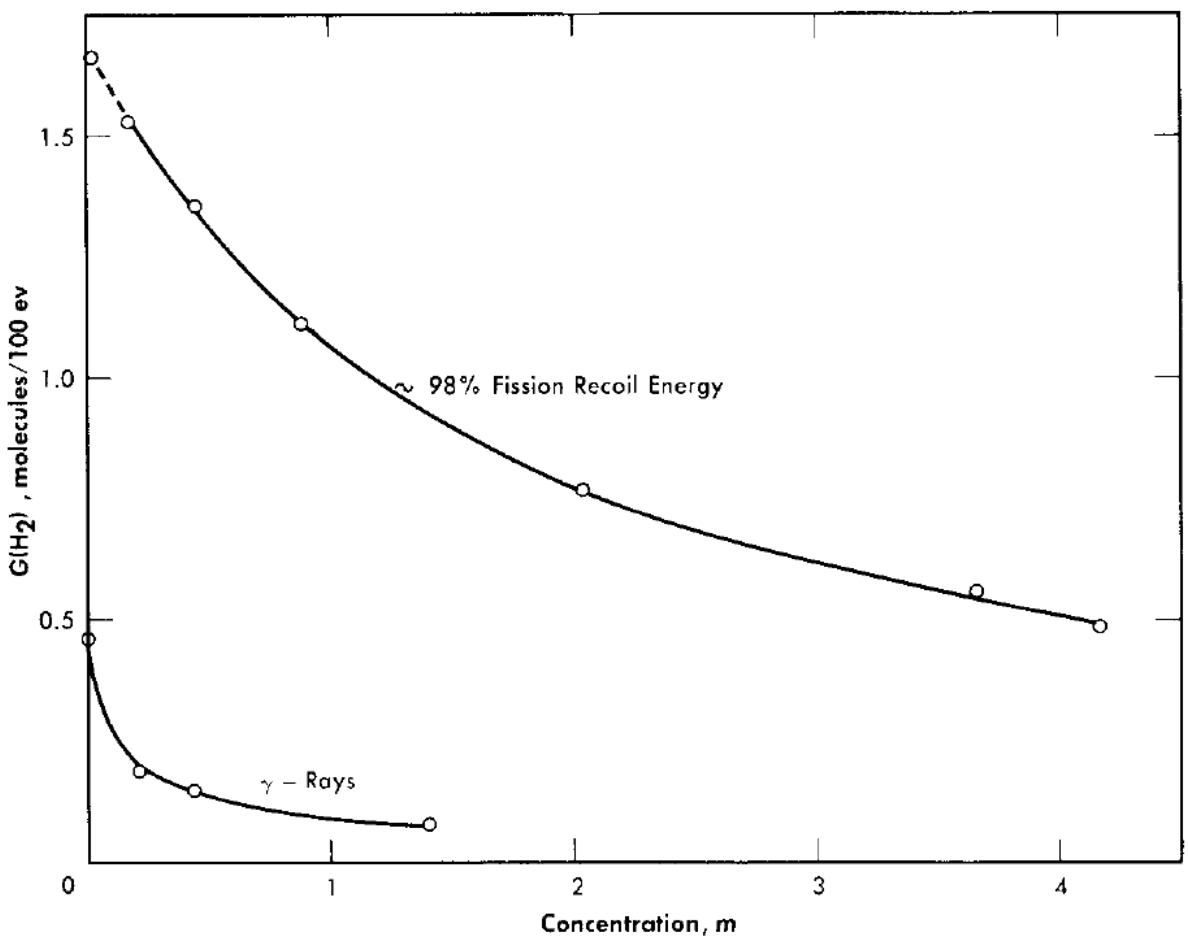

Figure 2: Hydrogen production as a function of uranium concentration in H_2SO_4 solution.

To determine the uncertainty in radiolytic gas production, the H_2 production rate is examined for uranyl sulfate solutions. There is a clear trend displayed in Figure 2 that shows as the concentration of uranium in solution increases, there is a decrease in the production of hydrogen, independent of temperature. [1] Table 4a2.2-1 of the SHINE PSAR states that the SHINE system has uranium concentrations between [Proprietary Information], which is approximately [Proprietary Information]. [2]

Table 1 provides quantitative results for the H_2 generation rate in uranyl sulfate solution at different uranium concentrations and enrichments. The H_2 production rate values were determined by averaging between three and six individual measurements at each uranium concentration point. These values were found to be within 2 percent of each other. [3] The production rates were analyzed by burning evolved hydrogen and oxygen gas on a heated platinum filament through the Saunders-Taylor technique. This method of analysis has been tested and shown to have errors on the order of one percent. [4]

Table 1:H_2 production rate in uranyl sulfate solutions [1]

Uranium Concentration [g/L]		Fission energy/ total energy	H2 Production Rate [molecule/100 eV]
g U/liter	g U235/liter		
0.399	0.372	0.688	1.61
4.03	3.76	0.957	1.66
18.6	1.63	0.906	1.48
38.1	0.274	0.619	0.95
40.7	37.9	0.995	1.53
102.1	37.4	0.995	1.35
105.2	38.9	0.995	1.2
108.4	40.1	0.995	1.35
202.3	0.063	0.273	0.69
202.5	37.6	0.995	1.11
203.4	189.6	0.999	1.11
227	1.63	0.906	0.98
310.4	0.096	0.364	0.62
386	1.63	0.906	0.8
431.3	37.8	0.995	0.77
436.8	3.1	0.949	0.73
477.2	0.148	0.467	0.56
713.5	33.5	0.995	0.56
796	37.4	0.995	0.49

This data is used to determine the uncertainty in hydrogen production rates for uranyl sulfate solutions. The SHINE system is expected to have a fission to total energy ratio close to 1, since it operates similar to a typical thermal fission reactor with regards to power generation. Data with a fission to total energy ratio of less than 0.900 is excluded in determining uncertainty because it lies too far outside the expected bounds of the SHINE system. Since the hydrogen production rate also depends on the fission to total energy ratio, the data is normalized by calculating the approximate fission production rate from the available data.

[Proprietary Information] Equation 1

Equation 1 shows the measured G value as an average G value for the solution, where $G(H_2)_{fission,corrected}$ is the G value for fission energy as a function of uranium concentration, $G(H_2)_{other}$ is the G value from other radiation effects such as fast electrons, ff is the fission energy to total energy ratio, and $S(C_U)$ is a suppression factor for the solution as a function of uranium concentration, representing the decrease in hydrogen production as a result of the increase in uranium concentration. The suppression factor is approximated [Proprietary Information].

[Proprietary Information]

Making this substitution and rearranging the equation gives the hydrogen production rate from fission in Equation 2.

[Proprietary Information] Equation 2

Plotting the relevant data, an estimation of the hydrogen production rate with no uranium in solution, $G(H_2)_0$, is determined. Figure 3 shows the data and fitting function.

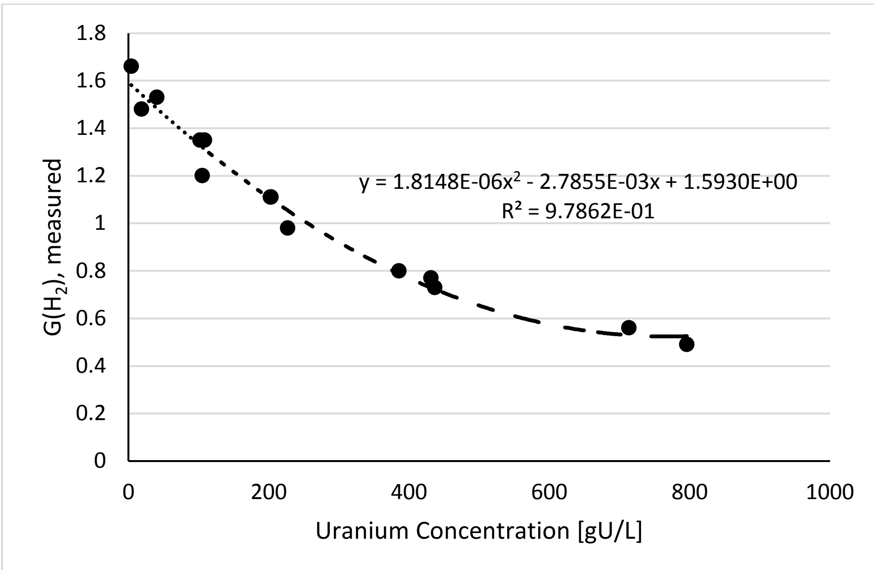

Figure 3: Measured $G(H_2)$ as a function of Uranium Concentration, fission to total energy ratio greater than 0.900, no correction for fission energy fraction

The zero-intercept of the fitting function is used as an estimate of the hydrogen production rate if there were no uranium in solution.

$$G(H_2)_0 = 1.593 \left[\frac{molecule}{100\ eV\ absorbed}\right]$$

The non-fission H_2 production rate is estimated from Figure 1 to be 0.5. Using the suppression factor, the corrected production rate from fission is estimated. The uncertainty in the estimated fission production rate and the fitting equation is then determined. Figure 4 shows the corrected experimental fission production rate estimate and the fitting function.

[Proprietary Information]

Figure 4: Corrected hydrogen production rate from fission

$$Uncertainty = \frac{(G(H_2)_{measured,fiss,c} - G(H_2)_{fit,fiss,c})}{G(H_2)_{fit,fiss,c}} \qquad \text{Equation 3}$$

Equation 3 is used to calculate the uncertainty in the hydrogen production rate data. Table 2 gives a summary of the concentration data and uncertainty in production rates.

Table 2: Summary of uncertainties in hydrogen production rate

gU/liter	Fission energy/ total energy	pH	G_exp	G_measured,fiss,c	G_fit,fiss,c	Uncertainty [%]
18.6	0.906	2.9	1.48	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
227.0	0.906		0.98	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
386.0	0.906		0.80	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
436.8	0.949		0.73	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
4.03	0.957	3.26	1.66	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
40.7	0.995	2.42	1.53	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
102.1	0.995	2	1.35	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
105.2	0.995	0.1	1.20	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
108.4	0.995		1.35	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
202.5	0.995	1.61	1.11	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
431.3	0.995	1.32	0.77	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
713.5	0.995		0.56	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
796.0	0.995	1.03	0.49	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
203.4	0.999		1.11	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

3 Data Near Operating Range of TSV

Because the range of data used in the previous section is significantly larger than the operating range of the TSV, a smaller subset of data near the expected TSV operating range was also examined for uncertainty. The results of using this subset of data are provided in Appendix A.

4 Results

For uranyl sulfate solutions with fission energy to total energy ratios greater than 0.900, the maximum uncertainty in available radiolytic gas production rate data was found to be 10.9 percent. It is also noted that the data point [Proprietary Information]. [3] Excluding this data point would decrease the calculated uncertainty; however, this data point is retained in the analysis as a conservatism for the purposes of estimating uncertainty.

Given the trends and consistency in available data, it is estimated that the uncertainty in $G(H_2)$ from fission as a function of uranium concentration is less than 15 percent.

5 References

1. *Fluid Fuel Reactors.* Ed. J Lane, H MacPherson, F Maslan. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc. 1958. PDF.
2. *SHINE Preliminary Safety Analysis Report, Rev. 0.* SHINE Medical Technologies. 2013.
3. ORNL-52-8-103, *Radiation Chemistry of Aqueous Reactor Solutions*. J. W. Boyle *et al*. Oak Ridge National Laboratory. 1952. PDF.
4. *The Photolysis of Acetone in the Presence of Mercury*. K. Saunders and H. A. Taylor. AIP Publishing. 1941. PDF.

Appendix A. Data Points Near the Expected Operating Range of the TSV

Since measurements taken at uranium concentrations far from the planned concentrations in the SHINE TSV may affect the uncertainty analysis, a smaller subset of the production rate data was also analyzed, as shown in this appendix. The uranium concentration in the TSV is expected to be [Proprietary Information]. [2] Data within 50 percent of this uranium concentration range was considered for additional uncertainty analysis.

Table A-1 gives the subset of data points considered with uranium concentrations ranging from [Proprietary Information]. The fission energy correction process described in the main body of this report was considered acceptable and applied using the $G(H_2)_0$ value found previously.

Table A-1: Data Points near Expected Operating Range of TSV [1]

[Proprietary Information]

A linear trend within this data subset was determined to be acceptable given the slowly changing nature of the larger data set. Figure A-1 shows the fission corrected production rate data and least squares regression linear curve fit. An error band at ±10% is included with the regression line.

[Proprietary Information]

Figure A-1: Linear Fit of Fission Corrected $G(H_2)$ Values near Expected TSV Operating Range

Uncertainties between the measured $G(H_2)$ values and the linear fit are less than 10 percent. Table A-2 shows the uncertainty measurements of the data points used in the linear fit.

Table A-2: Uncertainty of Linear Fit for $G(H_2)$ Values near Expected TSV Operating Range

[Proprietary Information]

The expected TSV operating range with respect to uranium concentration [Proprietary Information]. The original curve fit appears [Proprietary Information]. Overlaying the linear curve fit line on the original fit (using the full data set) is shown in Figure A-2. Table A-3 shows the fission corrected $G(H_2)$ production rate values at select points for the original and linear curve fits.

[

Proprietary Information

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Figure A-2: Comparison of Fission Corrected Original and Linear Fits for $G(H_2)$ Values near Expected TSV Operating Range

Table A-3: Difference between Original and Linear Curve Fits over Expected TSV Operating Range

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Differences between the linear fit and original fit over the operating range of the TSV do not deviate by greater than a few percent. There were no significant changes found in the expected uncertainty when using a fit that considers the entire data set or the referenced subset of points within 50 percent of the uranium concentration range of the TSV. Accounting for the multiple production rate measurements (see section 2), the expected level of uncertainty in the measurement method (see section 2), and the deviation of the data from the regression lines (10.9 percent considering the full data set, 8.4 percent considering the restricted subset), a bounding uncertainty of 15 percent for the radiolysis production rate is considered acceptable.