THESIS

INVESTIGATION OF TRITIUM ATOM EXCHANGE IN PLASTIC LIQUID SCINTILLATION VIALS

Submitted by

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ABSTRACT

INVESTIGATION OF TRITIUM ATOM EXCHANGE IN PLASTIC LIQUID SCINTILLATION VIALS

Tritium is a naturally occurring radionuclide; it is an analyte of interest in many air, soil, and water samples. It has been shown that long term storage and study of tritium samples results in a reduction in tritium activity not attributed to the natural radioactive decay. Several explanations have been offered through past literatures including diffusion, LSC cocktail degradation, and change in quenching effects. Another possible explanation for the decrease in activity is that tritium may have been organically bound to the plastic possibly due to exchangeable hydrogen atoms along the plastic carbon chain. The hypothesis that tritium can be incorporated into the plastic, interchanging the ^{1}H atoms in the plastic with ^{3}H atoms, was experimentally tested. The experiment consisted of adding deionized water into a previously used plastic vial which had contained tritium to determine if the deionized water had now become tritiated. The results showed that the longer the tritiated water is stored in the vials, the greater the loss of tritium activity in plastic vials is compared to glass vials. An increase in the time that the tritiated water is stored also increases the activity of the tritium found in the deionized water in plastic vials but not in the glass vials. The combination of these two observations supports the hypothesis that tritium exchange may have occurred between the tritiated water and the hydrogen within the plastic vials.

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CHAPTER 1 INTRODUCTION

Tritium, an isotope of hydrogen, is a naturally occurring cosmogenic radionuclide. One of the most common ways that tritium is formed is in the atmosphere by the bombardment of fast neutrons from cosmic rays onto ^{14}N (Nir, Kruger, Lingenfelter & Flamm, 1966). The reaction is shown in equation 1.1:

$$^{14}N + n^{o} \rightarrow {}^{15}N \rightarrow {}^{12}C + {}^{3}H. \qquad (1.1)$$

The production of tritium in the atmosphere yields an activity of approximately 4 megacuries, or 148,000 terabecquerel, per year with a natural equilibrium level of 70 megacuries (NCRP 62, 1979). Curie (Ci) and becquerel (Bq) are both units of radioactivity; Bq is the unit in the International System of Units (SI) for radioactivity whereas Curie is the unit in the non-SI units used in the United States; they represent the number of decays or disintegrations per second. In addition to the natural tritium production in the atmosphere, the surface nuclear weapons testing during World War II and the Cold War increased the tritium inventory in the atmosphere to a maximum of 3100 megacuries (NCRP 62, 1979). Since tritium still has one proton and one electron, for the most part, it behaves chemically like normal hydrogen, ^{1}H. In any compounds containing hydrogen, ^{1}H, a ^{1}H atom can theoretically be replaced with tritium; for example, one common tritium compound is tritiated water, commonly designated as HTO (NCRP 62, 1979 & ICRP 119, 2012). HTO is water with one of the ^{1}H replaced by ^{3}H. In the atmosphere, tritium can exist in water vapor and after several reactions it can subsequently be precipitated onto the earth's surface, which contributes to the natural background radiation found in our water system (NCRP 62). The abundance of tritium in nature has prompted researchers to study tritium in the environment since the 1950's, which highlights the need for accurate counting.

Tritium is composed of one proton and two neutrons. Compared to stable hydrogen and deuterium, ^{1}H and ^{2}H, tritium has excess neutrons. As a result, tritium will undergo beta-minus decay, which essentially converts one of its neutrons to a proton as depicted in Figure 1. Along with the emission of a beta particle, all beta-minus decay will also emit an antineutrino. The kinetic energy of the beta-minus decay is then split between the beta particle and the antineutrino, yielding the polyenergenetic nature of the beta particles. For tritium, the beta particles have a mean energy of 5.68 keV and a maximum energy of 18.591 keV, with a half-life of 12.32 years (Baum, 2009). The beta particles emitted from tritium do not travel very far at these energies; for example, the range in air is 4.5 to 6 mm, the range in water is 5 µm, and in tissue it is approximately 7 µm (U.S. Department of Energy, 1999). The short ranges of these particles limit the useable detection instruments as most instruments will block these beta particles before reaching the detection medium. As a result, the most common and reliable way to detect tritium is through Liquid Scintillation Counting (LSC) (Health Physics Society, 2011).

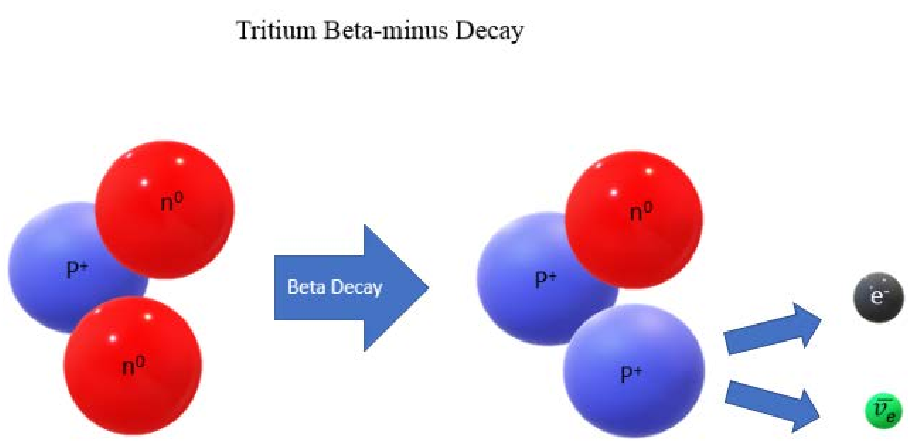

Figure 1. Schematic of Tritium Beta Minus Decay

Liquid Scintillation Counting follows the same concept as any scintillation counters. As ionizing radiation interacts with the scintillation material, it deposits its energy and the scintillator reaches an excited state and de-excites by the emission of light; this light can then be counted and measured to quantify ionizing radiation. The main advantage of liquid scintillation counting is the utilization of liquid scintillation cocktails that can be mixed directly with the sample to reduce the distance traveled by the ionizing radiation. This is particularly useful for low energy beta emitting radionuclides such as tritium and carbon-14. The liquid scintillator mixture can contain both organic and/or inorganic material and there are multiple commercial products that are used for different counting applications (Kessler, 2015). These liquid scintillator mixtures are often referred to as LSC cocktail. One advantage of scintillation counting is that the intensity of the light emitted is proportional to the energy of the ionizing radiation (Kessler, 2015). This trait allows the scintillation detector to discriminate different energies and act as a spectrometer. A common tritium energy spectrum is shown in Figure 2. The shape of the peak is common among beta decays, the peak is a classic representation of the polyenergetic characteristics of beta particles. The peak also appears on the left side of the spectrum, indicating the low energy characteristics of the tritium beta particles.

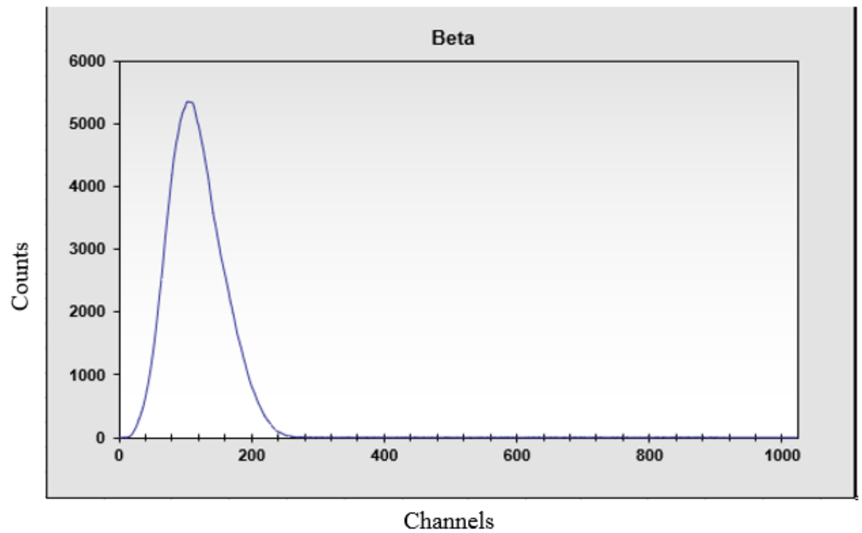

Figure 2. Tritium standard spectrum obtained using Hidex 300SL

Liquid scintillation counting of tritium has been utilized for several decades, as a result, past publications have identified several factors that may affect accurate background determination in LSC. One such factor is the effect of phosphorescence on the LSC cocktail. Phosphorescence occurs when the LSC cocktail is exposed to sunlight which excites the scintillation solution. In 1969, the effects of phosphorescence were observed to persist as long as 70 hours before dissipating (Moghissi, Kelley, Regnier & Carter, 1969). The effect of phosphorescence on the LSC cocktail can be reduced by changing the composition of LSC cocktail and avoid direct sunlight irradiations (Moghissi, Kelley, Regnier & Carter, 1969). The second factor that affects liquid scintillation counting is the chemiluminescence property of the LSC cocktail. Chemiluminescence is the emission of light during a chemical reaction (Welsh, 2011). Past research has demonstrated that the mixing of the LSC cocktail and the polyethylene vial yielded increased sample counts, which were attributed to the effects to chemiluminescence (Moghissi, Kelley, Regnier & Carter, 1969). Lastly, the effects of static electricity on the LSC background count have been observed by past researchers; this effect was more prominent when the sample had been automatically moved within the chamber multiple times (Moghissi, Kelley, Regnier &

Carter, 1969). The use of anti-static solution on the scintillation vials has proved to reduce the effects of static electricity on LSC with no observable effects on the efficiency of the counting instrument (Moghissi, Kelley, Regnier & Carter, 1969). These effects have since been reduced by improving the methods and materials used for LSC measurements for an accurate background measurement.

In the late 1960's, a concept known as the "figure of merit" or FOM was introduced. This value is calculated by using the equation

$$\mathrm{FOM} = \frac{\mathrm{E}^2}{\mathrm{B}}, \qquad (1.2)$$

where E is the efficiency in % and B is the background in cpm; the FOM is a value used to determine the signal to background ratio or another term, "background dominant determination" (Moghissi, Kelley, Regnier & Carter, 1969). This value is useful when comparing different counters with low or high background counts (Moghissi, Kelley, Regnier & Carter, 1969). The FOM has since then been adopted by LSC manufacturers to determine the optimized counting region for a radionuclide for the instrument, as FOM can also represent counting sensitivity (Passo & Cook, 2002). By adjusting the counting regions or channels and calculating the FOM, the highest FOM signifies the optimized window for a specific radionuclide against background.

One important concept in LSC measurements is the effect of quenching; a phenomenon that can significantly reduce the counting efficiency (Jakonić, Nikolov, Todorović & Vesković, 2014). There are four different types of quenching: "absorption or physical quenching, chemical quenching, photon or color quenching and solvent dilution quenching (Jakonić, Nikolov, Todorović & Vesković, 2014)." Essentially, absorption or physical quenching and photon or color quenching effects prevent the emitted light due the radiation interactions from reaching the photomultiplier tubes at its full intensity, while chemical quenching and solvent dilution quenching may prevent radiation energy transfer from a solvent molecule to the scintillating solute molecule, effectively preventing light emission. These quenching effects may reduce the counting efficiency or potentially shift the energy peaks (Kessler, 2015). To account for the quenching effects, standard procedures utilize quenching curves to perform quenching corrections. Quenching curves are generated by plotting a quench indicating parameter (QIP) against its associated efficiency and then matching the quench of the sample to adjust or correct the efficiency of the detector (Kessler, 2015). The four main types of QIP are: sample spectrum QIPs, external standard spectrum QIPs, internal standardization, and efficiency tracing DPM (Kessler, 2015). An example of a quench curve can be found in Figure 3. Properly accounting for the quenching effects of a sample is an important process for liquid scintillation counting, it must be carefully researched and implemented to obtain an accurate measurement.

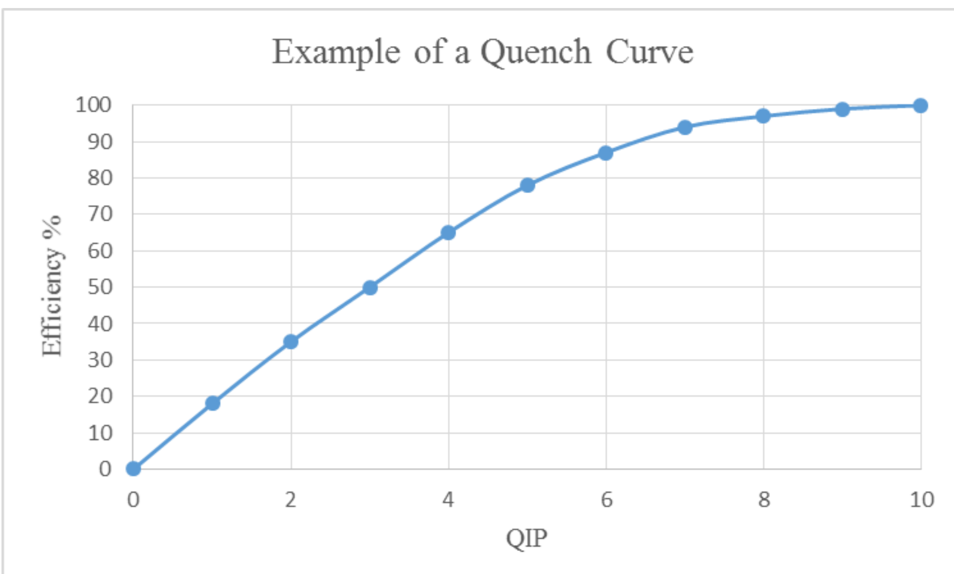

Figure 3. Example of a Quench Curve. The QIP could vary depending on the type of quenching effect the sample is experiencing. The efficiency will also vary depending on the effects from the QIP. Once the curve has been plotted, the efficiency of the instrument can be found be determining the magnitude of the QIP in the sample.

Scintillation technology has improved over the years. One such improvement is the utilization of multiple photomultiplier detectors. Since the mid 1980's, a double photomultiplier detector system has been used to eliminate thermal background and afterpulses (Pochwalski, Broda & Radoszewski, 1986). Some modernized systems now utilize triple-photomultiplier liquid scintillation detectors, depicted in Figure 4, with two different coincident outputs, which is often referred to as the TDCR or triple-to-double coincidence ratio technology (Pochwalski, Broda & Radoszewski, 1986). TDCR instruments work by comparing the triple coincidence to double coincidence of the photomultiplier tubes (Pochwalski, Broda & Radoszewski, 1986). "The under-lying theory is based on a statistical distribution law of the number of photons emitted by the scintillation process, (Priya, Gopalakrishnan & Goswami, 2014)." In recent studies, the TDCR for an instrument has been shown to approximate the overall counting efficiency for the Hidex 300SL when analyzing pure beta-emitting radionuclides (Priya, Gopalakrishnan & Goswami, 2014). This estimated efficiency calculated from TDCR is independent of the quenching effect, hence eliminating the need for quenching curves. TDCR technology has been developed to eliminate the cost of quenching standards, to minimize the radioactive waste generated from making quenching standards, and to reduce the time required to generate quenching curves.

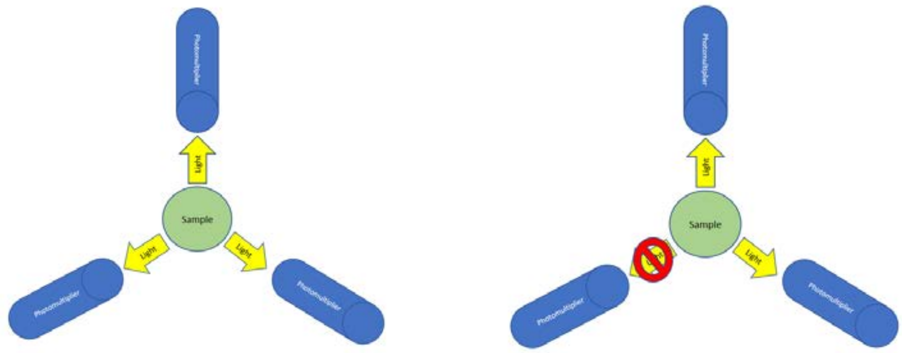

Figure 4. Example of a Triple Photomultiplier LSC Chamber. The left figure depicts an unobstructed light emission where the figure to the right have obstruction of the light, due to quenching effects.

As with all samples gathered from a population, statistical analysis is required to accurately characterize the true data. Statistical analysis is even more critical in the field of Health Physics since radiation decay is a stochastic or random process. A sample measurement, in addition to the radioactive decay that may affect its counts, will be subject to fluctuation. This fluctuation and the random nature of radiation fits the normal distribution model, which means that the "true" count is really the "true average" count (Johnson, 2017). This random behavior also applies to background counts. An instrument remaining in the same location, counting background for the same amount of time, can have different measurement results where the combination of such results will follow a normal distribution. The normal distribution is a common statistical model that fits many natural processes; it essentially describes the variations that occur naturally (Wackerly, Mendenhall & Scheaffer, 2008). Another common distribution used in measuring radioactivity is the Poisson distribution. The Poisson distribution is a good model for events with low chance of occurrence. It is useful for describing natural decay process because the probability of a single atom decaying is small (Wackerly, Mendenhall & Scheaffer, 2008; Johnson, 2017). As the number of decays or counts increases, the Poisson distribution behaves more like the normal distribution (Johnson, 2017). The Poisson distribution is commonly used in operational health physics, especially when only one measurement is utilized, because the standard deviation of a Poisson distributed mean is the square root of the mean (Johnson, 2017). These distributions describe the natural variation and the randomness of the radioactive decays. Selecting and performing the appropriate statistical analysis is important in distinguishing between the subtle increase in counts and the spread of these distributions.

One powerful statistical tool for health physicists is the t-test. The t-test is appropriate especially for analysis of small samples (Wackerly, Mendenhall & Scheaffer, 2008). The t-test is a hypothesis test that is used to compare two sample means. Hypothesis testing has four elements: 1. The null hypothesis, 2. The alternative hypothesis, 3. Test statistic and 4. The rejection region (Wackerly, Mendenhall & Scheaffer, 2008). The null hypothesis is the hypothesis that is to be tested; in health physics application, this hypothesis is usually the following: the mean of the sample is equal to the mean of the background. Next, the alternative hypothesis is the hypothesis that a researcher is trying to support; an example of an alternative hypothesis is that the sample mean is greater than the mean of the background (Wackerly, Mendenhall & Scheaffer, 2008). The test statistic is a calculated value that can be used to compare against the rejection region to determine whether to accept or reject the null hypothesis (Wackerly, Mendenhall & Scheaffer, 2008). The rejection region must be carefully chosen, it is based on either the type I error, type II error or both (Wackerly, Mendenhall & Scheaffer, 2008). Type I error, denoted by α, is made when the null hypothesis is rejected when it is true whereas the type II error, denoted by β, is made when the null hypothesis is accepted when the alternative hypothesis is true (Wackerly, Mendenhall & Scheaffer, 2008). These two errors are important concepts in health physics, as they are referred to as false alarm and missed detection (Johnson, 2017). In operational health physics, these errors are commonly accepted when set at 5%. To perform the t-test, the following formula is used to calculate the test statistic:

$$t = \frac{|M_1 - M_2|}{\sigma_{diff}} \tag{1.3}$$

where

$$\sigma_{diff} = \sqrt{\sigma_{M_1}^2 + \sigma_{M_2}^2} \tag{1.4}$$

(Johnson, 2017). Once the t-value is calculated, it can then be compared to the relevant rejection region. The t-value on its own can also be indicative of how big the difference between the two means is while taking account of the standard deviation of the mean. The bigger the magnitude of the t-value means that the difference in means is larger while accounting for statistical fluctuation. The utilization of a t-test is not only important but necessary in determining the presence of a small amount of radioactive material in a sample.

Tritium is a naturally occurring radioactive material from the atmosphere; it travels to the Earth's surface via rain and snow and follows where water would go. Logically, it is not unusual to find tritium in natural water. The need to distinguish between naturally occurring tritium and man-made tritium contamination in an environmental water sample can be of interest for public safety and regulators. LSC counting of tritium in water is common practice such as described by Environmental Protection Agency Method 906.0. This method recommends both glass and polyethylene vials as containers for the LSC vial depending on the LSC cocktail used (U.S. EPA, 1980). One advantage of polyethylene vials over regular glass vials is that polyethylene vials can yield a lower background as regular glass vials can contain naturally occurring potassium-40 atoms (^{40}K). ^{40}K undergoes beta-minus decay 89.28% of the time; it has a mean beta energy of

560.2 keV with a maximum beta energy of 1310.89 keV. Without using the optimized window, the fluctuating amount of ^{40}K in a vial can influence counting results. Therefore, low-potassium glass vials or polyethylene vials are recommended for tritium counting. However, past research has shown that long term storage of tritium in plastic vials can result in counting rate losses in addition to the natural radioactive decay (Nedjadi, Duc, Bochud & Bailat, 2016). Several factors have been identified as possible reasons for the counting rate losses: the stability of the scintillation cocktail, diffusion of the scintillation cocktail and sample through the polyethylene vials and long-term quenching changes within a sample (Nedjadi, Duc, Bochud & Bailat, 2016; Verrezen, Loots & Hurtgen, 2008; Feng, He, Wang & Chen, 2015). One additional hypothesis was proposed as a cause for the counting rate loss. Recall that tritium can exchange places with ^{1}H, theoretically, tritium can replace the ^{1}H found on the polyethylene carbon chain. If enough tritium bonded within the porous section of the plastic, when it decays, it may be subject to self-absorption before reaching the LSC cocktail, resulting in a loss of count. In a simple experiment performed by a previous CSU graduate student, tritiated water was allowed to soak in a plastic gallon container. The container was then dried, and deionized water was added to it. The deionized water was sampled and counted in the LSC, yielding an increased count in the optimized region for tritium. The experimental result showed that tritium was introduced to the deionized water within the dried plastic container; the unknown source of the tritium could be the result of ^{1}H and ^{3}H atom exchange along the polyethylene carbon chain. The main objective of the following experiment is to test the hypothesis that tritium atom exchange can occur within plastic LSC vials and as a result, reduce radioactivity measurements.

CHAPTER 2 MATERIALS AND METHODS

The following experiment is designed to determine if tritium could interchange with the hydrogen atoms that are present in the organic polymers found in the typical plastic LSC vials. It mirrors the simple experiment mentioned at the end of Chapter 1, but with additional controls to isolate variables. The main premise of the experiment is to soak a clean LSC vial with tritiated water for a predetermined amount of time, clean the vial via drying, and soak the dried vial with deionized water to see if there was any tritium being reabsorbed by the water. Both plastic and glass vials were used for comparison purpose. DWK Life Sciences (Kimble) Polyethylene 20 ml LSC vials were chosen for the plastic vials, and Wheaton Disposable Scintillation glass 20 ml LSC vials with foil lined caps were selected for the glass vials.

The experiment is broken up into two separate parts, with the major distinction being the tritiated water soaking time. In this experiment, soaking time is defined as the amount of time that a LSC vial is in contact with NIST traceable tritiated water. The first part allowed soaking times between one to seven days, while the second part utilized soaking times between 7 days through 84 days. The soaking times are displayed in Table 1.

Table 1. Tritiated Water Soaking Times

Tritiated Water Soaking Times							
Part I	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Part II	7 days	10 days	14 days	21 days	35 days	56 days	84 days

Five plastic vials and five glass vials were used for each soaking time duration. For each set of five, four were soaked in 8 mL of NIST traceable tritiated water with an activity of 2400 Bq/mL and the fifth vial was soaked in 8 mL of deionized water as control. The naming convention for the vials is listed in Table 2 and Table 3. The vials were weighed before and after adding their respective liquid to determine the volume of liquid added.

Table 2. Sample Labeling Naming Convention for Part I Experiment

Part I													
Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7	
1P1	1G1	2P1	2G1	3P1	3G1	4P1	4G1	5P1	5G1	6P1	6G1	7P1	7G1
1P2	1G2	2P2	2G2	3P2	3G2	4P2	4G2	5P2	5G2	6P2	6G2	7P2	7G2
1P3	1G3	2P3	2G3	3P3	3G3	4P3	4G3	5P3	5G3	6P3	6G3	7P3	7G3
1P4	1G4	2P4	2G4	3P4	3G4	4P4	4G4	5P4	5G4	6P4	6G4	7P4	7G4
1PB	1GB	2PB	2GB	3PB	3GB	4PB	4GB	5PB	5GB	6PB	6GB	7PB	7GB

Table 3. Sample Labeling Naming Convention for Part II Experiment

Part II													
Day 7		Day 10		Day 14		Day 21		Day 35		Day 56		Day 84	
7-2P1	7-2G1	10P1	10G1	14P1	14G1	21P1	21G1	35P1	35G1	56P1	56G1	84P1	84G1
7-2P2	7-2G2	10P2	10G2	14P2	14G2	21P2	21G2	35P2	35G2	56P2	56G2	84P2	84G2
7-2P3	7-2G3	10P3	10G3	14P3	14G3	21P3	21G3	35P3	35G3	56P3	56G3	84P3	84G3
7-2P4	7-2G4	10P4	10G4	14P4	14G4	21P4	21G4	35P4	35G4	56P4	56G4	84P4	84G4
7-2PB	7-2GB	10PB	10GB	14PB	14GB	21PB	21GB	35PB	35GB	56PB	56GB	84PB	84GB

After fulfilling the predetermined soaking time, the contents of the vials were transferred to a set of clean plastic vials. The remaining drops were removed and discarded via disposable pipettes. The transferred contents were labeled as “waste” with the vials labeled following the original samples conventions with an additional W added to it. The waste samples were kept for further analysis; however, this process was not introduced and correctly implemented until Part I, day 4 of the experiment and Part II, day 14 of the experiment, so some of the waste data were lost as missed opportunities or failed data gathering. The now empty vials that had their previous contents removed were then transferred to an Across International vacuum drying oven. The vacuum chamber was purged with nitrogen gas to remove any atmospheric water vapor and the vials were then dried for two days at a setting of 80 degrees Celsius and a vacuum pressure of 630 mmHg. After drying, the vials were weighed prior to adding deionized water and weighed once again after the addition of water for volume determination. The newly added deionized water underwent a reabsorption time of 7 days, where the objective is to allow tritium that may have been bound to the LSC vials to exchange back with the hydrogen in the deionized water.

For Part I of the experiment, 12 ml of the Ultima Gold LLT (Low Level Tritium) Liquid Scintillation Cocktail was added immediately to each vial after adding the deionized water for counting. The samples were counted again after 7 days. The two sets of measurement methodology attempted to determine if atom exchange would occur in the early or later part of the 7-day reabsorption time. The first set of the measurements was coined as initial measurement or initial count. Due to the time constraints between samples, a five-minute count of the sample was used for the initial measurement. The initial measurement was performed immediately after adding the deionized water and the LSC cocktail to determine if the atom exchange is a fast reaction. After 7 days, the second set of measurements was performed where the samples were counted twice for one hour each. They were counted consecutively in the following order: Plastic Vial 1, Plastic Vial 2, Plastic Vial 3, Plastic Vial 4, Plastic Vial Background, Glass Vial 1, Glass Vial 2, Glass Vial 3, Glass Vial 4, Glass Vial Background and repeated once again in the same order. All samples were counted using the Hidex 300SL Liquid Scintillation Counter with at least 15 minutes of dark adapt process. These sample count data are considered raw data until they have gone through statistical analysis.

For Part II of the experiment, after adding the deionized water post the drying process, the samples were stored for the duration of the reabsorption time prior to adding the LSC cocktail to allow atom exchange to only occur between the deionized water and the vials without the presence of the cocktail. After reaching their respective soaking time, 12 mL of LSC cocktail was added to each sample and transported for measurement. A graphical summary of the experiment can be found in Figure 5.

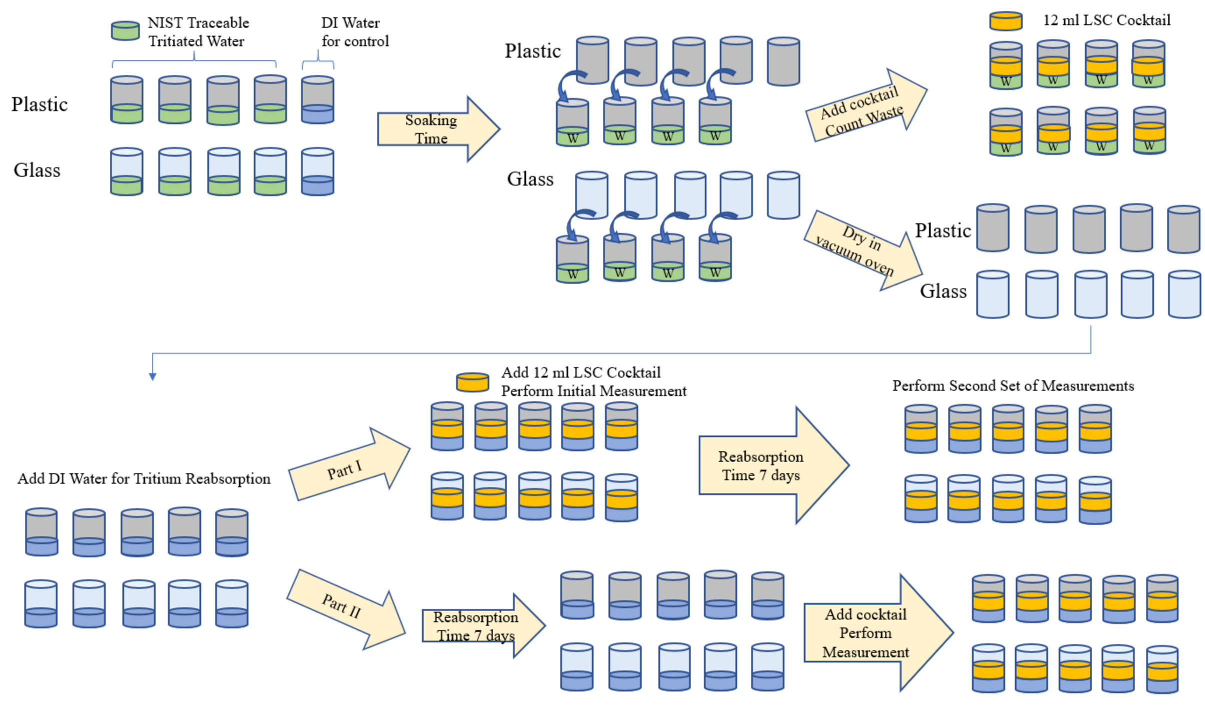

Figure 5. A graphical summary of the experiment

All samples in Part II of the experiment were counted twice for one hour each. They were counted consecutively in the following order: Plastic Vial 1, Plastic Vial 2, Plastic Vial 3, Plastic Vial 4, Plastic Vial Background, Glass Vial 1, Glass Vial 2, Glass Vial 3, Glass Vial 4, Glass Vial Background and repeated once again in the same order. All samples were counted using the Hidex 300SL Liquid Scintillation Counter with at least 15 minutes of dark adapt process. These sample count data are considered raw data until they have gone through statistical analysis. Counting results can be found in the Results section. Results are reported within the optimized window. The optimized window differs between Part I and Part II of the experiment as the counting chamber had to be exchanged due to mechanical issues.

Due to inconsistencies in the data observed in Part II of the experiment, the counting method was modified to five consecutive 30-minute counts per vial. Detailed reasoning is provided in the Results section.

The waste samples gathered prior to the drying process were all immediately measured for their radioactivity via the Hidex 300SL Liquid Scintillation Counter with at least 15 minutes of dark adapt process. All waste samples were counted twice during the measurement at 300 seconds each. As previously mentioned, the waste data gathering procedures were not introduced and correctly implemented until Part I, day 4 of the experiment and Part II, day 14 of the experiment so some of the data were incorrectly gathered or lost as a missed opportunity.

The final control experiment utilized the remaining NIST traceable tritiated water standard. This experiment attempted to characterize the activity of the tritiated water in plastic vials without undergoing the drying process for comparison purpose. The remaining NIST traceable tritiated water yielded 6 vials of 8 ml standard labeled S1-S6. These vials followed a soaking time found in Table 4 prior to adding the LSC cocktail for measurements. These samples were then counted twice for 300 seconds each using the Hidex 300SL Liquid Scintillation Counter with at least 15 minutes of dark adapt process. This aforementioned experiment will be referred to as the "Tritium degradation in plastic vial experiment".

Table 4. Soaking Time for Tritium Degradation in Plastic Vial Experiment

Soaking Time for Tritium Degradation in Plastic Vial Experiment						
Vial	S1 = 10 days	S2 = 14 days	S3 = 21 days	S4 = 35 days	S5 = 56 days	S6 = 84 days

CHAPTER 3 RESULTS

The raw data counts were obtained using the Hidex 300SL Liquid Scintillation Counter along with an Excel macro for visual representation of the data supplied by the manufacturer found in Appendix A. All data reported in this section was measured within the optimized window. The raw counting data for Part I and Part II of the experiment can be found in Table 5 through Table 10.

Part I – Measurement Data

Initial measurement – Immediately after adding fresh deionized water and LSC cocktail

Table 5. Part I Experiment Raw Data Initial Count for Plastic Vials

Plastic Vial Gross Counts in FOM 75-125							
Plastic	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**
Vial 1	33	27	21	17	30	32	30
Vial 2	30	22	20	30	35	18	22
Vial 3	21	28	20	24	30	21	26
Vial 4	26	33	24	26	22	27	22
Bkg	23	22	21	20	30	20	26

Table 6. Part I Experiment Raw Data Initial Count for Glass Vials

Glass Vial Gross Counts in Optimized Window 25-170							
Glass	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**
Vial 1	102	126	112	116	101	105	93
Vial 2	100	131	109	102	127	90	108
Vial 3	102	107	97	96	97	109	97
Vial 4	107	101	106	109	106	105	101
Bkg	100	98	97	103	100	117	117

7 Days after adding the deionized water and the LSC cocktail

Table 7. Part I Experiment Raw Data Count for Plastic Vials After 7 Days

Plastic Gross Counts in Optimized Window 75-125							
Plastic	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**
Vial 1	312	306	345	311	370	188	331

Vial 2	288	301	320	304	325	195	307
Vial 3	320	309	331	327	268	172	289
Vial 4	310	316	307	299	255	166	301
Bkg	273	299	289	260	304	154	295
Vial 1	296	306	290	275	294	177	310
Vial 2	313	296	319	297	291	201	315
Vial 3	284	288	310	296	291	143	248
Vial 4	255	308	305	317	306	156	285
Bkg	282	271	306	291	279	187	298

*****Due to human error, D6 data was set counted for 2017 seconds instead of 3600 seconds resulting in a smaller raw count

Table 8. Part I Experiment Raw Data Count for Glass Vials After 7 Days

Glass Gross Counts in Optimized Window 25-170							
Glass	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**
Vial 1	1276	1315	1341	1259	1288	679	1343
Vial 2	1291	1299	1296	1258	1306	747	1282
Vial 3	1287	1220	1229	1372	1248	691	1303
Vial 4	1267	1239	1261	1290	1290	750	1187
Bkg	1253	1276	1230	1194	1263	778	1266
Vial 1	1206	1318	1217	1278	1266	705	1303
Vial 2	1309	1259	1251	1303	1219	723	1197
Vial 3	1288	1178	1179	1213	1242	712	1242
Vial 4	1231	1273	1286	1301	1243	704	1302
Bkg	1286	1317	1368	1260	1284	840	1226

*****Due to human error, D6 data was set counted for 2017 seconds instead of 3600 seconds resulting in a smaller raw count

Part II – Measurement Data

7 Days after adding deionized water

Table 9. Part II Experiment Raw Data Count for Plastic Vials After 7 Days

Plastic Gross Counts in Optimized Window 21-185							
Plastic	**D7**	**D10**	**D14**	**D21**	**D35**	**D56**	**D84**
Vial 1	2204	1096	1746	1278	1468	1563	1885
Vial 2	3752	1152	3103	6061	7937	1083	1130
Vial 3	2493	1071	1130	1821	1383	1969	5784
Vial 4	3613	1170	2780	1207	1132	2140	2093
Bkg	1665	1099	2424	964	974	892	903
Vial 1	1788	1095	1158	989	929	939	1067
Vial 2	1834	1076	1202	1291	1024	936	1127
Vial 3	1884	1272	2505	1309	1215	1414	1605

Vial 4	1705	1239	1202	1707	1041	971	1029
Bkg	981	1221	1020	965	5227	1081	1814

Table 10. Part II Experiment Raw Data Count for Glass Vials After 7 Days

Glass Gross Counts in Optimized Window 18-162							
Glass	**D7**	**D10**	**D14**	**D21**	**D35**	**D56**	**D84**
Vial 1	1361	1353	1471	1337	1374	1341	1244
Vial 2	1457	1415	1428	1269	1349	1305	1282
Vial 3	1327	1375	1439	2470	1285	1363	1262
Vial 4	1358	1386	1418	4529	1425	1334	1156
Bkg	1341	1314	1324	1261	1259	1311	1166
Vial 1	1444	1381	1483	1306	1288	1308	1202
Vial 2	1529	1417	1436	1321	1387	1268	1195
Vial 3	1435	1375	1445	2336	1440	1330	1234
Vial 4	1377	1362	1383	4587	1483	1272	1195
Bkg	1386	1370	1422	1246	1216	1281	1183

Upon examination of the gross count data, the counts of the plastic vials, and only the plastic vials, displayed a strange inconsistency. For example, for vial 35P2 (35 days of tritiated water soaking, sample vial 2) the two counts of the same vial yielded 7937 and 1024 counts. For a 1-hour count, the difference is concerning. By examining the spectra of the plastic vials shown in Figure 6, the peak, or the increased counts, between channels 0-200 appeared sporadically within a same vial. This inconsistency is not a normal characteristic of tritium's beta radiation. Since these peaks are within the tritium optimized window for plastic, further investigation was warranted to determine the source of these sporadic peaks.

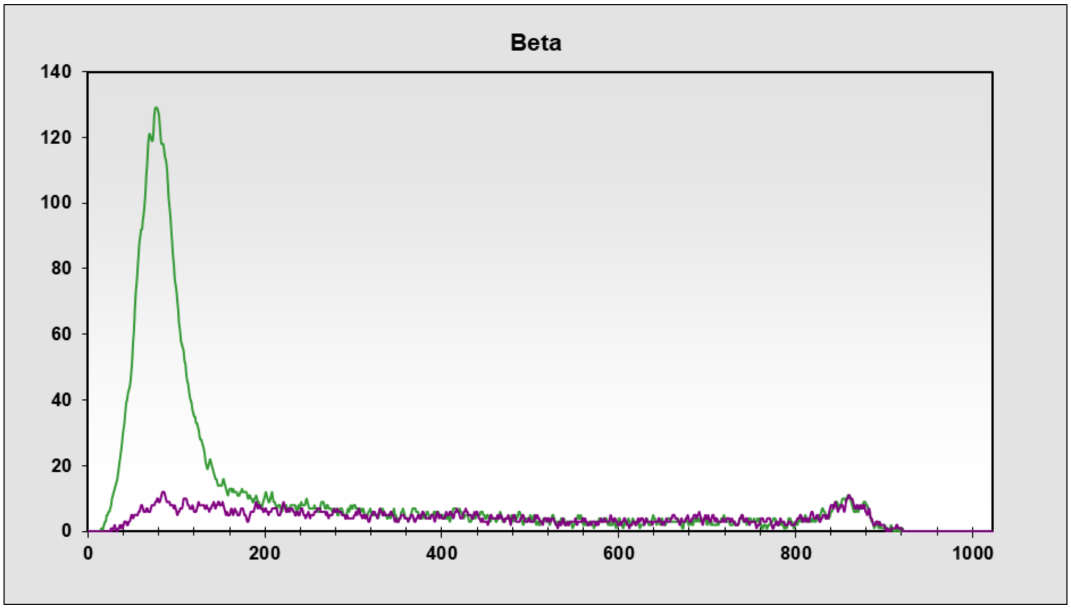

Figure 6. Two separate spectra of vial 35P2 where the sporadic peak appeared and disappeared between channels 0-200.

As stated earlier, these sporadic peaks, only appeared on plastic vials and not glass vials. In addition, these peaks were not present during Part I of the experiment. It was noted that during Part I of the experiment, the humidity was significantly higher in the Fort Collins area. Although the exact value of the humidity of the room was not recorded, the refrigeration unit built into the Hidex 300SL was generating large amount of excess water from condensation, yielding approximately one gallon of water every two to three days. During Part II of the experiment, no excess water was generated. Based on these observations and literature research, it was hypothesized that these peaks were the results of static electricity and a small counting experiment was designed to determine the validity of the hypothesis.

The small counting experiment involved two plastic vials which were counted in 5-minute intervals six times in a row. The vials were counted in the following order: Vial 1, 5-minute interval times six, Vial 2, 5-minute interval times six, back to vial one for 10 total repeats. If the observed phenomenon was due to static electricity, it would be possible that the static electricity would deposit its energy during the first couple of minutes upon placing the vials into the counting chamber. The results of this test are shown in Table 11 and Table 12:

Table 11. Static Electricity Experiment Result for Vial 1

Vial 1 - 300s Count, Window 0-200										
Counts	**Series 1**	**Series 2**	**Series 3**	**Series 4**	**Series 5**	**Series 6**	**Series 7**	**Series 8**	**Series 9**	**Series 10**
1st 5 minutes	196	1021	321	139	91	105	1063	162	552	1888
2nd 5 minutes	95	113	90	83	83	87	240	120	117	459
3rd 5 minutes	21	104	74	94	83	98	135	101	105	355
4th 5 minutes	99	77	92	94	92	70	119	102	95	129
5th 5 minutes	102	91	82	72	81	80	109	100	96	116
6th 5 minutes	90	84	91	82	93	96	116	91	87	109

Table 12. Static Electricity Experiment Result for Vial 2

Vial 2 - 300s Count, Window 0-200										
Counts	**Series 1**	**Series 2**	**Series 3**	**Series 4**	**Series 5**	**Series 6**	**Series 7**	**Series 8**	**Series 9**	**Series 10**
1st 5 minutes	27	74	1424	461	178	424	295	146	1073	112
2nd 5 minutes	95	99	115	94	88	155	165	102	103	88
3rd 5 minutes	85	80	123	123	85	141	181	88	97	8
4th 5 minutes	68	80	88	101	87	552	144	94	86	87
5th 5 minutes	95	70	101	93	82	487	111	83	79	73
6th 5 minutes	90	100	90	103	67	289	106	98	92	88

The result of the small counting experiment seems to support the hypothesis that static electricity is the culprit for the sporadic peaks, as most of the high counts appeared during the first 15 minutes post movement of the vial with the exception of Vial 2, 6th series. Using the information gathered from this counting experiment, all of the vials in Part II of the experiment were recounted to remove the sporadic peaks from the samples. The recounts consisted of five separate 30-minute counts, with the anticipation to discard the data from the first 30 minutes of counting. The decision to discard the first 30-minutes of counting was based on the small counting experiment, as the static electricity peak tends to disappear after 15 minutes; the 30 minutes of stabilizing time was a conservative decision to remove static electricity from the sample. The results of the recounts can be found in Table 13 and Table 14.

Table 13. Part II Experiment Raw Data Recount for Plastic Vials After 7 Days

Part II - Plastic Vials Recount, Optimized Window 21-185					
	Count1	**Count 2**	**Count 3**	**Count4**	**Count5**
7-2P1	1176	530	410	383	494
7-2P2	511	462	433	452	387
7-2P3	930	468	413	433	407
7-2P4	631	470	429	417	456
7-2PB	1281	594	638	436	398
10P1	546	447	451	464	466
10P2	675	421	414	426	427
10P3	421	421	431	431	405
10P4	417	467	421	450	452
10PB	962	399	372	411	423
14P1	781	535	532	482	478
14P2	461	448	443	443	505
14P3	452	415	396	493	448
14P4	429	470	445	367	461
14PB	1127	691	456	404	432
21P1	762	471	501	464	456
21P2	516	442	412	396	400
21P3	618	454	445	463	485
21P4	730	562	528	530	523
21PB	385	455	354	390	372
35P1	509	439	456	424	447
35P2	429	436	401	396	425
35P3	1025	550	453	449	426
35P4	852	400	387	424	412
35PB	688	442	381	382	393
56P1	762	549	478	509	505
56P2	519	454	455	454	458
56P3	512	472	465	422	424
56P4	522	454	414	436	474
56PB	552	415	403	370	383
84P1	642	452	443	434	436
84P2	482	449	477	464	441
84P3	600	472	495	447	434
84P4	443	433	417	411	440
84PB	424	412	371	381	408

Table 14. Part II Experiment Raw Data Recount for Glass Vials After 7 Days

Part II - Glass Vials Recount, Optimized Window 18-162					
	Count1	**Count 2**	**Count 3**	**Count4**	**Count5**
7-2G1	620	598	611	592	574
7-2G2	628	630	624	629	648
7-2G3	568	590	593	577	579
7-2G4	518	610	647	644	644
7-2GB	606	622	580	650	607
10G1	630	572	587	582	627
10G2	629	662	630	575	662
10G3	647	656	640	614	652
10G4	621	592	650	626	667
10GB	615	599	602	609	567
14G1	670	613	695	580	625
14G2	618	603	604	581	620
14G3	638	633	663	615	601
14G4	666	612	653	597	578
14GB	631	579	563	604	567
21G1	621	619	601	609	570
21G2	660	604	582	585	592
21G3	1163	1174	1194	1162	1203
21G4	2138	2180	2179	2128	2074
21GB	628	564	631	588	623
35G1	618	590	600	600	614
35G2	618	642	636	595	627
35G3	648	644	618	607	623
35G4	701	684	668	669	643
35GB	590	590	623	624	620
56G1	615	631	635	604	669
56G2	570	597	580	593	567
56G3	626	657	654	640	649
56G4	626	599	646	618	622
56GB	602	644	592	594	648
84G1	638	595	591	577	608
84G2	610	579	603	600	616
84G3	590	591	596	625	627
84G4	616	600	603	590	673
84GB	616	587	634	578	551

The recounted data for Part II of the experiment show that the increased low-energy peaks only appeared in the first of the five 30-minutes counts for plastic vials. As previously mentioned, these low-energy peaks are not normal characteristics of tritium behavior; therefore, for Part II of the experiment, only the recounted data, without the first 30 minutes, are used for statistical analysis.

The statistical analysis is used to determine if the samples in question have a statistically significant increase in tritium activity compared to the controls used in the experiment. Since each vial contains different amounts of deionized water from pipetting uncertainties, the results are normalized via the volume of the deionized water. The volume of the water is determined using mass measurements along with the conversion 1 g/cm^3 or 1g/ml, neglecting the 0.3% difference in density from 4 degrees Celsius and 22 degrees Celsius. After the data have been normalized to their respective volume, a student t-test is performed to test the null hypothesis that the sample mean is the same as the control mean. The sample mean is calculated by obtaining the weighted average of the samples for the day. For example, for the plastic samples for day 1 (samples 7P1, 7P2, 7P3, and 7P4), the weighted average is calculated using equation 3.1

$$\mathrm{M_w} = \frac{\sum_i w_i M_i}{\sum_i w_i}, \tag{3.1}$$

with,

$$w_i = \frac{1}{\sigma_i^2}, \tag{3.2}$$

where M_i is the average of the number of counts within a sample, and σ_i is the standard deviation of the counts within that sample (Cember & Johnson, 2009). This formula is applied to samples that had been counted multiple times.

For samples that have been counted only once, such as the initial data, the data are assumed to be Poisson distributed and therefore the mean count of the sample is the sample count and the standard deviation of the count within the sample is calculated by the square root of the mean count.

The standard deviation of the weighted mean is calculated by

$$\sigma_{Mw} = \sqrt{\frac{1}{w_1 + w_2 + \cdots . w_n}}. \qquad (3.3)$$

The t-test is then conducted by using M_w and σ_{Mw} of the samples and comparing the calculated sample mean (M_w) and standard deviation (σ_{Mw}) to the control mean (μ_B) and control standard deviation (σ_B). Using these values, the t-score can be evaluated using equation 3.4 (Cember & Johnson, 2009):

$$t = \frac{M_w - \mu_B}{\sqrt{\sigma^2{}_{Mw} + \sigma^2{}_B}}. \qquad (3.4)$$

In this experiment, when t is positive, the sample counts are greater than the control and when t is negative, the background counts are greater than the sample. The greater the magnitude of the t-score, the bigger the indication that the sample differs from the control.

Part I Sample Statistical Analysis

Recall for Part I of the experiment, two separate data measurements were performed per sample. The first one is the initial measurement, or immediately adding water and LSC cocktail post drying. After seven days, the second measurement is performed. The student t-test scores per day are compiled in Table 15 and Table 16.

Table 15. Part I – Initial Count T-Score Comparison

Part I – Initial Count T-Score Comparison		
Soaking Time (Days)	**Plastic T-Score**	**Glass T-Score**
1	0.2389	0.2103
2	0.3270	0.6183
3	0.0088	0.3150

4	0.2225	0.0848
5	-0.0896	0.2313
6	0.2301	-0.4232
7	-0.0923	-0.5791

Table 16. Part I – After 7 Days Count T-Score Comparison

Part I - After 7 Days of Reabsorption Time T-Score Comparison		
Soaking Time (Days)	**Plastic T-Score**	**Glass T-Score**
1	2.2045	0.7388
2	1.0798*	0.7537
3	1.5758	-0.3759
4	1.1543	1.3154
5	-0.0782	-1.8307
6	0.6676	-1.8650
7	2.0793	1.6339

*Day 2 plastic t-score had an anomaly as the two measurements of 2P1 were the same, resulting a sample standard deviation of zero. For calculation purposes, as the standard deviation approaches zero, the t-score increases and approaches a maximum of 1.0798. Therefore, the day 2 plastic t-score is a maximum value and not an exact t-score from the sample data.

Part II Sample Statistical Analysis

In Part II of the experiment, recall that the initial measurement was omitted as to allow DI water to interact with the vial without the presence of the LSC cocktail. Results are taken after 7 days of soaking. The results in Table 17 are also taken from the recounted data with the first 30-minutes removed to achieve consistent reading of the samples.

Table 17. Part II - T-Score Comparison

Part II - T-Score Comparison (After 7 Days Reabsorption Time)		
Soaking Times (Days)	**Plastic T-Score**	**Glass T-Score**
7	-1.4273	-0.2877
10	2.1237	1.3205
14	-0.4551	1.5123
21	1.5780	4.1050
35	0.8262	0.2945
56	2.8180	0.5472
84	2.8101	0.4136

Waste Data

The tritiated water used to soak the vials was transferred into clean plastic vials and measured for comparison purposes. The counts are gathered in the optimized window then divided by the absolute yield of the instrument within the optimized window. The absolute yield is determined by counting the NIST standard in the optimized window and applying it in equation 3.5:

$$\text{Absolute yield} = \frac{\text{measurement}}{\text{standard activity}}. \tag{3.5}$$

Table 18 and Table 19 show the activity per milliliter of the waste from Part I and Part II of the experiment in units of disintegration per second.

Table 18. Activity of the Waste from Plastic Vials

Activity of the Waste from Plastic Vials										
Plastic Bq/ml	D4	D5	D6	D7	D10*	D14	D21	D35	D56	D84
Vial 1	2194	2185	2188	2198	1486	2126	2121	2095	2091	2066
Vial 2	2189	2184	2177	2187	1437	2121	2134	2097	2091	2076
Vial 3	2187	2188	2190	2187	1556	2130	2120	2095	2085	2076
Vial 4	2187	2191	2185	2182	1466	2137	2131	2098	2093	2081
Average	2189	2187	2185	2189	1486	2129	2127	2096	2090	2075

*****D10 waste data had a procedural error yielding skewed data

Table 19. Activity of the Waste from Glass Vials

Activity of the Waste from Glass Vials										
Glass Bq/ml	D4	D5	D6	D7	D10*	D14	D21	D35	D56	D84
Vial 1	2181	2191	2181	2186	1534	2163	2166	2134	2147	2116
Vial 2	2182	2187	2181	2185	1379	2162	2167	2138	2126	2109
Vial 3	2182	2179	2182	2187	1576	2159	2162	2139	2128	2119
Vial 4	2184	2176	2182	2180	1725	2158	2166	2132	2122	2116
Average	2182	2183	2181	2184	1554	2160	2165	2136	2131	2115

*****D10 waste data had a procedural error yielding skewed data

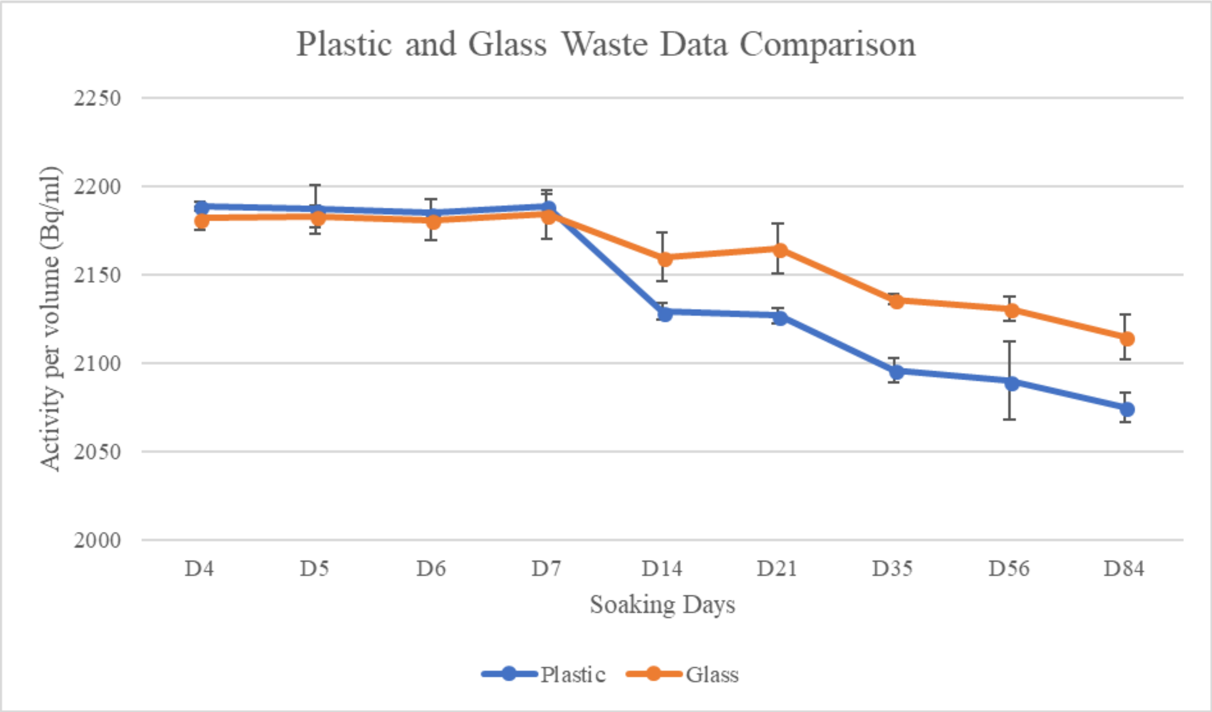

Figure 7. Plastic and Glass Waste Data Comparison. Although there are activity loss per ml of the waste, there seem to have a greater loss of activity in plastic compare to glass. The error bars are based on 2 sigma confidence intervals. D10 waste data had been omitted from this graph due to procedural error.

Tritium Standard Degradation in Plastic LSC Vial Experiment Data

Table 20. Tritium Degradation in Plastic Vial Experiment Data

Tritium Degradation in Plastic Vial Experiment Data						
Vial	S1 = 10 days	S2 = 14 days	S3 = 21 days	S4 = 35 days	S5 = 56 days	S6 = 84 days
Bq/ml	2112	2101	2094	2072	2062	2035

The results for the tritium degradation in plastic vial experiment in Table 20 can be used to compare to the waste data soaked in plastic in Part II as they utilize the same standard and had undergone the same amount of soaking times. The major difference between the waste data and the aforementioned experiment data is whether the tritiated water had been transferred to a new plastic vial.

CHAPTER 4 DISCUSSION

The t-score is a gauge that indicates whether the samples may differ from the control; the larger the magnitude of the t-score, the stronger the indicator. Strictly looking at the t-score comparison in both experiments, the plastic vials reached a t-score of 2.8 after a soaking time of 56 days. Assuming there is no difference between the sample mean and the background mean, using a degree of freedom of 3, the probability of an individual sample getting a t-value of greater than 2.8 is approximately 0.0339. The probability of having two samples having a t-score over 2.8 out of seven samples is

$$\binom{7}{2} * 0.0339^2 * (1 - 0.0339)^5 = 0.02.$$

Therefore, there is only a 2% chance of obtaining this result, assuming the samples does not contain tritium. A t-score of 2.8 is relatively unlikely to occur by chance within a normal distribution, which potentially indicates that there is an increase in tritium activity in the deionized water. When observing the data in the glass vials, the t-scores remained within -2 and 2, with the exception of day 21 glass vials, even as the soaking time increases. The t-scores between -2 and 2 is approximately 96% of the normal distribution. Although a t-score of 2.8 is unlikely to occur by chance, it is only a subtle increase in activity compared to the control vials.

Comparing the waste results from plastic and glass yielded an interesting observation. The amount of activity found per milliliter of waste had gradually decreased in both plastic and glass, but the decrease in plastic was greater compared to glass as depicted in Figure 7. The extra decrease in activity in plastic vials seems to be consistent when compared to the tritium degradation in plastic vial experiment. There were three previously mentioned factors that may contribute to a decrease in activity: degradation of the LSC cocktail, diffusion, and long-term quenching factor. None of these three factors can explain the additional loss of activity within the plastic vials. The LSC cocktail used is the same in both the plastic and glass vials; if degradation had occurred, the changes should be the similar in both plastic and glass vials. In addition, this factor only applies when a sample is stored in the presence of the cocktail and measured before and after storage. For the diffusion factor, since the radiation count was reported in Bq/ml, any diffused tritiated water will be normalized against the volume of the waste provided that composition of the solution is assumed to stay constant. However, both the plastic and glass vials contain the same material, 12 ml of LSC cocktail and approximately 8 ml of standard, the quenching effects should behave the same in both plastic and glass vials. In addition, the TDCR accounts for any quenching effects, negating any long-term quenching changes that may reduce the activity per ml in the waste samples. Furthermore, the long-term quenching factor only matter if the sample is stored in the presence of the cocktail. The loss of activity in the plastic sample in the waste seems to correlate with an increase in t-score as soaking time increases. Between the two observations, it is plausible that some of the lost activity in the plastic vials has reappeared in the deionized water, indicating that there was some tritium exchanged between the plastic vials and the tritiated water. The longer the tritiated water had been soaked, the more atom exchanges could have occurred, and the t-score comparison data seems to support the atom exchange hypothesis. However, the increase in activity of the deionized water seems to be much lower than the activity loss in the plastic vials. It is possible that the deionized water requires more soaking time than 7-days to reach a full equilibrium to allow tritium to exchange back into the deionized water. If the experiment was to be repeated, a longer deionized water reabsorption time should be utilized to attempt to reabsorb the lost tritium in the plastic. It is also possible that organically bound tritium will be harder to remove which will result in an equilibrium that favors tritium in plastic, rendering a longer reabsorption time ineffective.

The results from the tritium degradation in plastic vial experiment seem to have a slightly lower activity per volume compare to the waste data. This phenomenon can possibly be explained by diffusion. Since the contents of the tritium degradation in plastic vial experiment remained in the vials, it differs from the procedures found in Part I and Part II of the experiment. The mass measurements of the samples after their respective soaking times were not gathered due to an oversight. As a result, the exact volumes of the tritium standard remaining in the vials were uncertain. The volumes used in Table 20 were tritium standard volume data gathered before their respective soaking times during which diffusion could have occurred resulting in a lower activity per volume in the samples.

The glass data observed in day-21 seem to indicate an outlier. Explanations need to be explored and tested to fully understand why two of the vials yielded double and quadruple the counts compared to the glass vials of the same day. The spectra of these two vials can be found in Figure 8, and the two peaks seem to resemble the low tritium standard peaks found in Figure 9. Comparing the heights of the peaks for vials 21G3 and 21G4 to the low tritium standards, it seems that there may be a small tritium contamination at an activity below 2.4 Bq. It is possible that these two vials had a small contamination post the drying procedures which resulted in the increased counts.

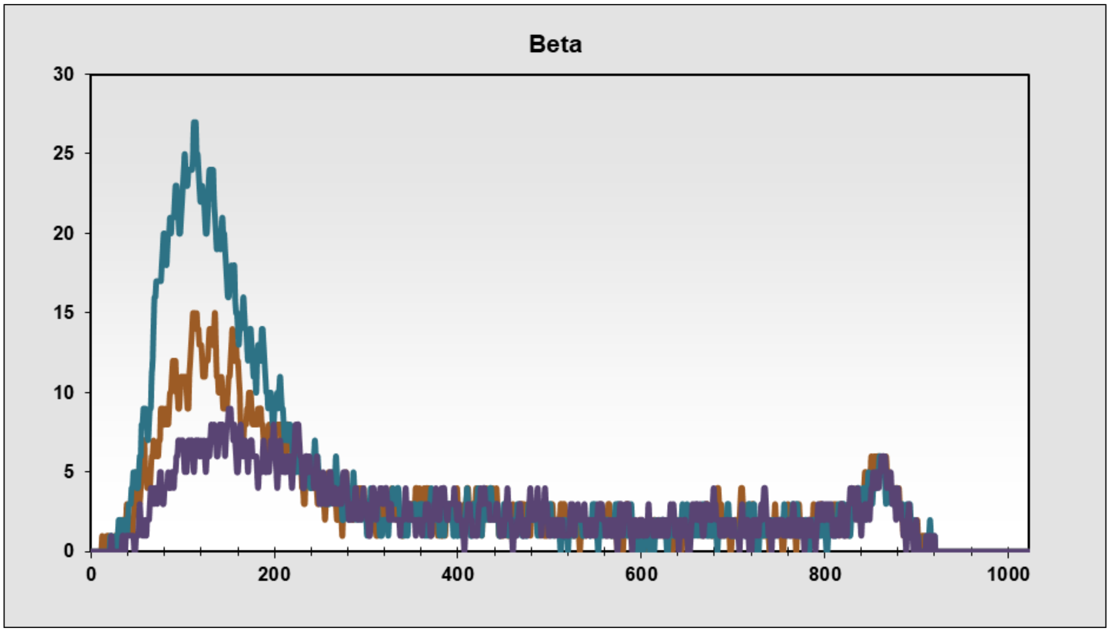

Figure 8. Day 21, glass vials 3, 4 (21G3 and 21G4) and background

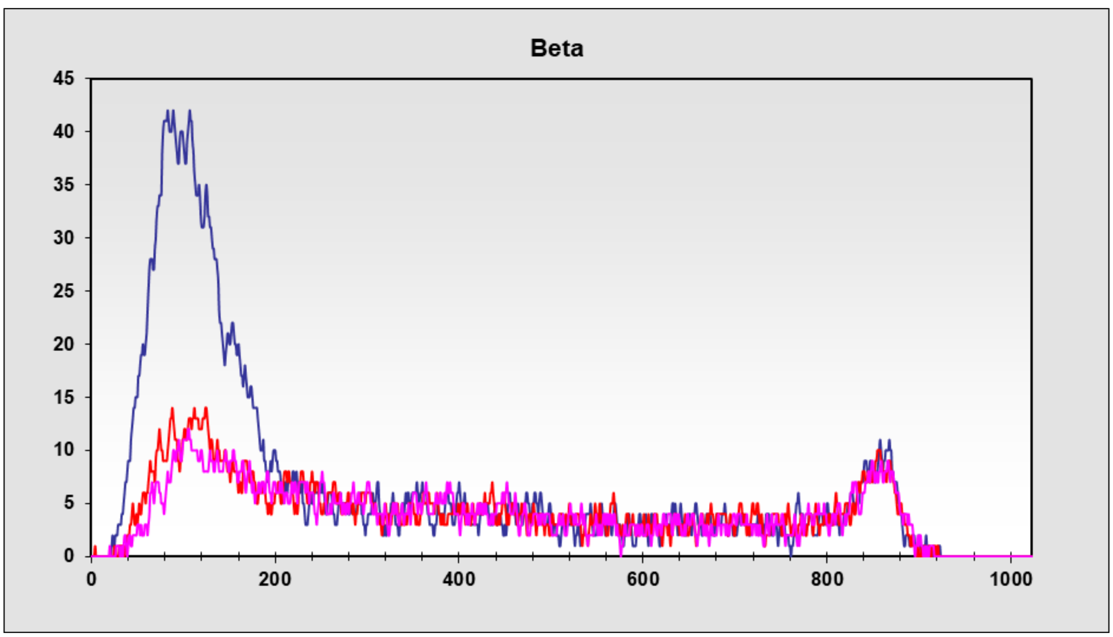

Figure 9. Low Tritium Standard Spectra. 2.3 Bq, 0.49 Bq, 0.23 Bq

CHAPTER 5 CONCLUSION

The experimental results show that within the same timeframe, tritium activity decreases at a faster rate in plastic LSC vials when compared to the glass LSC vials. This result is consistent with the existing research. The excess loss of tritium activity, however, cannot be easily explained as the experimental controls refute some of the current explanations for the phenomenon. In addition, there is some evidence via the student t-tests that suggests that the deionized water used in plastic had traces of tritium in them. These traces of tritium are more evident as the tritiated water soaking time increases, indicating that tritiated water soaking time is a variable that affects tritium reabsorption in deionized water. Together, these two observations support the hypothesis that tritium exchange may have occurred between the tritiated water and the hydrogen within the plastic vials. Although only a fraction of the tritium was reabsorbed from the plastic vials, the atom exchange hypothesis may explain the tritium activity degradation found in plastic vials when the samples have been stored for an extended period of time. Additional research may also be warranted to explore the tritium exchange rate as well as the equilibrium constant to provide appropriate future models for safe storage and usage of tritiated compounds.

REFERENCES

Baum, E. M., Ernesti, M. C., Knox, H. D., Miller, T. R., Watson, A. M. & Travis, S. D., (2009). *Nuclides and Isotopes Chart of the Nuclides Seventeenth Edition,* Schenectady, NY: Bechtel Marine Propulsion Corporation.

Cember, H. & Johnson, T. E. (2009). *Introduction to Health Physics Fourth Edition*. McGraw-Hill Medical.

Feng, X., He, Q., Wang, J., & Chen, J. (2015). The effect of sample stability on the determination of radioactivity for various radionuclides by liquid scintillation counting. *Applied Radiation and Isotopes, 104*, 147-154. https://doi.org/10.1016/j.apradiso.2015.06.032

Health Physics Society. (2011). *Tritium*. Retrieved from http://hps.org/documents/tritium_fact_sheet.pdf

ICRP, 2012. Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.).

Jakonić, I., Nikolov, J., Todorović, N., Tenjović, B. & Vesković, M. (2014). Study on quench effects in liquid scintillation counting during tritium measurements. *Journal of Radioanalytical and Nuclear Chemistry,302*(1), 253-259. http://dx.dox.org/10.1007/s10967-014-3191-1

Johnson, T. E. (2017). *Introduction to Health Physics Fifth Edition*. New York: McGraw-Hill Education.

Kaufman, S. & Libby, W. F. (1954). The Natural Distribution of Tritium. *Physical Review.*,*93*(6), 1337-1344. https://doi.org/10.1103/PhysRev.93.1337

Kessler, M. J. (2015). *Liquid Scintillation Analysis*: *Science and Technology*. Waltham, MA: PerkinElmer, Inc.

Moghissi, A. A., Kelley, H. L., Regnier, J. E. & Carter, M. W. (1969). Low-Level Counting by Liquid Scintillation – I. Tritium Measurement in Homogeneous Systems. *The International Journal of Applied Radiation and Isotopes, 20(3)*, 145-156. https://doi.org/10.1016/0020-708X(69)90026-X

National Council on Radiation Protection Measurements, & National Committee on Radiation Protection Measurements. (1979). *Tritium in the Environment : Recommendations of the National Council on Radiation Protection and Measurements.* (NCRP report; no. 62). Washington: NCRP.

Nedjadi, Y., Duc, P., Bochud, F. & Bailat, C. (2016). On the stability of 3H and 63Ni Ultima Gold liquid scintillation sources. *Applied Radiation and Isotopes, 118,* 25-31. https://doi.org/10.1016/j.apradiso.2016.08.017

Nir, A., Kruger, S. T., Lingenfelter R. E. & Flamm, E. J. (1966). Natural Tritium. *Reviews of Geophysics*, 4(4), 441. https://doi-org.ezproxy2.library.colostate.edu/10.1029/RG004i004p00441

Passo, C. J. & Cook, G. (2002). Time Resolved Liquid Scintillation Counting: (TR-LSC™) for Environmental ^{3}H Analysis. *PerkinElmer Life Sciences, Inc.* Boston, MA. https://www.perkinelmer.com/pdfs/downloads/app_trlsctimeresolvedliquidscintcounting.pdf

Pochwalski, K., Broda, R. & Radoszewski, T. (1988). Standardization of pure beta emitters by liquid-scintillation counting. *International Journal of Radiation Applications & Instrumentation. Part A, Applied Radiation & Isotopes, 39*(2), 165-172 https://doi.org/10.1016/0883-2889(88)90162-1

Priya, S., Gopalakrishnan, R. K. & Goswami, A. (2014). TDCR measurements of 3 H, 63 Ni and 55 Fe using Hidex 300SL LSC device. *Journal of Radioanalytical and Nuclear Chemistry, 302*(1), 353-359. https://doi-org.ezproxy2.library.colostate.edu/10.1007/s10967-014-3190-2

U.S. Department of Energy. (1999). *DOE Handbook Tritium Handling and Safe Storage*. DOE-HDBK-1129-99. Washington, D.C.

U.S. EPA, EMSL. (1980). "Method 906.0: Tritium in Drinking Water." Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA/600/4/80/032.

Verrezen, F., Loots, H., & Hurtgen, C. (2008). A performance comparison of nine selected liquid scintillation cocktails. *Applied Radiation and Isotopes, 66*(6), 1038-1042. https://doi.org/10.1016/j.apradiso.2008.02.050

Wackerly, D. D., Mendenhall, W. & Scheaffer, R. L. (2008). *Mathematical Statistics with Applications 7th Edition.* Belmont, CA: Thomson Learning, Inc.

Welsh, E. (2011). What is chemiluminescence. *Science in School, 19*, 62-68. https://www.scienceinschool.org/2011/issue19/chemiluminescence

APPENDIX

Experiment 2, Plastic Vials – Day 7 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.012

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTF	SPECT	ROI_α	ROI_β	$ROI_{\alpha\ Tri}$	$ROI_{\beta\ Tri}$
1	1	1	25	D01	1800	2985	99	168	0.59	5638	5587		1,176		112
1	1	2	25	D01	1800	2249	74	101	0.736	5639	5588		530		94
1	1	3	25	D01	1800	2149	71	92	0.777	5640	5589		410		87
1	1	4	25	D01	1800	2125	70	90	0.778	5641	5590		383		83
1	1	5	25	D01	1800	2247	74	99	0.752	5642	5591		494		104
1	2	1	26	D02	1800	2348	78	105	0.743	5643	5592		511		98
1	2	2	26	D02	1800	2269	75	97	0.776	5644	5593		462		97
1	2	3	26	D02	1800	2241	74	96	0.776	5645	5594		433		106
1	2	4	26	D02	1800	2208	73	97	0.757	5646	5595		452		99
1	2	5	26	D02	1800	2124	70	90	0.782	5647	5596		387		74
1	3	1	27	D03	1800	2861	95	143	0.664	5648	5597		930		176
1	3	2	27	D03	1800	2225	74	99	0.747	5649	5598		468		80
1	3	3	27	D03	1800	2188	72	94	0.773	5650	5599		413		80
1	3	4	27	D03	1800	2127	70	92	0.769	5651	5600		433		99
1	3	5	27	D03	1800	2248	74	95	0.781	5652	5601		407		80
1	4	1	28	D04	1800	2436	81	112	0.722	5653	5602		631		114
1	4	2	28	D04	1800	2242	74	97	0.768	5654	5603		470		110
1	4	3	28	D04	1800	2162	72	92	0.777	5655	5604		429		103
1	4	4	28	D04	1800	2334	77	101	0.767	5656	5605		417		81
1	4	5	28	D04	1800	2223	74	96	0.771	5657	5606		456		102
1	5	1	29	D05	1800	3295	109	180	0.609	5658	5607		1,281		211
1	5	2	29	D05	1800	2433	81	111	0.727	5659	5608		594		104
1	5	3	29	D05	1800	2480	82	115	0.717	5660	5609		638		112
1	5	4	29	D05	1800	2163	72	93	0.77	5661	5610		436		86
1	5	5	29	D05	1800	2129	70	90	0.786	5662	5611		398		85
1	6	1	33	E01	1800	2558	85	130	0.655	5663	5612		778		157
1	6	2	33	E01	1800	2449	81	124	0.656	5664	5613		751		151
1	6	3	33	E01	1800	2558	85	130	0.654	5665	5614		760		153
1	6	4	33	E01	1800	2537	84	128	0.659	5666	5615		753		155
1	6	5	33	E01	1800	2439	81	125	0.65	5667	5616		713		129
1	7	1	34	E02	1800	2577	85	130	0.659	5668	5617		774		173
1	7	2	34	E02	1800	2508	83	127	0.658	5669	5618		774		167
1	7	3	34	E02	1800	2557	85	126	0.673	5670	5619		765		177
1	7	4	34	E02	1800	2597	86	131	0.659	5671	5620		778		174
1	7	5	34	E02	1800	2647	88	136	0.644	5672	5621		814		176
1	8	1	35	E03	1800	2563	85	127	0.672	5673	5622		717		139
1	8	2	35	E03	1800	2526	84	129	0.652	5674	5623		756		155
1	8	3	35	E03	1800	2492	83	125	0.659	5675	5624		726		143
1	8	4	35	E03	1800	2596	86	129	0.669	5676	5625		735		159
1	8	5	35	E03	1800	2540	84	129	0.655	5677	5626		739		146
1	9	1	36	E04	1800	2473	82	119	0.691	5678	5627		671		164
1	9	2	36	E04	1800	2569	85	130	0.654	5679	5628		768		166
1	9	3	36	E04	1800	2542	84	129	0.656	5680	5629		776		178
1	9	4	36	E04	1800	2566	85	131	0.649	5681	5630		791		162
1	9	5	36	E04	1800	2549	84	130	0.651	5682	5631		798		153
1	10	1	37	E05	1800	2623	87	131	0.664	5683	5632		759		162
1	10	2	37	E05	1800	2514	83	126	0.665	5684	5633		766		165
1	10	3	37	E05	1800	2607	86	129	0.671	5685	5634		744		161
1	10	4	37	E05	1800	2585	86	130	0.662	5686	5635		789		170
1	10	5	37	E05	1800	2544	84	129	0.657	5687	5636		756		152

Experiment 2, Plastic Vials – Day 10 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.003

Dfile	Samp.	Repe.	Vial	VName	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2399	79	107	0.745	5688	5637		546		89
1	1	2	25	D01	1800	2235	74	96	0.77	5689	5638		447		85
1	1	3	25	D01	1800	2285	76	99	0.763	5690	5639		451		79
1	1	4	25	D01	1800	2191	72	94	0.776	5691	5640		464		123
1	1	5	25	D01	1800	2214	73	95	0.771	5692	5641		466		106
1	2	1	26	D02	1800	2438	81	115	0.701	5693	5642		675		120
1	2	2	26	D02	1800	2154	71	92	0.773	5694	5643		421		92
1	2	3	26	D02	1800	2154	71	92	0.779	5695	5644		414		104
1	2	4	26	D02	1800	2232	74	96	0.772	5696	5645		426		105
1	2	5	26	D02	1800	2170	72	93	0.769	5697	5646		427		83
1	3	1	27	D03	1800	2161	71	94	0.766	5698	5647		421		89
1	3	2	27	D03	1800	2290	76	97	0.784	5699	5648		421		100
1	3	3	27	D03	1800	2219	73	94	0.782	5700	5649		431		110
1	3	4	27	D03	1800	2175	72	93	0.774	5701	5650		431		95
1	3	5	27	D03	1800	2146	71	92	0.771	5702	5651		405		83
1	4	1	28	D04	1800	2213	73	94	0.778	5703	5652		417		79
1	4	2	28	D04	1800	2235	74	97	0.767	5704	5653		467		104
1	4	3	28	D04	1800	2162	72	94	0.764	5705	5654		421		81
1	4	4	28	D04	1800	2173	72	94	0.762	5706	5655		450		106
1	4	5	28	D04	1800	2231	74	96	0.767	5707	5656		452		95
1	5	1	29	D05	1800	2789	92	142	0.654	5708	5657		962		190
1	5	2	29	D05	1800	2146	71	90	0.793	5709	5658		399		101
1	5	3	29	D05	1800	2128	70	90	0.785	5710	5659		372		86
1	5	4	29	D05	1800	2164	72	92	0.777	5711	5660		411		86
1	5	5	29	D05	1800	2068	68	89	0.773	5712	5661		423		95
1	6	1	33	E01	1800	2540	84	127	0.665	5713	5662		768		162
1	6	2	33	E01	1800	2533	84	126	0.667	5714	5663		726		165
1	6	3	33	E01	1800	2506	83	124	0.669	5715	5664		718		134
1	6	4	33	E01	1800	2634	87	131	0.67	5716	5665		748		160
1	6	5	33	E01	1800	2656	88	133	0.662	5717	5666		800		172
1	7	1	34	E02	1800	2599	86	130	0.663	5718	5667		777		145
1	7	2	34	E02	1800	2659	88	132	0.669	5719	5668		813		185
1	7	3	34	E02	1800	2509	83	129	0.644	5720	5669		784		136
1	7	4	34	E02	1800	2601	86	129	0.671	5721	5670		737		161
1	7	5	34	E02	1800	2564	85	131	0.65	5722	5671		807		163
1	8	1	35	E03	1800	2622	87	131	0.667	5723	5672		796		163
1	8	2	35	E03	1800	2598	86	134	0.643	5724	5673		812		164
1	8	3	35	E03	1800	2688	89	136	0.658	5725	5674		796		140
1	8	4	35	E03	1800	2607	86	133	0.652	5726	5675		777		163
1	8	5	35	E03	1800	2599	86	132	0.652	5727	5676		806		177
1	9	1	36	E04	1800	2632	87	130	0.672	5728	5677		758		149
1	9	2	36	E04	1800	2627	87	128	0.683	5729	5678		748		165
1	9	3	36	E04	1800	2619	87	130	0.666	5730	5679		814		185
1	9	4	36	E04	1800	2591	86	127	0.676	5731	5680		765		154
1	9	5	36	E04	1800	2599	86	131	0.66	5732	5681		793		160
1	10	1	37	E05	1800	2537	84	127	0.663	5733	5682		757		146
1	10	2	37	E05	1800	2563	85	131	0.647	5734	5683		748		138
1	10	3	37	E05	1800	2534	84	126	0.666	5735	5684		750		134
1	10	4	37	E05	1800	2533	84	128	0.656	5736	5685		760		143
1	10	5	37	E05	1800	2502	83	124	0.668	5737	5686		729		152

Experiment 2, Plastic Vials – Day 14 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VName	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT										ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2695	89	128	0.698	5772	5721											781		146
1	1	2	25	D01	1800	2358	78	105	0.748	5773	5722											535		110
1	1	3	25	D01	1800	2396	79	105	0.76	5774	5723											532		114
1	1	4	25	D01	1800	2247	74	98	0.76	5775	5724											482		104
1	1	5	25	D01	1800	2252	75	100	0.745	5776	5725											478		94
1	2	1	26	D02	1800	2251	74	98	0.758	5777	5726											461		89
1	2	2	26	D02	1800	2262	75	98	0.764	5778	5727											448		89
1	2	3	26	D02	1800	2234	74	97	0.765	5779	5728											443		99
1	2	4	26	D02	1800	2157	71	94	0.764	5780	5729											443		101
1	2	5	26	D02	1800	2250	74	99	0.75	5781	5730											505		111
1	3	1	27	D03	1800	2279	75	98	0.767	5782	5731											452		88
1	3	2	27	D03	1800	2209	73	92	0.794	5783	5732											415		93
1	3	3	27	D03	1800	2224	74	93	0.791	5784	5733											396		94
1	3	4	27	D03	1800	2216	73	96	0.762	5785	5734											493		143
1	3	5	27	D03	1800	2219	73	94	0.78	5786	5735											448		113
1	4	1	28	D04	1800	2229	74	95	0.775	5787	5736											429		90
1	4	2	28	D04	1800	2199	73	96	0.762	5788	5737											470		105
1	4	3	28	D04	1800	2241	74	97	0.766	5789	5738											445		101
1	4	4	28	D04	1800	2123	70	88	0.8	5790	5739											367		94
1	4	5	28	D04	1800	2278	75	99	0.765	5791	5740											461		97
1	5	1	29	D05	1800	3193	106	165	0.644	5792	5741											1,127		240
1	5	2	29	D05	1800	2494	83	115	0.719	5793	5742											691		139
1	5	3	29	D05	1800	2238	74	96	0.775	5794	5743											456		107
1	5	4	29	D05	1800	2105	70	91	0.768	5795	5744											404		84
1	5	5	29	D05	1800	2251	74	97	0.771	5796	5745											432		101
1	6	1	33	E01	1800	2620	87	134	0.649	5797	5746											821		164
1	6	2	33	E01	1800	2513	83	129	0.649	5798	5747											739		147
1	6	3	33	E01	1800	2627	87	136	0.64	5799	5748											859		182
1	6	4	33	E01	1800	2495	83	122	0.678	5800	5749											727		171
1	6	5	33	E01	1800	2648	88	132	0.664	5801	5750											776		157
1	7	1	34	E02	1800	2579	85	132	0.646	5802	5751											768		158
1	7	2	34	E02	1800	2647	88	132	0.666	5803	5752											752		163
1	7	3	34	E02	1800	2554	85	127	0.667	5804	5753											743		169
1	7	4	34	E02	1800	2551	84	125	0.678	5805	5754											726		154
1	7	5	34	E02	1800	2556	85	129	0.658	5806	5755											752		150
1	8	1	35	E03	1800	2619	87	129	0.673	5807	5756											782		168
1	8	2	35	E03	1800	2579	85	130	0.658	5808	5757											790		193
1	8	3	35	E03	1800	2722	90	140	0.647	5809	5758											829		171
1	8	4	35	E03	1800	2555	85	126	0.674	5810	5759											762		175
1	8	5	35	E03	1800	2652	88	131	0.673	5811	5760											774		186
1	9	1	36	E04	1800	2623	87	135	0.647	5812	5761											807		163
1	9	2	36	E04	1800	2627	87	132	0.662	5813	5762											748		148
1	9	3	36	E04	1800	2682	89	131	0.678	5814	5763											796		206
1	9	4	36	E04	1800	2497	83	126	0.657	5815	5764											742		157
1	9	5	36	E04	1800	2562	85	127	0.669	5816	5765											734		149
1	10	1	37	E05	1800	2563	85	130	0.655	5817	5766											771		150
1	10	2	37	E05	1800	2475	82	123	0.668	5818	5767											721		156
1	10	3	37	E05	1800	2491	82	122	0.675	5819	5768											677		137
1	10	4	37	E05	1800	2493	83	126	0.655	5820	5769											737		149
1	10	5	37	E05	1800	2537	84	124	0.676	5821	5770											728		169

Experiment 2, Plastic Vials – Day 21 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	SPECTR	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2632	87	127	0.69	5822	5771		762		118
1	1	2	25	D01	1800	2216	73	97	0.758	5823	5772		471		95
1	1	3	25	D01	1800	2251	74	99	0.752	5824	5773		501		109
1	1	4	25	D01	1800	2223	74	97	0.76	5825	5774		464		97
1	1	5	25	D01	1800	2175	72	96	0.75	5826	5775		456		92
1	2	1	26	D02	1800	2344	78	104	0.747	5827	5776		516		87
1	2	2	26	D02	1800	2304	76	97	0.785	5828	5777		442		102
1	2	3	26	D02	1800	2093	69	89	0.775	5829	5778		412		91
1	2	4	26	D02	1800	2061	68	88	0.775	5830	5779		396		81
1	2	5	26	D02	1800	2191	73	91	0.796	5831	5780		400		85
1	3	1	27	D03	1800	2445	81	111	0.729	5832	5781		618		138
1	3	2	27	D03	1800	2232	74	96	0.771	5833	5782		454		106
1	3	3	27	D03	1800	2213	73	96	0.764	5834	5783		445		99
1	3	4	27	D03	1800	2222	74	96	0.766	5835	5784		463		108
1	3	5	27	D03	1800	2211	73	95	0.767	5836	5785		485		124
1	4	1	28	D04	1800	2581	85	118	0.726	5837	5786		730		178
1	4	2	28	D04	1800	2338	77	103	0.752	5838	5787		562		158
1	4	3	28	D04	1800	2204	73	98	0.748	5839	5788		528		110
1	4	4	28	D04	1800	2288	76	99	0.763	5840	5789		530		149
1	4	5	28	D04	1800	2227	74	98	0.752	5841	5790		523		124
1	5	1	29	D05	1800	2142	71	90	0.788	5842	5791		385		91
1	5	2	29	D05	1800	2239	74	96	0.77	5843	5792		455		108
1	5	3	29	D05	1800	2003	66	84	0.793	5844	5793		354		90
1	5	4	29	D05	1800	2105	70	90	0.779	5845	5794		390		85
1	5	5	29	D05	1800	2091	69	88	0.787	5846	5795		372		91
1	6	1	33	E01	1800	2636	87	132	0.662	5847	5796		764		164
1	6	2	33	E01	1800	2560	85	129	0.658	5848	5797		778		170
1	6	3	33	E01	1800	2550	84	129	0.658	5849	5798		748		151
1	6	4	33	E01	1800	2538	84	128	0.657	5850	5799		769		170
1	6	5	33	E01	1800	2570	85	126	0.678	5851	5800		733		171
1	7	1	34	E02	1800	2625	87	134	0.648	5852	5801		826		164
1	7	2	34	E02	1800	2535	84	125	0.672	5853	5802		755		173
1	7	3	34	E02	1800	2423	80	122	0.659	5854	5803		727		177
1	7	4	34	E02	1800	2471	82	122	0.675	5855	5804		742		167
1	7	5	34	E02	1800	2514	83	123	0.678	5856	5805		740		174
1	8	1	35	E03	1800	3211	106	176	0.606	5857	5806		1,355		368
1	8	2	35	E03	1800	3151	104	174	0.601	5858	5807		1,373		366
1	8	3	35	E03	1800	3343	111	183	0.605	5859	5808		1,387		357
1	8	4	35	E03	1800	3169	105	174	0.605	5860	5809		1,365		359
1	8	5	35	E03	1800	3260	108	180	0.603	5861	5810		1,411		377
1	9	1	36	E04	1800	4291	142	268	0.532	5862	5811		2,438		712
1	9	2	36	E04	1800	4328	144	269	0.536	5863	5812		2,464		735
1	9	3	36	E04	1800	4270	142	269	0.527	5864	5813		2,474		732
1	9	4	36	E04	1800	4290	142	267	0.534	5865	5814		2,413		682
1	9	5	36	E04	1800	4197	139	260	0.536	5866	5815		2,377		691
1	10	1	37	E05	1800	2574	85	129	0.663	5867	5816		765		181
1	10	2	37	E05	1800	2409	80	122	0.653	5868	5817		707		138
1	10	3	37	E05	1800	2487	82	129	0.64	5869	5818		767		141
1	10	4	37	E05	1800	2484	82	127	0.651	5870	5819		745		155
1	10	5	37	E05	1800	2463	82	130	0.627	5871	5820		774		144

Experiment 2, Plastic Vials – Day 35 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.002

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT	ROI$_\alpha$	ROI$_\beta$	ROI$_{\alpha\ Tri}$	ROI$_{\beta\ Tri}$
1	1	1	25	D01	1800	2198	73	98	0.743	5906	5855		509		92
1	1	2	25	D01	1800	2167	72	94	0.767	5907	5856		439		98
1	1	3	25	D01	1800	2121	70	93	0.753	5908	5857		456		93
1	1	4	25	D01	1800	2057	68	89	0.768	5909	5858		424		99
1	1	5	25	D01	1800	2093	69	92	0.754	5910	5859		447		86
1	2	1	26	D02	1800	2162	72	94	0.766	5911	5860		429		97
1	2	2	26	D02	1800	2113	70	91	0.769	5912	5861		436		114
1	2	3	26	D02	1800	2170	72	92	0.781	5913	5862		401		86
1	2	4	26	D02	1800	2073	69	87	0.791	5914	5863		396		110
1	2	5	26	D02	1800	2171	72	92	0.78	5915	5864		425		107
1	3	1	27	D03	1800	2952	98	153	0.639	5916	5865		1,025		188
1	3	2	27	D03	1800	2239	74	101	0.736	5917	5866		550		112
1	3	3	27	D03	1800	2185	72	95	0.764	5918	5867		453		94
1	3	4	27	D03	1800	2135	71	92	0.769	5919	5868		449		109
1	3	5	27	D03	1800	2185	72	94	0.767	5920	5869		426		91
1	4	1	28	D04	1800	2553	85	129	0.655	5921	5870		852		170
1	4	2	28	D04	1800	2138	71	90	0.788	5922	5871		400		103
1	4	3	28	D04	1800	2116	70	91	0.774	5923	5872		387		98
1	4	4	28	D04	1800	2121	70	93	0.753	5924	5873		424		96
1	4	5	28	D04	1800	2056	68	87	0.783	5925	5874		412		109
1	5	1	29	D05	1800	2461	81	117	0.697	5926	5875		688		110
1	5	2	29	D05	1800	2186	72	96	0.755	5927	5876		442		93
1	5	3	29	D05	1800	2101	69	90	0.777	5928	5877		381		83
1	5	4	29	D05	1800	2098	69	90	0.771	5929	5878		382		89
1	5	5	29	D05	1800	2108	70	89	0.785	5930	5879		393		100
1	6	1	33	E01	1800	2545	84	129	0.656	5931	5880		774		147
1	6	2	33	E01	1800	2414	80	122	0.656	5932	5881		723		158
1	6	3	33	E01	1800	2568	85	130	0.655	5933	5882		767		166
1	6	4	33	E01	1800	2546	84	125	0.675	5934	5883		746		176
1	6	5	33	E01	1800	2519	83	126	0.661	5935	5884		758		161
1	7	1	34	E02	1800	2549	84	128	0.66	5936	5885		767		139
1	7	2	34	E02	1800	2578	85	132	0.649	5937	5886		789		154
1	7	3	34	E02	1800	2586	86	133	0.646	5938	5887		806		163
1	7	4	34	E02	1800	2492	83	126	0.658	5939	5888		761		169
1	7	5	34	E02	1800	2603	86	130	0.662	5940	5889		765		144
1	8	1	35	E03	1800	2577	85	130	0.659	5941	5890		784		169
1	8	2	35	E03	1800	2606	86	133	0.651	5942	5891		796		176
1	8	3	35	E03	1800	2588	86	132	0.652	5943	5892		783		159
1	8	4	35	E03	1800	2498	83	124	0.669	5944	5893		731		168
1	8	5	35	E03	1800	2595	86	130	0.662	5945	5894		767		149
1	9	1	36	E04	1800	2662	88	135	0.656	5946	5895		853		187
1	9	2	36	E04	1800	2691	89	137	0.651	5947	5896		853		183
1	9	3	36	E04	1800	2532	84	131	0.642	5948	5897		826		190
1	9	4	36	E04	1800	2577	85	131	0.651	5949	5898		814		168
1	9	5	36	E04	1800	2569	85	132	0.648	5950	5899		797		172
1	10	1	37	E05	1800	2504	83	124	0.668	5951	5900		736		144
1	10	2	37	E05	1800	2497	83	124	0.668	5952	5901		730		144
1	10	3	37	E05	1800	2524	84	127	0.658	5953	5902		758		146
1	10	4	37	E05	1800	2612	87	133	0.651	5954	5903		774		152
1	10	5	37	E05	1800	2516	83	128	0.654	5955	5904		753		138

Experiment 2, Plastic Vials – Day 56 Recount, Optimized within windows 21-185

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECT	PECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2442	81	117	0.69	5956	5905		762		162
1	1	2	25	D01	1800	2245	74	102	0.733	5957	5906		549		109
1	1	3	25	D01	1800	2135	71	95	0.742	5958	5907		478		94
1	1	4	25	D01	1800	2161	71	97	0.736	5959	5908		509		100
1	1	5	25	D01	1800	2196	73	97	0.754	5960	5909		505		111
1	2	1	26	D02	1800	2250	74	100	0.743	5961	5910		519		113
1	2	2	26	D02	1800	2100	69	92	0.76	5962	5911		454		101
1	2	3	26	D02	1800	2171	72	94	0.763	5963	5912		455		98
1	2	4	26	D02	1800	2092	69	92	0.754	5964	5913		454		99
1	2	5	26	D02	1800	2083	69	92	0.748	5965	5914		458		98
1	3	1	27	D03	1800	2219	73	99	0.743	5966	5915		512		108
1	3	2	27	D03	1800	2086	69	91	0.763	5967	5916		472		111
1	3	3	27	D03	1800	2155	71	95	0.748	5968	5917		465		92
1	3	4	27	D03	1800	2130	70	92	0.77	5969	5918		422		85
1	3	5	27	D03	1800	2097	69	90	0.768	5970	5919		424		103
1	4	1	28	D04	1800	2296	76	101	0.751	5971	5920		522		115
1	4	2	28	D04	1800	2099	69	92	0.754	5972	5921		454		111
1	4	3	28	D04	1800	2041	68	87	0.775	5973	5922		414		108
1	4	4	28	D04	1800	2033	67	89	0.755	5974	5923		436		94
1	4	5	28	D04	1800	2115	70	94	0.747	5975	5924		474		101
1	5	1	29	D05	1800	2196	73	99	0.737	5976	5925		552		142
1	5	2	29	D05	1800	2106	70	90	0.777	5977	5926		415		107
1	5	3	29	D05	1800	2070	68	88	0.777	5978	5927		403		91
1	5	4	29	D05	1800	2056	68	87	0.784	5979	5928		370		86
1	5	5	29	D05	1800	2037	67	87	0.779	5980	5929		383		83
1	6	1	33	E01	1800	2475	82	124	0.664	5981	5930		772		166
1	6	2	33	E01	1800	2500	83	126	0.66	5982	5931		781		169
1	6	3	33	E01	1800	2444	81	124	0.652	5983	5932		770		160
1	6	4	33	E01	1800	2512	83	126	0.662	5984	5933		748		159
1	6	5	33	E01	1800	2566	85	131	0.651	5985	5934		821		178
1	7	1	34	E02	1800	2391	79	121	0.656	5986	5935		705		143
1	7	2	34	E02	1800	2460	81	122	0.667	5987	5936		743		172
1	7	3	34	E02	1800	2470	82	124	0.662	5988	5937		704		151
1	7	4	34	E02	1800	2507	83	126	0.66	5989	5938		737		151
1	7	5	34	E02	1800	2508	83	125	0.668	5990	5939		714		138
1	8	1	35	E03	1800	2501	83	128	0.649	5991	5940		789		168
1	8	2	35	E03	1800	2490	82	129	0.642	5992	5941		815		167
1	8	3	35	E03	1800	2530	84	126	0.664	5993	5942		799		195
1	8	4	35	E03	1800	2529	84	127	0.661	5994	5943		782		195
1	8	5	35	E03	1800	2596	86	130	0.661	5995	5944		787		177
1	9	1	36	E04	1800	2420	80	124	0.649	5996	5945		767		138
1	9	2	36	E04	1800	2399	79	122	0.651	5997	5946		740		154
1	9	3	36	E04	1800	2451	81	126	0.643	5998	5947		789		164
1	9	4	36	E04	1800	2523	84	127	0.658	5999	5948		779		176
1	9	5	36	E04	1800	2477	82	127	0.649	6000	5949		770		151
1	10	1	37	E05	1800	2403	80	120	0.662	6001	5950		743		173
1	10	2	37	E05	1800	2517	83	129	0.649	6002	5951		800		168
1	10	3	37	E05	1800	2406	80	120	0.664	6003	5952		719		137
1	10	4	37	E05	1800	2536	84	126	0.667	6004	5953		751		166
1	10	5	37	E05	1800	2592	86	131	0.657	6005	5954		792		161

Experiment 2, Plastic Vials – Day 84 Recount, Optimized within windows 21-185

Data files
DFile 1: example.csv
Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	21	185
Alpha	500	950

FOM	0.004

Dfile	Samp.	Repe.	Vial	VName	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT	ROI_α	ROI_β	$ROI_{\alpha\ Tri}$	$ROI_{\beta\ Tri}$
1	1	1	25	D01	1800	2320	77	110	0.702	6040	5989		642		114
1	1	2	25	D01	1800	2115	70	92	0.763	6041	5990		452		112
1	1	3	25	D01	1800	2103	70	92	0.755	6042	5991		443		88
1	1	4	25	D01	1800	2088	69	89	0.773	6043	5992		434		106
1	1	5	25	D01	1800	2016	67	88	0.76	6044	5993		436		102
1	2	1	26	D02	1800	2159	71	96	0.745	6045	5994		482		108
1	2	2	26	D02	1800	2077	69	91	0.754	6046	5995		449		97
1	2	3	26	D02	1800	2050	68	90	0.754	6047	5996		477		117
1	2	4	26	D02	1800	2121	70	92	0.768	6048	5997		464		118
1	2	5	26	D02	1800	2016	67	88	0.756	6049	5998		441		103
1	3	1	27	D03	1800	2413	80	112	0.713	6050	5999		600		120
1	3	2	27	D03	1800	2144	71	94	0.758	6051	6000		472		87
1	3	3	27	D03	1800	2138	71	96	0.74	6052	6001		495		94
1	3	4	27	D03	1800	2050	68	91	0.744	6053	6002		447		100
1	3	5	27	D03	1800	1960	65	88	0.739	6054	6003		434		87
1	4	1	28	D04	1800	2064	68	91	0.748	6055	6004		443		93
1	4	2	28	D04	1800	2103	70	92	0.759	6056	6005		433		97
1	4	3	28	D04	1800	2003	66	87	0.762	6057	6006		417		102
1	4	4	28	D04	1800	2000	66	86	0.773	6058	6007		411		112
1	4	5	28	D04	1800	2040	67	90	0.753	6059	6008		440		99
1	5	1	29	D05	1800	2084	69	91	0.755	6060	6009		424		89
1	5	2	29	D05	1800	2056	68	88	0.776	6061	6010		412		97
1	5	3	29	D05	1800	2025	67	87	0.769	6062	6011		371		77
1	5	4	29	D05	1800	2010	66	88	0.756	6063	6012		381		58
1	5	5	29	D05	1800	2029	67	88	0.762	6064	6013		408		95
1	6	1	33	E01	1800	2552	85	131	0.647	6065	6014		775		141
1	6	2	33	E01	1800	2477	82	126	0.654	6066	6015		738		129
1	6	3	33	E01	1800	2514	83	127	0.657	6067	6016		731		145
1	6	4	33	E01	1800	2503	83	126	0.66	6068	6017		741		161
1	6	5	33	E01	1800	2446	81	126	0.646	6069	6018		743		144
1	7	1	34	E02	1800	2492	83	124	0.666	6070	6019		744		146
1	7	2	34	E02	1800	2449	81	123	0.661	6071	6020		723		145
1	7	3	34	E02	1800	2562	85	129	0.661	6072	6021		773		168
1	7	4	34	E02	1800	2479	82	123	0.667	6073	6022		727		157
1	7	5	34	E02	1800	2527	84	127	0.661	6074	6023		774		171
1	8	1	35	E03	1800	2443	81	123	0.656	6075	6024		736		149
1	8	2	35	E03	1800	2406	80	121	0.658	6076	6025		741		165
1	8	3	35	E03	1800	2396	79	124	0.643	6077	6026		749		165
1	8	4	35	E03	1800	2550	84	130	0.649	6078	6027		782		166
1	8	5	35	E03	1800	2501	83	128	0.649	6079	6028		777		165
1	9	1	36	E04	1800	2473	82	124	0.66	6080	6029		773		180
1	9	2	36	E04	1800	2412	80	122	0.658	6081	6030		734		161
1	9	3	36	E04	1800	2434	81	123	0.655	6082	6031		747		169
1	9	4	36	E04	1800	2470	82	123	0.667	6083	6032		722		145
1	9	5	36	E04	1800	2585	86	133	0.646	6084	6033		830		188
1	10	1	37	E05	1800	2538	84	126	0.667	6085	6034		748		156
1	10	2	37	E05	1800	2469	82	124	0.663	6086	6035		710		135
1	10	3	37	E05	1800	2467	82	127	0.644	6087	6036		780		153
1	10	4	37	E05	1800	2524	84	124	0.677	6088	6037		727		158
1	10	5	37	E05	1800	2443	81	119	0.681	6089	6038		681		153

Experiment 2, Glass Vials – Day 7 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.012

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	SPECT	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2985	99	168	0.59	5638	5587		1,105		81
1	1	2	25	D01	1800	2249	74	101	0.736	5639	5588		465		67
1	1	3	25	D01	1800	2149	71	92	0.777	5640	5589		347		56
1	1	4	25	D01	1800	2125	70	90	0.778	5641	5590		316		55
1	1	5	25	D01	1800	2247	74	99	0.752	5642	5591		413		67
1	2	1	26	D02	1800	2348	78	105	0.743	5643	5592		441		67
1	2	2	26	D02	1800	2269	75	97	0.776	5644	5593		390		68
1	2	3	26	D02	1800	2241	74	96	0.776	5645	5594		366		73
1	2	4	26	D02	1800	2208	73	97	0.757	5646	5595		395		75
1	2	5	26	D02	1800	2124	70	90	0.782	5647	5596		328		53
1	3	1	27	D03	1800	2861	95	143	0.664	5648	5597		836		136
1	3	2	27	D03	1800	2225	74	99	0.747	5649	5598		395		49
1	3	3	27	D03	1800	2188	72	94	0.773	5650	5599		336		49
1	3	4	27	D03	1800	2127	70	92	0.769	5651	5600		369		68
1	3	5	27	D03	1800	2248	74	95	0.781	5652	5601		331		48
1	4	1	28	D04	1800	2436	81	112	0.722	5653	5602		553		78
1	4	2	28	D04	1800	2242	74	97	0.768	5654	5603		382		71
1	4	3	28	D04	1800	2162	72	92	0.777	5655	5604		347		69
1	4	4	28	D04	1800	2334	77	101	0.767	5656	5605		349		52
1	4	5	28	D04	1800	2223	74	96	0.771	5657	5606		374		53
1	5	1	29	D05	1800	3295	109	180	0.609	5658	5607		1,163		157
1	5	2	29	D05	1800	2433	81	111	0.727	5659	5608		508		66
1	5	3	29	D05	1800	2480	82	115	0.717	5660	5609		568		87
1	5	4	29	D05	1800	2163	72	93	0.77	5661	5610		348		50
1	5	5	29	D05	1800	2129	70	90	0.786	5662	5611		340		60
1	6	1	33	E01	1800	2558	85	130	0.655	5663	5612		620		94
1	6	2	33	E01	1800	2449	81	124	0.656	5664	5613		598		104
1	6	3	33	E01	1800	2558	85	130	0.654	5665	5614		611		104
1	6	4	33	E01	1800	2537	84	128	0.659	5666	5615		592		93
1	6	5	33	E01	1800	2439	81	125	0.65	5667	5616		574		87
1	7	1	34	E02	1800	2577	85	130	0.659	5668	5617		628		116
1	7	2	34	E02	1800	2508	83	127	0.658	5669	5618		630		111
1	7	3	34	E02	1800	2557	85	126	0.673	5670	5619		624		120
1	7	4	34	E02	1800	2597	86	131	0.659	5671	5620		629		109
1	7	5	34	E02	1800	2647	88	136	0.644	5672	5621		648		122
1	8	1	35	E03	1800	2563	85	127	0.672	5673	5622		568		95
1	8	2	35	E03	1800	2526	84	129	0.652	5674	5623		590		90
1	8	3	35	E03	1800	2492	83	125	0.659	5675	5624		593		90
1	8	4	35	E03	1800	2596	86	129	0.669	5676	5625		577		92
1	8	5	35	E03	1800	2540	84	129	0.655	5677	5626		579		93
1	9	1	36	E04	1800	2473	82	119	0.691	5678	5627		518		96
1	9	2	36	E04	1800	2569	85	130	0.654	5679	5628		610		100
1	9	3	36	E04	1800	2542	84	129	0.656	5680	5629		647		127
1	9	4	36	E04	1800	2566	85	131	0.649	5681	5630		644		112
1	9	5	36	E04	1800	2549	84	130	0.651	5682	5631		644		104
1	10	1	37	E05	1800	2623	87	131	0.664	5683	5632		606		101
1	10	2	37	E05	1800	2514	83	126	0.665	5684	5633		622		111
1	10	3	37	E05	1800	2607	86	129	0.671	5685	5634		580		96
1	10	4	37	E05	1800	2585	86	130	0.662	5686	5635		650		110
1	10	5	37	E05	1800	2544	84	129	0.657	5687	5636		607		94

Experiment 2, Glass Vials – Day 10 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.003

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2399	79	107	0.745	5688	5637		482		61
1	1	2	25	D01	1800	2235	74	96	0.77	5689	5638		380		63
1	1	3	25	D01	1800	2285	76	99	0.763	5690	5639		385		51
1	1	4	25	D01	1800	2191	72	94	0.776	5691	5640		381		80
1	1	5	25	D01	1800	2214	73	95	0.771	5692	5641		386		69
1	2	1	26	D02	1800	2438	81	115	0.701	5693	5642		600		83
1	2	2	26	D02	1800	2154	71	92	0.773	5694	5643		359		63
1	2	3	26	D02	1800	2154	71	92	0.779	5695	5644		338		68
1	2	4	26	D02	1800	2232	74	96	0.772	5696	5645		355		71
1	2	5	26	D02	1800	2170	72	93	0.769	5697	5646		365		60
1	3	1	27	D03	1800	2161	71	94	0.766	5698	5647		353		60
1	3	2	27	D03	1800	2290	76	97	0.784	5699	5648		355		68
1	3	3	27	D03	1800	2219	73	94	0.782	5700	5649		344		65
1	3	4	27	D03	1800	2175	72	93	0.774	5701	5650		364		67
1	3	5	27	D03	1800	2146	71	92	0.771	5702	5651		336		49
1	4	1	28	D04	1800	2213	73	94	0.778	5703	5652		359		57
1	4	2	28	D04	1800	2235	74	97	0.767	5704	5653		395		73
1	4	3	28	D04	1800	2162	72	94	0.764	5705	5654		355		55
1	4	4	28	D04	1800	2173	72	94	0.762	5706	5655		364		72
1	4	5	28	D04	1800	2231	74	96	0.767	5707	5656		371		59
1	5	1	29	D05	1800	2789	92	142	0.654	5708	5657		881		149
1	5	2	29	D05	1800	2146	71	90	0.793	5709	5658		322		62
1	5	3	29	D05	1800	2128	70	90	0.785	5710	5659		311		60
1	5	4	29	D05	1800	2164	72	92	0.777	5711	5660		360		58
1	5	5	29	D05	1800	2068	68	89	0.773	5712	5661		360		66
1	6	1	33	E01	1800	2540	84	127	0.665	5713	5662		630		106
1	6	2	33	E01	1800	2533	84	126	0.667	5714	5663		572		94
1	6	3	33	E01	1800	2506	83	124	0.669	5715	5664		587		90
1	6	4	33	E01	1800	2634	87	131	0.67	5716	5665		582		100
1	6	5	33	E01	1800	2656	88	133	0.662	5717	5666		627		110
1	7	1	34	E02	1800	2599	86	130	0.663	5718	5667		629		86
1	7	2	34	E02	1800	2659	88	132	0.669	5719	5668		662		108
1	7	3	34	E02	1800	2509	83	129	0.644	5720	5669		630		93
1	7	4	34	E02	1800	2601	86	129	0.671	5721	5670		575		97
1	7	5	34	E02	1800	2564	85	131	0.65	5722	5671		662		104
1	8	1	35	E03	1800	2622	87	131	0.667	5723	5672		647		106
1	8	2	35	E03	1800	2598	86	134	0.643	5724	5673		656		115
1	8	3	35	E03	1800	2688	89	136	0.658	5725	5674		640		74
1	8	4	35	E03	1800	2607	86	133	0.652	5726	5675		614		101
1	8	5	35	E03	1800	2599	86	132	0.652	5727	5676		652		120
1	9	1	36	E04	1800	2632	87	130	0.672	5728	5677		621		98
1	9	2	36	E04	1800	2627	87	128	0.683	5729	5678		592		112
1	9	3	36	E04	1800	2619	87	130	0.666	5730	5679		650		122
1	9	4	36	E04	1800	2591	86	127	0.676	5731	5680		626		109
1	9	5	36	E04	1800	2599	86	131	0.66	5732	5681		667		105
1	10	1	37	E05	1800	2537	84	127	0.663	5733	5682		615		100
1	10	2	37	E05	1800	2563	85	131	0.647	5734	5683		599		89
1	10	3	37	E05	1800	2534	84	126	0.666	5735	5684		602		83
1	10	4	37	E05	1800	2533	84	128	0.656	5736	5685		609		90
1	10	5	37	E05	1800	2502	83	124	0.668	5737	5686		567		96

Experiment 2, Glass Vials – Day 14 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrowin 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	PECT	ROI$_{\alpha}$	ROI$_{\beta}$	ROI$_{\alpha}$ Tri	ROI$_{\beta}$ Tri
1	1	1	25	D01	1800	2695	89	128	0.698	5772	5721		684		106
1	1	2	25	D01	1800	2358	78	105	0.748	5773	5722		453		72
1	1	3	25	D01	1800	2396	79	105	0.76	5774	5723		460		80
1	1	4	25	D01	1800	2247	74	98	0.76	5775	5724		408		71
1	1	5	25	D01	1800	2252	75	100	0.745	5776	5725		402		59
1	2	1	26	D02	1800	2251	74	98	0.758	5777	5726		375		53
1	2	2	26	D02	1800	2262	75	98	0.764	5778	5727		376		58
1	2	3	26	D02	1800	2234	74	97	0.765	5779	5728		372		65
1	2	4	26	D02	1800	2157	71	94	0.764	5780	5729		365		67
1	2	5	26	D02	1800	2250	74	99	0.75	5781	5730		430		77
1	3	1	27	D03	1800	2279	75	98	0.767	5782	5731		379		49
1	3	2	27	D03	1800	2209	73	92	0.794	5783	5732		345		62
1	3	3	27	D03	1800	2224	74	93	0.791	5784	5733		326		69
1	3	4	27	D03	1800	2216	73	96	0.762	5785	5734		405		100
1	3	5	27	D03	1800	2219	73	94	0.78	5786	5735		379		88
1	4	1	28	D04	1800	2229	74	95	0.775	5787	5736		355		61
1	4	2	28	D04	1800	2199	73	96	0.762	5788	5737		385		69
1	4	3	28	D04	1800	2241	74	97	0.766	5789	5738		362		64
1	4	4	28	D04	1800	2123	70	88	0.8	5790	5739		298		60
1	4	5	28	D04	1800	2278	75	99	0.765	5791	5740		391		62
1	5	1	29	D05	1800	3193	106	165	0.644	5792	5741		974		170
1	5	2	29	D05	1800	2494	83	115	0.719	5793	5742		588		94
1	5	3	29	D05	1800	2238	74	96	0.775	5794	5743		384		70
1	5	4	29	D05	1800	2105	70	91	0.768	5795	5744		331		56
1	5	5	29	D05	1800	2251	74	97	0.771	5796	5745		361		67
1	6	1	33	E01	1800	2620	87	134	0.649	5797	5746		670		112
1	6	2	33	E01	1800	2513	83	129	0.649	5798	5747		613		104
1	6	3	33	E01	1800	2627	87	136	0.64	5799	5748		695		126
1	6	4	33	E01	1800	2495	83	122	0.678	5800	5749		580		123
1	6	5	33	E01	1800	2648	88	132	0.664	5801	5750		625		114
1	7	1	34	E02	1800	2579	85	132	0.646	5802	5751		618		102
1	7	2	34	E02	1800	2647	88	132	0.666	5803	5752		603		104
1	7	3	34	E02	1800	2554	85	127	0.667	5804	5753		604		112
1	7	4	34	E02	1800	2551	84	125	0.678	5805	5754		581		101
1	7	5	34	E02	1800	2556	85	129	0.658	5806	5755		620		103
1	8	1	35	E03	1800	2619	87	129	0.673	5807	5756		638		124
1	8	2	35	E03	1800	2579	85	130	0.658	5808	5757		633		131
1	8	3	35	E03	1800	2722	90	140	0.647	5809	5758		663		109
1	8	4	35	E03	1800	2555	85	126	0.674	5810	5759		615		126
1	8	5	35	E03	1800	2652	88	131	0.673	5811	5760		601		118
1	9	1	36	E04	1800	2623	87	135	0.647	5812	5761		666		112
1	9	2	36	E04	1800	2627	87	132	0.662	5813	5762		612		101
1	9	3	36	E04	1800	2682	89	131	0.678	5814	5763		653		141
1	9	4	36	E04	1800	2497	83	126	0.657	5815	5764		597		98
1	9	5	36	E04	1800	2562	85	127	0.669	5816	5765		578		97
1	10	1	37	E05	1800	2563	85	130	0.655	5817	5766		631		109
1	10	2	37	E05	1800	2475	82	123	0.668	5818	5767		579		100
1	10	3	37	E05	1800	2491	82	122	0.675	5819	5768		563		96
1	10	4	37	E05	1800	2493	83	126	0.655	5820	5769		604		100
1	10	5	37	E05	1800	2537	84	124	0.676	5821	5770		567		117

Experiment 2, Glass Vials – Day 21 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECT	PECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2632	87	127	0.69	5822	5771		688		90
1	1	2	25	D01	1800	2216	73	97	0.758	5823	5772		391		58
1	1	3	25	D01	1800	2251	74	99	0.752	5824	5773		420		81
1	1	4	25	D01	1800	2223	74	97	0.76	5825	5774		384		69
1	1	5	25	D01	1800	2175	72	96	0.75	5826	5775		378		57
1	2	1	26	D02	1800	2344	78	104	0.747	5827	5776		444		60
1	2	2	26	D02	1800	2304	76	97	0.785	5828	5777		357		67
1	2	3	26	D02	1800	2093	69	89	0.775	5829	5778		347		64
1	2	4	26	D02	1800	2061	68	88	0.775	5830	5779		335		56
1	2	5	26	D02	1800	2191	73	91	0.796	5831	5780		338		57
1	3	1	27	D03	1800	2445	81	111	0.729	5832	5781		525		86
1	3	2	27	D03	1800	2232	74	96	0.771	5833	5782		386		76
1	3	3	27	D03	1800	2213	73	96	0.764	5834	5783		376		71
1	3	4	27	D03	1800	2222	74	96	0.766	5835	5784		380		70
1	3	5	27	D03	1800	2211	73	95	0.767	5836	5785		413		85
1	4	1	28	D04	1800	2581	85	118	0.726	5837	5786		631		132
1	4	2	28	D04	1800	2338	77	103	0.752	5838	5787		475		113
1	4	3	28	D04	1800	2204	73	98	0.748	5839	5788		467		88
1	4	4	28	D04	1800	2288	76	99	0.763	5840	5789		449		102
1	4	5	28	D04	1800	2227	74	98	0.752	5841	5790		448		89
1	5	1	29	D05	1800	2142	71	90	0.788	5842	5791		312		60
1	5	2	29	D05	1800	2239	74	96	0.77	5843	5792		377		71
1	5	3	29	D05	1800	2003	66	84	0.793	5844	5793		290		53
1	5	4	29	D05	1800	2105	70	90	0.779	5845	5794		328		58
1	5	5	29	D05	1800	2091	69	88	0.787	5846	5795		300		59
1	6	1	33	E01	1800	2636	87	132	0.662	5847	5796		621		120
1	6	2	33	E01	1800	2560	85	129	0.658	5848	5797		619		110
1	6	3	33	E01	1800	2550	84	129	0.658	5849	5798		601		102
1	6	4	33	E01	1800	2538	84	128	0.657	5850	5799		609		106
1	6	5	33	E01	1800	2570	85	126	0.678	5851	5800		570		116
1	7	1	34	E02	1800	2625	87	134	0.648	5852	5801		660		114
1	7	2	34	E02	1800	2535	84	125	0.672	5853	5802		604		101
1	7	3	34	E02	1800	2423	80	122	0.659	5854	5803		582		114
1	7	4	34	E02	1800	2471	82	122	0.675	5855	5804		585		107
1	7	5	34	E02	1800	2514	83	123	0.678	5856	5805		592		116
1	8	1	35	E03	1800	3211	106	176	0.606	5857	5806		1,163		282
1	8	2	35	E03	1800	3151	104	174	0.601	5858	5807		1,174		277
1	8	3	35	E03	1800	3343	111	183	0.605	5859	5808		1,194		261
1	8	4	35	E03	1800	3169	105	174	0.605	5860	5809		1,162		259
1	8	5	35	E03	1800	3260	108	180	0.603	5861	5810		1,203		276
1	9	1	36	E04	1800	4291	142	268	0.532	5862	5811		2,138		541
1	9	2	36	E04	1800	4328	144	269	0.536	5863	5812		2,182		582
1	9	3	36	E04	1800	4270	142	269	0.527	5864	5813		2,179		561
1	9	4	36	E04	1800	4290	142	267	0.534	5865	5814		2,128		517
1	9	5	36	E04	1800	4197	139	260	0.536	5866	5815		2,074		521
1	10	1	37	E05	1800	2574	85	129	0.663	5867	5816		628		121
1	10	2	37	E05	1800	2409	80	122	0.653	5868	5817		564		84
1	10	3	37	E05	1800	2487	82	129	0.64	5869	5818		631		83
1	10	4	37	E05	1800	2484	82	127	0.651	5870	5819		588		95
1	10	5	37	E05	1800	2463	82	130	0.627	5871	5820		623		90

Experiment 2, Glass Vials – Day 35 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.002

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2198	73	98	0.743	5906	5855		436		55
1	1	2	25	D01	1800	2167	72	94	0.767	5907	5856		378		72
1	1	3	25	D01	1800	2121	70	93	0.753	5908	5857		386		62
1	1	4	25	D01	1800	2057	68	89	0.768	5909	5858		356		61
1	1	5	25	D01	1800	2093	69	92	0.754	5910	5859		371		53
1	2	1	26	D02	1800	2162	72	94	0.766	5911	5860		351		63
1	2	2	26	D02	1800	2113	70	91	0.769	5912	5861		354		72
1	2	3	26	D02	1800	2170	72	92	0.781	5913	5862		328		53
1	2	4	26	D02	1800	2073	69	87	0.791	5914	5863		324		70
1	2	5	26	D02	1800	2171	72	92	0.78	5915	5864		353		71
1	3	1	27	D03	1800	2952	98	153	0.639	5916	5865		899		125
1	3	2	27	D03	1800	2239	74	101	0.736	5917	5866		481		84
1	3	3	27	D03	1800	2185	72	95	0.764	5918	5867		385		63
1	3	4	27	D03	1800	2135	71	92	0.769	5919	5868		376		71
1	3	5	27	D03	1800	2185	72	94	0.767	5920	5869		358		59
1	4	1	28	D04	1800	2553	85	129	0.655	5921	5870		743		120
1	4	2	28	D04	1800	2138	71	90	0.788	5922	5871		327		69
1	4	3	28	D04	1800	2116	70	91	0.774	5923	5872		326		72
1	4	4	28	D04	1800	2121	70	93	0.753	5924	5873		357		65
1	4	5	28	D04	1800	2056	68	87	0.783	5925	5874		342		71
1	5	1	29	D05	1800	2461	81	117	0.697	5926	5875		617		83
1	5	2	29	D05	1800	2186	72	96	0.755	5927	5876		378		62
1	5	3	29	D05	1800	2101	69	90	0.777	5928	5877		314		59
1	5	4	29	D05	1800	2098	69	90	0.771	5929	5878		306		46
1	5	5	29	D05	1800	2108	70	89	0.785	5930	5879		316		59
1	6	1	33	E01	1800	2545	84	129	0.656	5931	5880		618		93
1	6	2	33	E01	1800	2414	80	122	0.656	5932	5881		590		110
1	6	3	33	E01	1800	2568	85	130	0.655	5933	5882		600		107
1	6	4	33	E01	1800	2546	84	125	0.675	5934	5883		600		119
1	6	5	33	E01	1800	2519	83	126	0.661	5935	5884		614		111
1	7	1	34	E02	1800	2549	84	128	0.66	5936	5885		618		91
1	7	2	34	E02	1800	2578	85	132	0.649	5937	5886		642		101
1	7	3	34	E02	1800	2586	86	133	0.646	5938	5887		636		109
1	7	4	34	E02	1800	2492	83	126	0.658	5939	5888		595		103
1	7	5	34	E02	1800	2603	86	130	0.662	5940	5889		627		89
1	8	1	35	E03	1800	2577	85	130	0.659	5941	5890		648		113
1	8	2	35	E03	1800	2606	86	133	0.651	5942	5891		644		112
1	8	3	35	E03	1800	2588	86	132	0.652	5943	5892		618		102
1	8	4	35	E03	1800	2498	83	124	0.669	5944	5893		607		123
1	8	5	35	E03	1800	2595	86	130	0.662	5945	5894		623		99
1	9	1	36	E04	1800	2662	88	135	0.656	5946	5895		701		125
1	9	2	36	E04	1800	2691	89	137	0.651	5947	5896		684		119
1	9	3	36	E04	1800	2532	84	131	0.642	5948	5897		668		126
1	9	4	36	E04	1800	2577	85	131	0.651	5949	5898		669		115
1	9	5	36	E04	1800	2569	85	132	0.648	5950	5899		643		112
1	10	1	37	E05	1800	2504	83	124	0.668	5951	5900		590		93
1	10	2	37	E05	1800	2497	83	124	0.668	5952	5901		590		96
1	10	3	37	E05	1800	2524	84	127	0.658	5953	5902		623		92
1	10	4	37	E05	1800	2612	87	133	0.651	5954	5903		624		100
1	10	5	37	E05	1800	2516	83	128	0.654	5955	5904		620		96

Experiment 2, Glass Vials – Day 56 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.005

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTR	PECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2442	81	117	0.69	5956	5905		665		100
1	1	2	25	D01	1800	2245	74	102	0.733	5957	5906		484		82
1	1	3	25	D01	1800	2135	71	95	0.742	5958	5907		406		58
1	1	4	25	D01	1800	2161	71	97	0.736	5959	5908		440		71
1	1	5	25	D01	1800	2196	73	97	0.754	5960	5909		434		78
1	2	1	26	D02	1800	2250	74	100	0.743	5961	5910		434		69
1	2	2	26	D02	1800	2100	69	92	0.76	5962	5911		377		69
1	2	3	26	D02	1800	2171	72	94	0.763	5963	5912		378		63
1	2	4	26	D02	1800	2092	69	92	0.754	5964	5913		388		64
1	2	5	26	D02	1800	2083	69	92	0.748	5965	5914		384		68
1	3	1	27	D03	1800	2219	73	99	0.743	5966	5915		435		71
1	3	2	27	D03	1800	2086	69	91	0.763	5967	5916		393		69
1	3	3	27	D03	1800	2155	71	95	0.748	5968	5917		402		61
1	3	4	27	D03	1800	2130	70	92	0.77	5969	5918		355		58
1	3	5	27	D03	1800	2097	69	90	0.768	5970	5919		358		70
1	4	1	28	D04	1800	2296	76	101	0.751	5971	5920		447		87
1	4	2	28	D04	1800	2099	69	92	0.754	5972	5921		387		78
1	4	3	28	D04	1800	2041	68	87	0.775	5973	5922		339		72
1	4	4	28	D04	1800	2033	67	89	0.755	5974	5923		349		60
1	4	5	28	D04	1800	2115	70	94	0.747	5975	5924		412		78
1	5	1	29	D05	1800	2196	73	99	0.737	5976	5925		474		101
1	5	2	29	D05	1800	2106	70	90	0.777	5977	5926		342		71
1	5	3	29	D05	1800	2070	68	88	0.777	5978	5927		335		67
1	5	4	29	D05	1800	2056	68	87	0.784	5979	5928		303		57
1	5	5	29	D05	1800	2037	67	87	0.779	5980	5929		317		55
1	6	1	33	E01	1800	2475	82	124	0.664	5981	5930		615		106
1	6	2	33	E01	1800	2500	83	126	0.66	5982	5931		631		104
1	6	3	33	E01	1800	2444	81	124	0.652	5983	5932		635		105
1	6	4	33	E01	1800	2512	83	126	0.662	5984	5933		604		107
1	6	5	33	E01	1800	2566	85	131	0.651	5985	5934		669		126
1	7	1	34	E02	1800	2391	79	121	0.656	5986	5935		570		93
1	7	2	34	E02	1800	2460	81	122	0.667	5987	5936		597		109
1	7	3	34	E02	1800	2470	82	124	0.662	5988	5937		580		106
1	7	4	34	E02	1800	2507	83	126	0.66	5989	5938		593		99
1	7	5	34	E02	1800	2508	83	125	0.668	5990	5939		567		95
1	8	1	35	E03	1800	2501	83	128	0.649	5991	5940		626		101
1	8	2	35	E03	1800	2490	82	129	0.642	5992	5941		657		111
1	8	3	35	E03	1800	2530	84	126	0.664	5993	5942		654		124
1	8	4	35	E03	1800	2529	84	127	0.661	5994	5943		640		140
1	8	5	35	E03	1800	2596	86	130	0.661	5995	5944		649		124
1	9	1	36	E04	1800	2420	80	124	0.649	5996	5945		626		95
1	9	2	36	E04	1800	2399	79	122	0.651	5997	5946		599		104
1	9	3	36	E04	1800	2451	81	126	0.643	5998	5947		646		116
1	9	4	36	E04	1800	2523	84	127	0.658	5999	5948		618		115
1	9	5	36	E04	1800	2477	82	127	0.649	6000	5949		622		102
1	10	1	37	E05	1800	2403	80	120	0.662	6001	5950		602		120
1	10	2	37	E05	1800	2517	83	129	0.649	6002	5951		644		112
1	10	3	37	E05	1800	2406	80	120	0.664	6003	5952		592		88
1	10	4	37	E05	1800	2536	84	126	0.667	6004	5953		594		108
1	10	5	37	E05	1800	2592	86	131	0.657	6005	5954		648		104

Experiment 2, Glass Vials – Day 84 Recount, Optimized within windows 18-162

Data files

DFile 1: example.csv

Default path: C:\Program Files\Mikrow in 2000\Transfer\

Import Data | Add Data | Export selected data

ROI	Min	Max
Beta	18	162
Alpha	500	950

FOM	0.003

Dfile	Samp.	Repe.	Vial	VNam	Time	CNT(1)	CPM(1)	DPM(1)	TDCR(1	PECTI	SPECT	ROIα	ROIβ	ROIα Tri	ROIβ Tri
1	1	1	25	D01	1800	2320	77	110	0.702	6040	5989		568		83
1	1	2	25	D01	1800	2115	70	92	0.763	6041	5990		379		73
1	1	3	25	D01	1800	2103	70	92	0.755	6042	5991		373		60
1	1	4	25	D01	1800	2088	69	89	0.773	6043	5992		367		76
1	1	5	25	D01	1800	2016	67	88	0.76	6044	5993		370		80
1	2	1	26	D02	1800	2159	71	96	0.745	6045	5994		413		69
1	2	2	26	D02	1800	2077	69	91	0.754	6046	5995		381		65
1	2	3	26	D02	1800	2050	68	90	0.754	6047	5996		398		74
1	2	4	26	D02	1800	2121	70	92	0.768	6048	5997		385		71
1	2	5	26	D02	1800	2016	67	88	0.756	6049	5998		366		72
1	3	1	27	D03	1800	2413	80	112	0.713	6050	5999		512		79
1	3	2	27	D03	1800	2144	71	94	0.758	6051	6000		398		59
1	3	3	27	D03	1800	2138	71	96	0.74	6052	6001		421		63
1	3	4	27	D03	1800	2050	68	91	0.744	6053	6002		368		58
1	3	5	27	D03	1800	1960	65	88	0.739	6054	6003		370		57
1	4	1	28	D04	1800	2064	68	91	0.748	6055	6004		367		66
1	4	2	28	D04	1800	2103	70	92	0.759	6056	6005		353		66
1	4	3	28	D04	1800	2003	66	87	0.762	6057	6006		348		67
1	4	4	28	D04	1800	2000	66	86	0.773	6058	6007		347		76
1	4	5	28	D04	1800	2040	67	90	0.753	6059	6008		382		71
1	5	1	29	D05	1800	2084	69	91	0.755	6060	6009		364		62
1	5	2	29	D05	1800	2056	68	88	0.776	6061	6010		345		62
1	5	3	29	D05	1800	2025	67	87	0.769	6062	6011		314		56
1	5	4	29	D05	1800	2010	66	88	0.756	6063	6012		322		37
1	5	5	29	D05	1800	2029	67	88	0.762	6064	6013		342		72
1	6	1	33	E01	1800	2552	85	131	0.647	6065	6014		638		92
1	6	2	33	E01	1800	2477	82	126	0.654	6066	6015		595		89
1	6	3	33	E01	1800	2514	83	127	0.657	6067	6016		591		89
1	6	4	33	E01	1800	2503	83	126	0.66	6068	6017		577		101
1	6	5	33	E01	1800	2446	81	126	0.646	6069	6018		608		97
1	7	1	34	E02	1800	2492	83	124	0.666	6070	6019		610		100
1	7	2	34	E02	1800	2449	81	123	0.661	6071	6020		579		92
1	7	3	34	E02	1800	2562	85	129	0.661	6072	6021		603		103
1	7	4	34	E02	1800	2479	82	123	0.667	6073	6022		600		116
1	7	5	34	E02	1800	2527	84	127	0.661	6074	6023		616		111
1	8	1	35	E03	1800	2443	81	123	0.656	6075	6024		590		102
1	8	2	35	E03	1800	2406	80	121	0.658	6076	6025		591		107
1	8	3	35	E03	1800	2396	79	124	0.643	6077	6026		596		111
1	8	4	35	E03	1800	2550	84	130	0.649	6078	6027		625		105
1	8	5	35	E03	1800	2501	83	128	0.649	6079	6028		627		100
1	9	1	36	E04	1800	2473	82	124	0.66	6080	6029		616		119
1	9	2	36	E04	1800	2412	80	122	0.658	6081	6030		600		111
1	9	3	36	E04	1800	2434	81	123	0.655	6082	6031		603		117
1	9	4	36	E04	1800	2470	82	123	0.667	6083	6032		590		96
1	9	5	36	E04	1800	2585	86	133	0.646	6084	6033		673		131
1	10	1	37	E05	1800	2538	84	126	0.667	6085	6034		616		108
1	10	2	37	E05	1800	2469	82	124	0.663	6086	6035		587		95
1	10	3	37	E05	1800	2467	82	127	0.644	6087	6036		634		99
1	10	4	37	E05	1800	2524	84	124	0.677	6088	6037		578		104
1	10	5	37	E05	1800	2443	81	119	0.681	6089	6038		551		103