ENCLOSURE 2
ATTACHMENT 3

SHINE MEDICAL TECHNOLOGIES, INC.

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

REPORT-TEC-01-15, REVISION 0
ESTIMATION OF UNCERTAINTY IN RADIOLYSIS GAS PRODUCTION IN THE TSV

8 pages follow

REPORT TITLE:	Estimation of Uncertainty in Radiolysis Gas Production in the TSV
REPORT NUMBER:	REPORT-TEC-01-15
REVISION NUMBER:	0

REVISION LOG

REVISION NUMBER	DESCRIPTION OF CHANGES	EFFECTIVE DATE OF REVISION
0	Original issue	9/19/14

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]

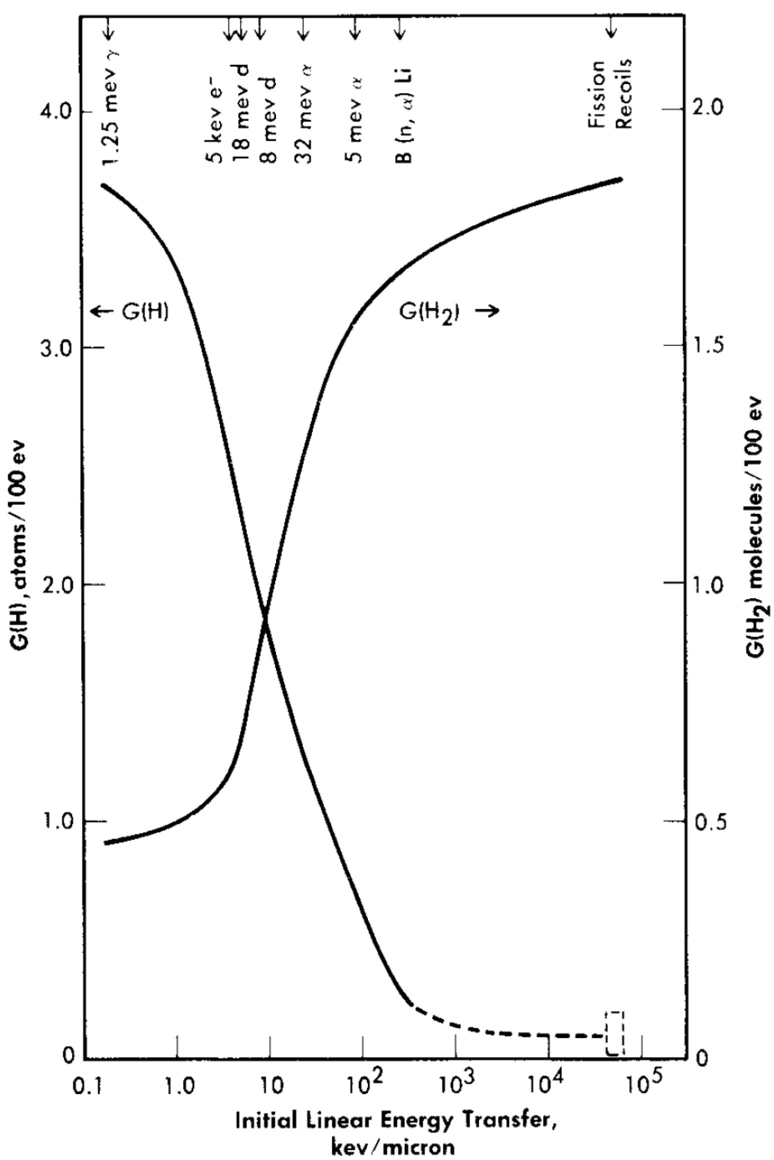

Figure 1: G(H) and $G(H_2)$, production rates as a function of LET

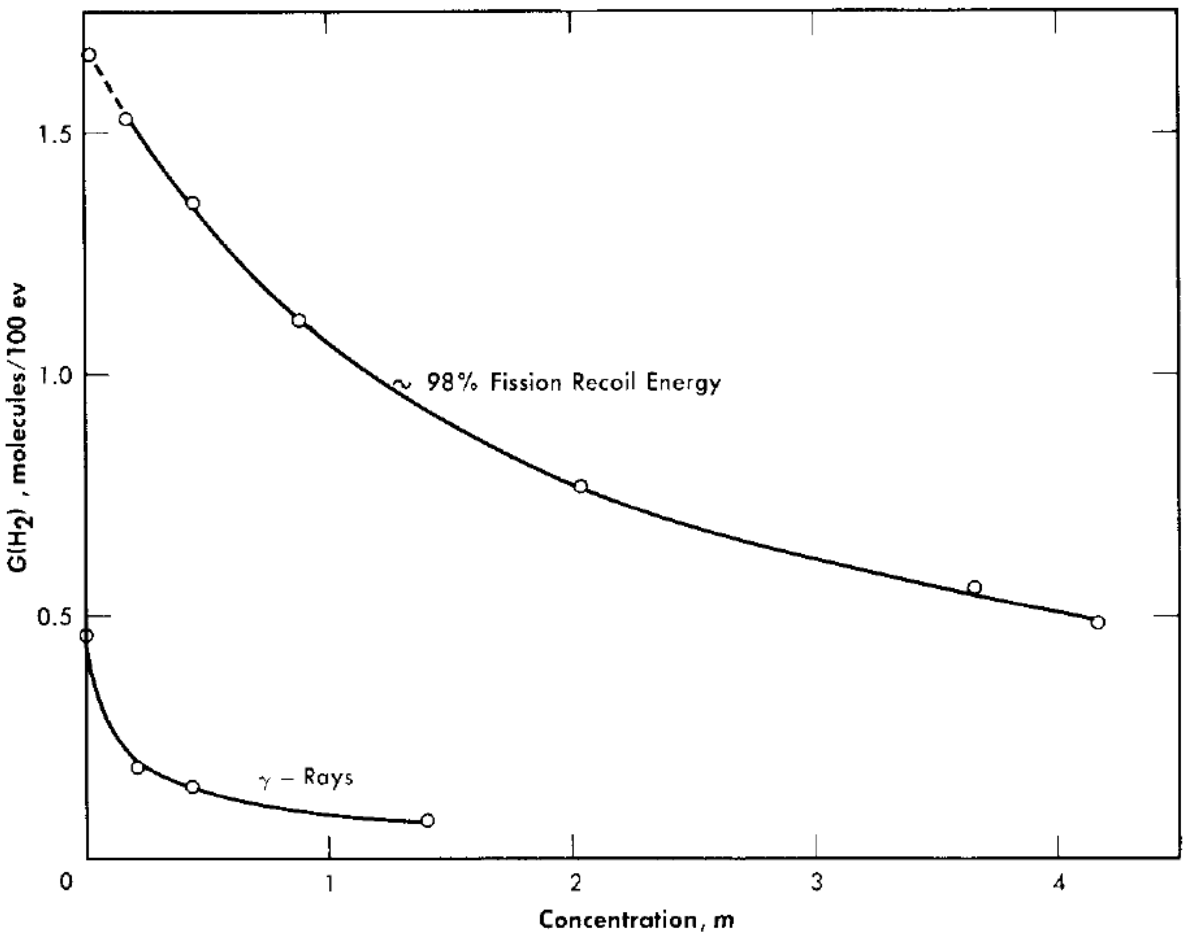

Figure 2: Hydrogen production as a function of uranium concentration in H_2SO_4 solution.

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.

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.

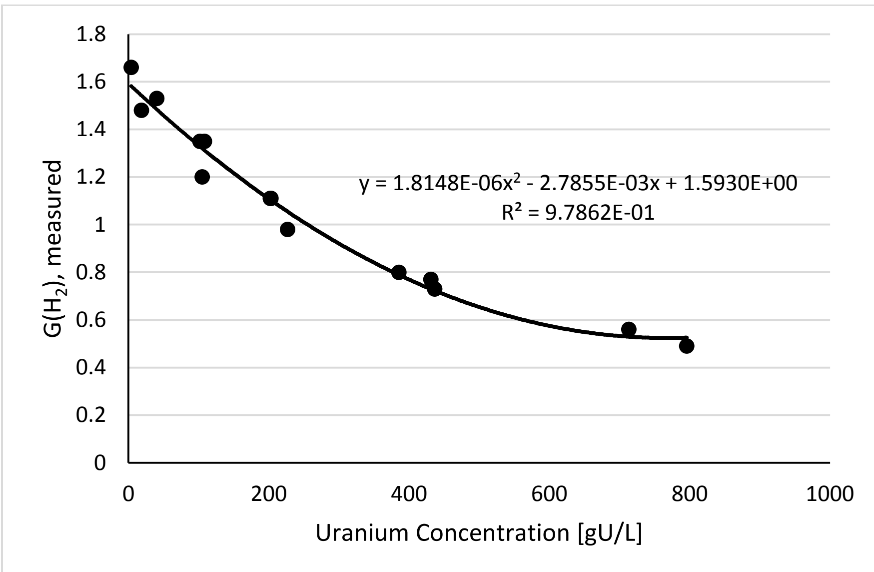

Figure 3: Measured $G(H_2)$ as a function of Uranium Concentration, fission to total energy ratio greater than 0.900, no correction for fission energy fraction

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

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

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	G_exp	G_measured,fiss,c	G_fit,fiss,c	Uncertainty [%]
18.6	0.906	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	1.66	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
40.7	0.995	1.53	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
102.1	0.995	1.35	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
105.2	0.995	1.20	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
108.4	0.995	1.35	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
202.5	0.995	1.11	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
431.3	0.995	0.77	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
713.5	0.995	0.56	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
796.0	0.995	0.49	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]
203.4	0.999	1.11	[Proprietary Information]	[Proprietary Information]	[Proprietary Information]

3 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 10.9 percent. 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.

4 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.