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# SAFEGUARDS MEASUREMENT EVALUATION PROGRAM

## URANIUM AND PLUTONIUM SAMPLES EXCHANGE ANNUAL REPORT

NEW BRUNSWICK LABORATORY

## JULY 2006–JUNE 2007

**B. Srinivasan, Kattathu Mathew, Michael Soriano, Joseph Waggoner, Usha Narayanan and Jon Neuhoff**

U.S. DEPARTMENT OF ENERGY • OFFICE OF SCIENCE • CHICAGO OFFICE • ARGONNE, ILLINOIS

## U.S. DEPARTMENT OF ENERGY

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# NEW BRUNSWICK LABORATORY: HISTORY AND MISSION

The New Brunswick Laboratory (NBL) is owned and operated by the United States Department of Energy through the Office of Science (SC). The laboratory was established in 1949 as an analytical chemistry laboratory in New Brunswick, New Jersey to provide support to the United States Atomic Energy Commission. At that time, it was staffed by scientists from the National Bureau of Standards who had contributed significantly to nuclear material measurement programs in the Manhattan Project. At the New Brunswick Laboratory, these scientists provided the technical expertise and skills to solve problems related to quantitative analyses of uranium-bearing materials. Over the years, these scientists and others following them have expanded the capabilities of the laboratory to include chemical and mass spectrometric analyses of plutonium and other trans-uranium elements, research and development activities in chemical analysis techniques, preparation of certified reference materials, and operation of the Safeguards Measurement Evaluation Program. In 1977, the laboratory moved from New Jersey to its present location at the Argonne National Laboratory site in Illinois.

The New Brunswick Laboratory serves as the U.S. government's central authority for both nuclear material measurements and measurement evaluation, and is the U.S. government's certifying authority for nuclear reference materials. The major mission of the New Brunswick Laboratory is to provide technical assistance to the Department of Energy in the following areas: measurement evaluation program operation, certified (nuclear) reference materials preparation, measurement techniques development, and measurement services to domestic and international customers. In addition to fulfilling these tasks, the laboratory helps the Department in three other areas: conducting technical audits, resolving shipper/receiver differences in material transfers, and assisting in nuclear nonproliferation programs.

# ACKNOWLEDGEMENTS

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# ABSTRACT

The New Brunswick Laboratory (NBL) has been tasked by the United States Department of Energy, Office of Science (SC) to evaluate the quality of measurement techniques in nuclear materials accounting practices at Department of Energy facilities. Both destructive and non-destructive methods of analysis come under this purview. The destructive methods are evaluated in the Safeguards Measurement Evaluation (SME) Program. The non-destructive methods are evaluated in the Calorimetric Exchange (CALEX) Program. This report describes the activities in the SME Program from July, 2006 through June, 2007.

Three Department of Energy facilities participated in the 2006-2007 SME Program partly to satisfy a Department of Energy requirement on independent verification of internal analytical control practices in their measurements. In addition to DOE facilities, a nuclear cycle development laboratory in Japan, the ABACC network laboratories in Argentina and Brazil, the Institute for Reference Materials and Measurements laboratory (IRMM) in Belgium, and the URENCO laboratory in the United Kingdom participated on a voluntary basis. Both IRMM and URENCO are participating for the first time.

In early 2006, work began on a new Safeguards Measurement Evaluation System (SMES) that will replace the currently used system based on FoxPro®. The new system will permit laboratories to enter their measurement results directly into the system and also retrieve evaluation reports directly, via the internet. A major portion of the development work was completed during this (report) period. Risk assessment and security plan documents are expected to be in place by November 2007. The system will be tested at NBL before allowing access first access to DOE personnel. Additional security measures will have to be implemented for access by non-DOE personnel.

The Measurement Evaluation Program Annual Meeting was successfully conducted in Nashville, Tennessee in July 2006. There were about thirty attendees; fourteen technical papers were presented. The minutes of the meeting was prepared and sent. Preparations for the 2007 annual meeting started in February 2007; the meeting will be held in Tucson, Arizona in July 2007.

Preparations were made in May-June 2006 for conducting two workshops, one in Argentina and the other in Brazil. The workshops will be held in August 2007. Hands-on-training in Davies-Gray procedure for uranium assay, and measurement uncertainty calculation (as recommended in the Guide to Expression of Uncertainty in Measurement) will be offered in these workshops. About 20 chemists and technicians are expected to attend each workshop.

The Measurement Evaluation Program staff attended the following scientific meetings and presented technical papers:

a) A paper reviewing the impact of using slightly different values of plutonium half-lives, especially $^{241}Pu$, in measurement evaluation program; several sources of half-lives, equally reliable, are found in published literature. The paper was presented at the 47$^{th}$ INMM (Institute of Nuclear Materials Management) Annual Meeting in July 2006 in Nashville, Tennessee, and also in the Plutonium Metals Exchange Workshop in September 2006 in Aiken, South Carolina.
b) A paper describing the new SMES was presented at the Plutonium Metal Exchange Workshop in June 2007 in Los Alamos, New Mexico.

The Measurement Evaluation Program staff submitted the following abstracts for presentation at technical meetings to be held in August – October 2007:

a) An abstract on the new SMES to the 48$^{th}$ INMM Annual Meeting to be held in July 2007 in Tucson, Arizona.
b) An abstract on measurement evaluation in chronometry and preparation of chronometry test material standards to the American Chemical Society Meeting to be held in August 2007 in Boston, Massachusetts.
c) An abstract on performance evaluation in nuclear safeguards program to the Conference on Nuclear safety and Nuclear Education to be held in October 2007 in Obninsk, Russia.

## A. INTRODUCTION

The New Brunswick Laboratory (NBL) is a nuclear material measurement laboratory of the U.S. Department of Energy (DOE). NBL reports to the DOE Office of Science, and provides technical support to the department in the following areas: the Measurement Evaluation Program and the Certified Reference Materials Program. In the Measurement Evaluation Program, NBL evaluates the quality of uranium and plutonium accountability measurement results generated by DOE facilities. The program has two parts; the Safeguards Measurement Evaluation (SME) Program for destructive analyses measurement results and the Calorimetry Exchange (CALEX) program for non-destructive analyses measurement results. This annual report pertains to the SME program activities during July 2006 – June 2007.

## B. SME PROGRAM

Material control and accountability measurements are essential elements in nuclear material safeguards work. The accountability measurements are carried out either by destructive methods or by non-destructive techniques. The methods must be capable of providing quantitative results within acceptable limits of accuracy and precision. Unacceptably large measurement bias and/or poor precision in measurements compromise the ability to detect material loss in processing or by theft or by diversion.

The SME Program evaluates elemental and isotopic-abundance measurement results of uranium and plutonium materials for accuracy and precision, and verifies whether these are within the method/material specific International Target Values (ITVs)[1]. Non-conformity of the results to ITVs may require review of experimental methods and procedures, revision of procedures and additional training.

## C. SME PROGRAM: 2006-2007

The 2006-2007 SME Program was confined to uranium measurements only. (NBL did not send plutonium samples because its plutonium laboratories were under “stand down” mode). The uranium shipments were delayed by about three months, and the results evaluations were also delayed due to circumstances beyond our control.

[1] Aigner H., Binner R., Kuhn E. et al. International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials. International Atomic Energy Agency Report STR-327

Delays in the program were partly due to time required for changes made in NBL organization as a result of the A-76 process. The process ended in May 2006 with NBL winning the new contract to operate as the most efficient organization (MEO). The new contract was implemented in October 2006. In the new contract, the services of two statisticians who have been providing help for several years to the Measurement Evaluation Program were either lost or curtailed. They were replaced with temporary help from personnel in the newly created Standards and Evaluation Division. Such changes in organization and staffing invariably go through some disruption and certain loss of operational efficiency before they are regained. The Measurement Evaluation Program suffered these changes during this report period. Now, the program has regained its efficiency and hopes to offer significantly better service in 2007-2008.

Significant contributions made during 2006-2007 are as follows:

a) Performance evaluation: Uranium assay and uranium isotope abundance results were evaluated.
b) New participants: Three laboratories, ORNL, IRMM and URENCO, joined the program in 2006-2007. NRC facilities were persuaded to re-join; it is expected that Paducah and Portsmouth laboratories will participate in 2007-2008.
c) Other exchange programs: Arrangements are being made for NBL to participate in a new uranium exchange program to be organized by the Atomic Weapons Establishment Laboratory in the United Kingdom.
d) New test samples: A new test sample of uranyl nitrate solution was added to the list of SME test samples that are available for shipment to 2007-2008 SME program participants. The uranium assay and uranium isotope abundances in the new test sample were characterized.
e) New database: Significant progress was made in developing a new Safeguards Measurement Evaluation System (SMES) database that will replace the currently used system based on FoxPro®. The new system is described in Section C.7.
f) Measurement Evaluation Program Annual Meetings: The 2006 annual meeting was held in Nashville, Tennessee on July 15, 2007 attended by about 30 persons from DOE as well as non-DOE facilities. Fourteen technical talks were presented at the meeting. Minutes of the annual meeting was prepared and sent to the attendees. Preparations were made to conduct the 2007 Measurement

Evaluation Program Annual Meeting. The meeting will be held in Tucson, Arizona on July 7, 2007.

g) ABACC workshops: Preparations were made to conduct two workshops in August 2007, one in Argentina and the other in Brazil for the benefit of chemists and technicians in ABACC network laboratories. The workshops will provide hands-on training on NBL modified Davies-Gray titration, and uncertainty estimations in safeguard measurements, the latter according to the Guide to the Expression of Uncertainty in Measurement.

h) Plutonium metal exchange workshop: NBL Measurement Evaluation Program personnel attended plutonium metal exchange workshops in Aiken, South Carolina (September 2006) and in Los Alamos, New Mexico (June 2007), and presented technical papers in the two workshops:

i) ACS meeting: An abstract on chronometry standards for performance evaluation in age measurements was submitted. The technical paper will be presented at the American Chemical Society Meeting to be held in Boston, Massachusetts (August 2007).

j) Conference on Nuclear safety and Nuclear Education: An abstract on “Nuclear Material Sample Measurement Comparison and Performance Evaluation in Support of Nonproliferation Programs" was submitted. The technical paper will be presented it the conference to be held in Obninsk, Russia (October 2007).

### C.1. SME Program Participants

DOE laboratories participation is mandated by the requirement in Chapter II.4.e. (7) of DOE Manual 474.1-1 of November 2000: *"Each facility's measurement control program must include participation in appropriate inter-laboratory control programs to provide independent verification of internal analytical quality control."* In addition to DOE laboratories, facilities outside the U.S. also participate on a voluntary basis with DOE approval. Table 1 lists the 2006-2007 program participants. Idaho National Laboratory (a DOE facility) could not participate this year because of instrument problems.

**Table 1. July 2006-June 2007 SME Program: Participants in Uranium Sample Analysis**

| |
|---|
| ABACC LABORATORIES (a group of laboratories in Argentina and Brazil) |
| LOS ALAMOS NATIONAL LABORATORY (DOE contractor laboratory) |
| NEW BRUNSWICK LABORATORY (DOE laboratory) |
| SAVANNAH RIVER SITE (DOE contractor laboratory) |
| TOKAI SAFEGUARDS ANALYTICAL LABORATORY (Japan) |
| INSTITUTE FOR REFERENCE MATERIALS (Belgium) |
| URENCO (Capenhurst) LTD (U.K.) |

### C.2. Materials and Measurement Methods

The materials used and the measurement methods evaluated are shown in Tables 2 and 3. Table 2 refers to uranium assay and Table 3 refers to isotopic-abundance measurements. The participants are identified by code letters to provide confidentiality.

**Table 2. Materials and methods for uranium assay. The participating laboratories are identified by code letters only. Numbers next to codes refer to number of times the laboratory participated in the program. For example, B1 means laboratory B participated in the program one time this year.**

| Method | UNH Solutions | $UO_2$ Pellet | $UF_6$ |
|---|---|---|---|
| Dichromate Titration (Davies-Gray) | B1, G1 | AC1, AD1, AE1, BA1, BC1, BF1 | AE1 |
| IDMS | B1 | | |

Notes: UNH, uranyl nitrate solutions; $UO_2$, uranium dioxide pellets; $UF_6$, uranium hexafluoride; IDMS, isotope dilution mass spectrometry.

**Table 3. Materials and methods for uranium isotopic abundances measurement. The participant laboratories are identified by code letters only. Numbers next to codes refer to number of times the laboratory participated in the program. For example, AA1 means laboratory AA participated in the program one time during this year.**

| Method | LEU | UF6 | UNH Solutions | UO2 Pellets |
|---|---|---|---|---|
| TIMS | T1 | AA1, F1 | B1, F1, W1 | AA1, BC1, T1 |
| ICPMS | | EA1 | EA1 | BE1 |
| GSMS | | BC1 | | |

Notes: UNH, uranyl nitrate solutions; LEU, low-enriched uranium of <20 wt % $^{235}U$; TIMS, thermal ionization mass spectrometry; ICPMS, inductively coupled plasma mass spectrometry; GSMS, gas source mass spectrometry.

### C.3. Test Materials, Shipping, and Analysis

Test materials: The SME Program test materials are made from Certified Reference Materials (CRMs) or Working Reference Materials (WRMs), or custom-made. The elemental concentrations and/or isotopic abundances in the test materials are characterized by experiments done at NBL.

Shipping: The test samples are usually shipped to participants at the beginning of the fiscal year. The shipments were delayed this year with concomitant reduction in participation frequency (see below).

Analysis: Typically, DOE laboratories analyze the test samples on a quarterly schedule. Non-DOE facilities analyze at lesser frequency, once or twice a year. The participation of DOE facilities this year was less than usual because participants did not receive the test samples on time. NBL hopes to restore the higher frequency of participation in 2007-2008 through on-time shipment and frequent customer contacts.

### C.4. SME Program Database

The measurement results submitted by the participating laboratories are entered manually into a FoxPro® database. The entered data are verified manually for correctness and tested for outliers. After excluding the outliers, the results are evaluated statistically using the FoxPro® application programs, and performance evaluation reports are generated.

This year data entry and report evaluation were done using both FoxPro® and the new SMES system. The double entry and double evaluations were done as a part of quality assurance work for the new system.

### C.5. Statistical Evaluation of Measurement Results

The measurement results are evaluated using statistical techniques. First, the percent relative difference (% RD) of each experimental result is calculated with respect to the corresponding reference value, the latter obtained from characterization measurements. The % RD is defined as follows:

% RD = 100 X {(observed value - reference value)/reference value}.

Next, each set of % RDs is examined for outliers using a number of statistical tests. A particular result is identified as a potential outlying value if at least two of the statistical tests show it to be an “outlier” at ≥ 99% significance level. The statistically-identified outliers are reviewed by the statistician and/or the Measurement Evaluation Program Coordinator, and are removed from the data set only after this review. The data set, without outliers, is then tested to identify significant sources of variation (attributable to day-to-day and/or analyst-to-analyst differences) using standard one-factor analysis of variance (ANOVA). If the ANOVA results indicate no significant variation, then the standard uncertainty is the simple standard deviation (σ) of the results divided by the square root of n, where n is the number of measurements. The coverage factor is the Student’s 95% “t” factor with n-1 degrees of freedom. For example, in a set of 8 results showing no day-to-day or analyst-to-analyst variation, the number of degrees of freedom is 7, and the coverage factor is 2.36.

If the ANOVA results indicate significant day-to-day and/or analyst-to-analyst variation (≥ 95%), then the standard uncertainty in the mean % RD is estimated from a combination of the mean square for the “error” and the mean square for the “model” quantities from the ANOVA, with degrees of freedom determined from Satterthwaite’s approximation. For measurements done on two days (or by two analysts), the formula for estimating the standard uncertainty in the mean % RD is reduced to the square root of the mean square for the “model” quantity obtained from ANOVA results. In this case, the coverage factor is 12.71 (i.e., the Student’s 95% “t” factor with one degree of freedom).

The uncertainties shown in the statistical reports are the 95% confidence limit (C.L.) of means. In the figures accompanying the reports, the 95% confidence interval (C.I.) of the mean is constructed from the C.L. Note that the C.I. represents the interval containing all values between the mean % RD minus the C.L. and the mean % RD plus the C.L. Thus, the 95% C.L. of the mean are just the two end points of the C.I.

A measurement is considered to be bias-free if the 95% C.I. included zero. Otherwise, measurement bias is indicated. The simple standard deviation (σ) of the % RDs represents the precision of the measurement results.

### C.6. Examples of Statistical Evaluation Reports

Two examples of the statistical analysis reports are shown in Figs.1 and 2, the former showing uranium assay results from Davies-Gray titration, and the latter from Isotope Dilution Mass Spectrometry (IDMS) measurements. There are 8 results in each set – two samples analyzed in duplicate on two different days.

There are no outliers in Fig.1. There is no evidence for significant day-to-day variation. The statistical significance is 44.3%. Note that variations are considered significant if they exceed 95%, and marginally significant if the value is between 90 and 95%. The mean % RD value is -0.154 and the 95% C.L. uncertainty is 0.070. The uncertainty is calculated using a coverage factor of 2.36 corresponding to 7 degrees of freedom. The mean value extended by the confidence limit (-0.154 $\pm$ 0.070) does not include zero, thereby indicating negative bias in the measurements. The standard deviation (a measure of precision) of the results is 0.083.

There are no outliers in Fig. 2. However, there is evidence for significant day-to-day variation (statistical significance of 96.6%). The mean % RD value is 0.015 and the uncertainty at 95% C.L. is 1.319. The uncertainty is calculated using a coverage factor of 12.7, corresponding to 1 degree of freedom. The mean value extended by the confidence limit (0.015 $\pm$ 1.319) overlaps with zero, indicating no statistically-significant bias. But, this conclusion is not meaningful since the uncertainty is very large. The standard deviation (a measure of precision) of the results is 0.149.

The bias and precision International Target Values (ITVs) are shown at the bottom of the reports. In Fig.1, the mean % RD of -0.154 is beyond the bias ITV of 0.1%; the precision of 0.083 is within the precision ITV of 0.1%. The measurement suffers from negative bias. In Fig.2, the mean % RD of 0.015 is within the ITV of 0.1%, and the precision of 0.149 is also within the ITV of 0.15%. However, no conclusion is possible regarding bias because of the large uncertainty in % RD (a consequence of day-to-day variation). The bias and precision of the measurements are easily seen in the visual representations in Figs. 1 and 2.

Statistical reports, similar to those shown in Figures 1 and 2, are generated for each set of results submitted by the laboratories. The reports are sent to the laboratories with a cover letter stating the conclusions of the performance evaluation. Copies of the cover letter and the report

are also sent to the respective DOE site offices supervising the work done in the laboratories. The site offices are responsible for initiating action to bring about improvements if bias and/or precision of measurement results are not within the respective target values. The NBL Measurement Evaluation Program staff will provide assistance through site visits, procedure reviews, and coordinating training sessions.

**Figure 1**

**SAMPLE DATA EVALUATION REPORT**

**No statistically significant difference due to analysis day**

U.S. Department of Energy
New Brunswick Laboratory
Safeguards Measurement Evaluation Program
Data Evaluation Report

**Day to Day ANOVA analysis**

Report for Laboratory: XX

U02 Pellet – U Concentration

Davies-Gray Titration

Date of Report: November 30, 2003

| Sample Number | Aliquant Number | Analysis Date | Reported %U | % Relative Difference | Analyst Code |
|---|---|---|---|---|---|
| 95EU0079-1 | 1 | 11/03/03 | 88.126 | -0.0034 | XXX |
| 95EU0079-1 | 2 | 11/03/03 | 87.990 | -0.1577 | XXX |
| 95EU0079-2 | 1 | 11/03/03 | 88.031 | -0.1112 | XXX |
| 95EU0079-2 | 2 | 11/03/03 | 87.892 | -0.2689 | XXX |
| 95EU0079-1 | 3 | 11/04/03 | 88.030 | -0.1123 | XXX |
| 95EU0079-1 | 4 | 11/04/03 | 87.950 | -0.2031 | XXX |
| 95EU0079-2 | 3 | 11/04/03 | 87.922 | -0.2349 | XXX |
| 95EU0079-2 | 4 | 11/04/03 | 88.002 | -0.1441 | XXX |

| | |
|---|---|
| **Number of Results Analyzed** | 8 |
| **Mean % Difference** | -0.154 |
| **Mean Absolute % Difference** | 0.154 |
| **95% C.L. of Mean (df = 7)** | 0.070 |
| **Standard Deviation** | 0.083 |
| **Between-Day Standard Deviation (df = 1)** | 0.054 |
| **Within-Day Standard Deviation (df = 6)** | 0.087 |
| **Statistical Significance of Between-Day Standard Deviation** | 44.3% |

**International target value for bias in Davies-Gray Titration is 0.1%.**

**International target value for precision in Davies-Gray Titration is 0.1%.**

**Figure 1 (cont.)**

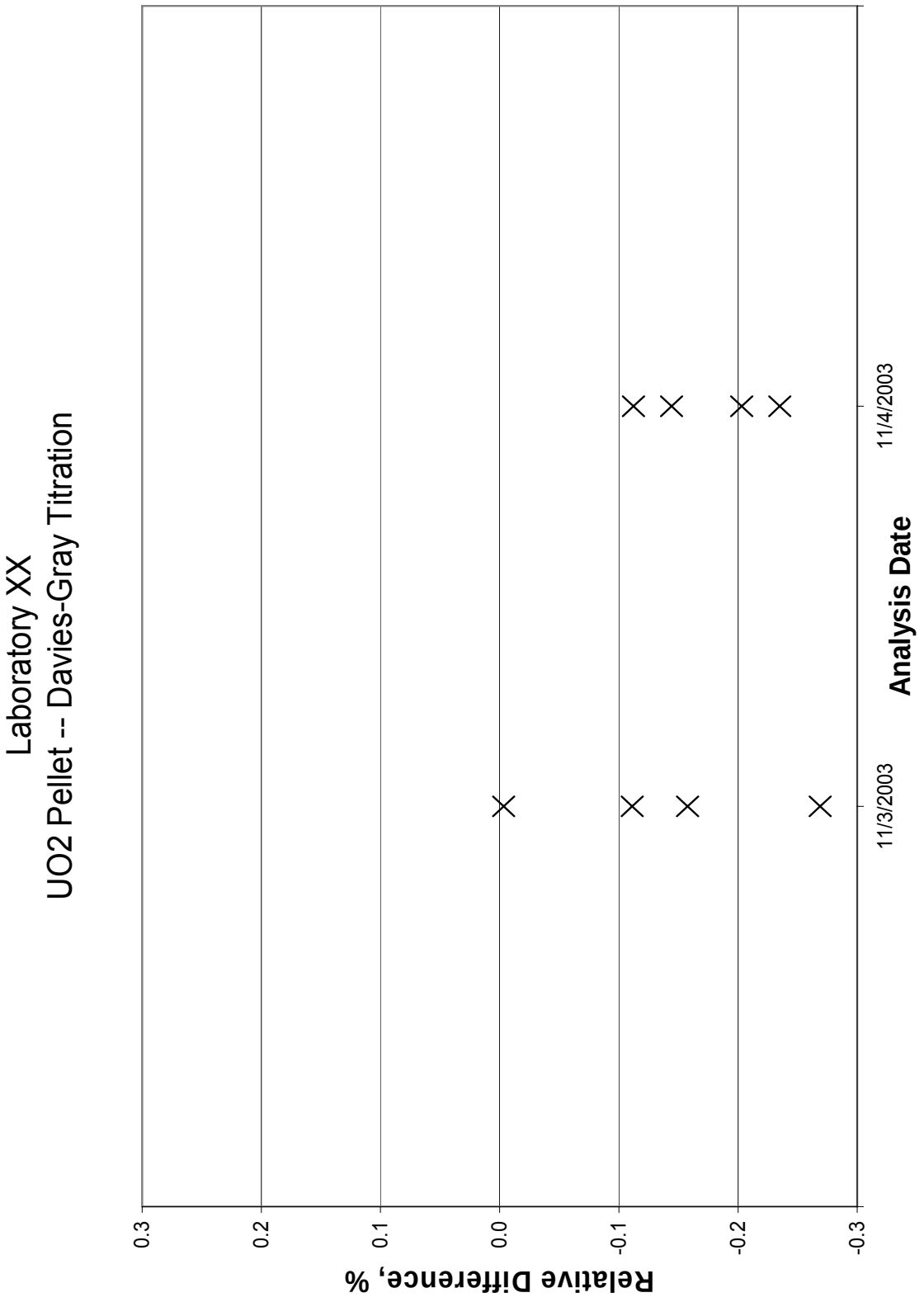


**Figure 2**

**SAMPLE DATA EVALUATION REPORT**

**Statistically significant difference due to analysis day**

U.S. Department of Energy
New Brunswick Laboratory
Safeguards Measurement Evaluation Program
Data Evaluation Report

**Day to Day ANOVA analysis**

Report for Laboratory: XX

UNH Solution – U Concentration

IDMS

Date of Report: November 30, 2003

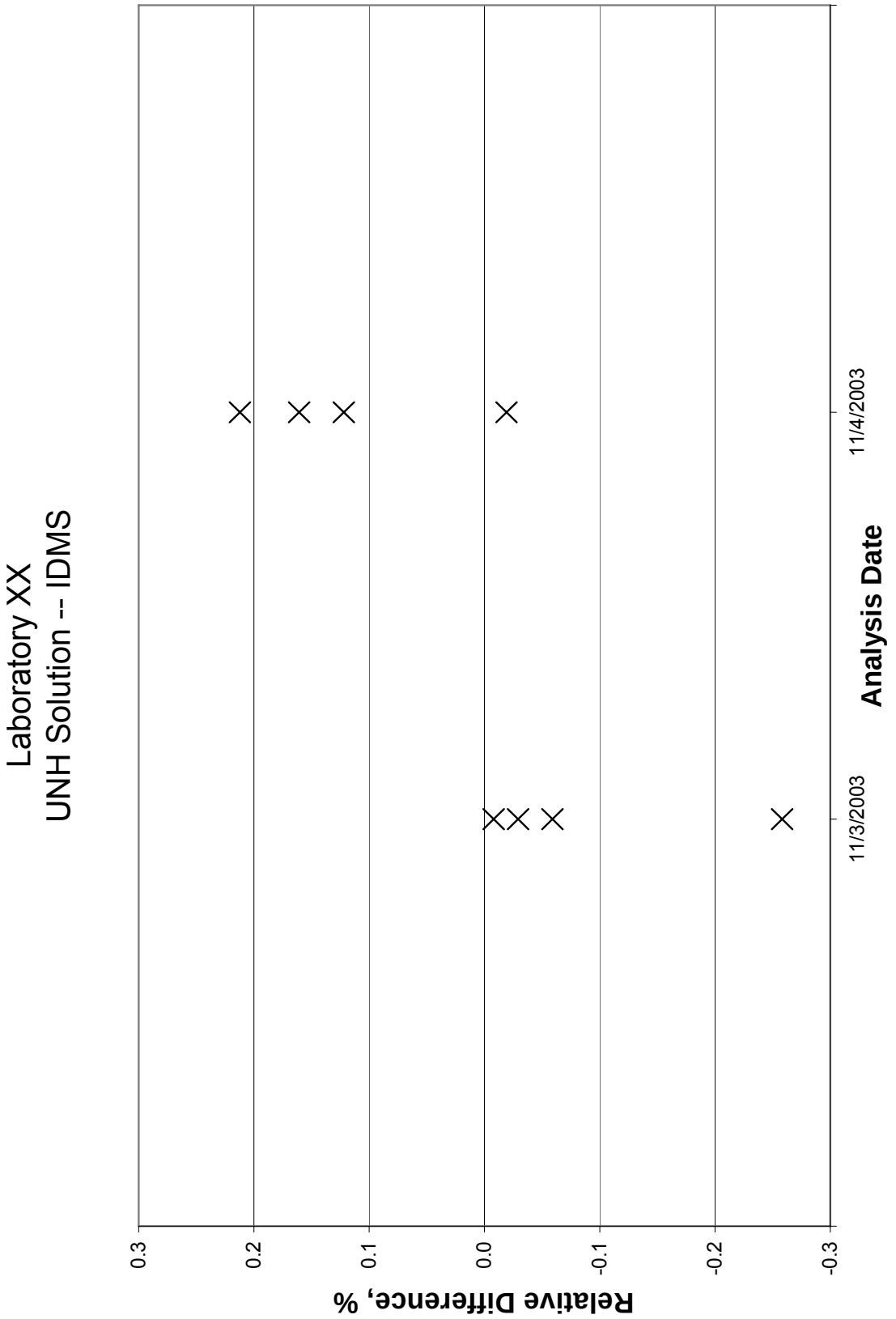
| Sample Number | Aliquant Number | Analysis Date | Reported %U | % Relative Difference | Analyst Code |
|---|---|---|---|---|---|
| 94NU0021-023 | 1 | 11/03/03 | 1.0000 | -0.0590 | XXX |
| 94NU0021-023 | 2 | 11/03/03 | 1.0003 | -0.0290 | XXX |
| 94NU0023-079 | 1 | 11/03/03 | 0.9991 | -0.0080 | XXX |
| 94NU0023-079 | 2 | 11/03/03 | 0.9996 | -0.2582 | XXX |
| 94NU0021-023 | 3 | 11/04/03 | 1.0022 | 0.1609 | XXX |
| 94NU0021-023 | 4 | 11/04/03 | 1.0004 | -0.0190 | XXX |
| 94NU0023-079 | 3 | 11/04/03 | 1.0004 | 0.1221 | XXX |
| 94NU0023-079 | 4 | 11/04/03 | 1.0013 | 0.2122 | XXX |

| | |
|---|---|
| **Number of Results Analyzed** | 8 |
| **Mean % Difference** | 0.015 |
| **Mean Absolute % Difference** | 0.109 |
| **95% C.L. of Mean (df = 1)** | 1.319 |
| **Standard Deviation** | 0.149 |
| **Between-Day Standard Deviation (df = 1)** | 0.294 |
| **Within-Day Standard Deviation (df = 6)** | 0.107 |
| **Statistical Significance of Between-Day Standard Deviation** | 96.6% |

**International target value for bias in IDMS is 0.1%.**

**International target value for precision in IDMS is 0.15%.**

**Figure 2 (cont.)**



### C.7. SMES Development

During the period of this report, significant progress was made in developing a new Safeguards Measurement Evaluation database application system (SMES) that will permit laboratories to submit their measurement results electronically and retrieve evaluation reports via the internet. SMES is being developed by computer professionals from Chickasaw Nation Industries - computer support contractor to DOE Chicago Office - and will be maintained by them. It is being designed with full consideration to quality assurance, security and confidentiality. SMES will be tested at NBL in the first quarter of FY 2008. It is expected to be available to DOE facilities little later in the year.

#### C.7.1. SMES Design

- User self-service: One of the main objectives of the SMES application is to provide access to participants to enter data, validate entries, and retrieve performance evaluation reports.

- Security through the Web: SMES will provide secure access through the Internet by using User ID/passwords, role-based access and encryption with considerations of confidentiality of data submitted and reports generated.

- Quality assurance/documentation: The SMES application is being developed and tested, and validated by computer professionals (DOE-CH contractor) using modern development techniques. The DOE standards for software development, change control and quality assurance are being followed.

- Modular programming: The SMES employs modular programming techniques and reusable code, and will be easy to maintain. The design allows for future expansions of the program, such as increase in the number of participants and evaluation of results from new methods of analyses.

- Modern technology: The SMES employs modern web-based technologies and uses a well supported modern database system (SQL).

### C.7.2. Specifications

- Java enterprise server architecture: SMES is designed around the Java 2 Enterprise Edition (J2EE) architecture. The system uses a dedicated J2EE Application Server.

- SQL database storage: SMES data is securely stored on an SQL database server for quick retrieval and updating of data; data backups are automated.

- Secure platform independent thin client: Laboratories will be able to enter their own measurement results to SMES via the Internet, eliminating the need to mail the data to NBL. SMES will support the most popular current web browsers with Secure Socket Layers (SSL) and will require no special browser add-ons.

- Role-based security: The system provides a number of access roles including those required for data entry, data validation and published report retrieval. SMES will provide access to participating laboratories and oversight agencies (e.g., DOE area office). Note that participant laboratories will have access only to their own data and reports.

- Historical Data: All historical data contained in the FoxPro® database will be migrated to SMES.

- Calculation Techniques: The time proven statistical analysis tools (e.g., outlier tests, calculation of mean and standard deviation of %RDs, tests to determine day-to-day and analyst-to-analyst variations, determination of 95% C.I. etc.) originally written for the FoxPro® application will be retained.

## D. ANALYSIS RESULTS AND REPORTING FORMAT, JULY 2006-JUNE 2007

The experimental results submitted by the participating laboratories from July, 2006 through June, 2007 are shown in Appendices A to B, and the results are discussed in Section E. Assay results are discussed first (Sections E.1 to E.3), followed by isotopic abundance results (Section E.4). In these discussions, the laboratories are identified by code letters to maintain confidentiality. Long-term (multi-year) evaluations are shown in figures 15 to 63 in Section F.

The measurement results were evaluated in terms of the mean % RD and its standard deviation for each material/method/laboratory combination (Tables 4 to 10). The tables also contain the following information: code letter for the participant, the method of analysis, the number of results (outliers removed), bias target values and precision target values.

The data presented in Tables 4 to 9 are shown graphically in Figures 3 to 14. There are two types of figures: the material-measurement skeletal figures to evaluate bias, and the material-measurement line figures to evaluate precision. In the material-measurement skeletal figures (odd number figures between Fig.3 and Fig.14), the mean % RDs are shown as diamonds. The vertical line represents the standard deviation for that set. The bias target values are shown as dotted horizontal lines. If the diamonds (extended by the respective standard deviation of the results) fall within the horizontal lines, then the measurements are said to satisfy the bias target values; those falling outside fail. The magnitude of bias (if any) can be estimated with reference to the mean % RD and its uncertainty at 95% C.L. No bias is indicated if the mean % RD extended by this uncertainty includes zero. If it fails to include zero, bias is indicated; above zero indicates positive bias and below zero indicates negative bias.

The material-measurement line figures (even number figures between Figure 3 and Figure 14) show precisions achieved in the measurements. The vertical line represents the standard deviation associated with each set of mean % RDs. If the top of the vertical line is below the corresponding precision target value - shown as a dotted horizontal line - then the laboratory has satisfied the precision target value. If the vertical line extends beyond the horizontal, then the laboratory has failed the precision criterion. In these figures, the diamonds represent the absolute values of the mean % RDs. The measurements are assumed to be bias-free if the diamonds fall on the abscissa or very close to it.

## E. PERFORMANCE EVALUATION: MATERIAL BY MATERIAL

The results for uranium assay are given in Sections E.1 to E.3 and uranium isotopic abundances are discussed in Section E.4.

### E.1. Uranyl Nitrate Solutions

Test samples of uranyl nitrate solutions were made from enriched uranium (> 0.7% in $^{235}U$) as well as natural uranium. Three different types of uranyl nitrate solutions are available: one solution from 50% enriched material, three different solutions from 90% enriched material, and three different solutions from natural uranium. The uranium concentrations of these solutions are in the range of 7 to 10 mg uranium per gram of solution. The uranium concentrations of the three natural uranium solutions are close to each other, but distinguishably different. The uranium contents of the three solutions from 90% material are also close to each other, but distinguishably different. These solutions are ideal test samples for Davies-Gray and high precision analyses methods; with good analytical techniques, these differences are easily seen.

#### E.1.1. Preparation and Packaging for Shipment

The uranyl nitrate solutions are in flame-sealed glass ampoules with break-off tips. Each ampoule is packed in a plastic bag. The bag is wrapped in absorbent cushioning material and sealed in another large plastic bag. The large bag is then kept inside a screw-cap fiberboard can for shipping.

#### E.1.2. Reference Value and Uncertainty

NBL used a modified Davies and Gray titration procedure to characterize the uranium concentrations of the test samples in the ampoules. The uncertainties (95% C.L.) in uranium concentrations are as follows: ± 0.1% for the 50% enriched uranium solution, ± 0.02% for the 90% enriched uranium solutions, and in the range of ± 0.02 to ± 0.05% for the natural uranium solutions.

A separate experiment demonstrated that the solutions did not suffer concentration change as a result of flame sealing. Samples withdrawn from sealed ampoules and from the original stock, showed negligible differences between them (the uranium concentrations agreed within a few hundredths of one percent).

### E.1.3. Performance Evaluation

The participating laboratories determined the uranium concentrations of the test samples using Davies-Gray titration and isotope dilution mass spectrometry (IDMS). The results, in terms of mean % RDs, are shown in Table 4, along with the target values for each method. The % RDs, along with standard deviations, appear in Fig. 3 to evaluate bias and in Fig. 4 to evaluate precision. Laboratory B missed the bias target value for IDMS and missed the precision target value for both Davies-Gray titration and IDMS. Laboratory G met bias and precision target values for Davies-Gray titration.

**Table 4. Inter-laboratory performance summary for uranium assay in UNH solutions**

| Method | Lab Code | Mean %RD | Standard Deviation | N | ITV (%)# | |
|---|---|---|---|---|---|---|
| | | | | | Bias | Precision |
| Davies-Gray Titration | B | 0.067917 | 0.146089 | 8 | 0.1 | 0.1 |
| | G | -0.009231 | 0.009976 | 8 | 0.1 | 0.1 |
| IDMS | B | -0.338673 | 0.837423 | 8 | 0.1 | 0.15 |

**Figure 3**

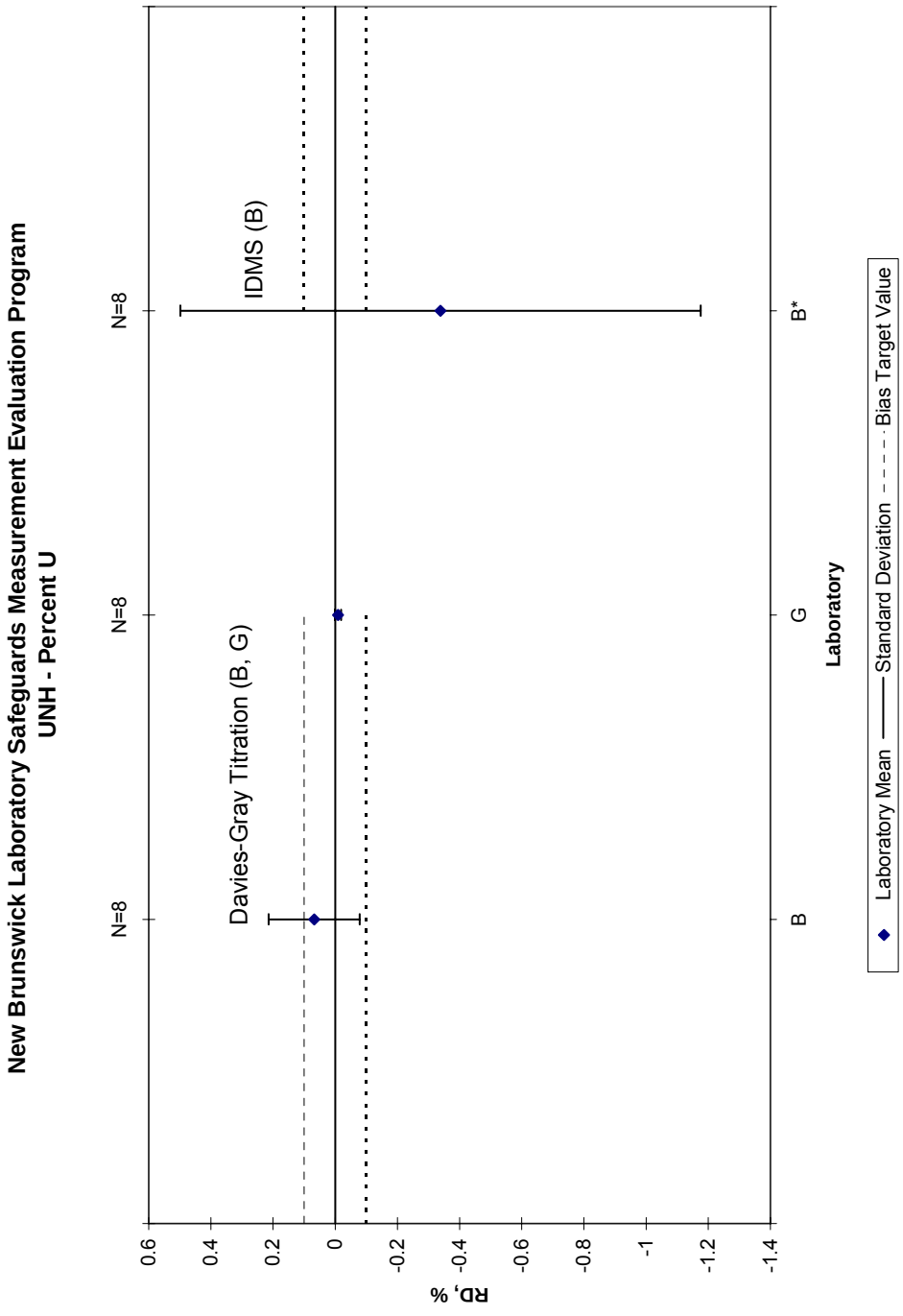
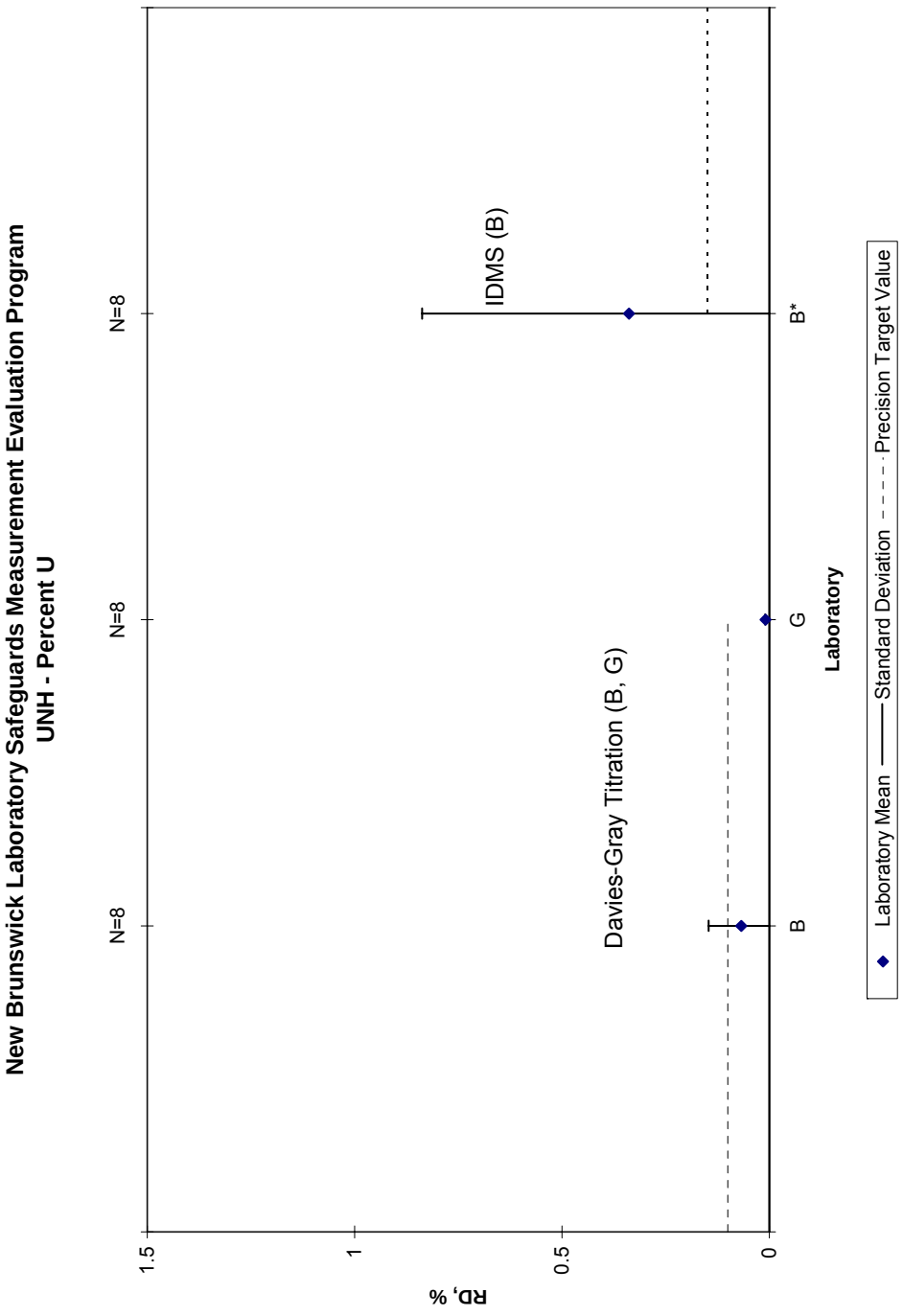

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH - Percent U
IDMS (B)
Davies-Gray Titration (B, G)
N=8
N=8
N=8
B
G
B*
Laboratory
RD, %
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 4**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH - Percent U
N=8
N=8
N=8
IDMS (B)
Davies-Gray Titration (B, G)
1.5
1
0.5
0
RD, %
B
G
B*
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

### E.2. Enriched Uranium Dioxide ($UO_2$) Pellet

The uranium dioxide ($UO_2$) pellets were originally made in a single batch at the Westinghouse Commercial Nuclear Fuel Division (a NRC licensee), using a high temperature sintering process at 1700°C for 20 hours in a reducing atmosphere. The $UO_2$ pellets are known to be stable. They suffer no compositional change on exposure to air and are resistant to moisture uptake. The pellets serve as a test material for both uranium assay and uranium isotopic abundance measurements. The $^{235}U$ content is about 4.5%.

#### E.2.1. Preparation and Packaging for Shipment

The $UO_2$ pellets are wrapped in low-lint tissue to prevent chipping, placed in snap-cap glass bottles, and then sealed in plastic bags. The bottles are shipped in fiberboard cans.

#### E.2.2. Reference Value and Uncertainty

The elemental uranium concentration of the pellets was determined by the NBL High-Precision Titration method. A uranium metal assay standard was used for quality control and traceability. The uranium concentration was measured with an uncertainty of about ± 0.02% at 95% C.L.

#### E.2.3. Performance Evaluation

Seven laboratories analyzed the uranium dioxide pellets for uranium concentration using Davies-Gray Titration. The mean % RDs along with uncertainties are shown in Table 5 along with the target values for each method. The % RDs along with standard deviations are shown in Fig. 5 to evaluate bias and in Fig. 6 to evaluate precision. All laboratories met the bias and precision ITVs. For Laboratory AD, the results show a negative bias seen only because of the excellent precision.

**Table 5. Inter-laboratory performance summary for uranium assay in $UO_2$ Pellets**

| Method | Lab Code | Mean %RD | Standard Deviation | N | ITV (%)# | |
|---|---|---|---|---|---|---|
| | | | | | Bias | Precision |
| Davies-Gray Titration | AC | -0.012765 | 0.022741 | 8 | 0.1 | 0.1 |
| | AD | -0.066238 | 0.010093 | 8 | 0.1 | 0.1 |
| | AE | -0.064111 | 0.068387 | 8 | 0.1 | 0.1 |
| | BA | -0.021488 | 0.034022 | 16 | 0.1 | 0.1 |
| | BC | -0.009939 | 0.055451 | 20 | 0.1 | 0.1 |
| | BF | 0.018368 | 0.0415 | 16 | 0.1 | 0.1 |
| | T | -0.002774 | 0.052497 | 18 | 0.1 | 0.1 |

**Figure 5**

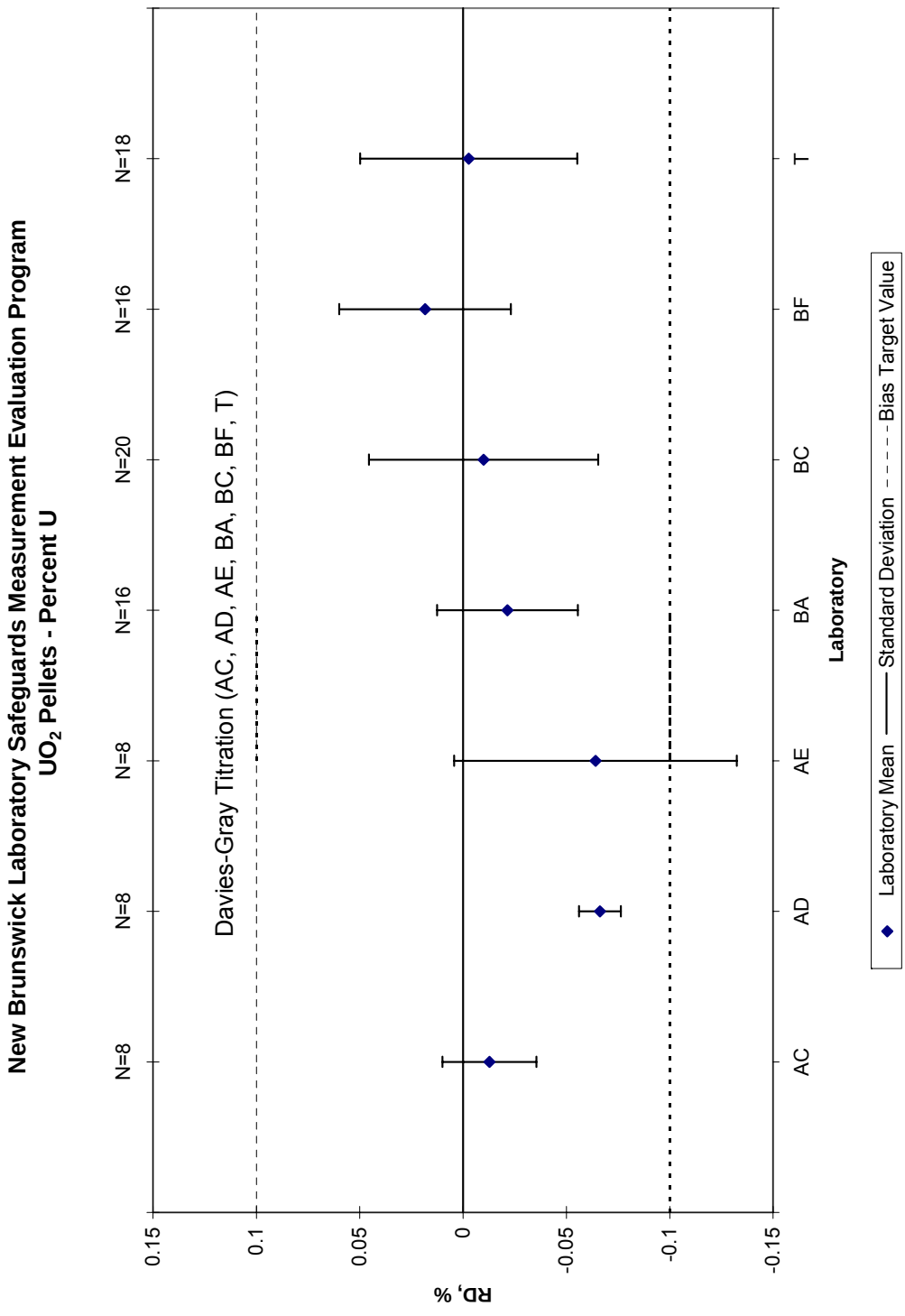
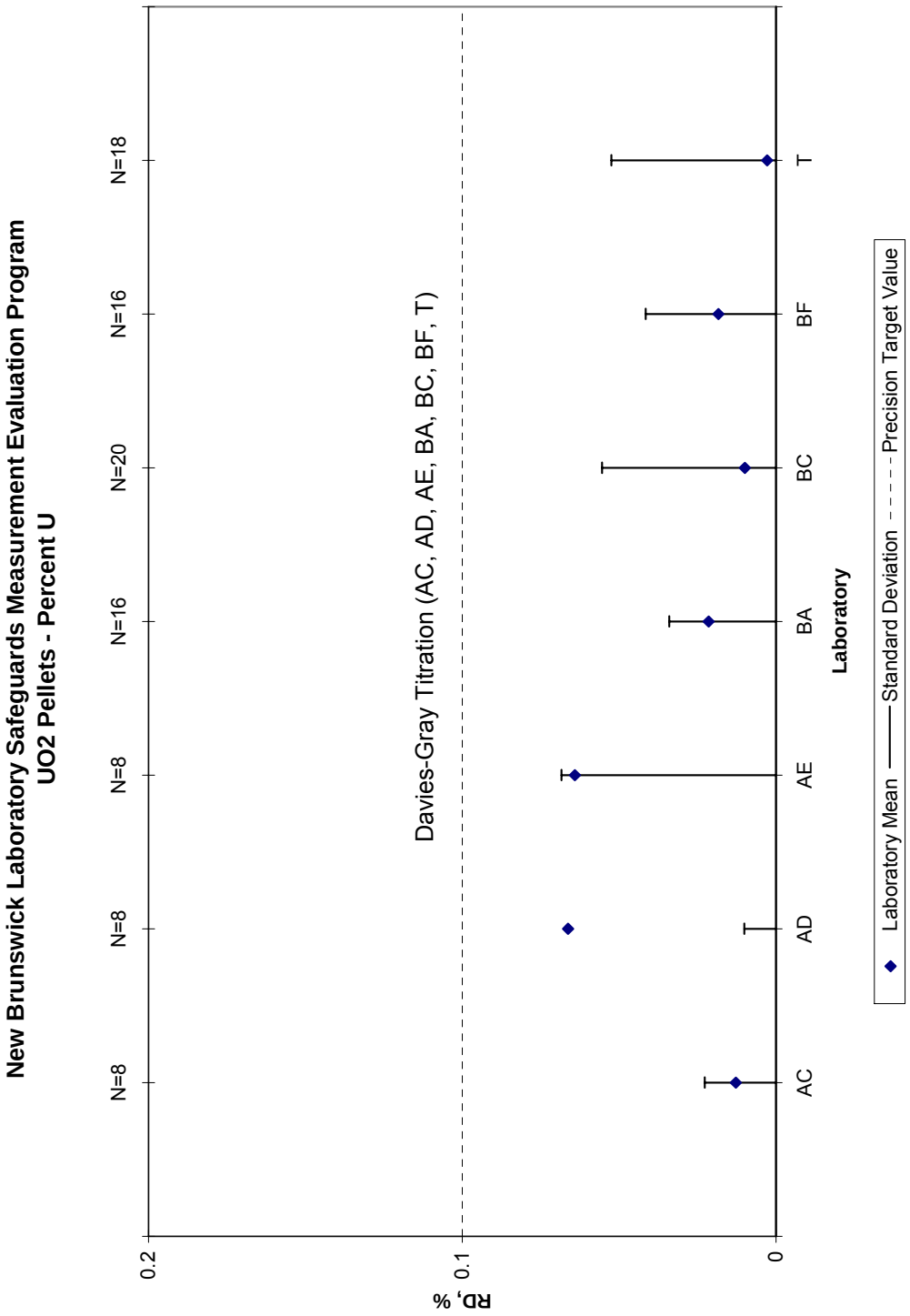

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellets - Percent U
Davies-Gray Titration (AC, AD, AE, BA, BC, BF, T)
N=8
N=8
N=8
N=16
N=20
N=16
N=18
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
RD, %
AC
AD
AE
BA
BC
BF
T
Laboratory
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 6**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellets - Percent U
Davies-Gray Titration (AC, AD, AE, BA, BC, BF, T)
RD, %
0.2
0.1
0
N=8
N=8
N=8
N=16
N=20
N=16
N=18
AC
AD
AE
BA
BC
BF
T
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

### E.3. Uranium Hexafluoride ($UF_6$)

In FY 1993, Portsmouth Gaseous Diffusion Plant donated two sampling manifolds to NBL for transferring $UF_6$ from 2S cylinders to P-10 tubes. One of the two manifolds was used to transfer natural $UF_6$, and the other to transfer enriched material. These manifolds have been taken out of service. Now, NBL is relying on Portsmouth Gaseous Diffusion facility for the preparation of $UF_6$ test samples.

#### E.3.1. Preparation and Packaging for Shipment

The Portsmouth Gaseous Diffusion facility prepared and packaged $UF_6$ test samples in P-10 tubes. Each test sample contained 7 to 12 g of $UF_6$. The enrichment level covers the rage of depleted to about 4.8 wt %.

#### E.3.2. Reference Value and Uncertainty

The $UF_6$ test samples used in the SME Program were not characterized for assay because of the "stand down" of $UF_6$ laboratory activities at NBL. Calculated values (based upon the assumption of 100% purity) were used instead. Characterized isotopic values were based upon Portsmouth data which were verified at NBL using gas source mass spectrometry (GSMS).

#### E.3.3. Performance Evaluation

Only one laboratory (AE) reported results for uranium assay in $UF_6$ using Davies-Gray Titration. The mean % RDs along with uncertainties are shown in Table 6 along with the target values for bias and precision. The % RDs along with standard deviations are shown in Fig.7 to evaluate bias and in Fig.8 to evaluate precision. The laboratory missed both bias and precision target values.

**Table 6. Performance summary for uranium assay in $UF_6$**

| Method | Lab Code | Mean %RD | Standard Deviation | N | ITV (%)# | |
|---|---|---|---|---|---|---|
| | | | | | Bias | Precision |
| Davies-Gray Titration | AE | -0.204605 | 0.110537 | 8 | 0.1 | 0.1 |

**Figure 7**

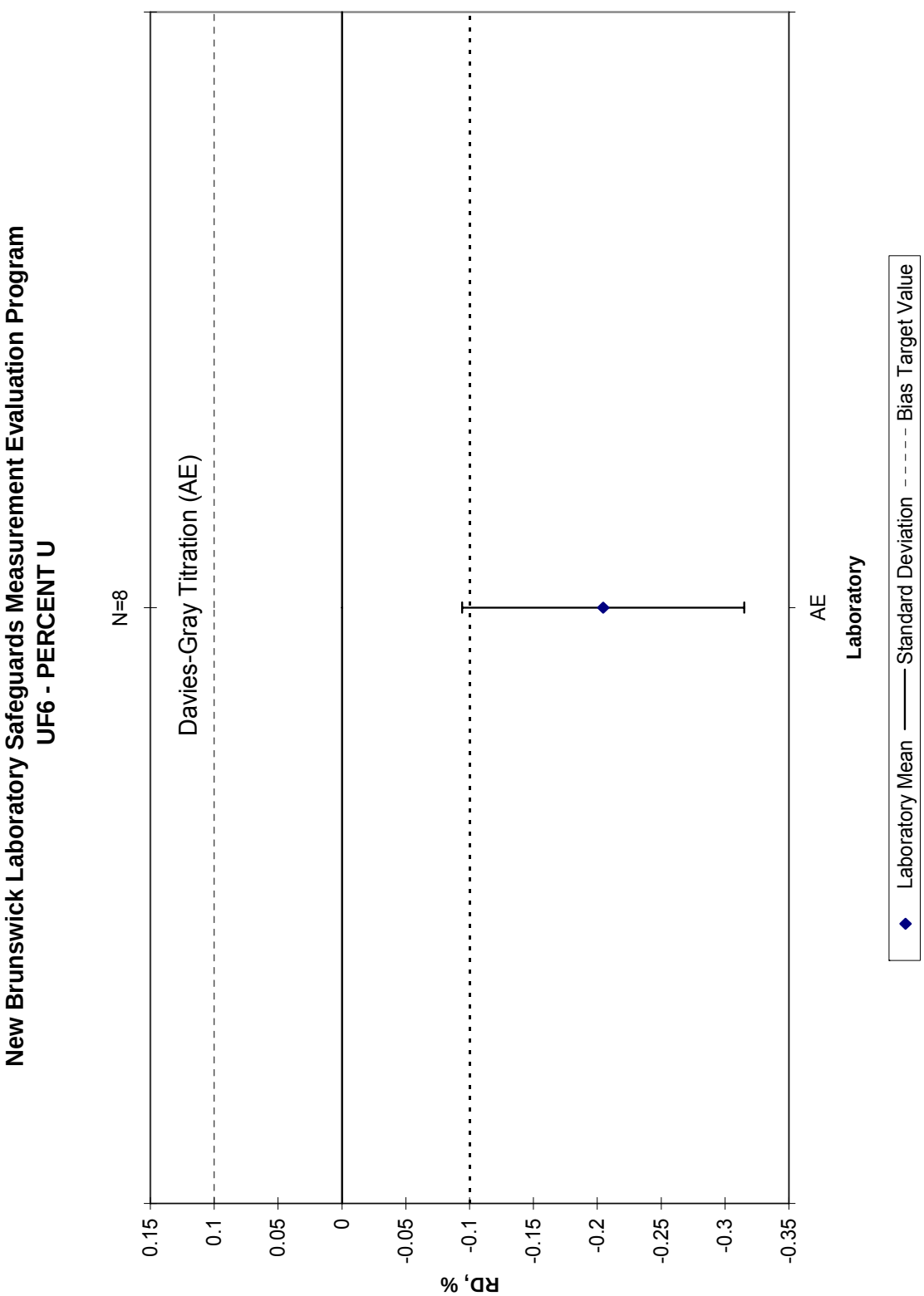
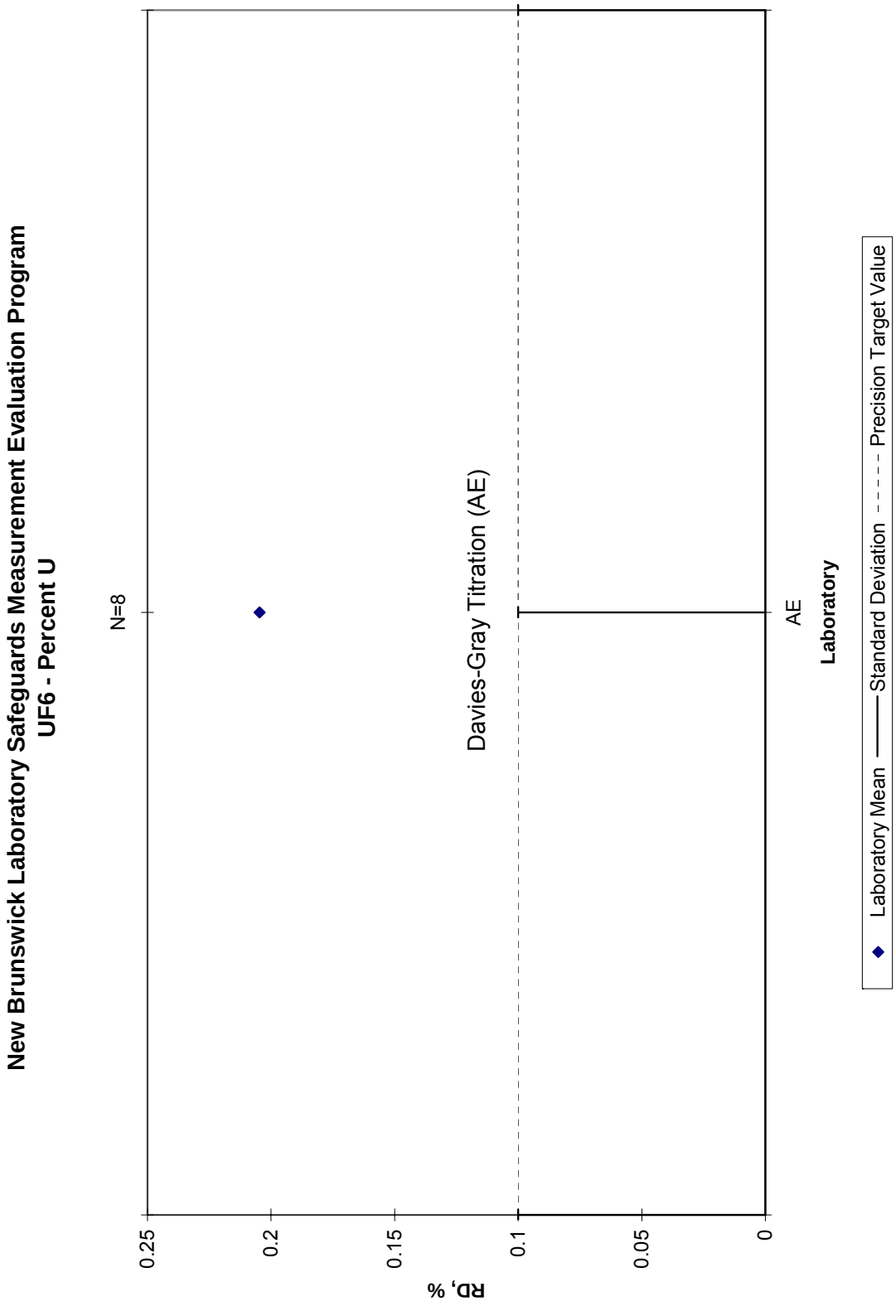

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UF6 - PERCENT U
Davies-Gray Titration (AE)
N=8
RD, %
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
AE
Laboratory
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 8**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
UF6 - Percent U
N=8
Davies-Gray Titration (AE)
RD, %
0.25
0.2
0.15
0.1
0.05
0
AE
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

### E.4. $^{235}$U Enrichment

A suite of enriched uranium test samples are available for evaluating isotopic abundance results. Highly-Enriched Uranium (HEU) test samples include three uranyl nitrate solutions with 90% enrichment, and one uranyl nitrate solution with 50% enrichment. Low-Enriched Uranium (LEU) samples comprise one uranyl nitrate solution with 4% enrichment, solid $UO_2$ pellets of about 4% enrichment, $UO_3$ powder of about 0.8% enrichment, and $UF_6$ solid of varying enrichments (from depleted uranium to 4.8 % in $^{235}$U).

#### E.4 1. Preparation and Packaging for Shipment

The uranyl nitrate solutions are in flame-sealed glass ampoules with break-off tips. The ampoules are sealed in plastic, wrapped in absorbent cushioning, sealed in plastic again, and packaged in cardboard tubes for shipping. Each solution contains 5-10 mg uranium/g solution.

The $UO_2$ pellets are packaged in a snap-cap glass bottle with a low-lint tissue for cushioning to prevent chipping. The glass bottles are sealed in plastic, and packaged in cardboard tubes for shipping.

The $UF_6$ test samples in P-10 tubes are packed in sealed plastic bags and shipped in cardboard containers with screw caps.

#### E.4.2. Reference Value and Uncertainty

The uranium isotopic abundances in the UNH, $UO_2$, and $UO_3$ test materials were characterized by thermal ionization mass spectrometry (TIMS). The experimental results were corrected for mass fractionation effects. The correction factors were determined through analyses of appropriate Certified Reference Materials performed under the same conditions as the test materials

$UF_6$ material was characterized by TIMS and/or gas source mass spectrometry (GSMS). The TIMS measurements required hydrolyzed $UF_6$ samples, whereas the GSMS measurements were performed directly.

The estimated uncertainties (95% C.L.) in $^{235}U$ abundance are as follows: 0.02% for the 4% enriched uranyl nitrate solution; < 0.01% for the 50% and 90% enriched solutions; 0.07% for $UO_2$ pellets; and ≤ 0.05% for $UF_6$.

### E.4.3. Performance Evaluation

The mean % RDs are shown in Table 7 for LEU materials (< 20% enriched), in Table 8 for $UF_6$ materials, and in Table 9 for HEU materials (> 20% enriched). Target values are also shown in the tables.

LEU analysis by TIMS: The % RDs along with standard deviations for the LEU material are shown in Fig. 9 to evaluate bias and in Fig.10 to evaluate precision. Laboratory T met the target values for both bias and precision. Figures 9 and 10 show that TIMS analyses reported by laboratory T are biased. The precision in the data, however, allows correction of this bias. Laboratory AA failed to meet the bias target value in the TIMS analysis of $UO_2$ bias; it missed both bias and precision target values for hydrolyzed $UF_6$.

LEU analysis by ICPMS: Bias and precision target values are not available for ICPMS; instead TIMS target values are used in the evaluation. Laboratory BE missed both bias and precision target values in $UO_2$ analysis. Laboratory EA met both target values in the analysis of hydrolyzed $UF_6$ material and in UNH material.

**Table 7. Inter-laboratory performance summary for $^{235}U$ enrichment in LEU**

| Method | Material | Lab Code | Mean %RD | Standard deviation | N | ITV | |
|---|---|---|---|---|---|---|---|
| | | | | | | Bias | Precision |
| TIMS | UO2 | T | 0.050396 | 0.029064 | 8 | 0.1 | 0.1 |
| | UO2 | T | 0.028566 | 0.018562 | 8 | 0.1 | 0.1 |
| | UO2 | AA | -0.127987 | 0.044229 | 8 | 0.1 | 0.1 |
| | UO2 | BC | 0.02919 | 0.092469 | 8 | 0.1 | 0.1 |
| | UF6(Hydrolyzed) | AA | 0.122452 | 0.165237 | 8 | 0.1 | 0.1 |
| ICPMS | UO2 | BE | -0.433192 | 0.206566 | 15 | N/A# | N/A# |
| | UNH | EA | -0.00945 | 0.022567 | 8 | N/A# | N/A# |
| | UF6(Hydrolyzed) | EA | 0.04672 | 0.036772 | 16 | N/A# | N/A# |

# ITVs not available for ICPMS; TIMS target values are used instead.

**Figure 9**

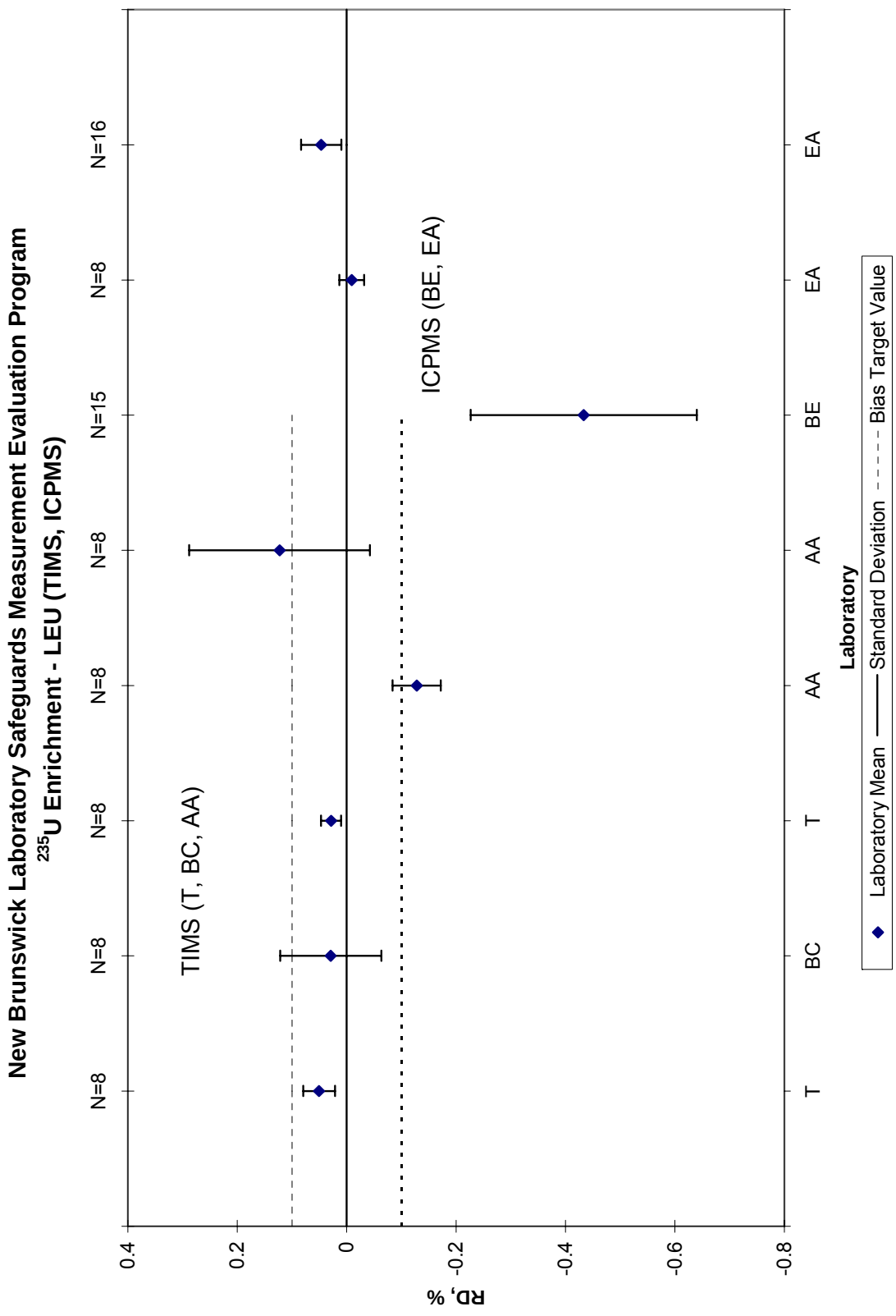
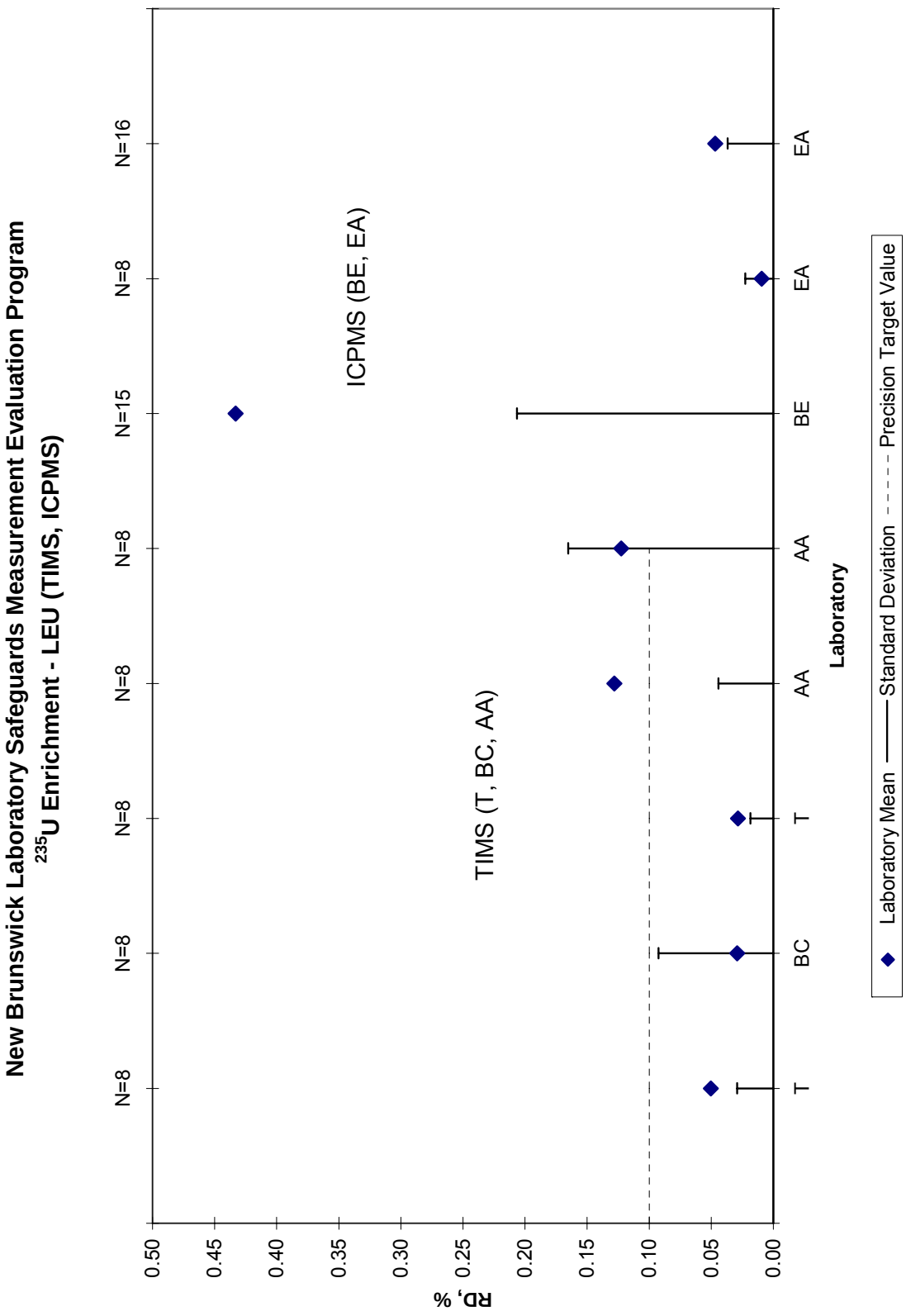

New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - LEU (TIMS, ICPMS)
TIMS (T, BC, AA)
ICPMS (BE, EA)
N=8
N=8
N=8
N=8
N=8
N=15
N=8
N=16
T
BC
T
AA
AA
BE
EA
EA
Laboratory
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
RD, %
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 10**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - LEU (TIMS, ICPMS)
RD, %
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
TIMS (T, BC, AA)
ICPMS (BE, EA)
N=8
N=8
N=8
N=8
N=15
N=8
N=16
T
BC
T
AA
AA
BE
EA
EA
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

LEU analysis by GSMS: Only one laboratory (BC) participated in the GSMS analysis of $UF_6$ material; the results were within the bias target value, but the precision missed the target value. The evaluations are shown in Figs. 11 and 12.

**Table 8. Inter-laboratory performance summary for $^{235}U$ enrichment in $UF_6$**

| Method | Lab Code | Mean %RD | Standard deviation | N | ITV | |
|---|---|---|---|---|---|---|
| | | | | | Bias | Precision |
| GSMS | BC | 0.016934 | 0.250105 | 12 | 0.05 | 0.05 |

**Figure 11**

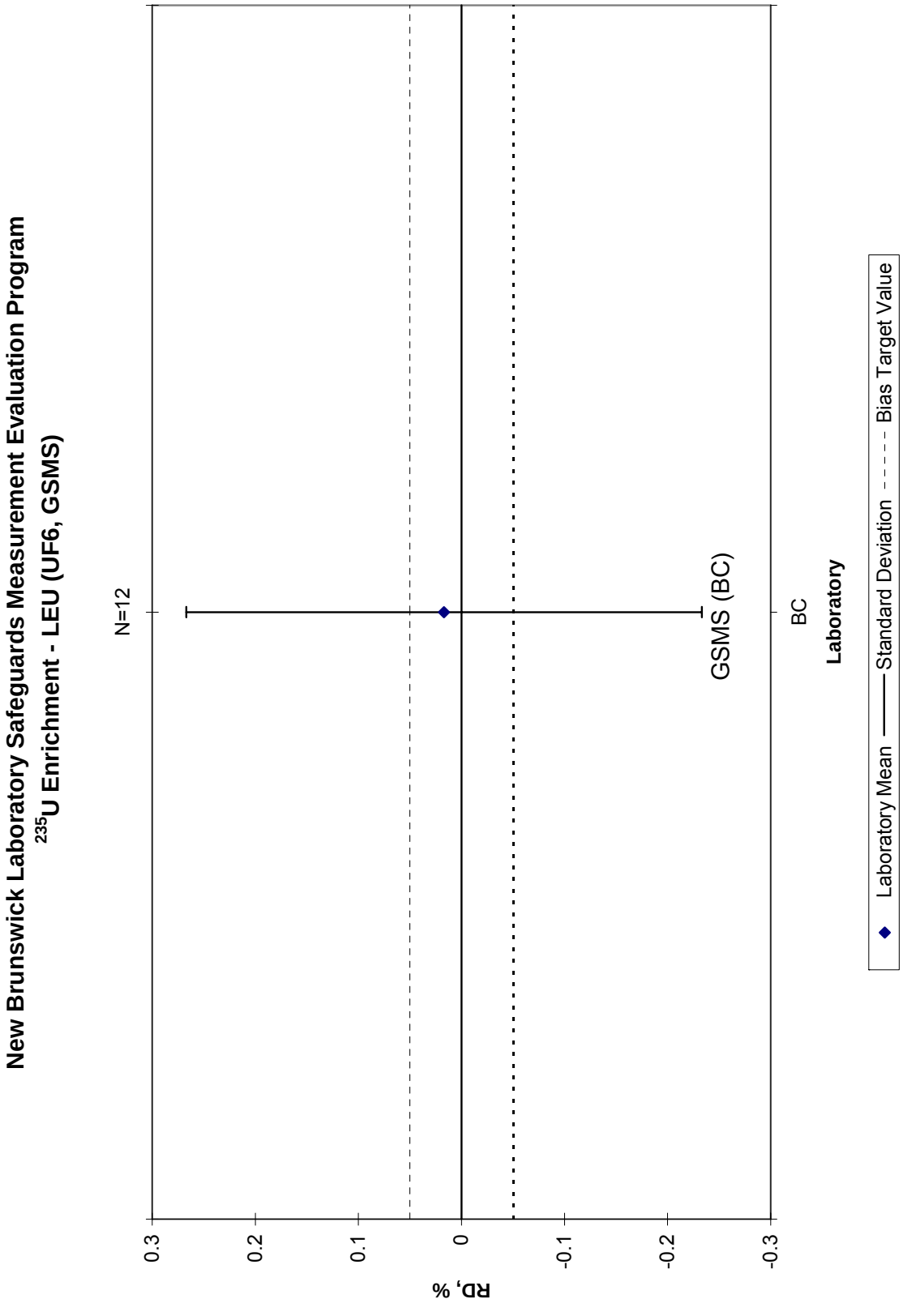
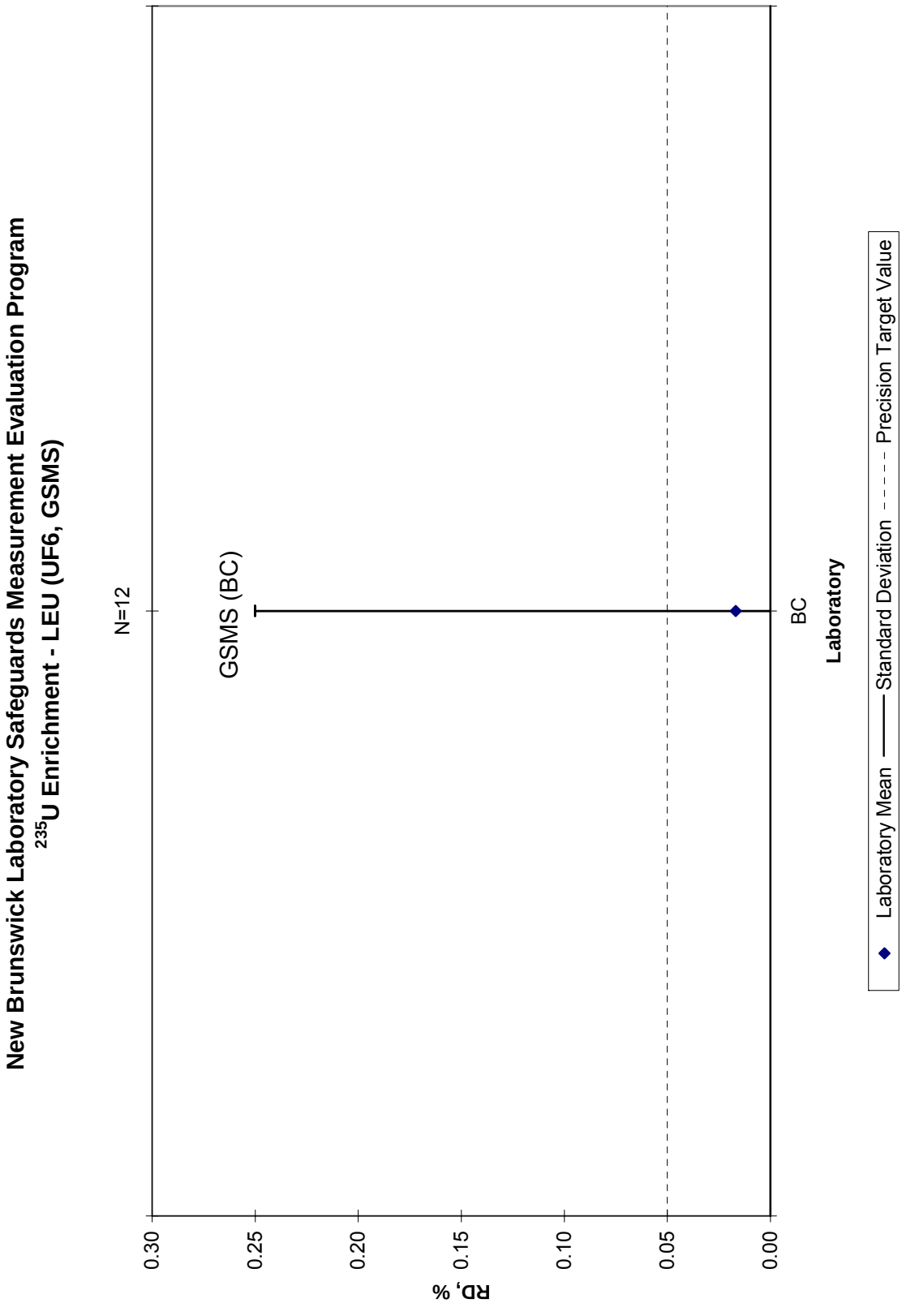

New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - LEU (UF6, GSMS)
N=12
GSMS (BC)
BC
Laboratory
RD, %
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 12**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - LEU (UF6, GSMS)
N=12
GSMS (BC)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
RD, %
BC
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

HEU analysis by TIMS: Three laboratories analyzed the HEU samples (UNH solutions) using TIMS. All three laboratories were able to measure $^{235}U$ abundance within the bias target value. Laboratories F and W were able to meet the precision target values whereas laboratory B missed it. The % RDs along with standard deviations are shown in Fig.13 to evaluate bias and in Fig.14 to evaluate precision.

**Table 9. Inter-laboratory performance summary for $^{235}U$ enrichment in HEU**

| Method | Lab Code | Mean %RD | Standard deviation | N | ITV | |
|---|---|---|---|---|---|---|
| | | | | | Bias | Precision |
| TIMS | B | 0.058385 | 0.166425 | 16 | 0.1 | 0.1 |
| | F | 0.003274 | 0.0164 | 16 | 0.1 | 0.1 |
| | W | 0.008732 | 0.011985 | 15 | 0.1 | 0.1 |

**Figure 13**

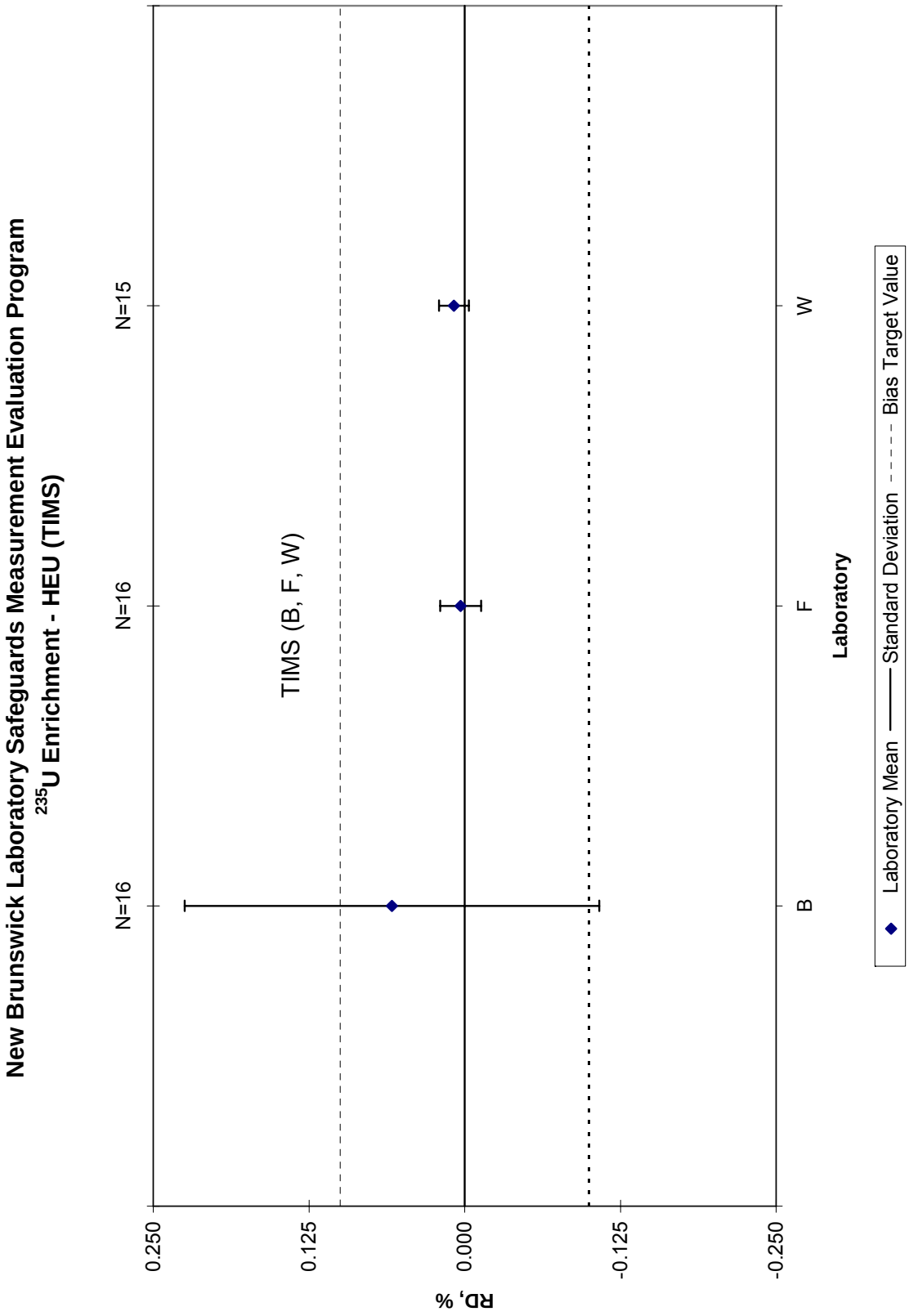
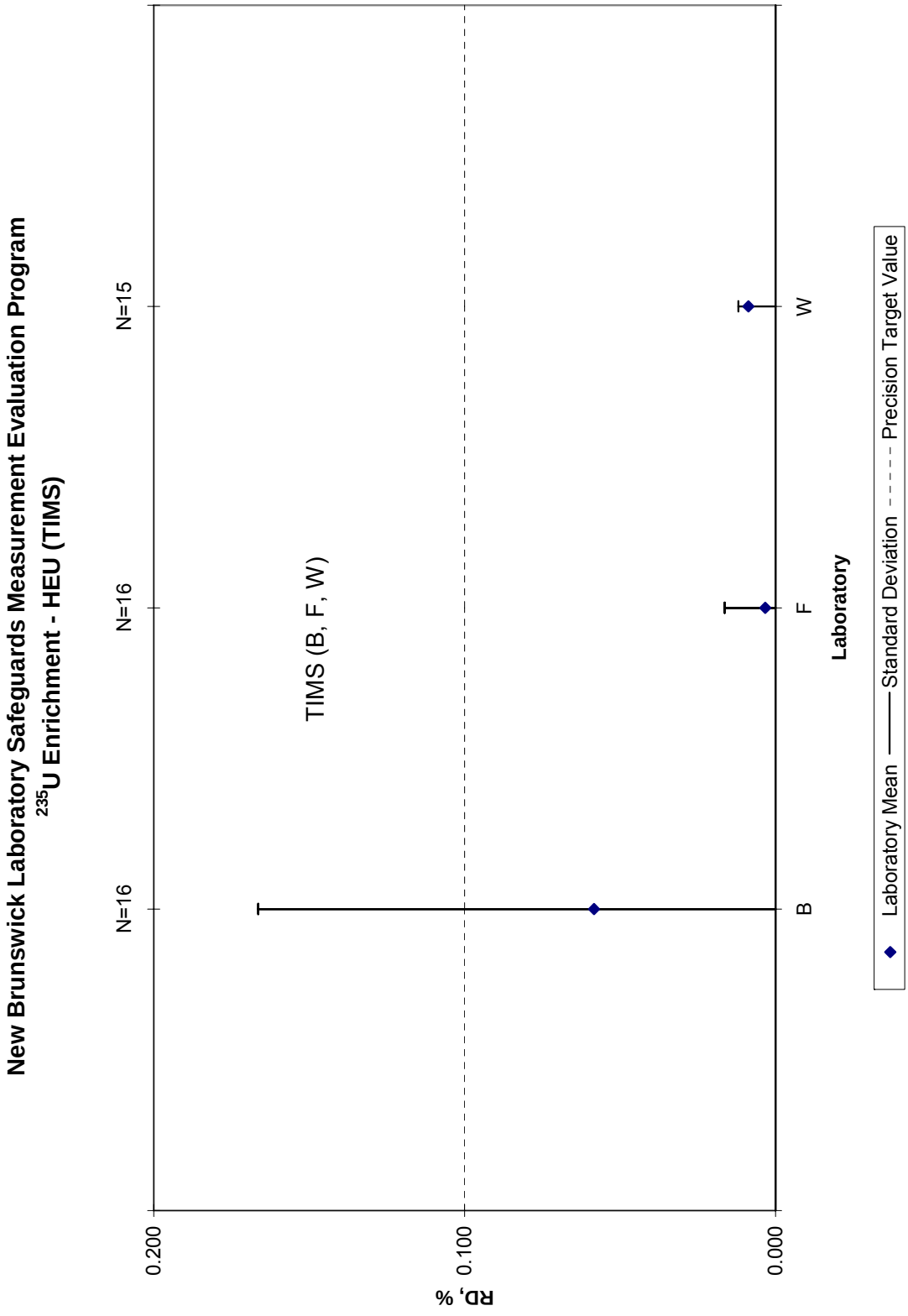

New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - HEU (TIMS)
TIMS (B, F, W)
N=16
N=16
N=15
0.250
0.125
0.000
-0.125
-0.250
RD, %
B
F
W
Laboratory
Laboratory Mean
Standard Deviation
Bias Target Value

**Figure 14**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
235U Enrichment - HEU (TIMS)
TIMS (B, F, W)
N=16
N=16
N=15
0.200
0.100
0.000
RD, %
B
F
W
Laboratory
Laboratory Mean
Standard Deviation
Precision Target Value

## F. LONG TERM EVALUTION OF URANIUM MEASUREMENTS, July 2003 - JUNE 2007

In this section, the uranium assay and isotopic abundances results are evaluated over a long-term period (4 years) for each laboratory. The long-term trends are good indicators for evaluating consistency in performance, and for identifying improvements made and problems encountered in analytical work.

The % RDs calculated from the submitted results are shown in Figs. 15 to 63. Each figure in this section (Figs. 15 to 63) shows results from a laboratory for a particular material/method combination. For example, Fig. 15 shows results from laboratory A for uranyl nitrate solution analyzed by IDMS and Fig. 16 shows results from the same laboratory for the analysis of the same solution by a different method (XRF-Liquid).

**Figure 15**

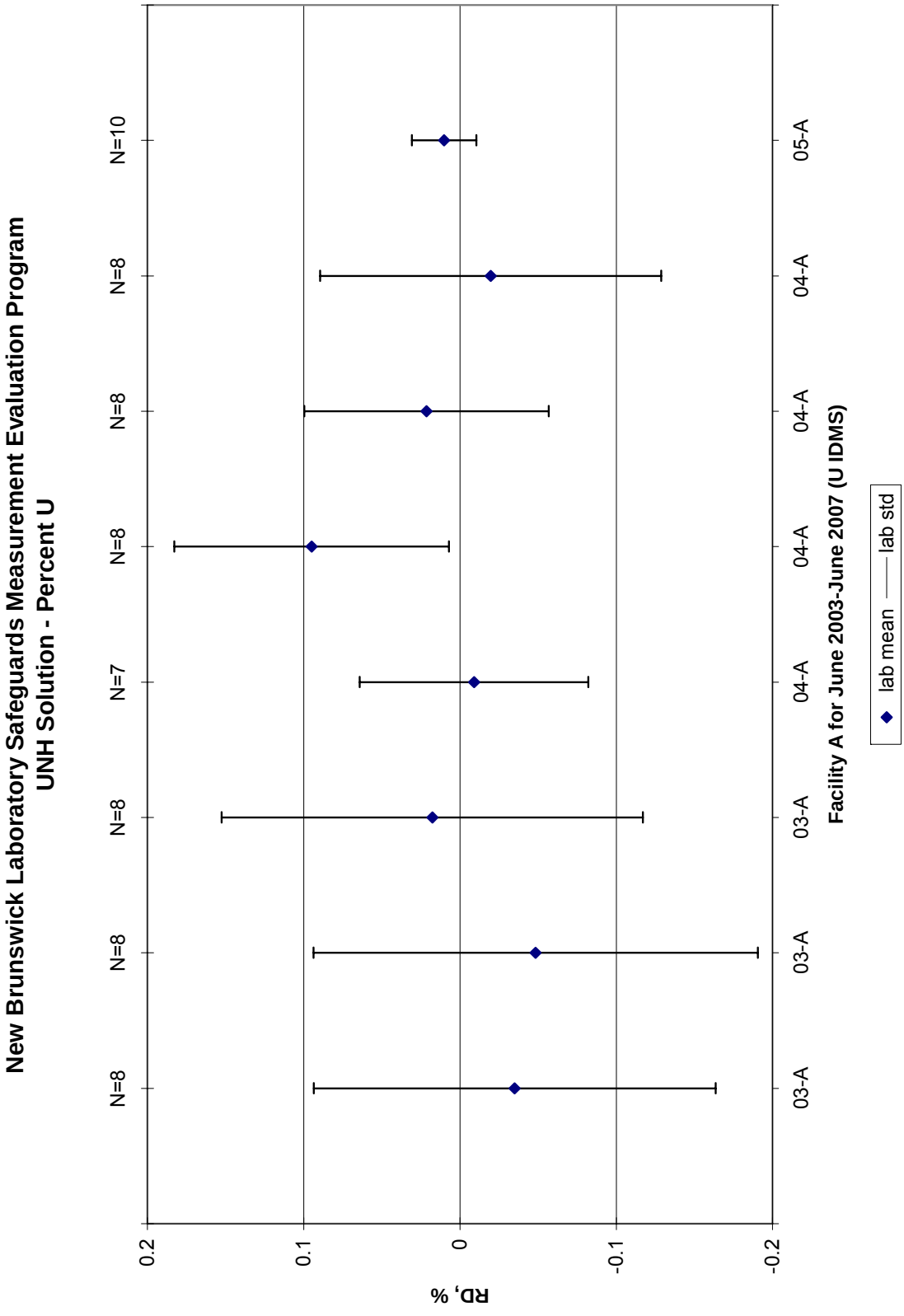

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
0.2
0.1
0
-0.1
-0.2
N=8
N=8
N=8
N=7
N=8
N=8
N=8
N=10
03-A
03-A
04-A
03-A
04-A
04-A
04-A
05-A
Facility A for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 16**

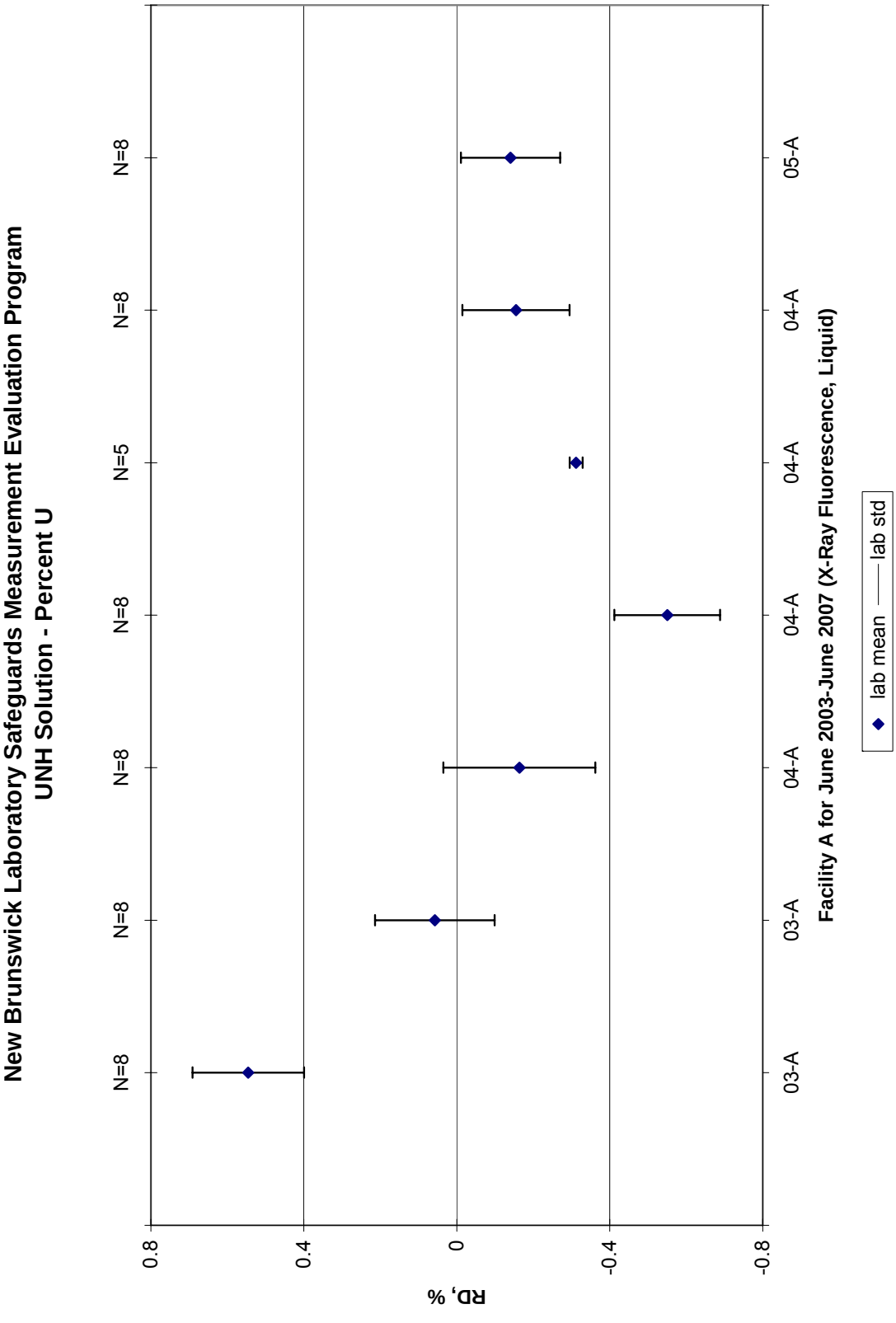

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
Facility A for June 2003-June 2007 (X-Ray Fluorescence, Liquid)
RD, %
0.8
0.4
0
-0.4
-0.8
N=8
N=8
N=8
N=5
N=8
N=8
03-A
03-A
04-A
04-A
04-A
04-A
05-A
lab mean
lab std

**Figure 17**

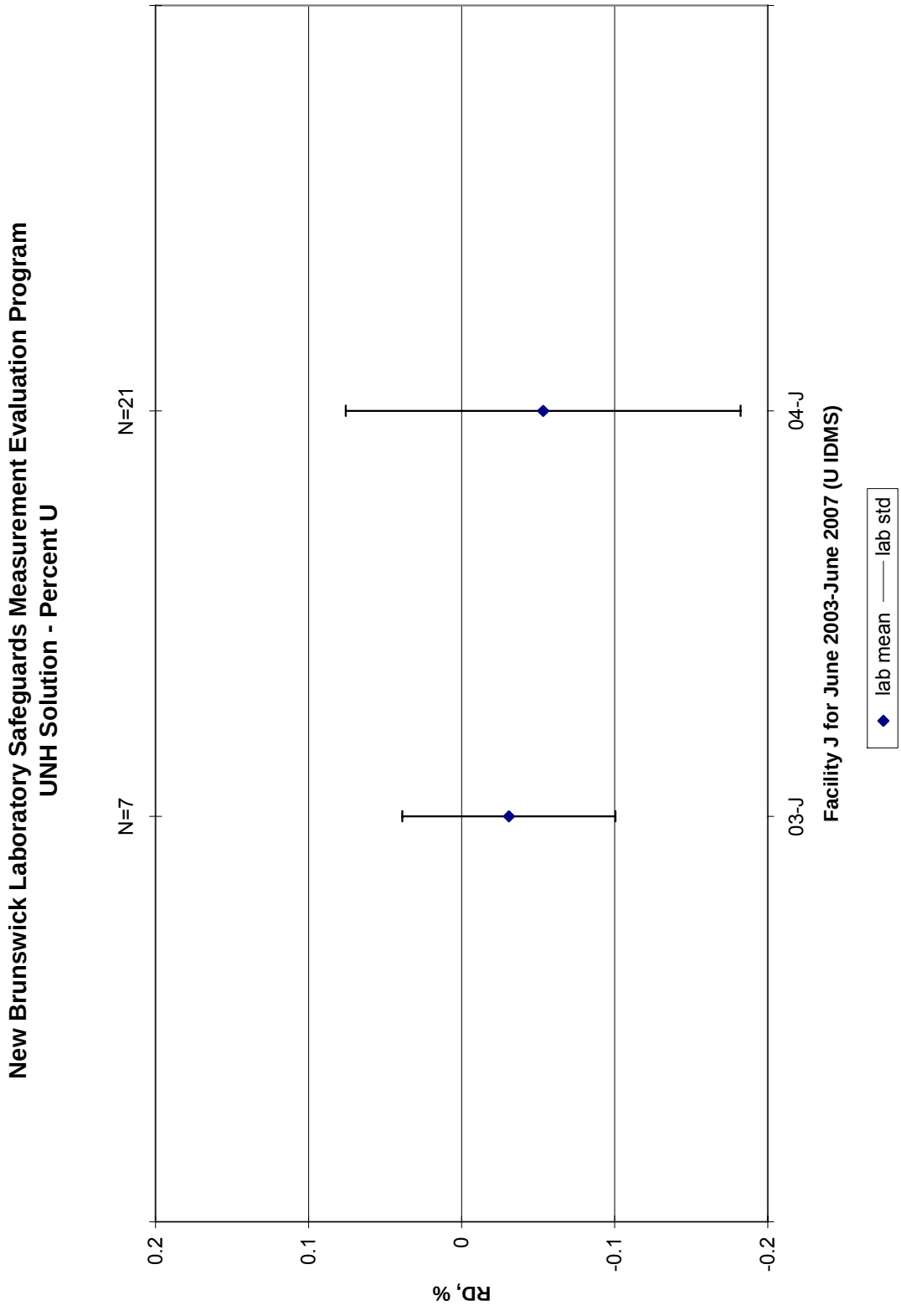

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
0.2
0.1
0
-0.1
-0.2
N=7
N=21
03-J
04-J
Facility J for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 18**

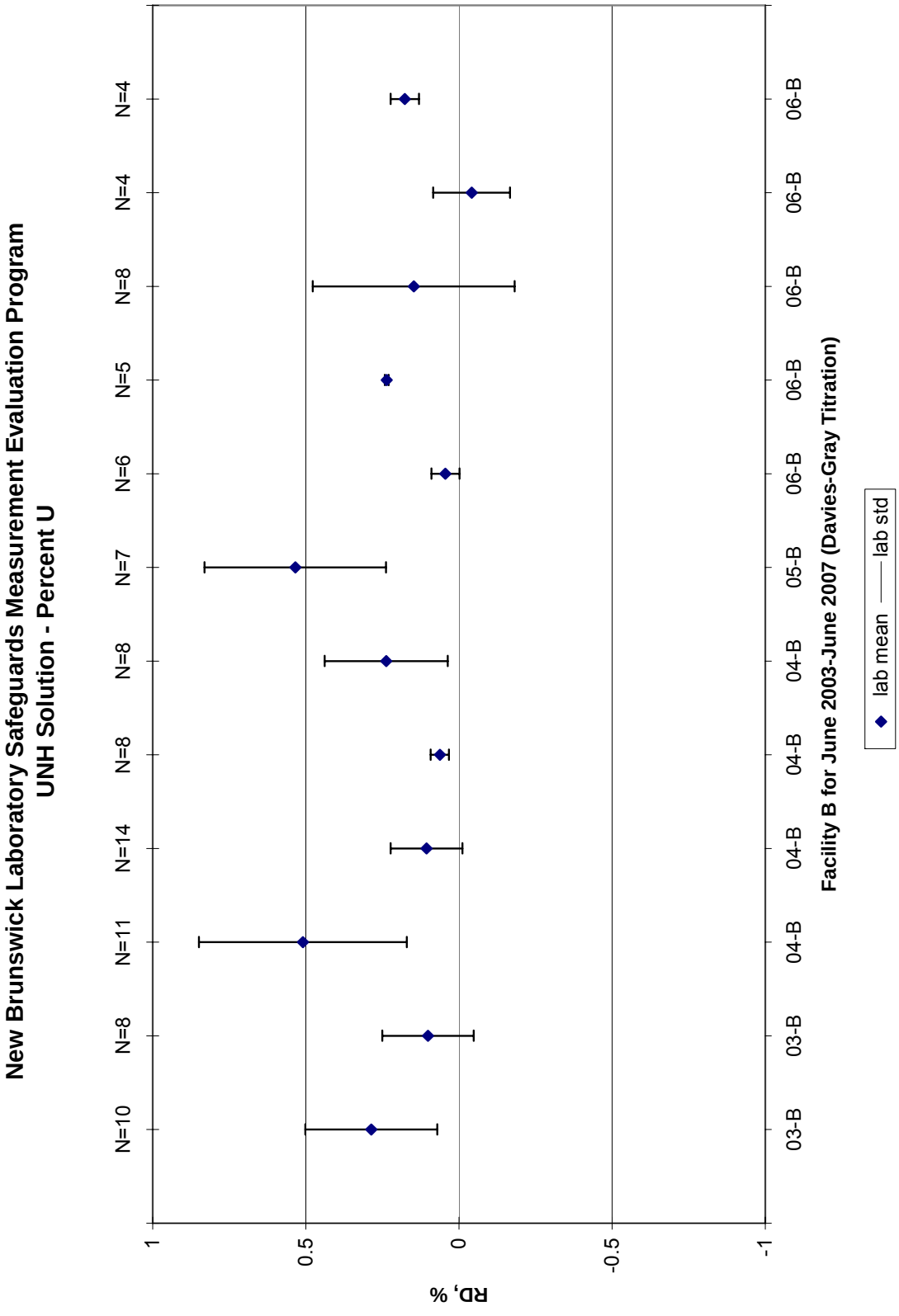

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
1
0.5
0
-0.5
-1
N=10
N=8
N=11
N=14
N=8
N=8
N=7
N=6
N=5
N=8
N=4
N=4
03-B
03-B
04-B
04-B
04-B
04-B
05-B
06-B
06-B
06-B
06-B
06-B
Facility B for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 19**

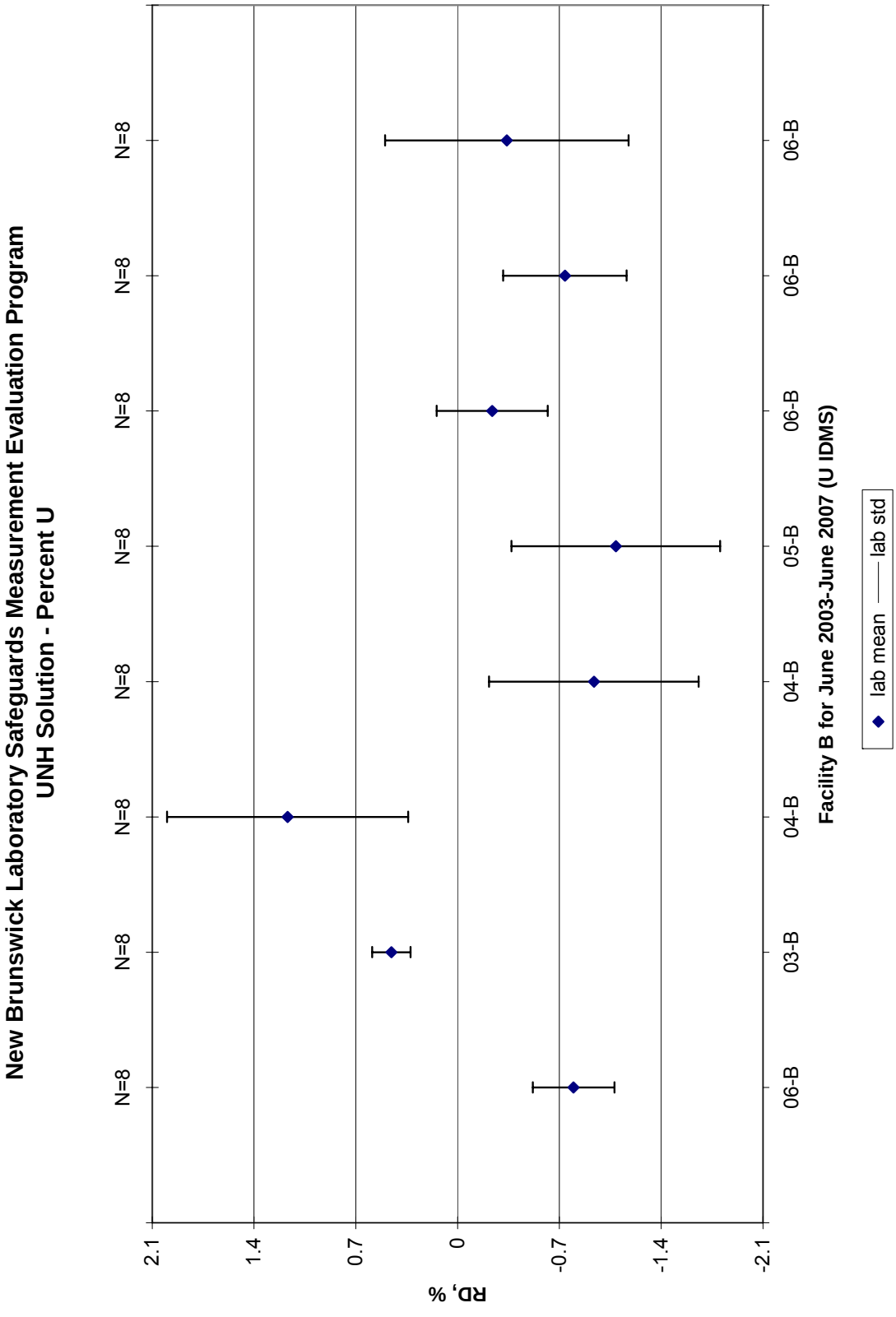

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
2.1
1.4
0.7
0
-0.7
-1.4
-2.1
N=8
06-B
03-B
04-B
05-B
06-B
Facility B for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 20**

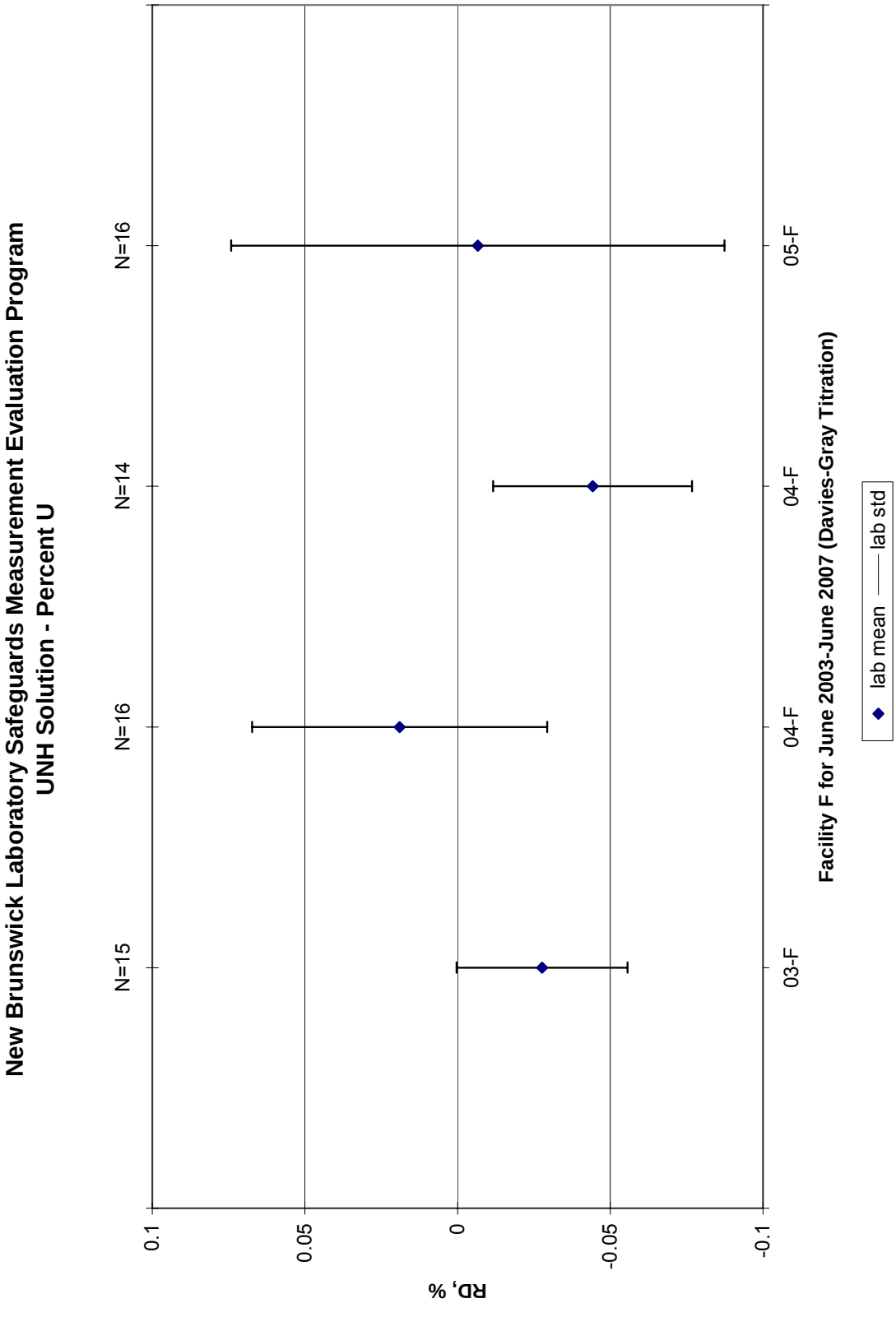

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
0.1
0.05
0
-0.05
-0.1
N=15
N=16
N=14
N=16
03-F
04-F
04-F
05-F
Facility F for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 21**

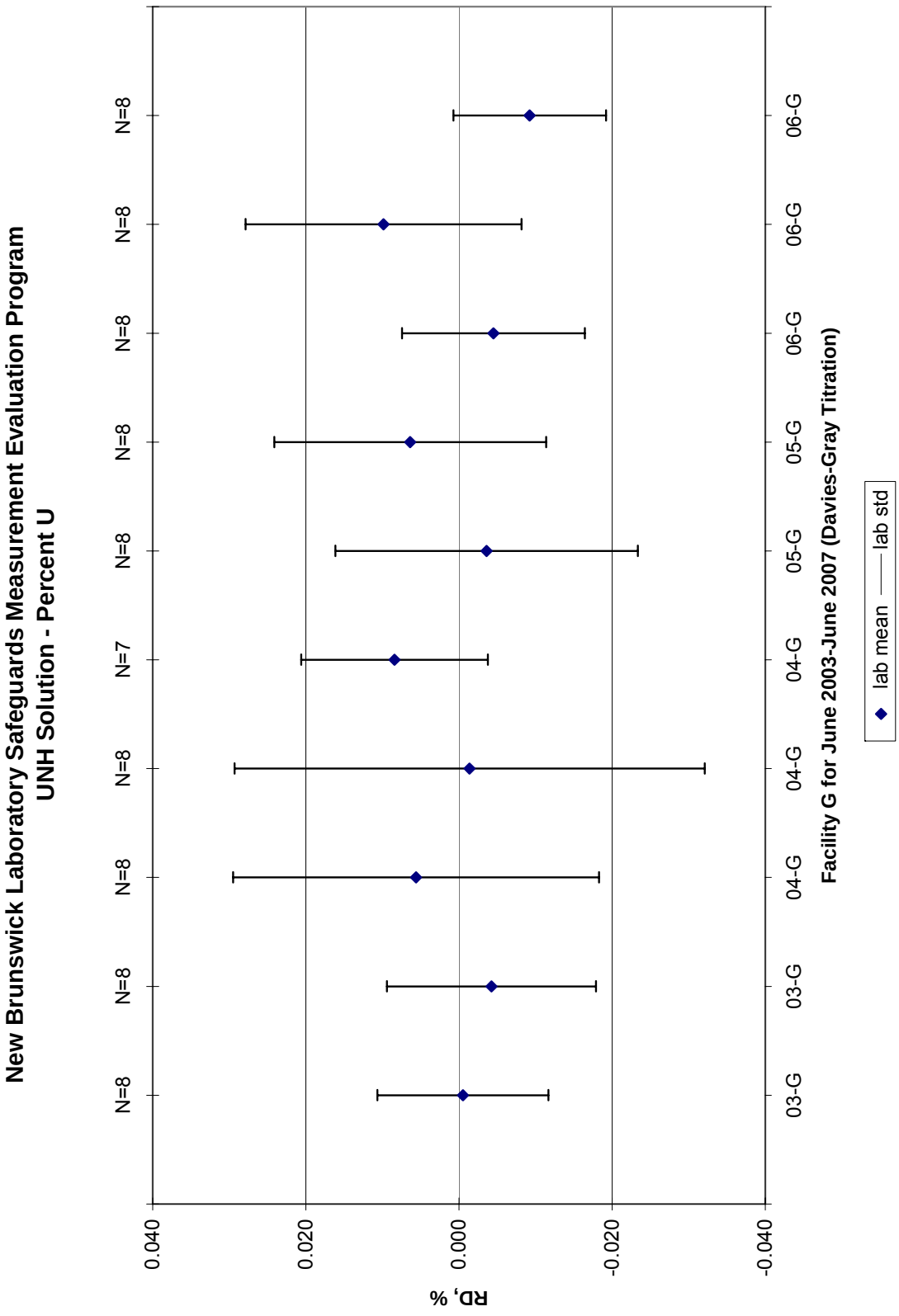

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
0.040
0.020
0.000
-0.020
-0.040
N=8
N=8
N=8
N=8
N=7
N=8
N=8
N=8
03-G
03-G
04-G
04-G
04-G
05-G
05-G
06-G
06-G
06-G
Facility G for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 22**

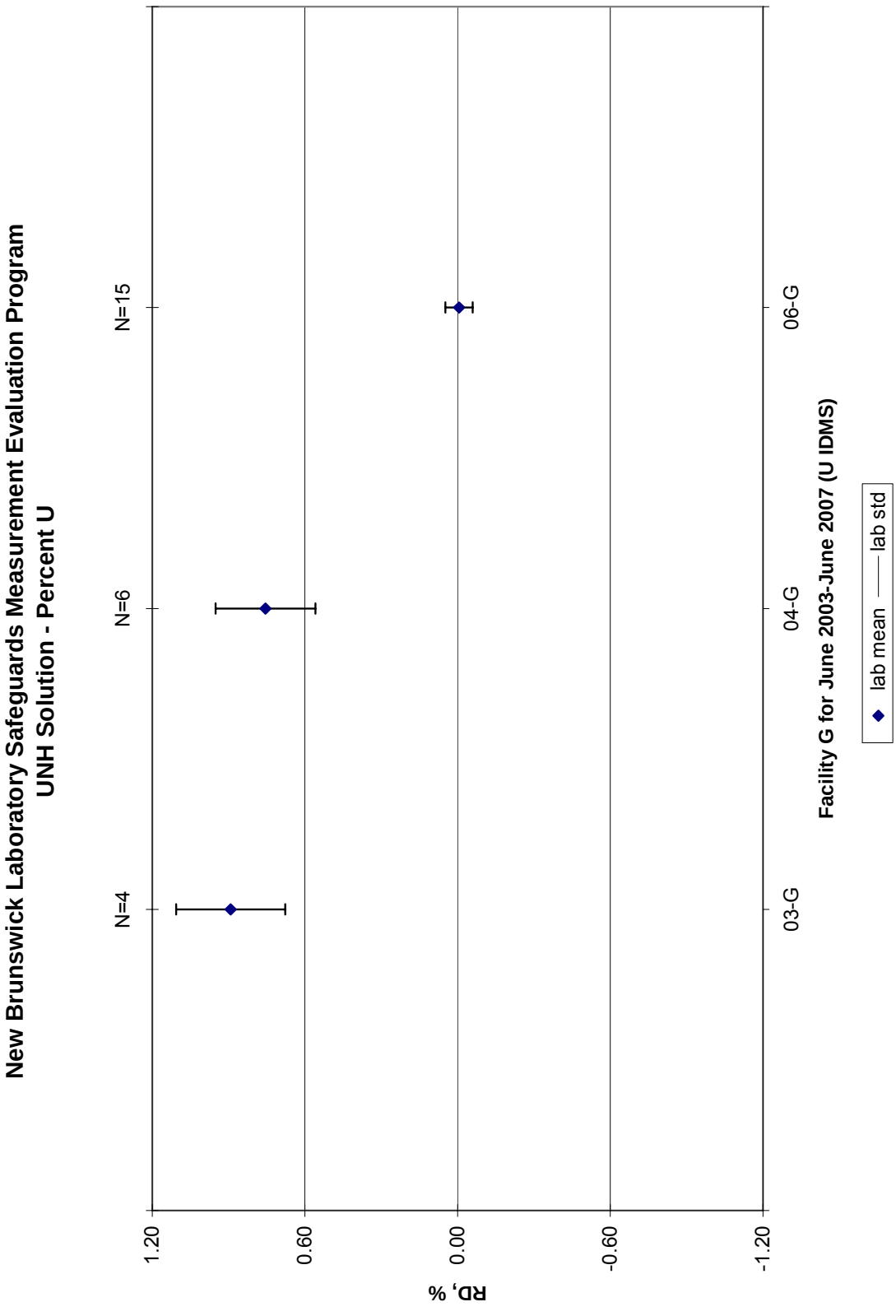

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
RD, %
1.20
0.60
0.00
-0.60
-1.20
N=4
N=6
N=15
03-G
04-G
06-G
Facility G for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 23**

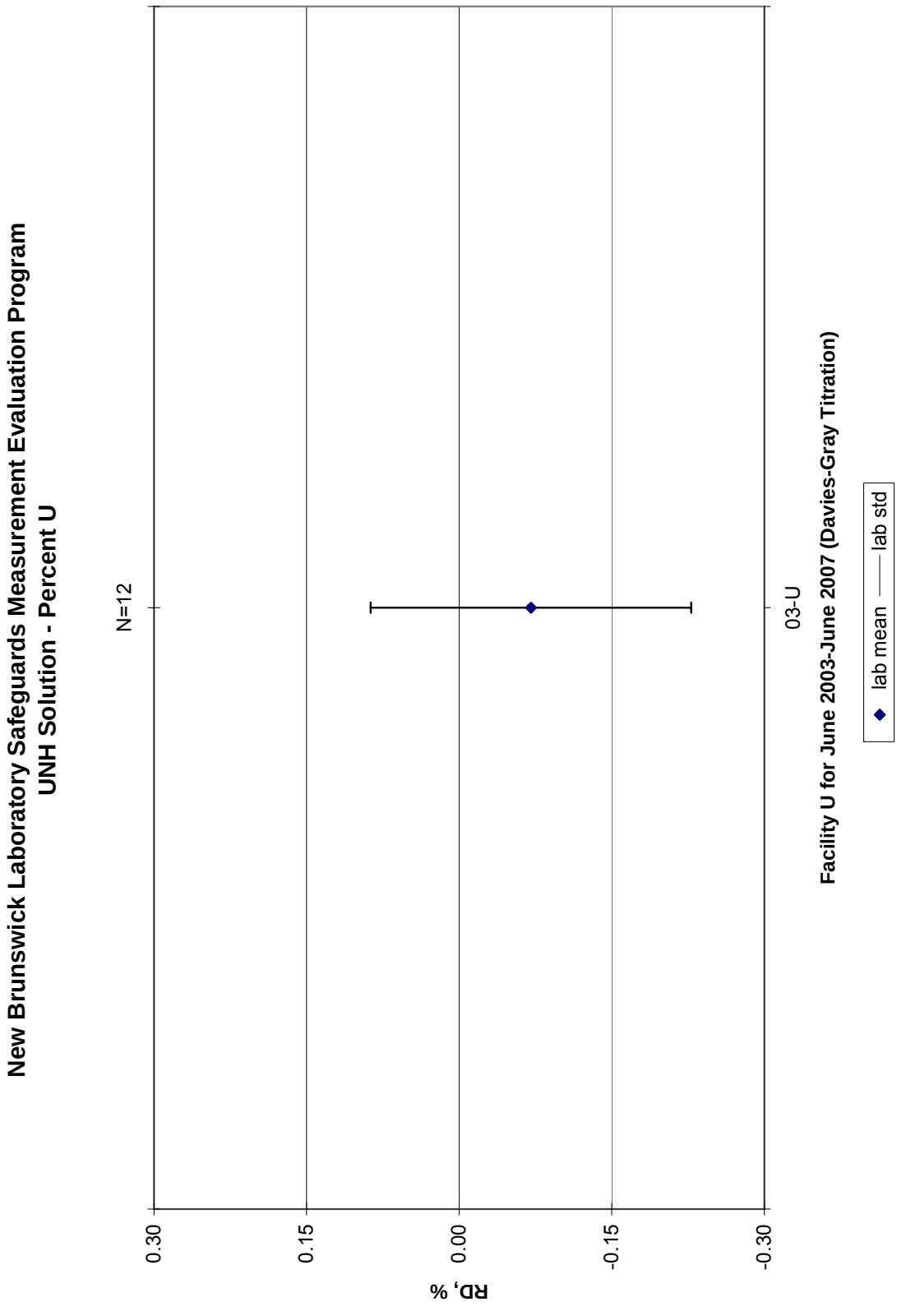

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
N=12
0.30
0.15
0.00
-0.15
-0.30
RD, %
03-U
Facility U for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 24**

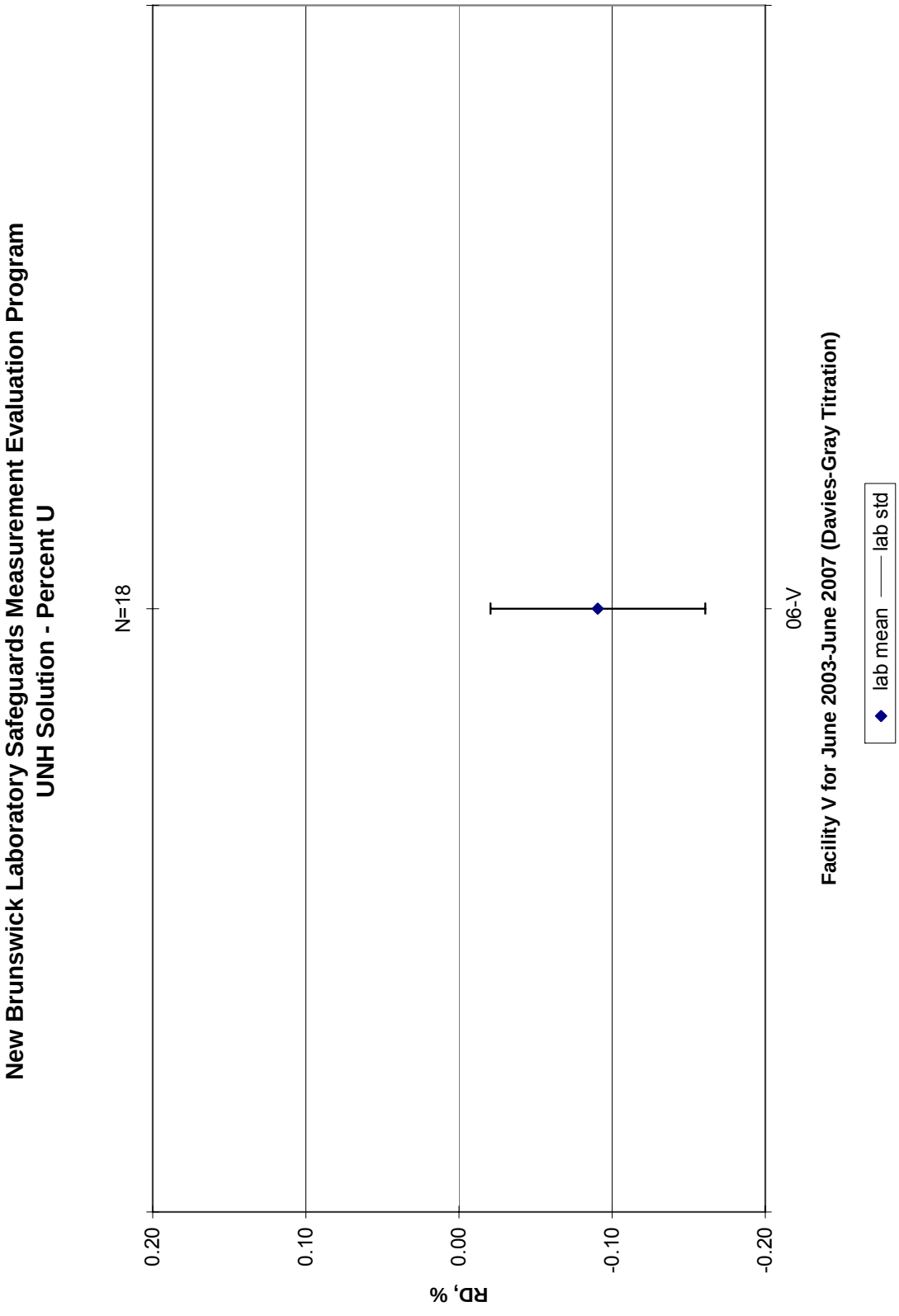

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UNH Solution - Percent U
N=18
06-V
RD, %
0.20
0.10
0.00
-0.10
-0.20
Facility V for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 25**

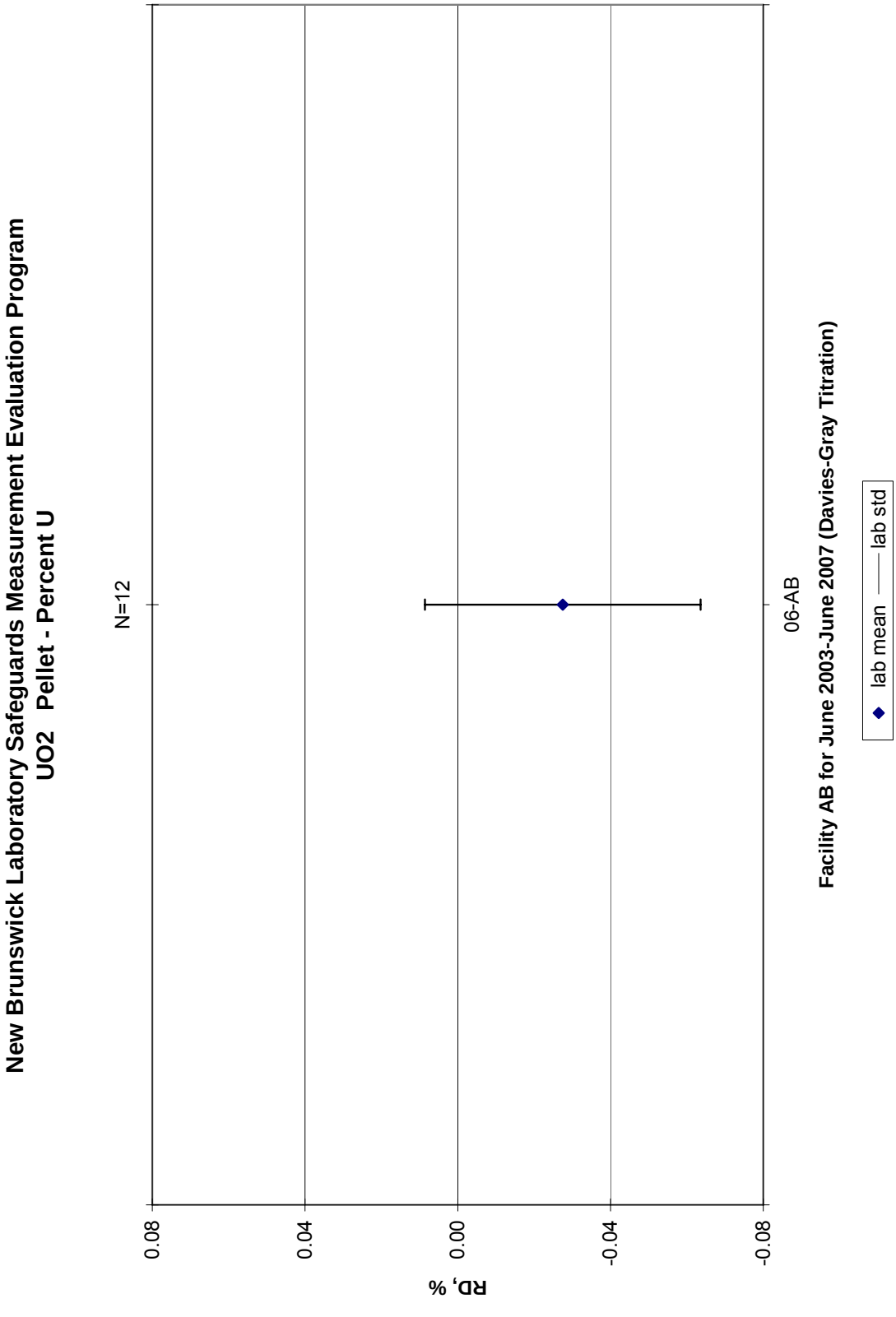

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
N=12
0.08
0.04
0.00
-0.04
-0.08
RD, %
06-AB
Facility AB for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 26**

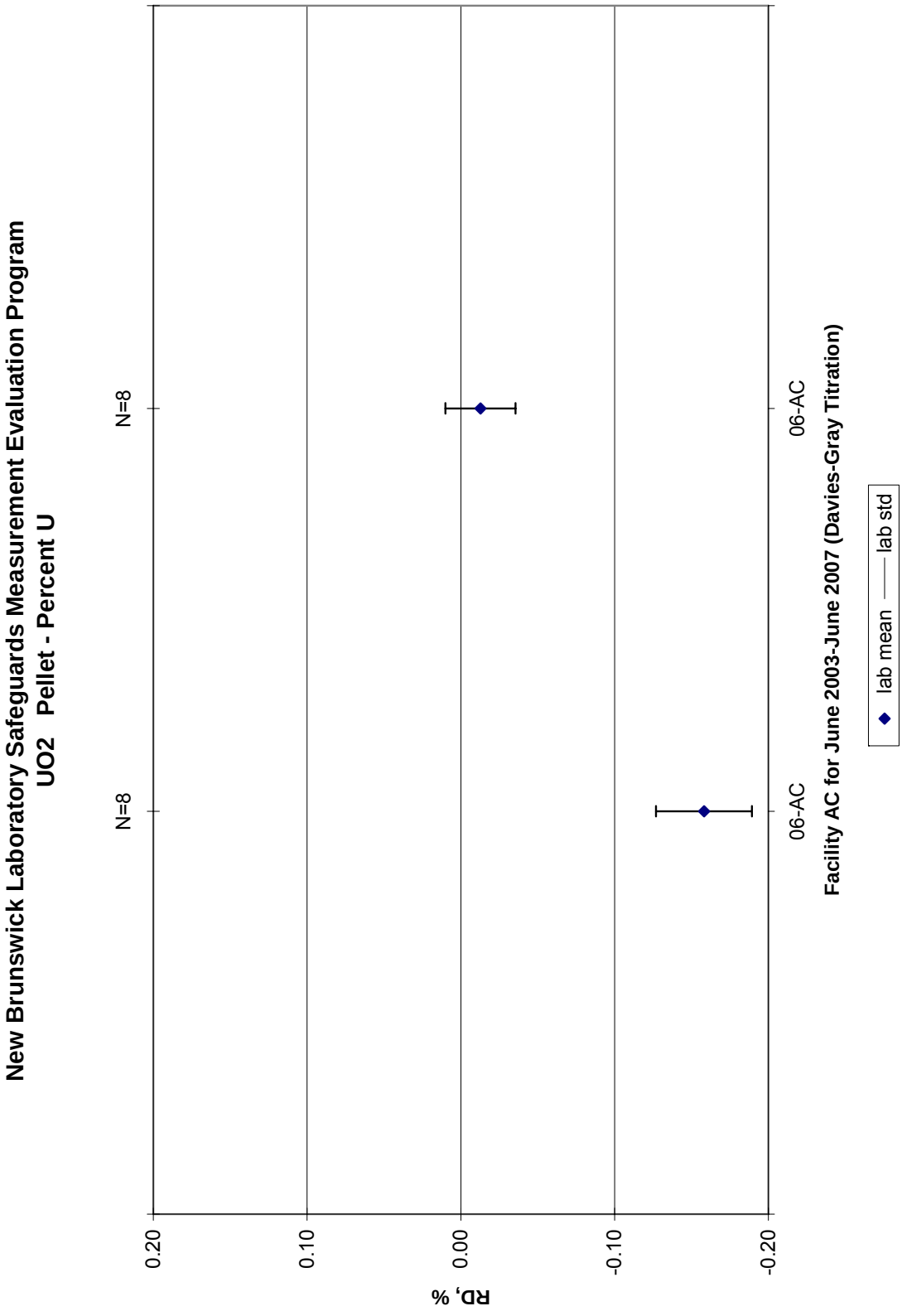

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.20
0.10
0.00
-0.10
-0.20
N=8
N=8
06-AC
06-AC
Facility AC for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 27**

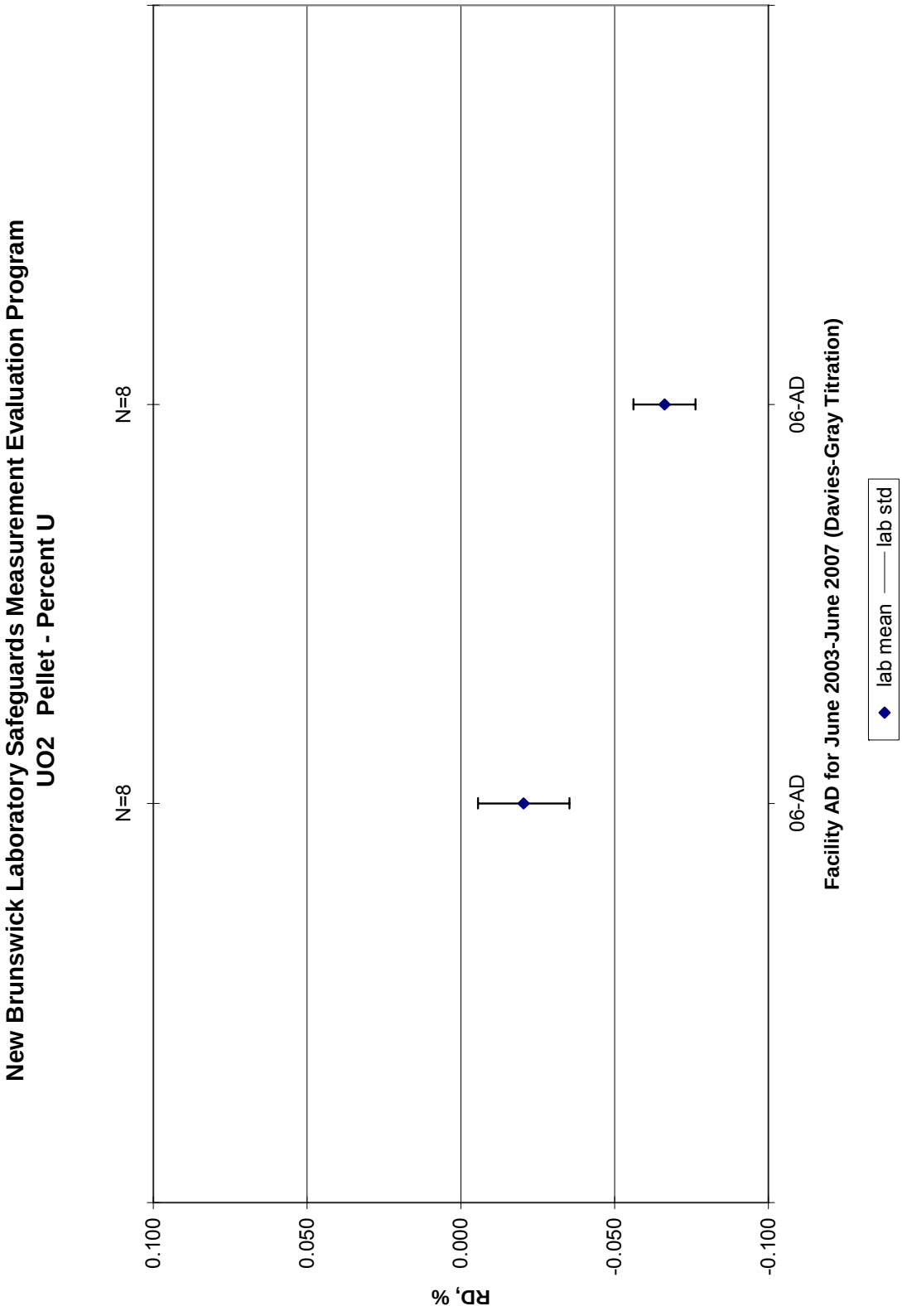

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.100
0.050
0.000
-0.050
-0.100
N=8
N=8
06-AD
06-AD
Facility AD for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 28**

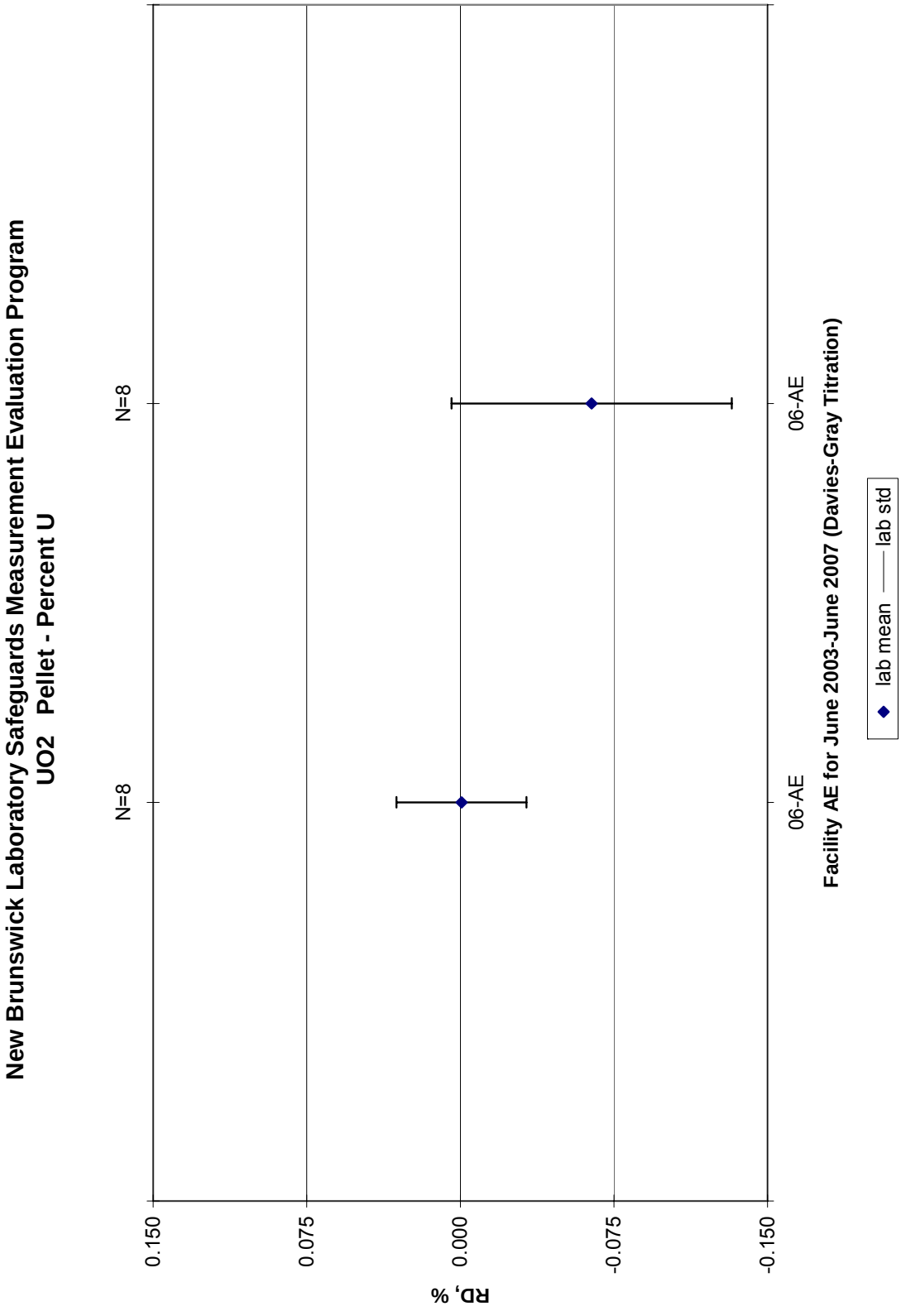

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.150
0.075
0.000
-0.075
-0.150
N=8
N=8
06-AE
06-AE
Facility AE for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 29**

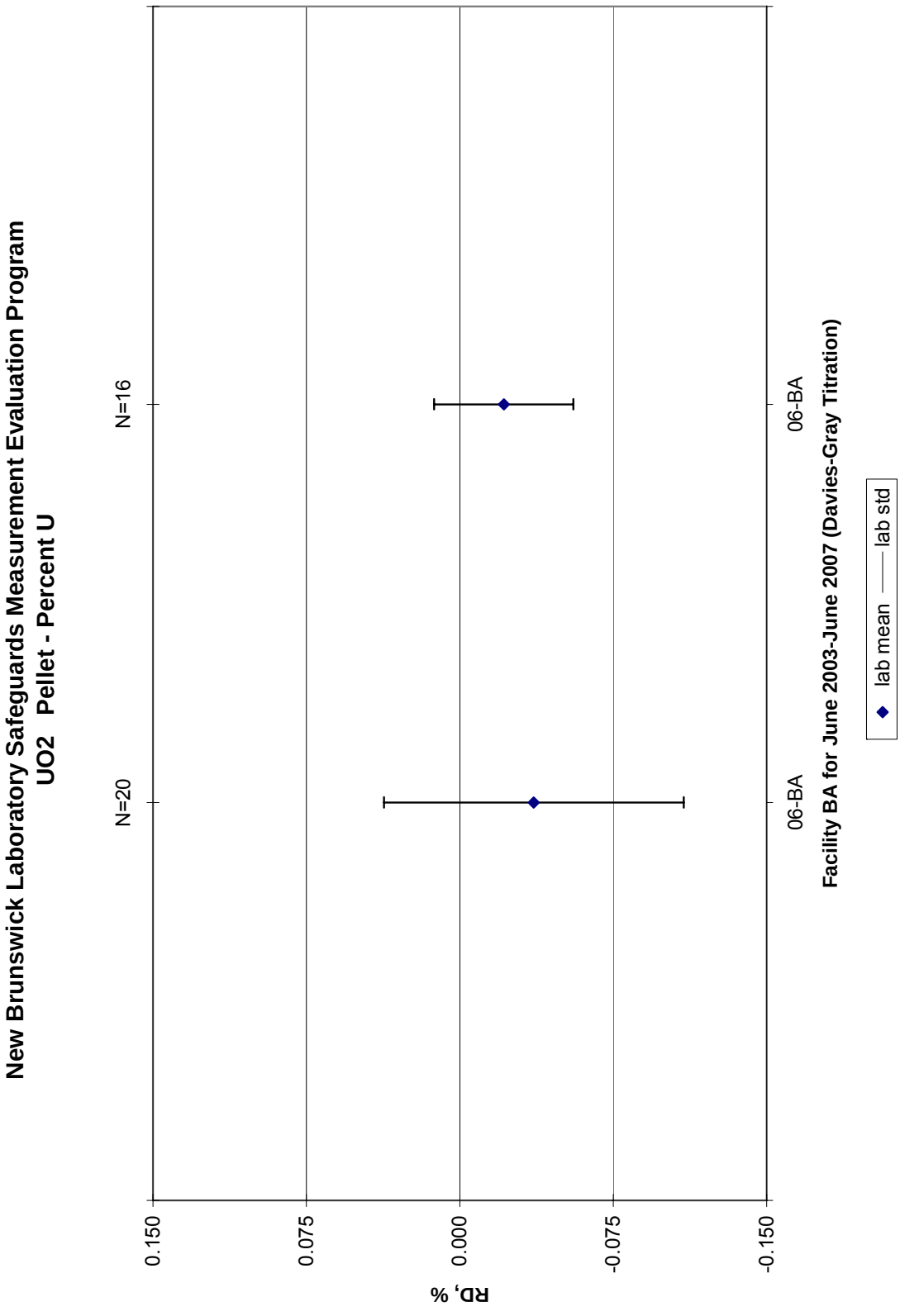

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.150
0.075
0.000
-0.075
-0.150
N=20
N=16
06-BA
06-BA
Facility BA for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 30**

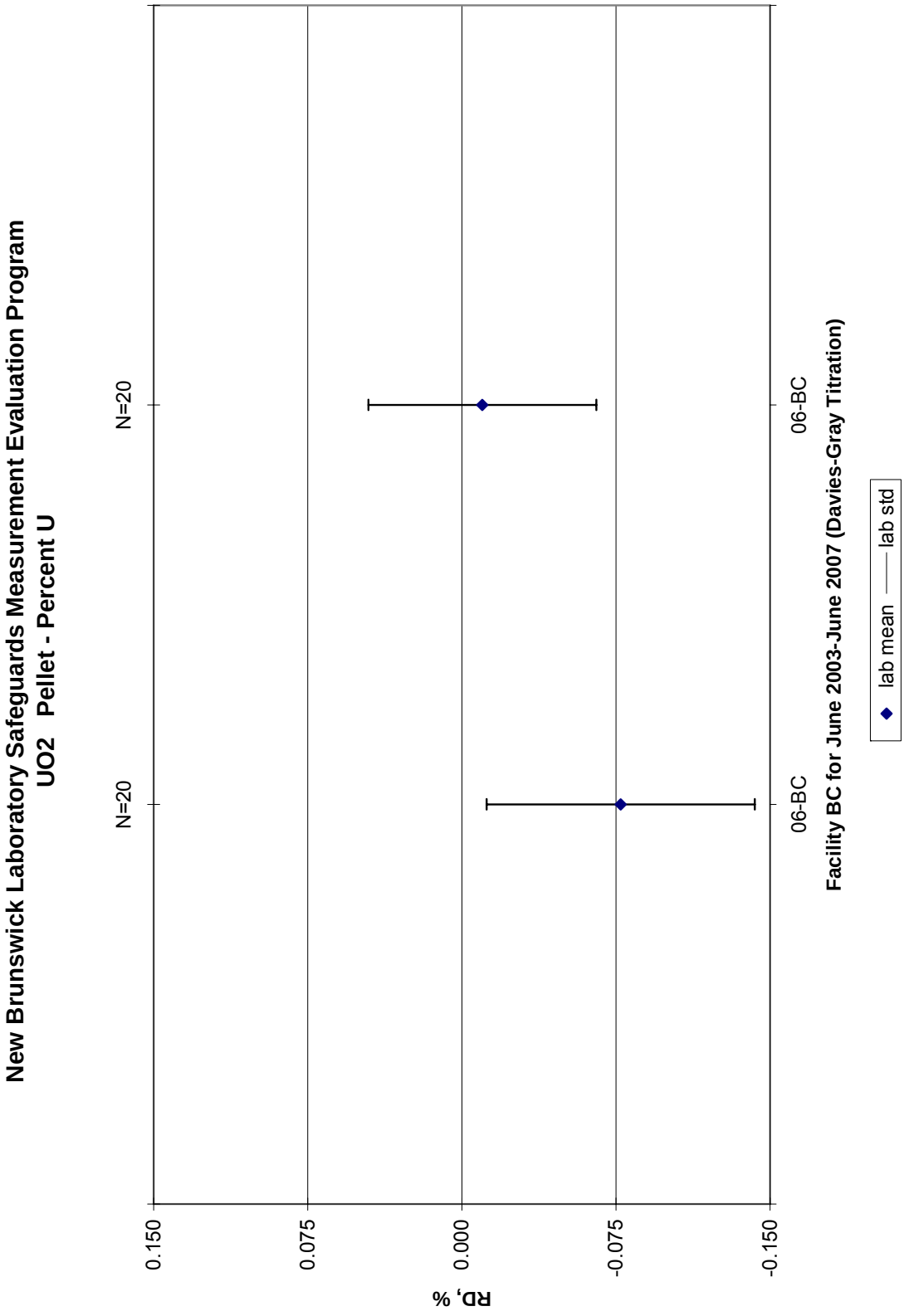

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.150
0.075
0.000
-0.075
-0.150
N=20
N=20
06-BC
06-BC
Facility BC for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 31**

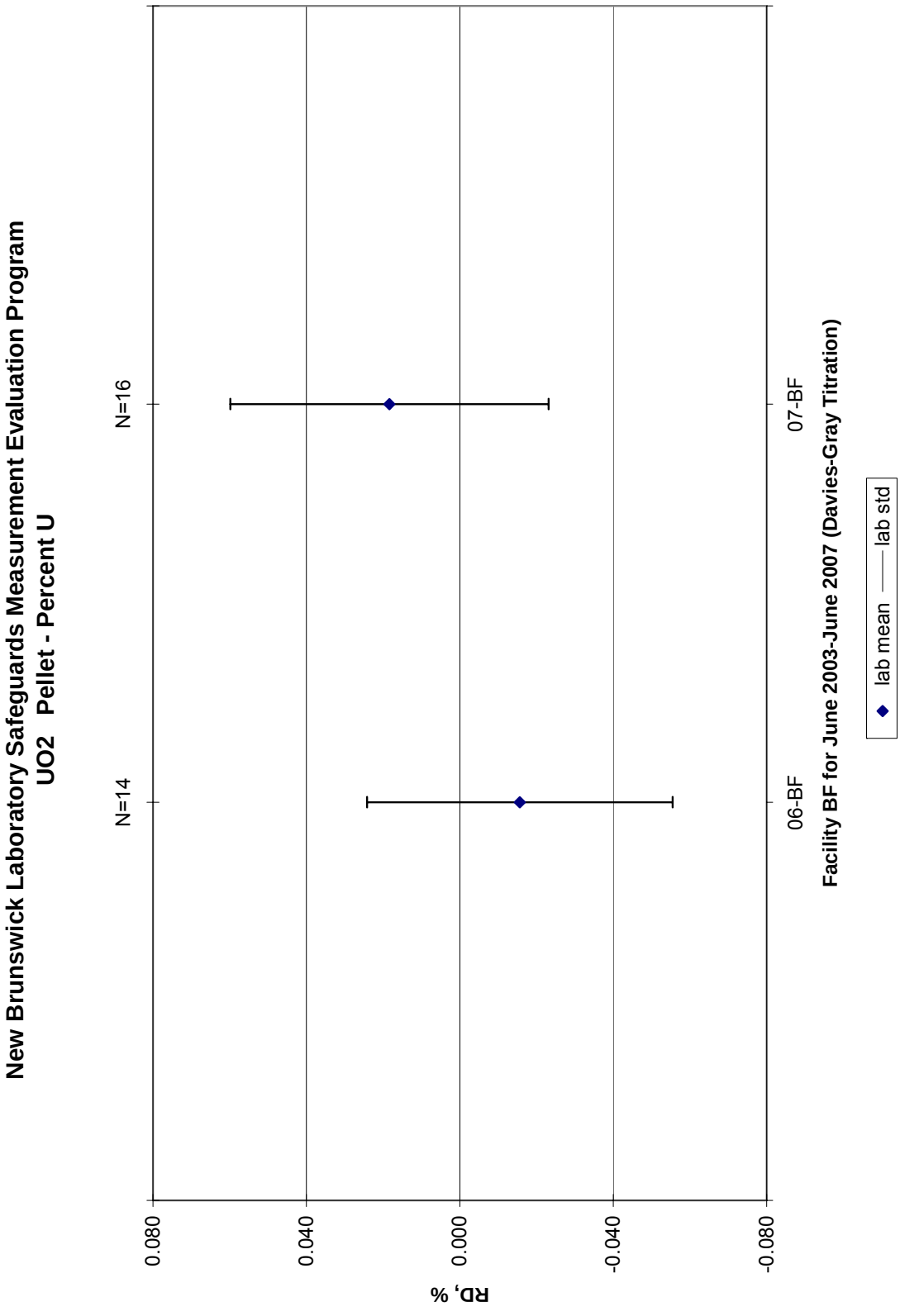

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.080
0.040
0.000
-0.040
-0.080
N=14
N=16
06-BF
07-BF
Facility BF for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 32**

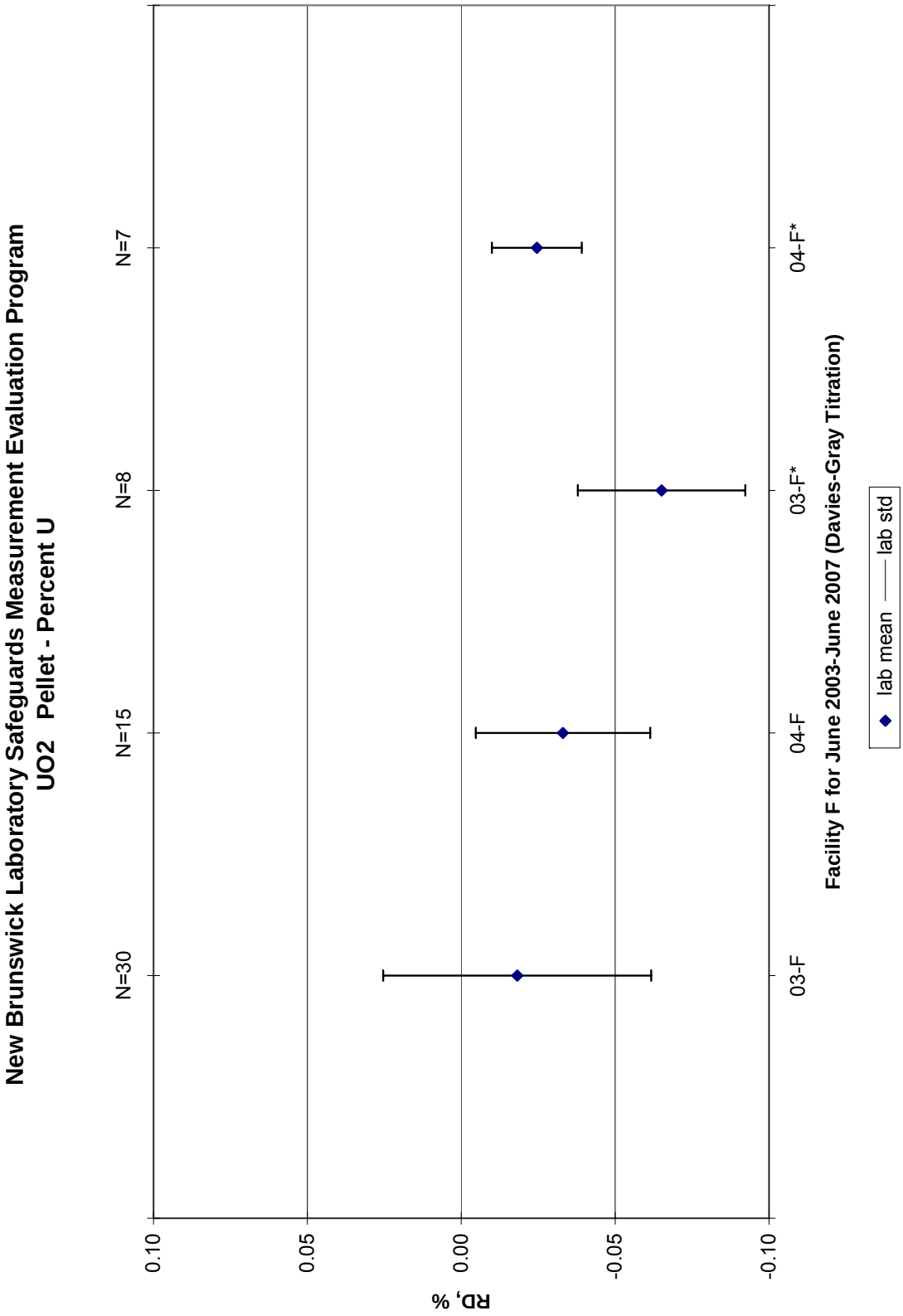

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.10
0.05
0.00
-0.05
-0.10
N=30
N=15
N=8
N=7
03-F
04-F
03-F*
04-F*
Facility F for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 33**

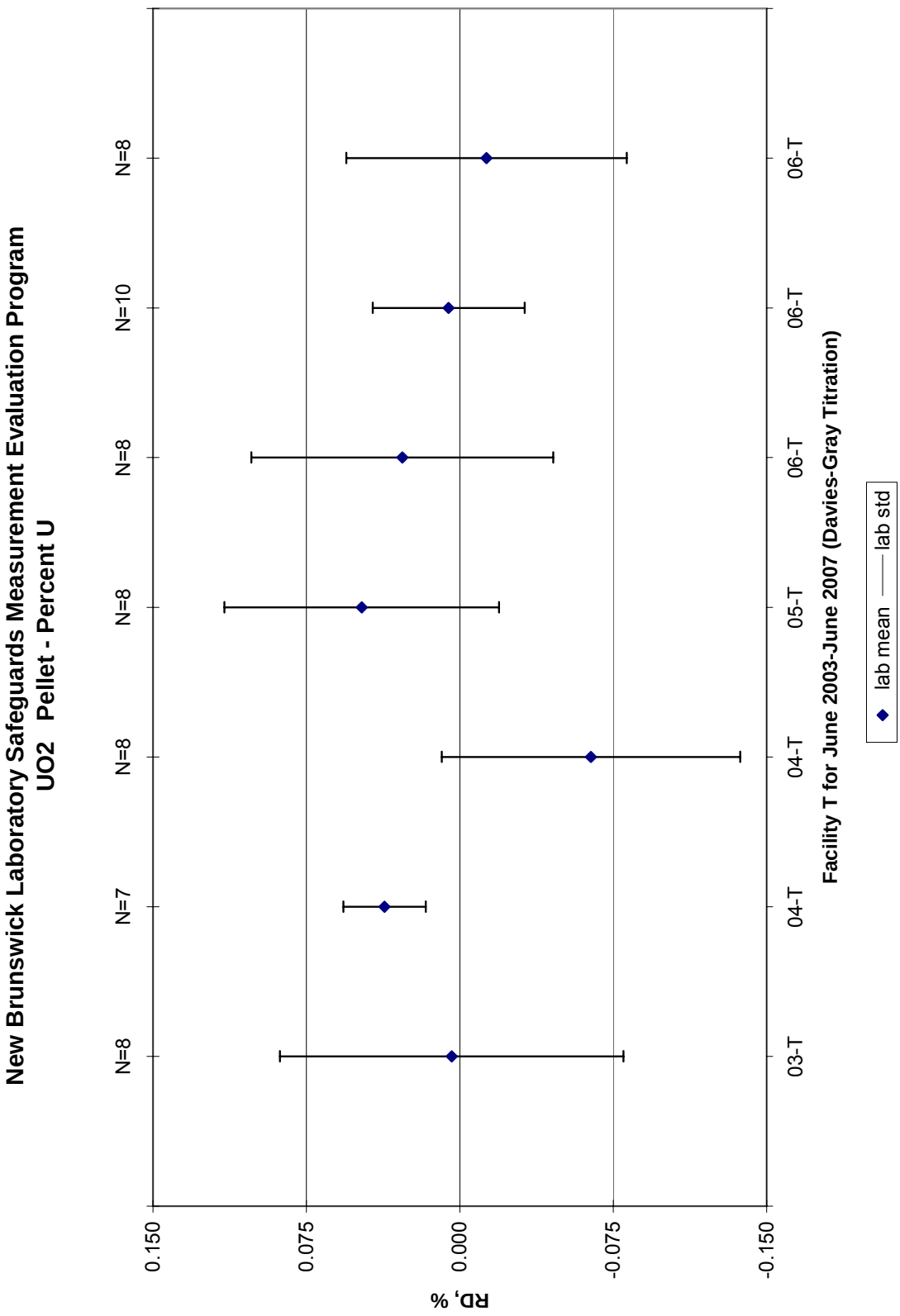

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
RD, %
0.150
0.075
0.000
-0.075
-0.150
N=8
N=7
N=8
N=8
N=8
N=10
N=8
03-T
04-T
04-T
05-T
06-T
06-T
06-T
Facility T for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 34**

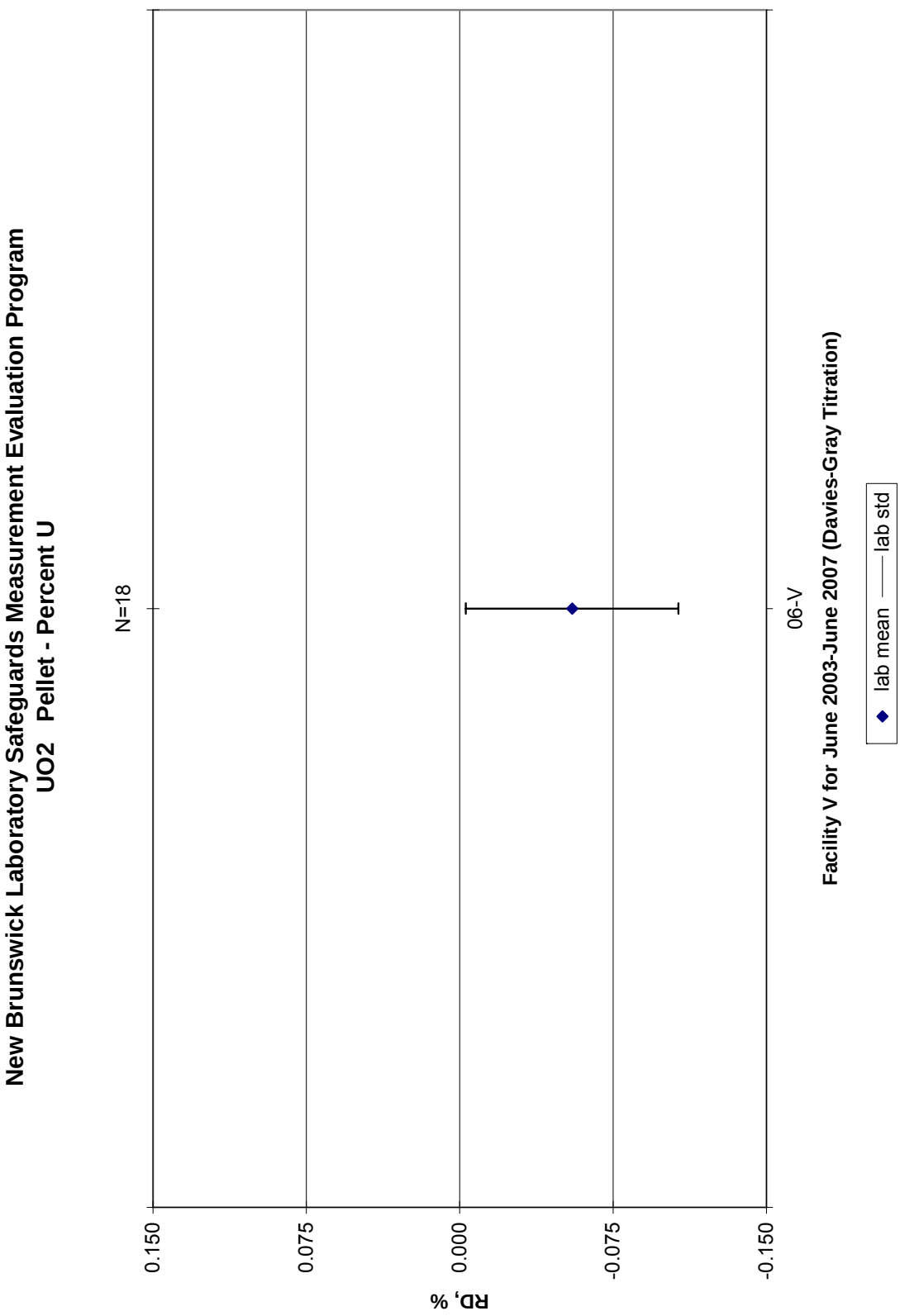

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 Pellet - Percent U
N=18
0.150
0.075
0.000
-0.075
-0.150
RD, %
06-V
Facility V for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 35**

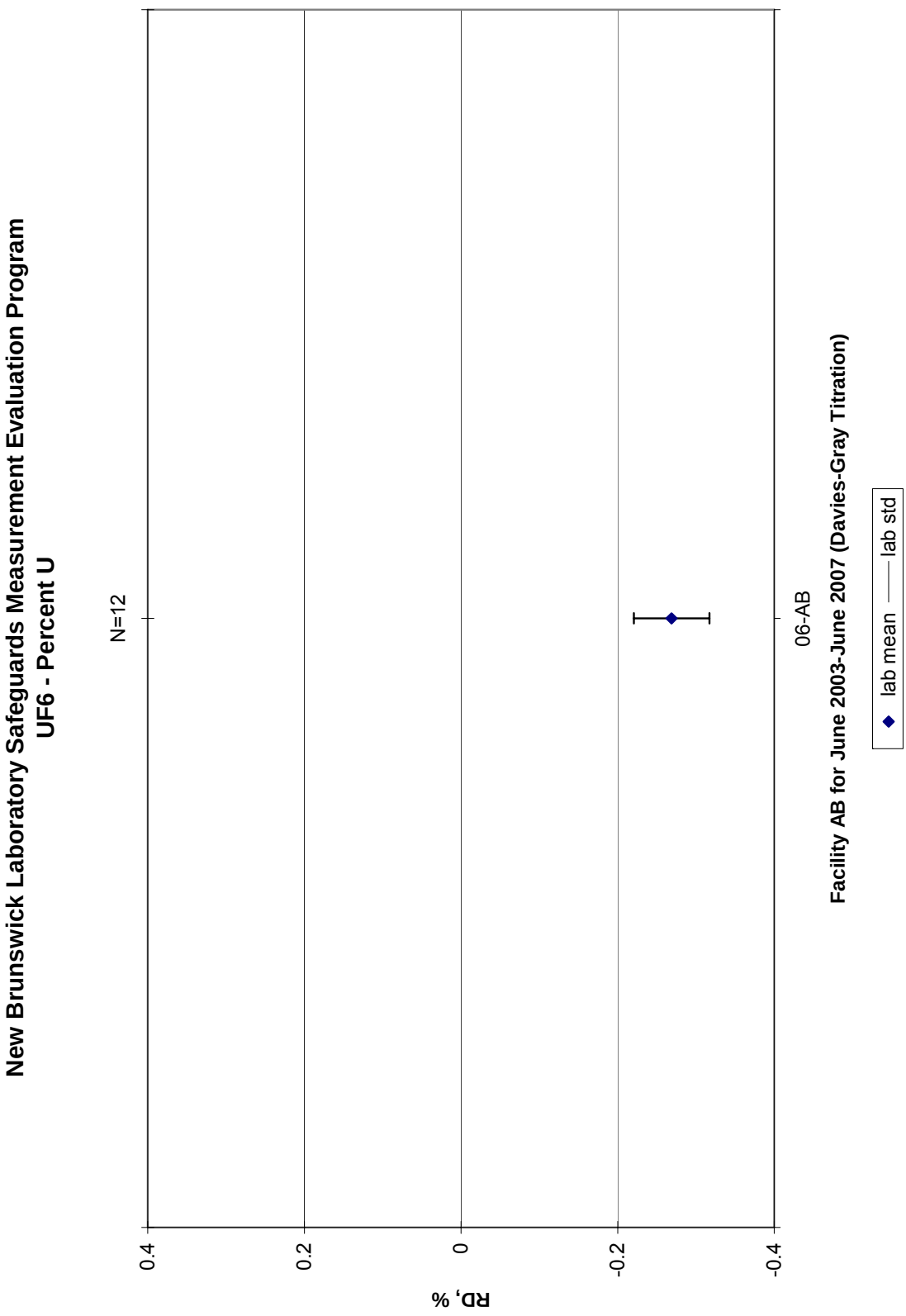

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UF6 - Percent U
N=12
0.4
0.2
0
-0.2
-0.4
RD, %
06-AB
Facility AB for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 36**

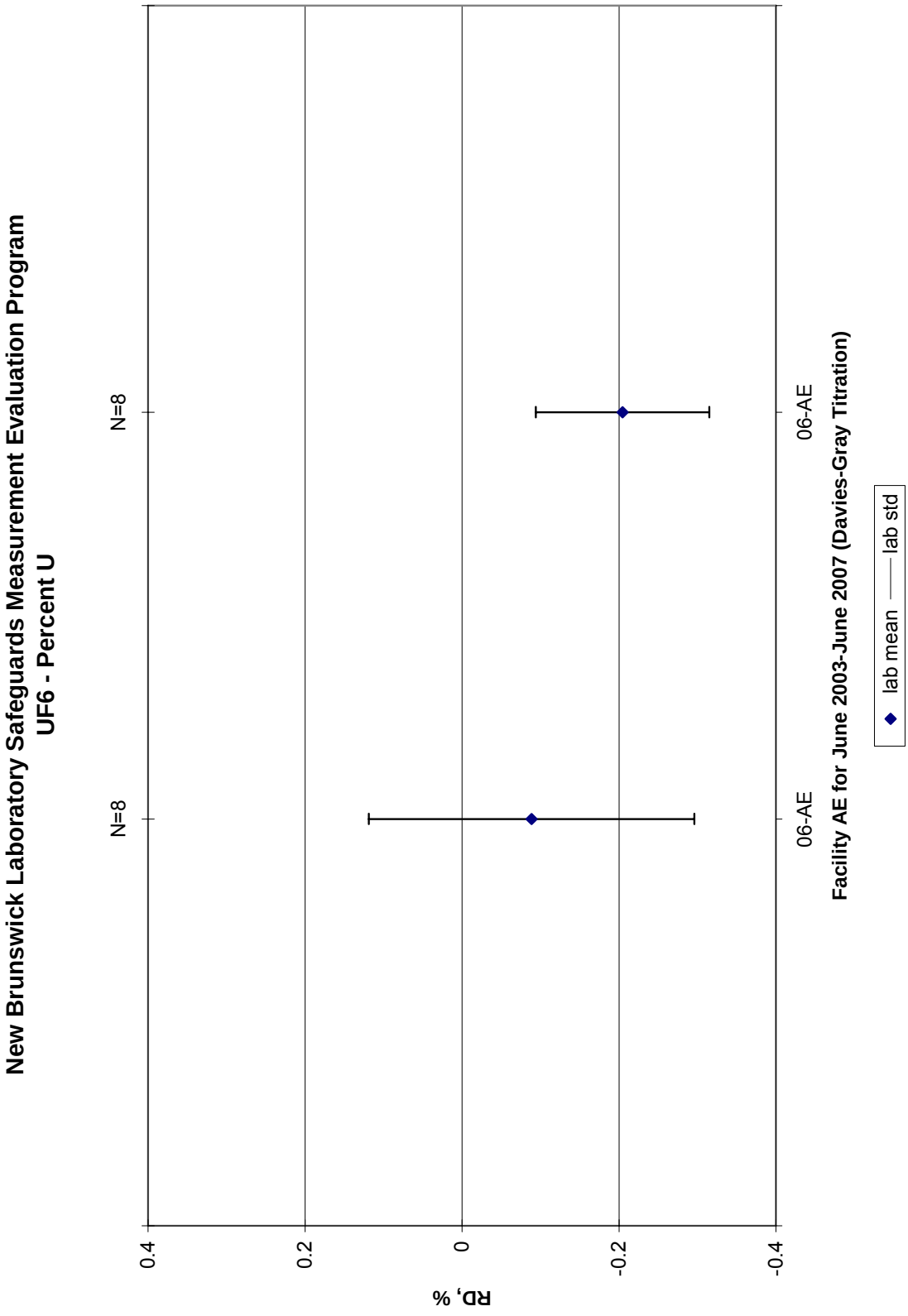

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UF6 - Percent U
Facility AE for June 2003-June 2007 (Davies-Gray Titration)
RD, %
0.4
0.2
0
-0.2
-0.4
N=8
N=8
06-AE
06-AE
lab mean
lab std

**Figure 37**

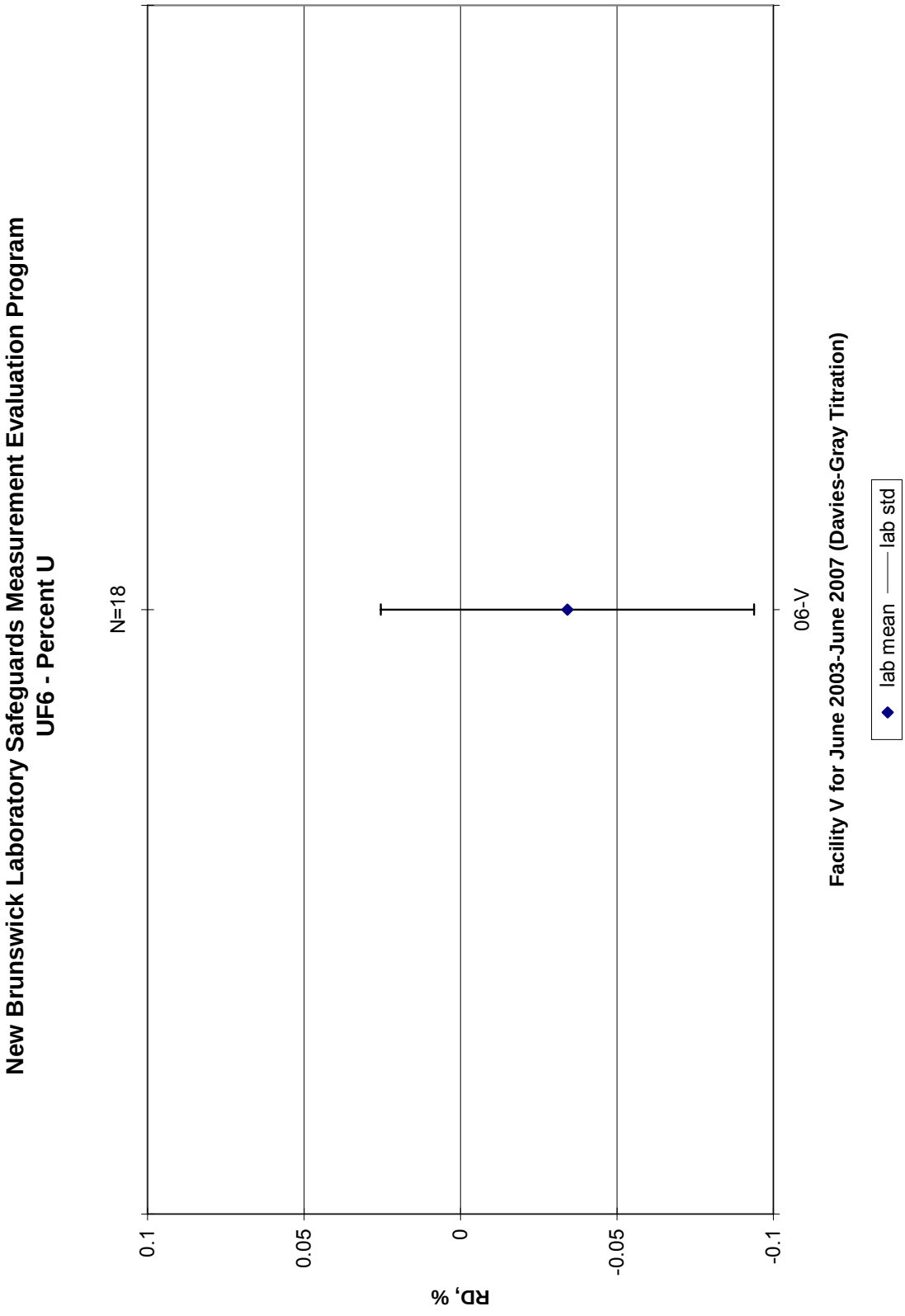

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UF6 - Percent U
N=18
06-V
Facility V for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std
RD, %
0.1
0.05
0
-0.05
-0.1

**Figure 38**

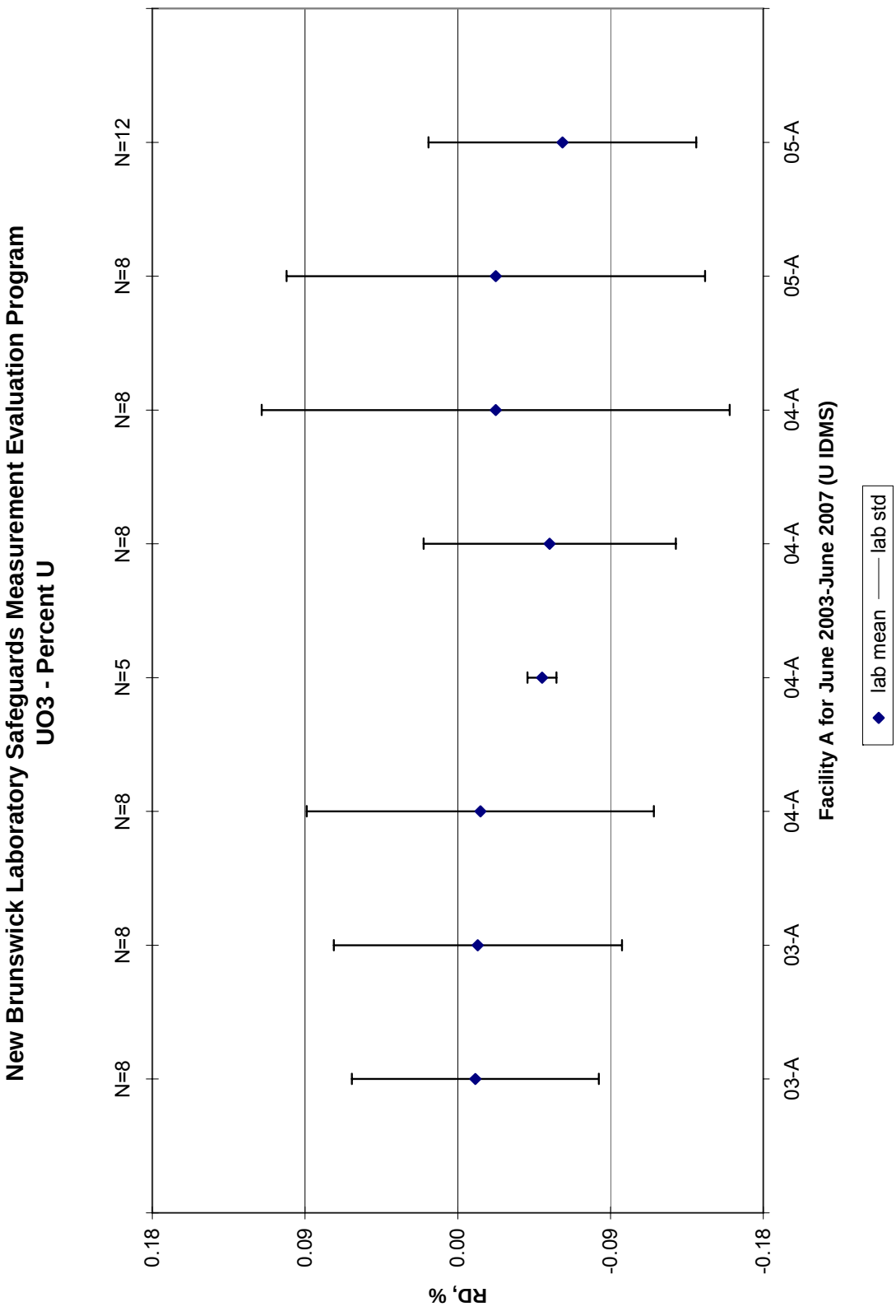

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
RD, %
0.18
0.09
0.00
-0.09
-0.18
N=8
N=8
N=8
N=5
N=8
N=8
N=12
03-A
03-A
04-A
04-A
04-A
04-A
05-A
05-A
Facility A for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 39**

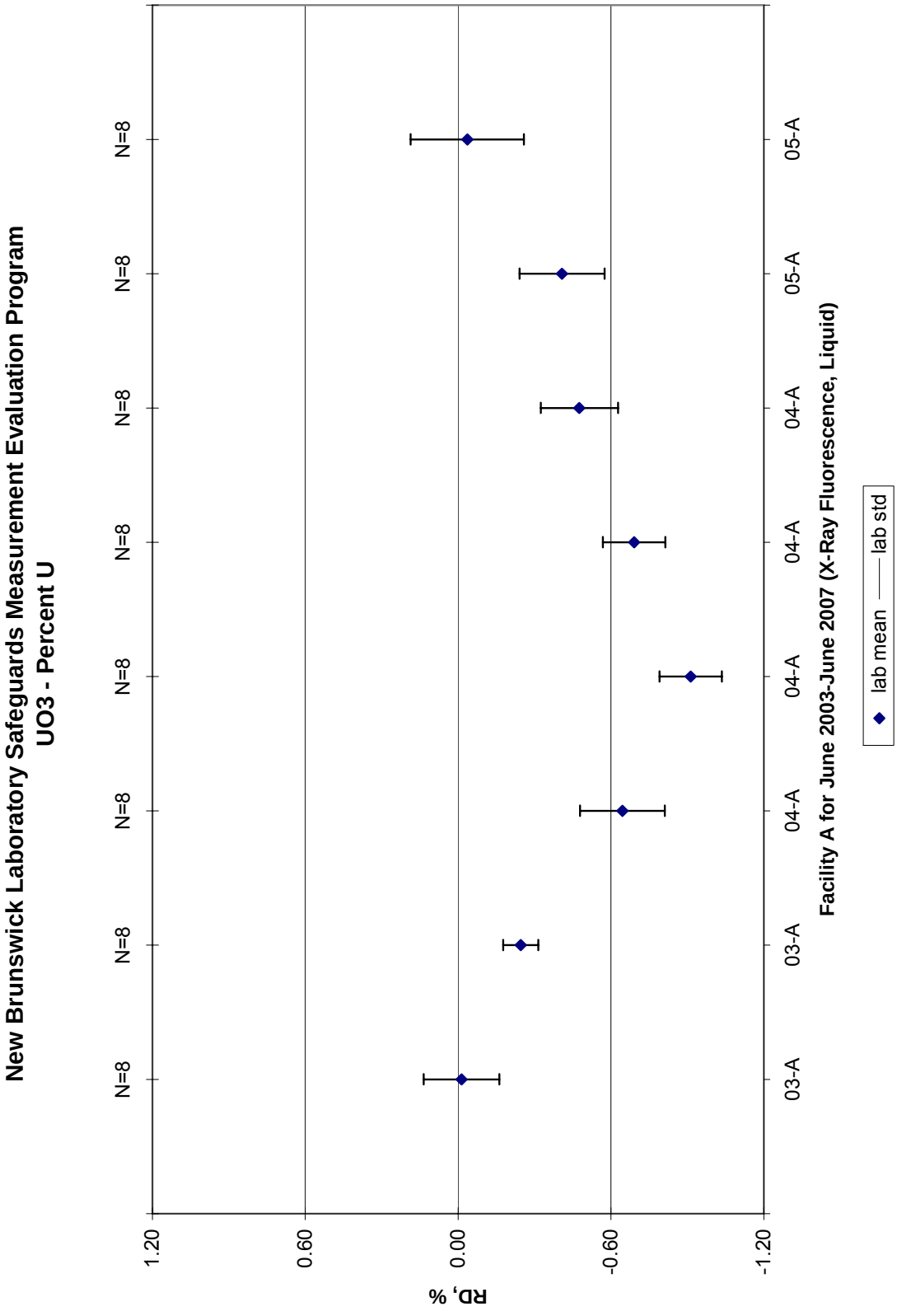

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
RD, %
1.20
0.60
0.00
-0.60
-1.20
N=8
03-A
04-A
05-A
lab mean
lab std
Facility A for June 2003-June 2007 (X-Ray Fluorescence, Liquid)

**Figure 40**

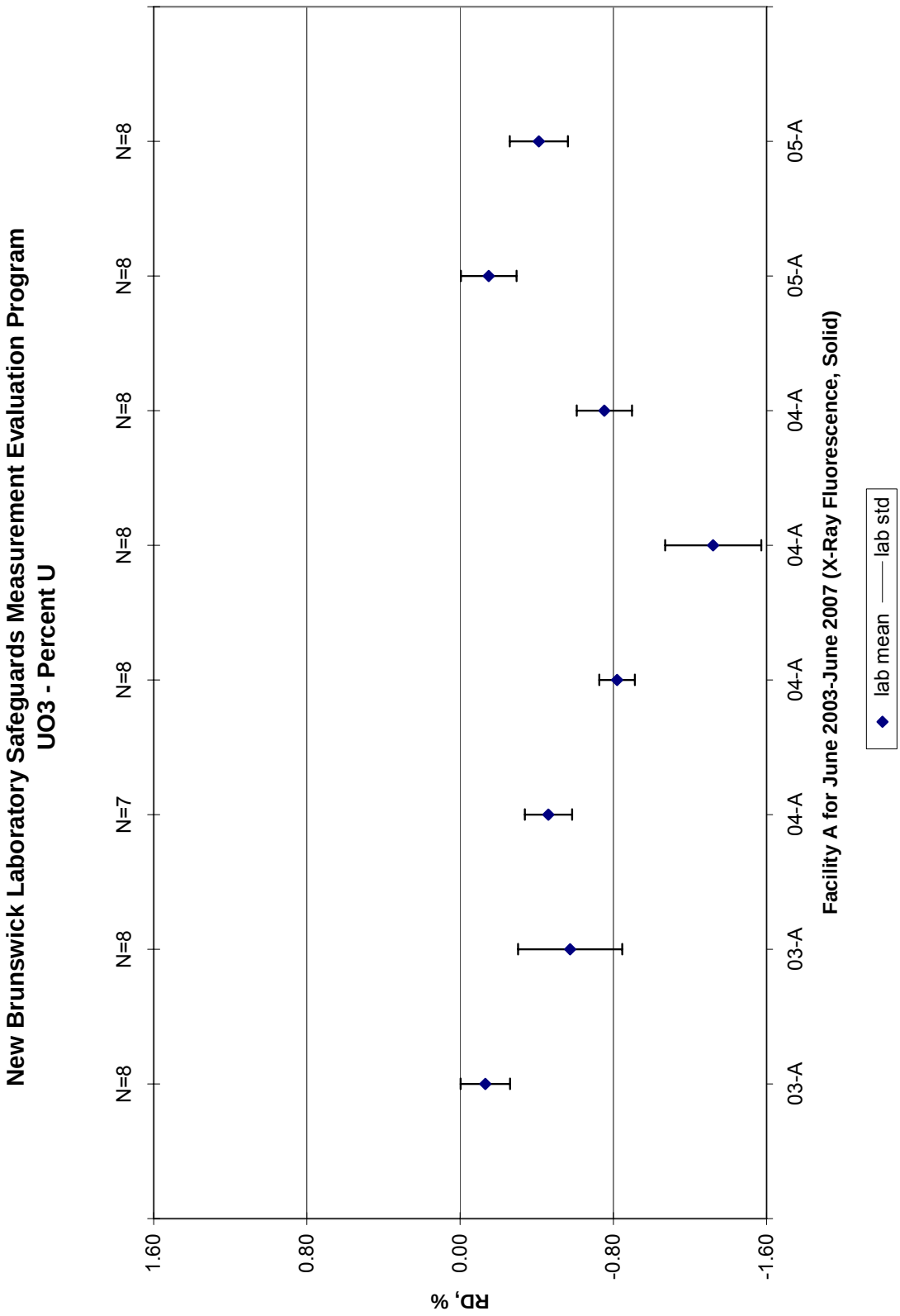

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
RD, %
1.60
0.80
0.00
-0.80
-1.60
N=8
N=8
N=7
N=8
N=8
N=8
N=8
03-A
03-A
04-A
04-A
04-A
04-A
05-A
05-A
Facility A for June 2003-June 2007 (X-Ray Fluorescence, Solid)
lab mean
lab std

**Figure 41**

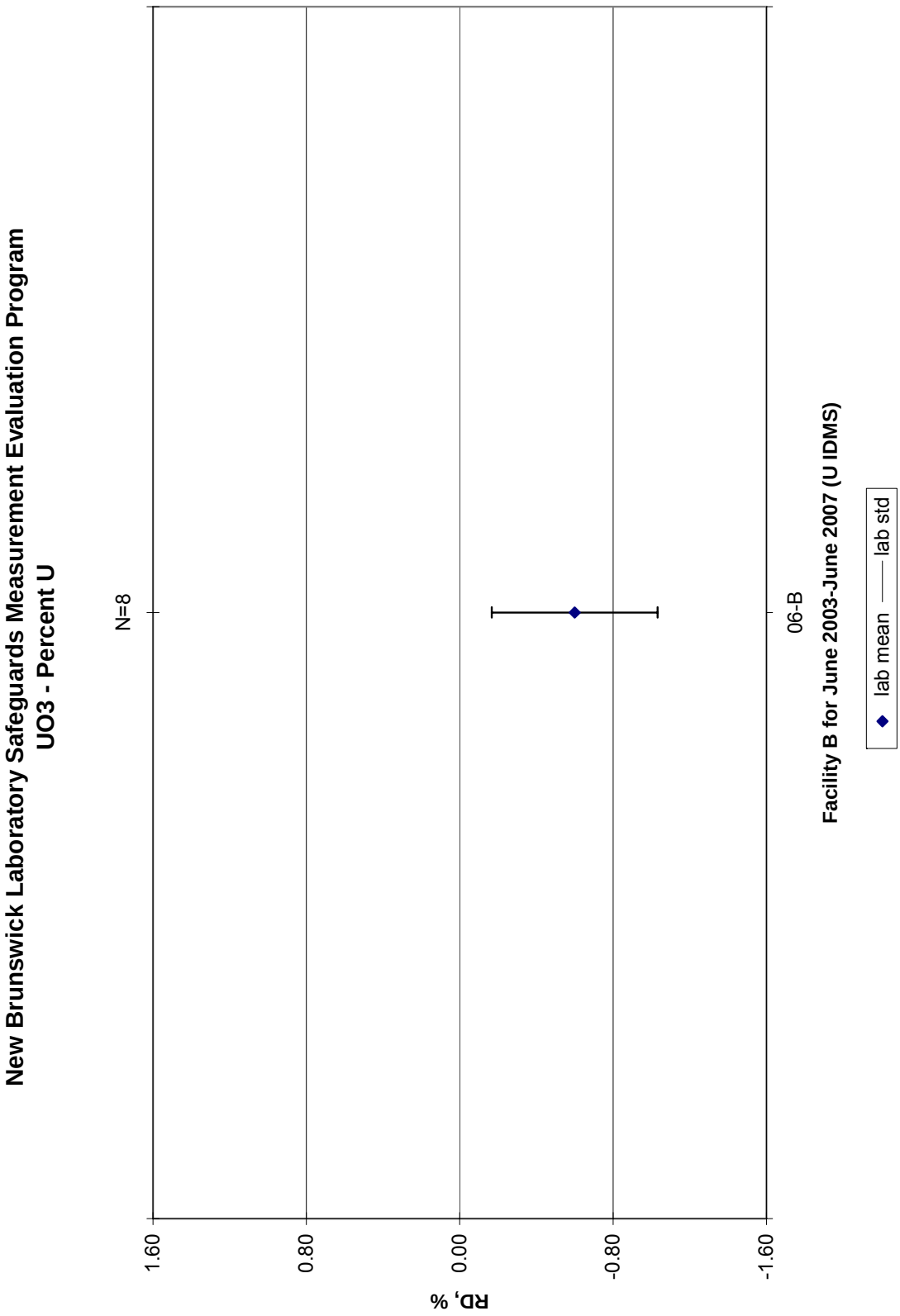

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
N=8
1.60
0.80
0.00
-0.80
-1.60
RD, %
06-B
Facility B for June 2003-June 2007 (U IDMS)
lab mean
lab std

**Figure 42**

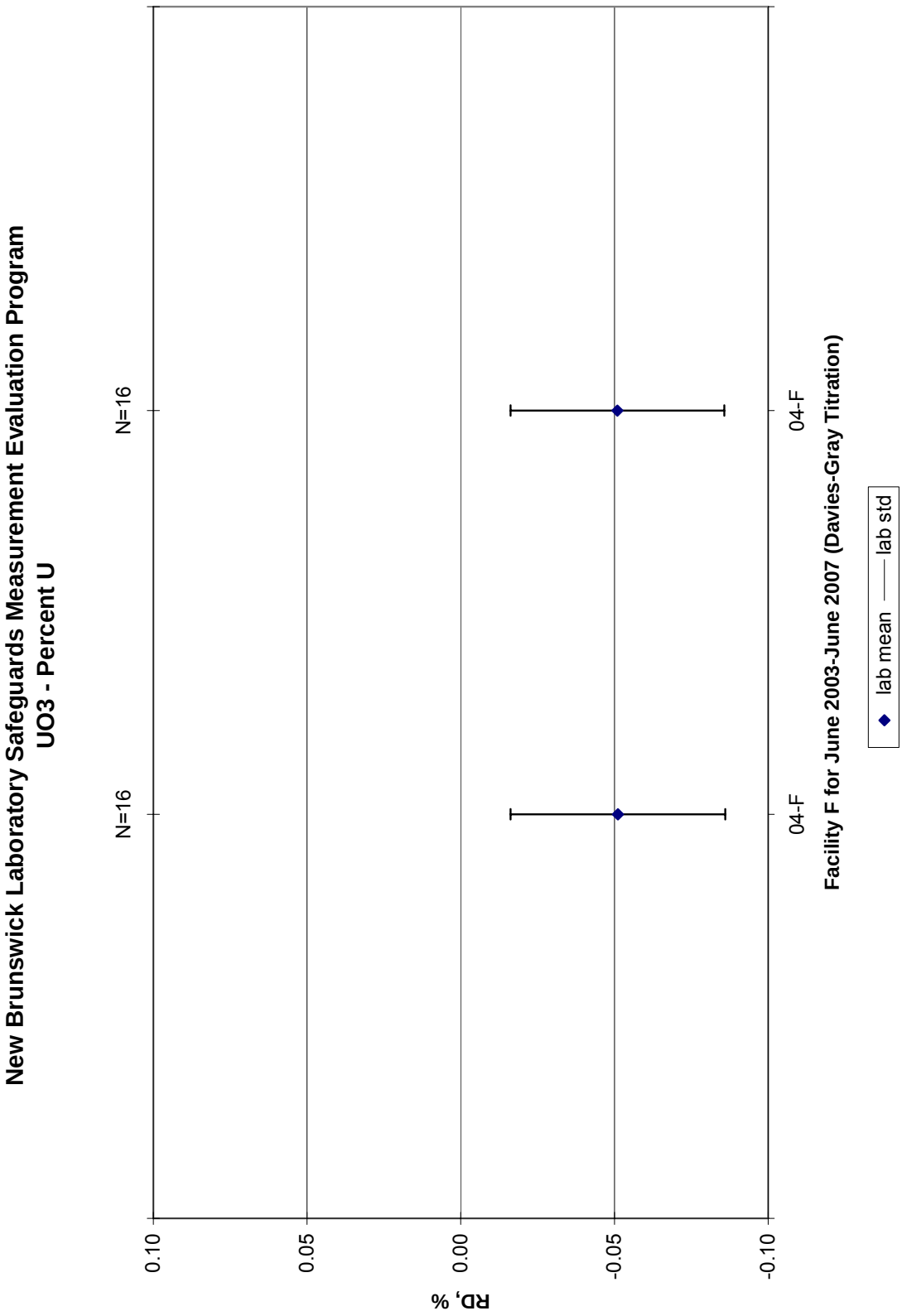

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
N=16
N=16
0.10
0.05
0.00
-0.05
-0.10
RD, %
04-F
04-F
Facility F for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 43**

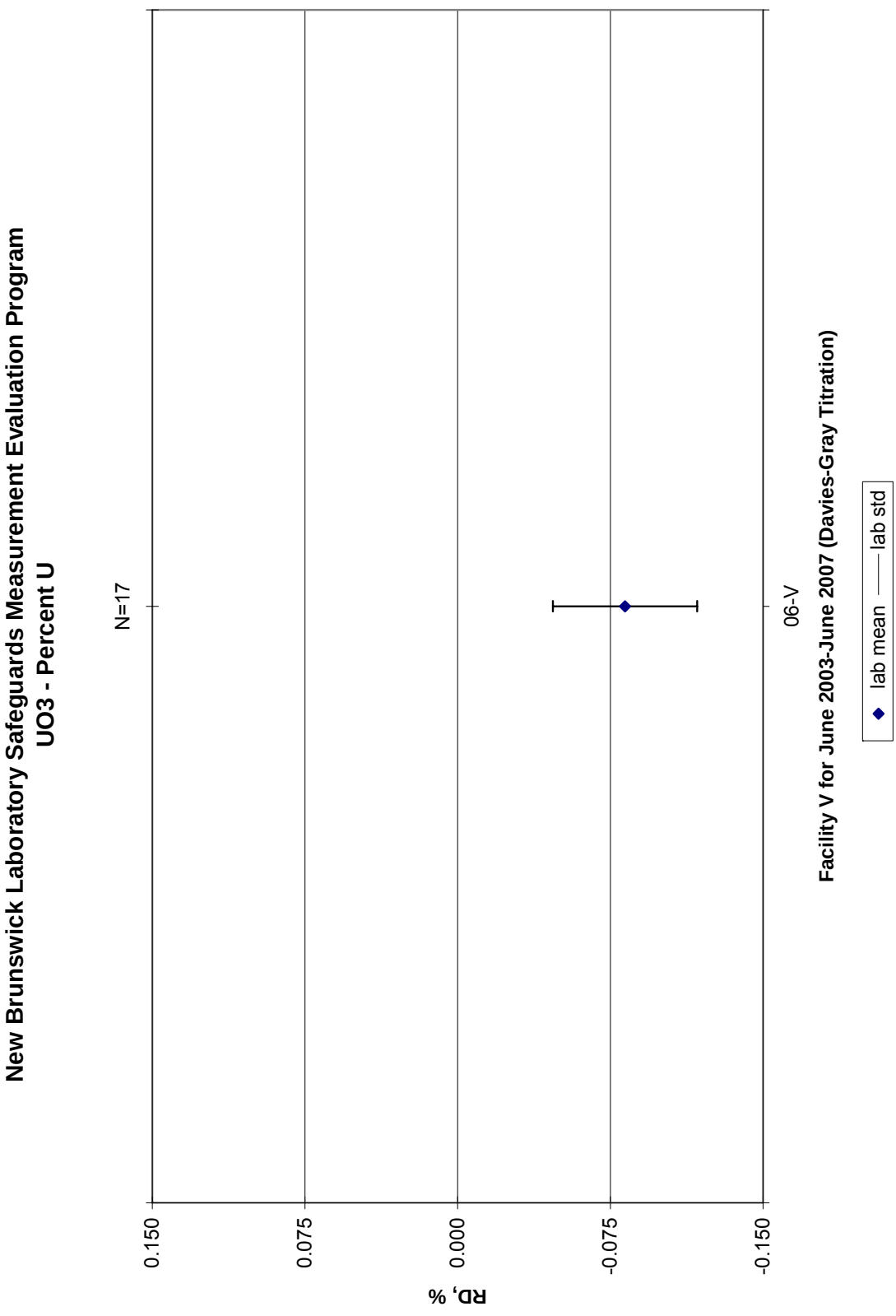

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO3 - Percent U
N=17
0.150
0.075
0.000
-0.075
-0.150
RD, %
06-V
Facility V for June 2003-June 2007 (Davies-Gray Titration)
lab mean
lab std

**Figure 44**

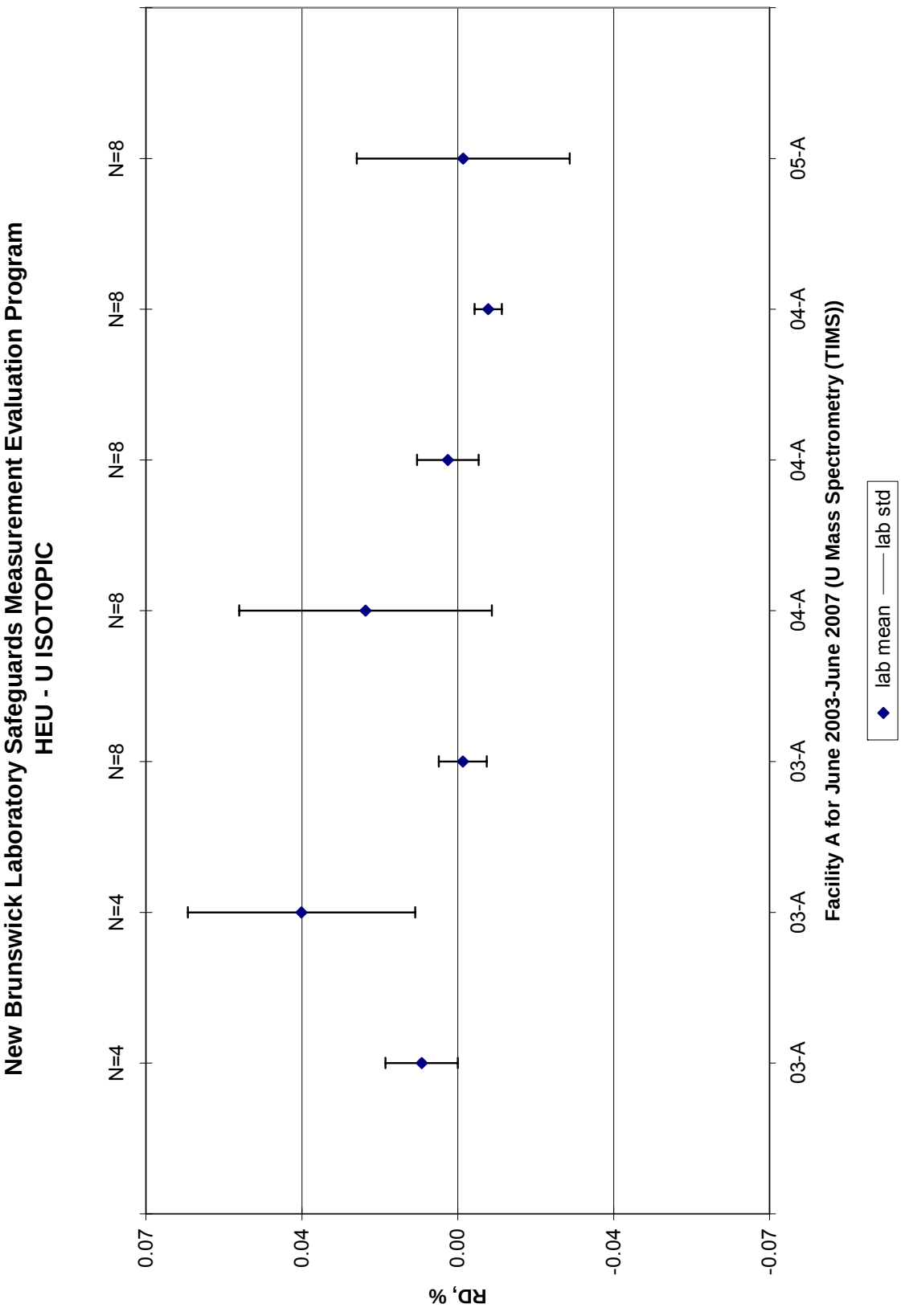

New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
RD, %
0.07
0.04
0.00
-0.04
-0.07
N=4
N=4
N=8
N=8
N=8
N=8
03-A
03-A
03-A
04-A
04-A
04-A
05-A
Facility A for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 45**

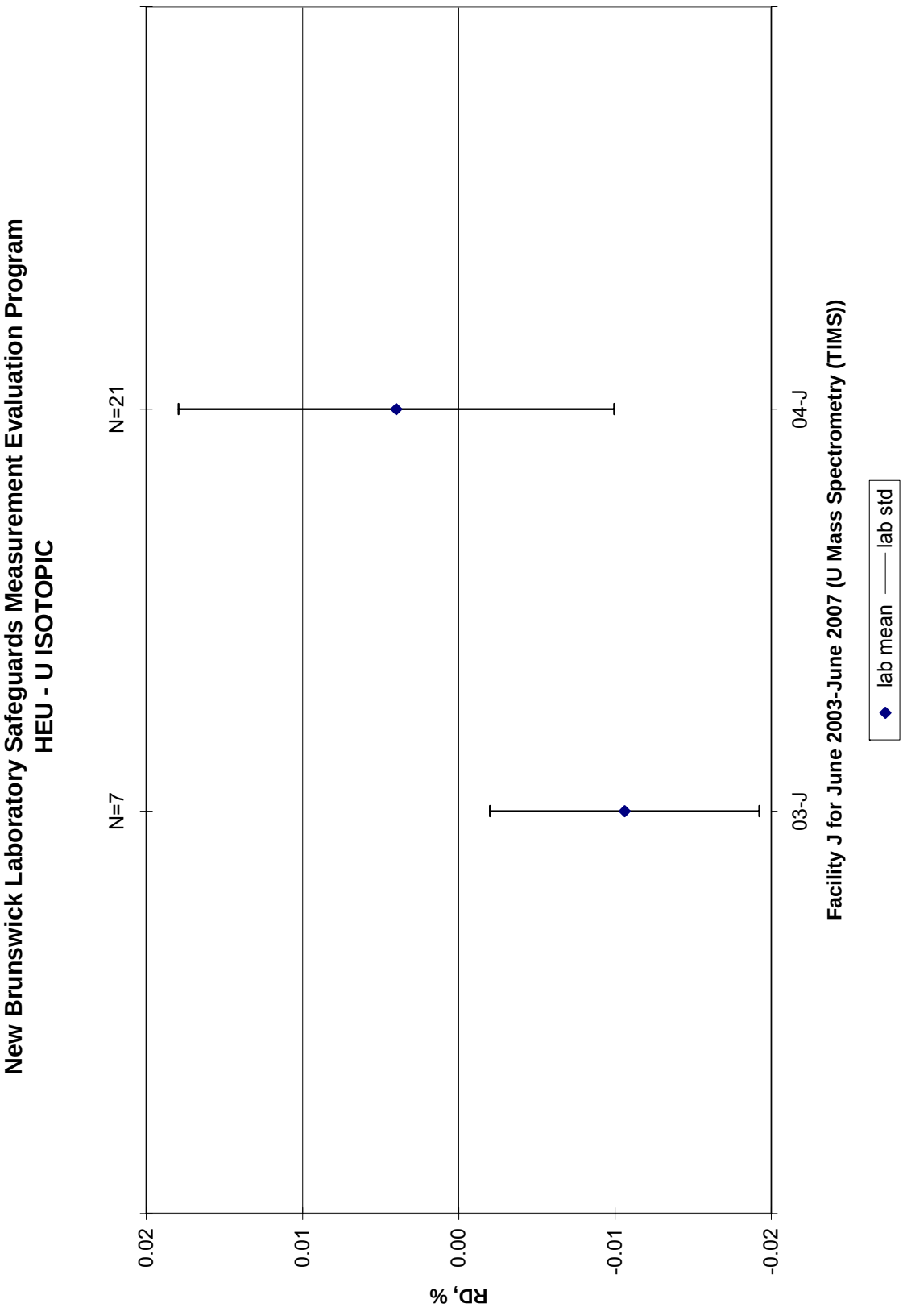

New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
RD, %
0.02
0.01
0.00
-0.01
-0.02
N=7
N=21
03-J
04-J
lab mean
lab std
Facility J for June 2003-June 2007 (U Mass Spectrometry (TIMS))

**Figure 46**

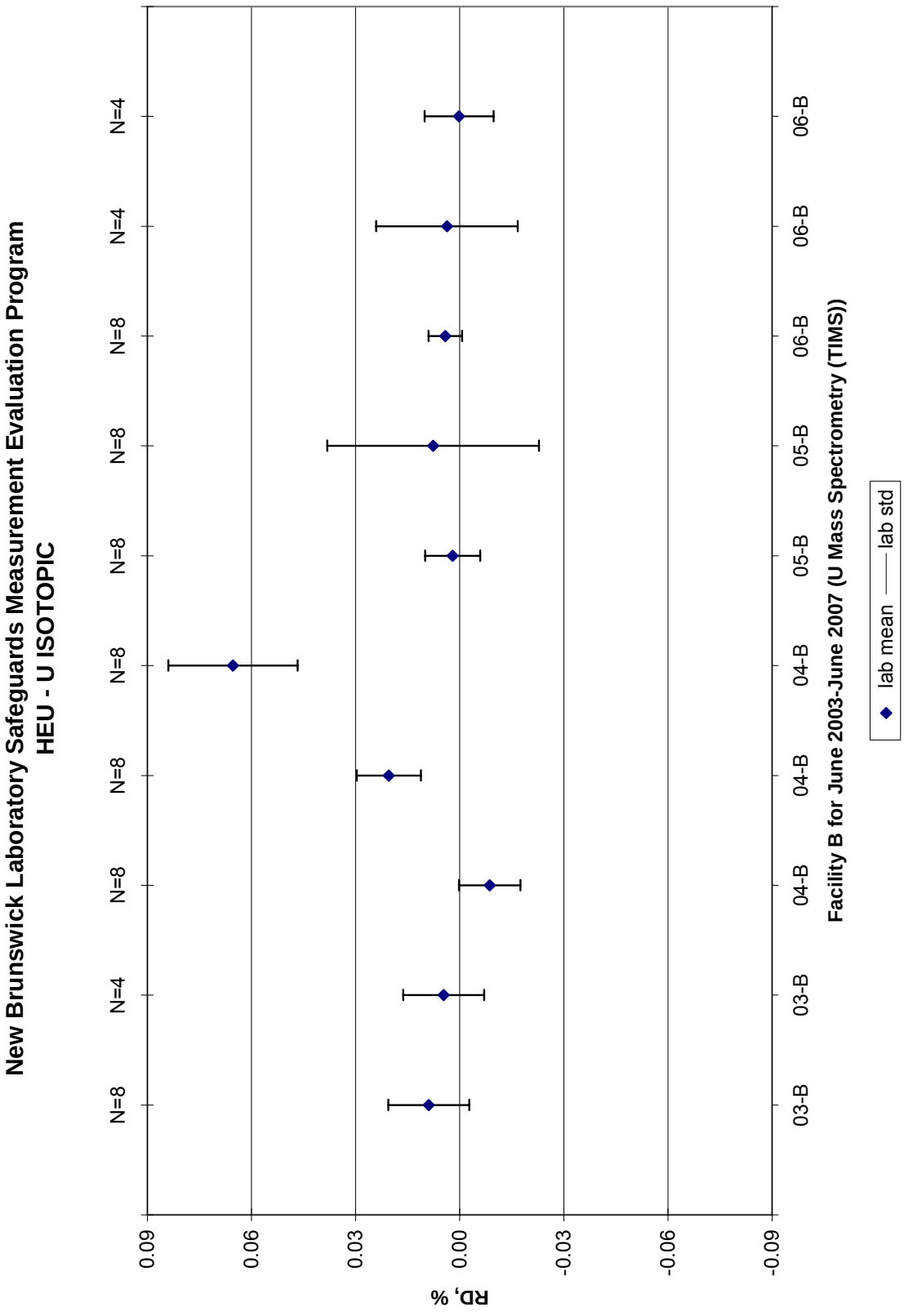

New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
RD, %
0.09
0.06
0.03
0.00
-0.03
-0.06
-0.09
N=8
N=4
N=8
N=8
N=8
N=8
N=4
N=4
03-B
03-B
04-B
04-B
04-B
05-B
05-B
06-B
06-B
06-B
Facility B for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 47**

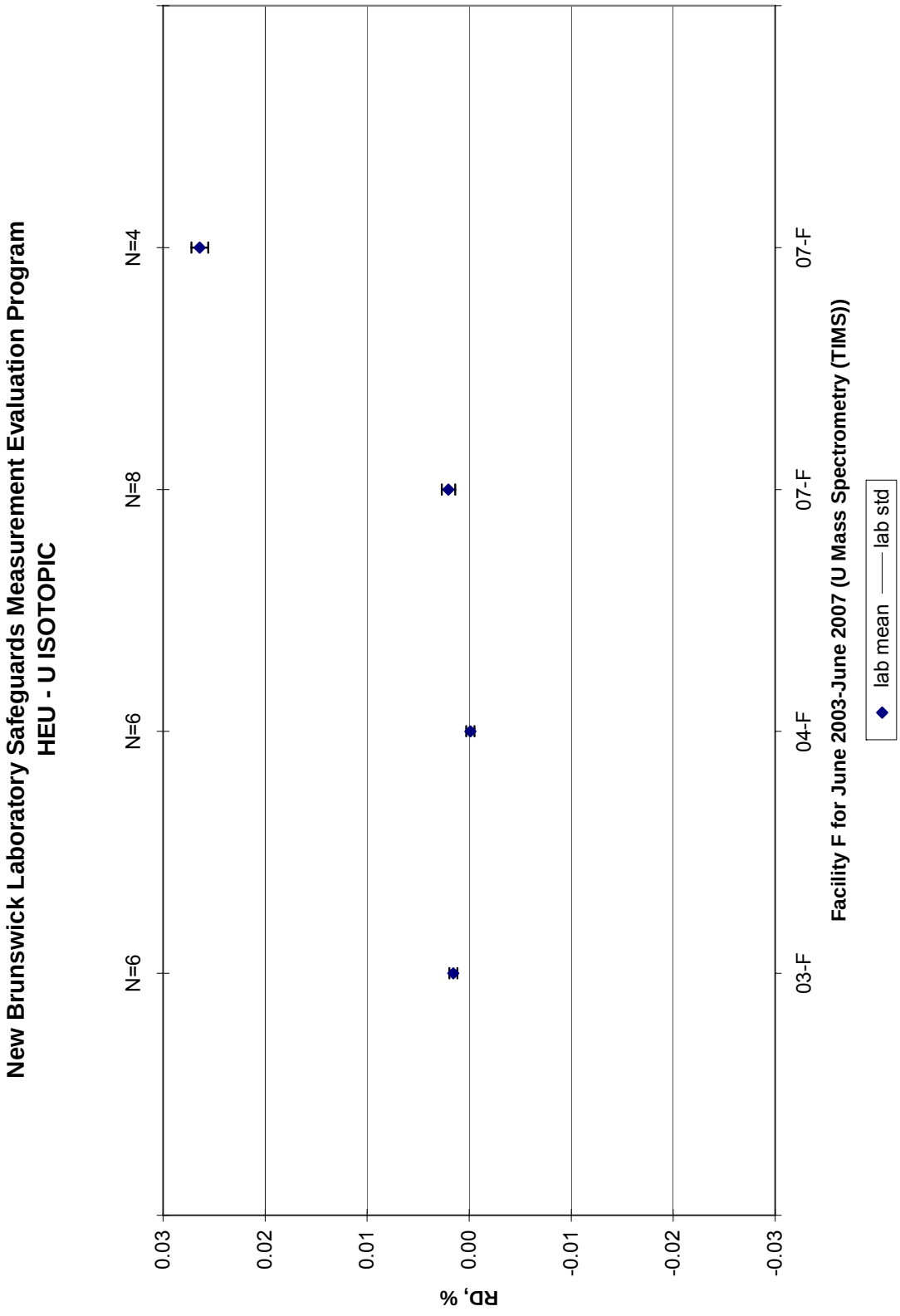

New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
RD, %
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
N=6
N=6
N=8
N=4
03-F
04-F
07-F
07-F
Facility F for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 48**

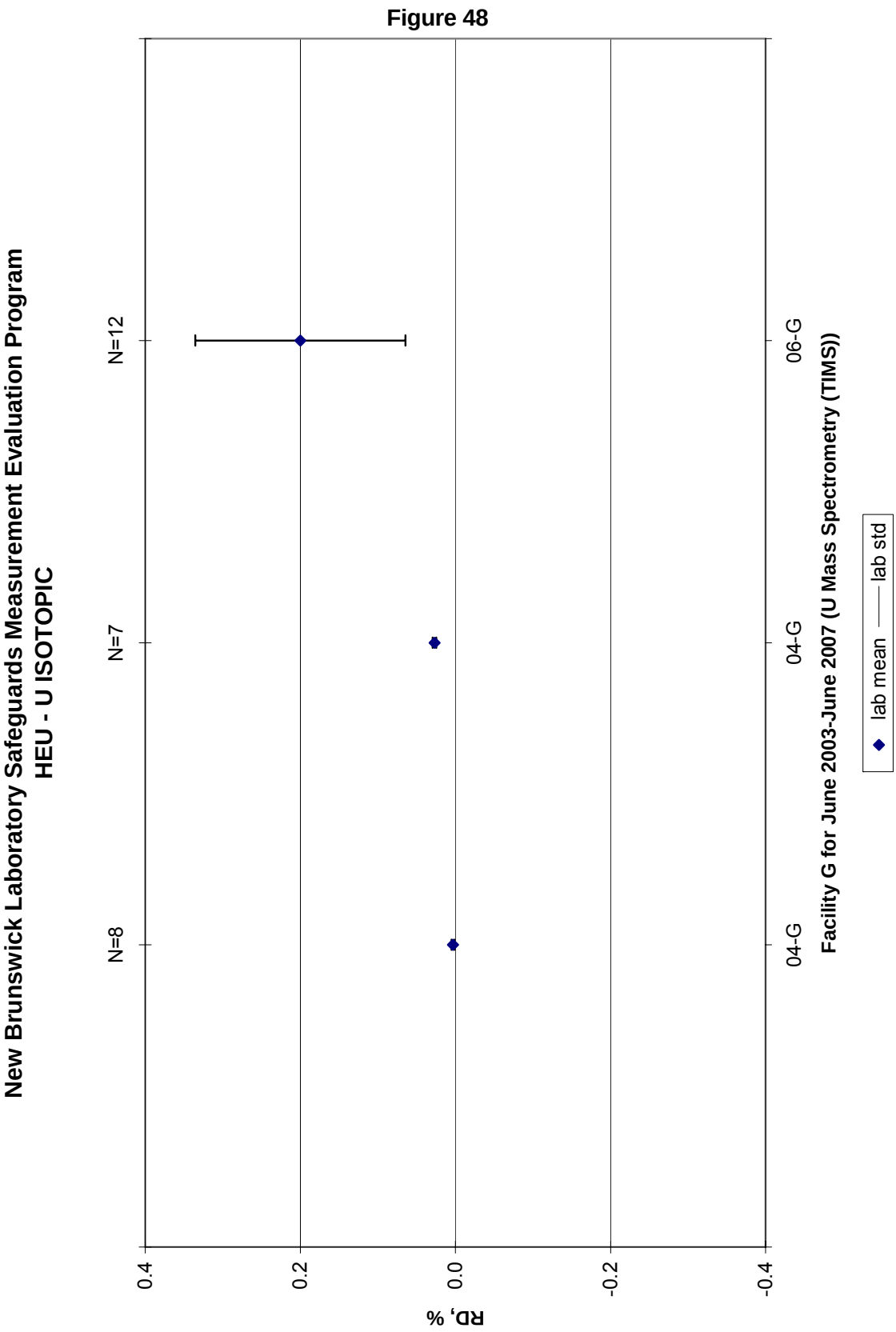
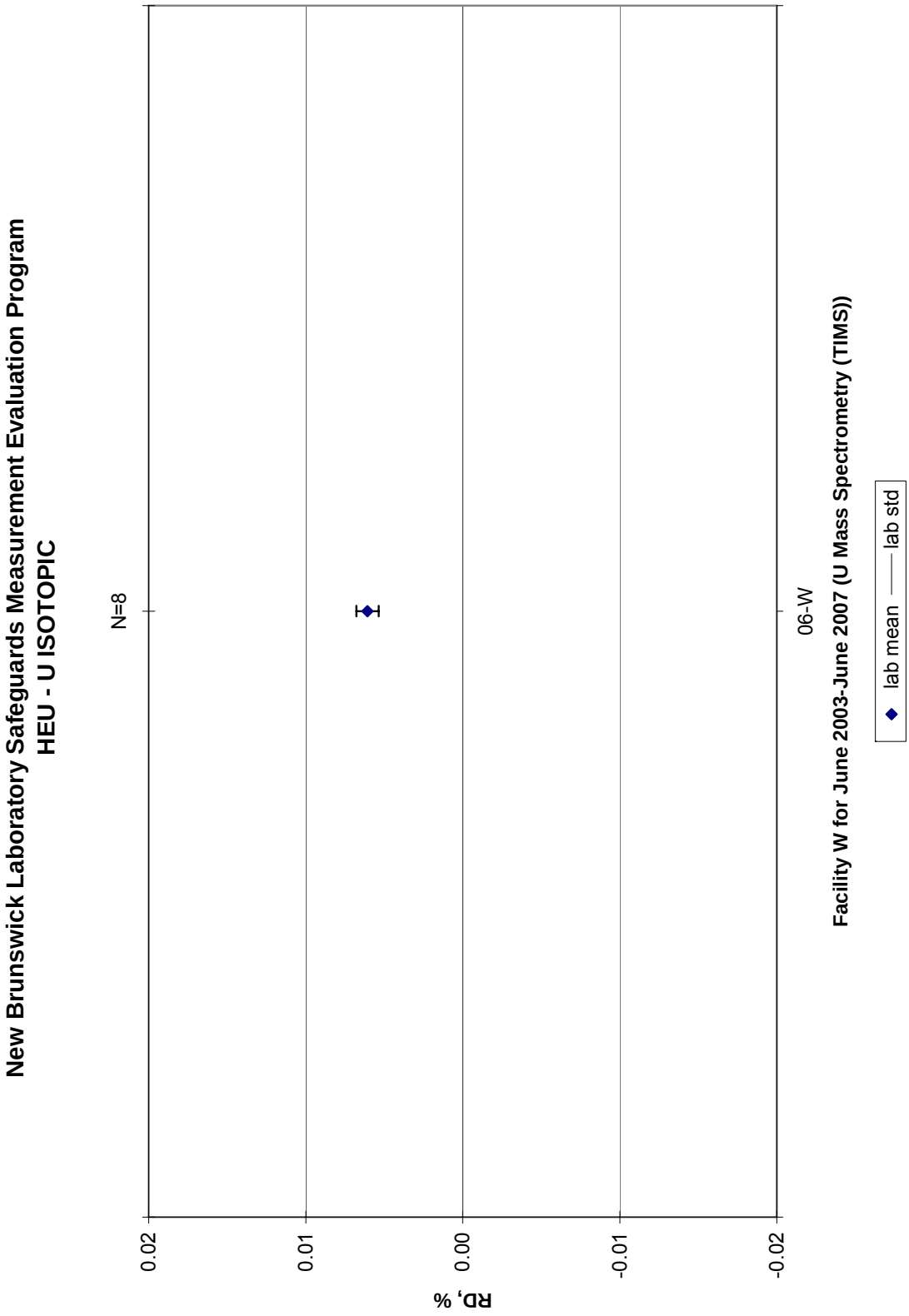

New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
N=8
N=7
N=12
04-G
04-G
06-G
0.4
0.2
0.0
-0.2
-0.4
RD, %
Facility G for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 49**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
HEU - U ISOTOPIC
N=8
0.02
0.01
0.00
-0.01
-0.02
RD, %
06-W
Facility W for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**New Brunswick Laboratory Safeguards Measurement Evaluation Program**
**LEU - U ISOTOPIC**

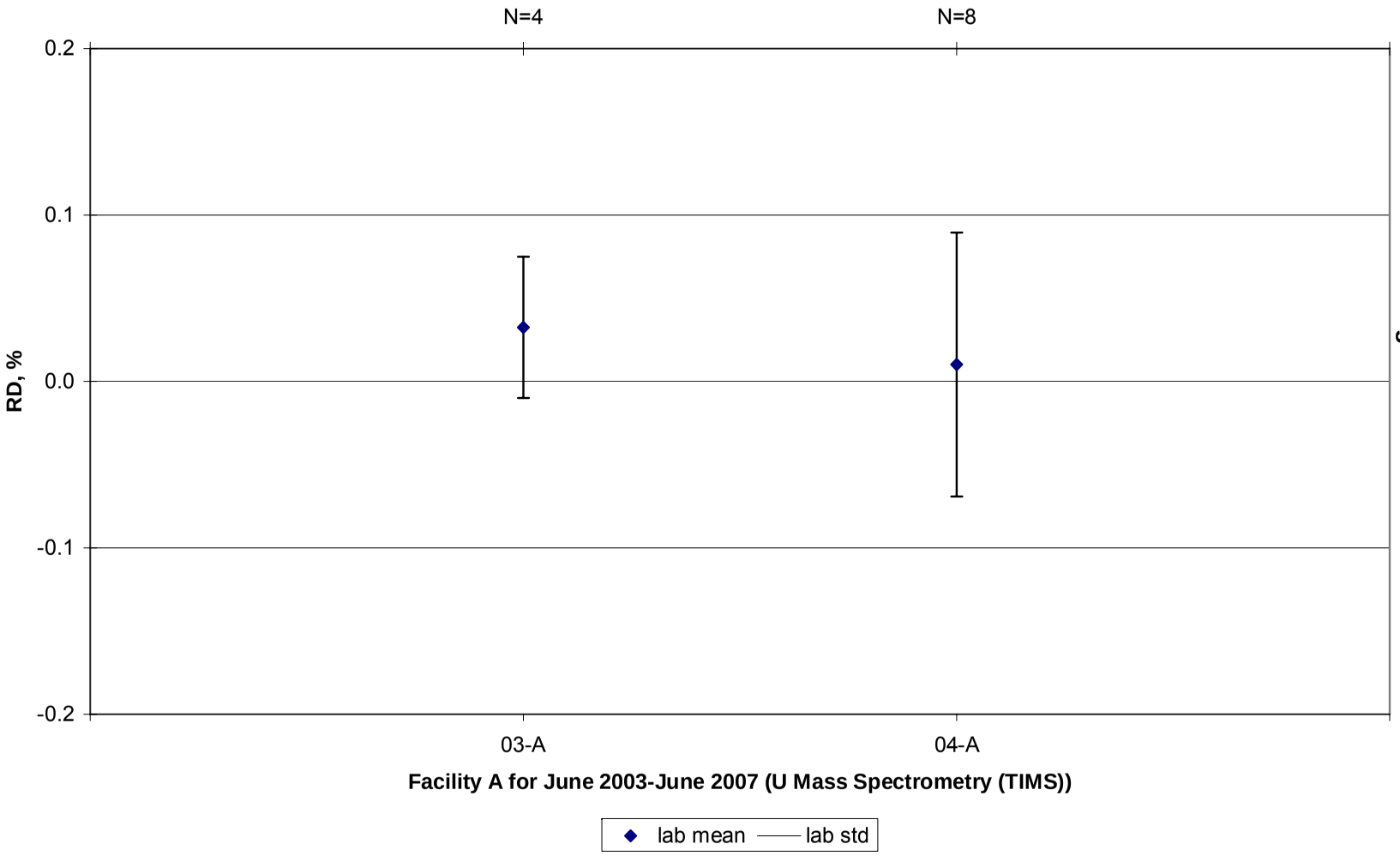



Figure 50

**Figure 51**

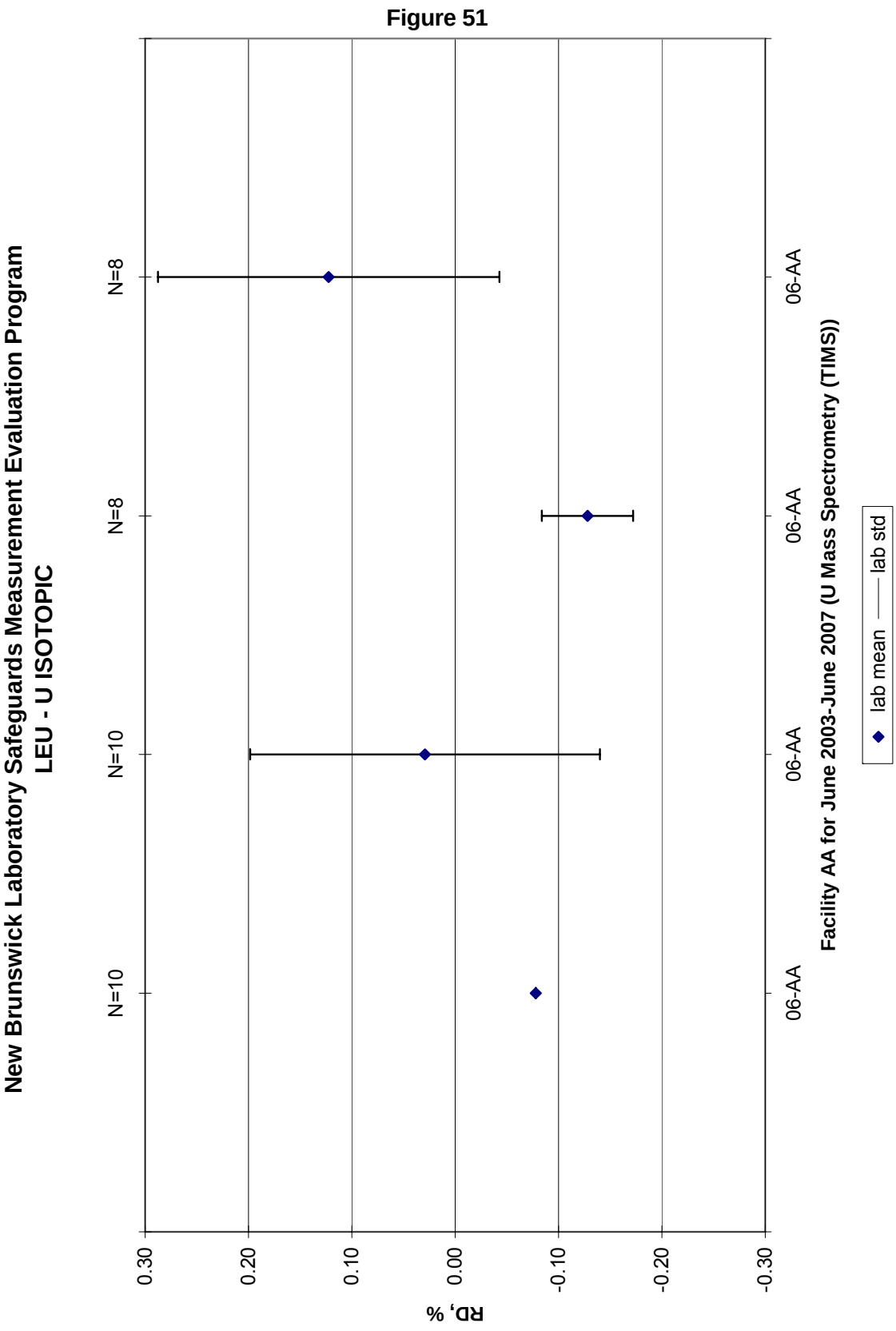

New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
Facility AA for June 2003-June 2007 (U Mass Spectrometry (TIMS))
RD, %
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
N=10
N=10
N=8
N=8
06-AA
06-AA
06-AA
06-AA
lab mean
lab std

**Figure 52**

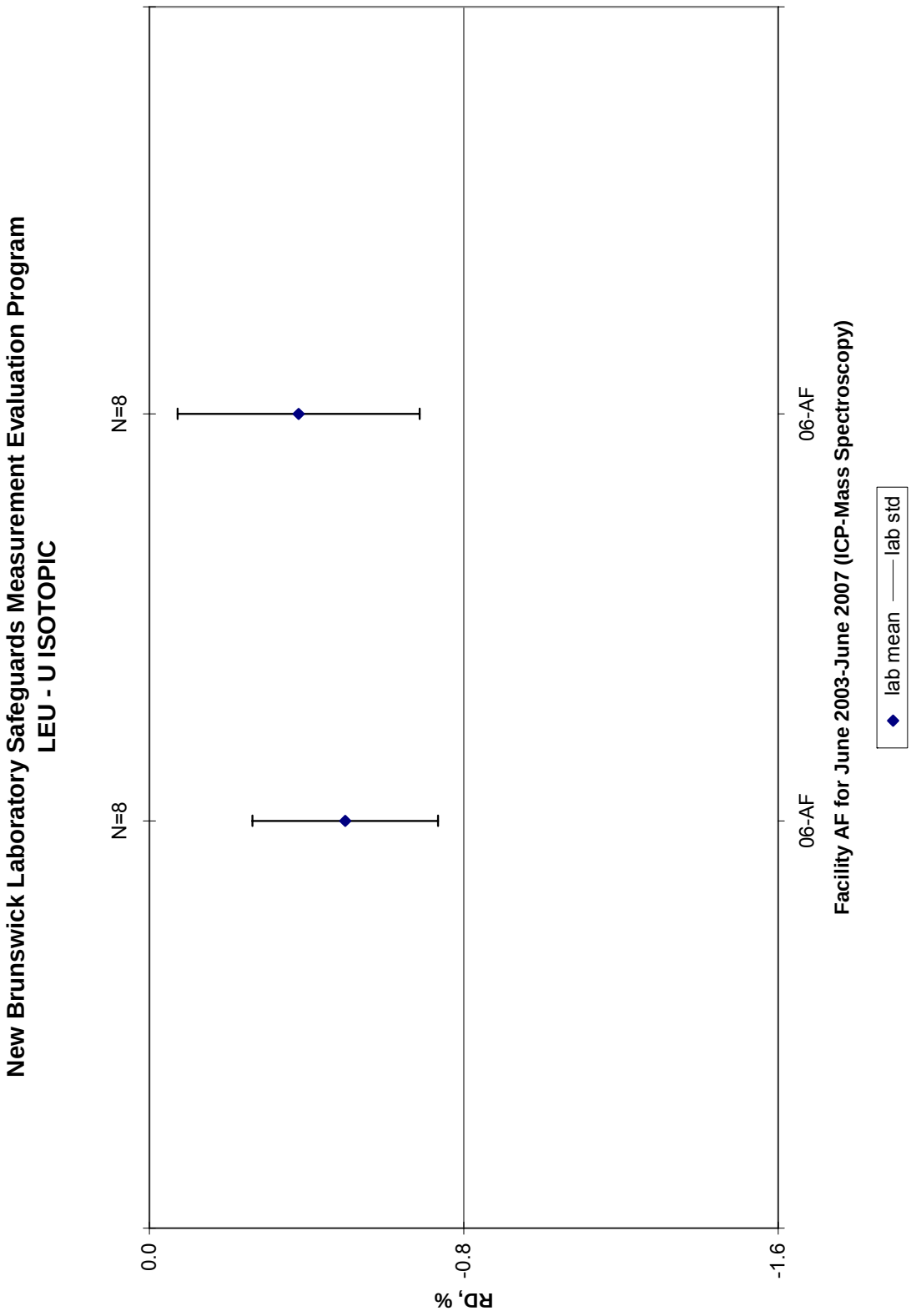

New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
N=8
N=8
06-AF
06-AF
0.0
-0.8
-1.6
RD, %
Facility AF for June 2003-June 2007 (ICP-Mass Spectroscopy)
lab mean
lab std

**Figure 53**

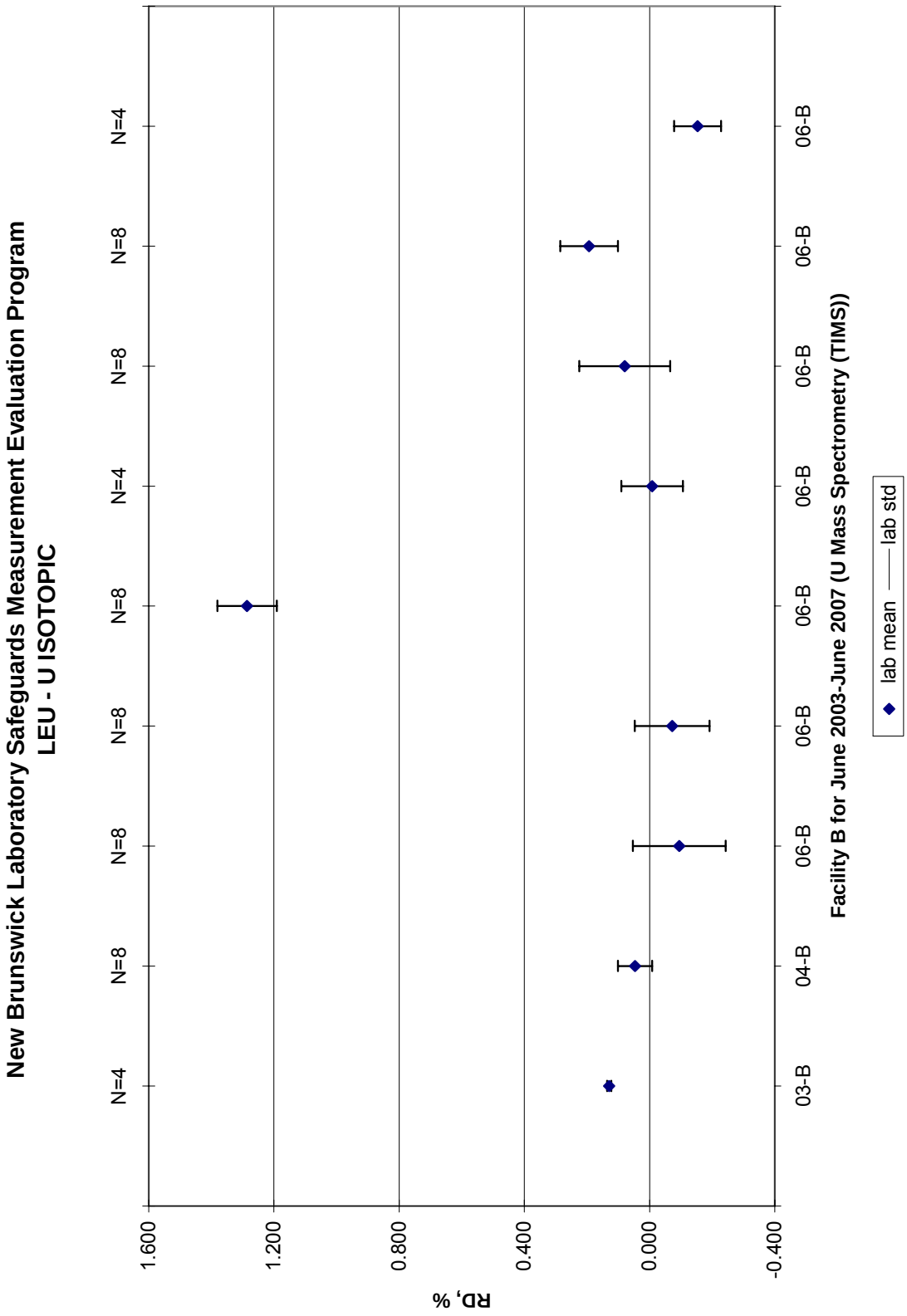

New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
RD, %
1.600
1.200
0.800
0.400
0.000
-0.400
N=4
N=8
N=8
N=8
N=4
N=8
N=8
N=4
03-B
04-B
06-B
06-B
06-B
06-B
06-B
06-B
Facility B for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 54**

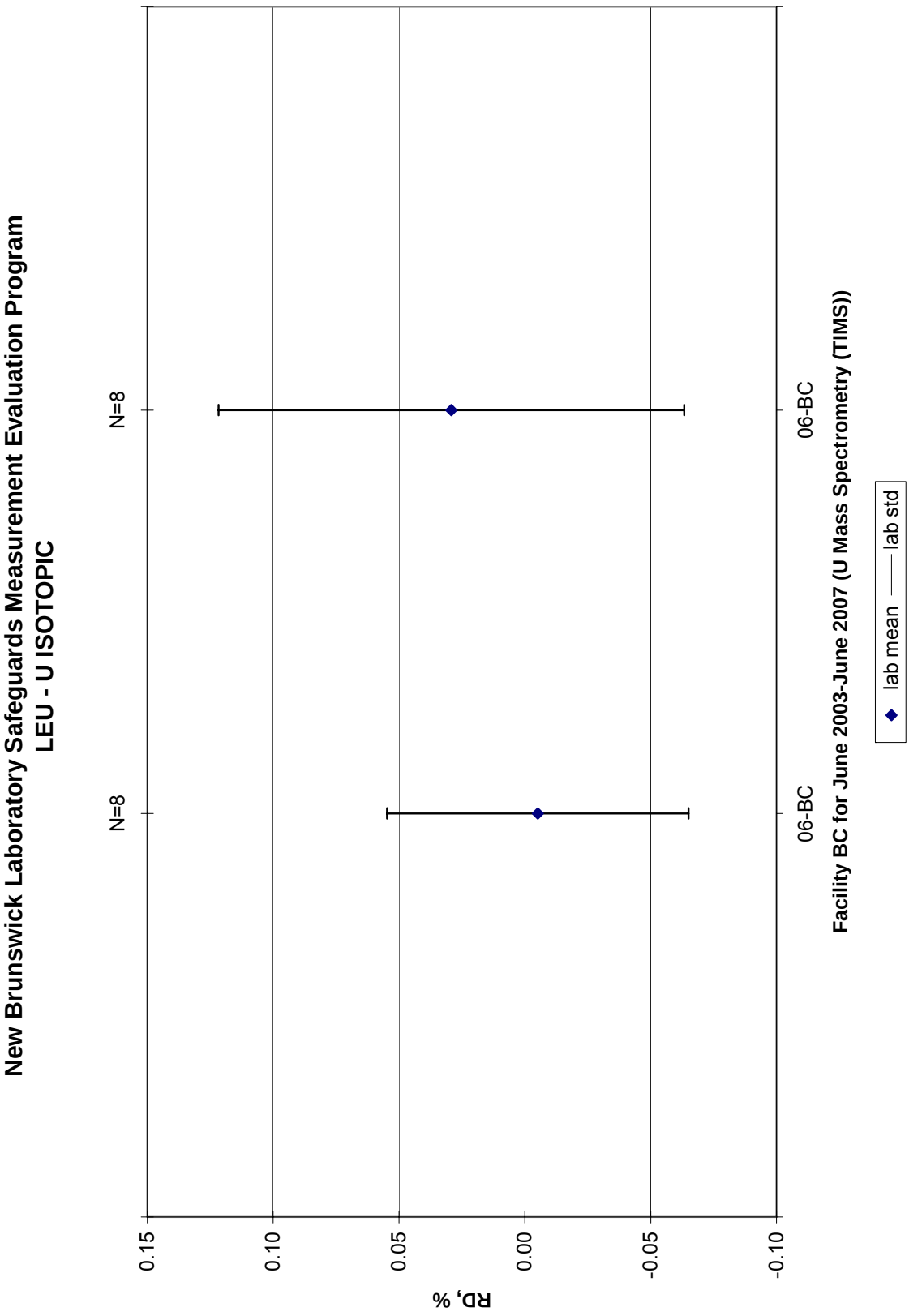
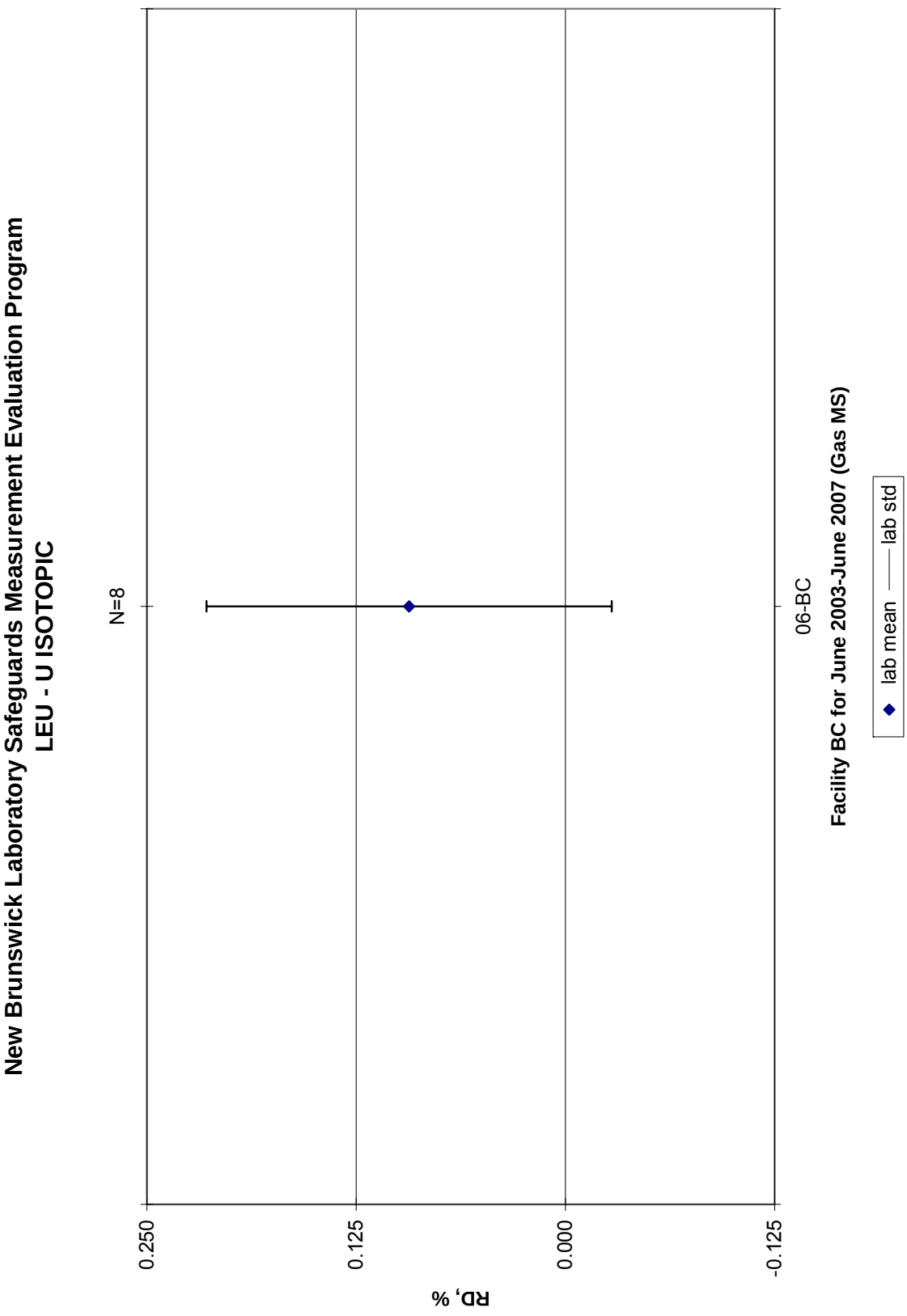

New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
RD, %
0.15
0.10
0.05
0.00
-0.05
-0.10
N=8
N=8
06-BC
06-BC
Facility BC for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 55**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
N=8
0.250
0.125
0.000
-0.125
RD, %
06-BC
Facility BC for June 2003-June 2007 (Gas MS)
lab mean
lab std

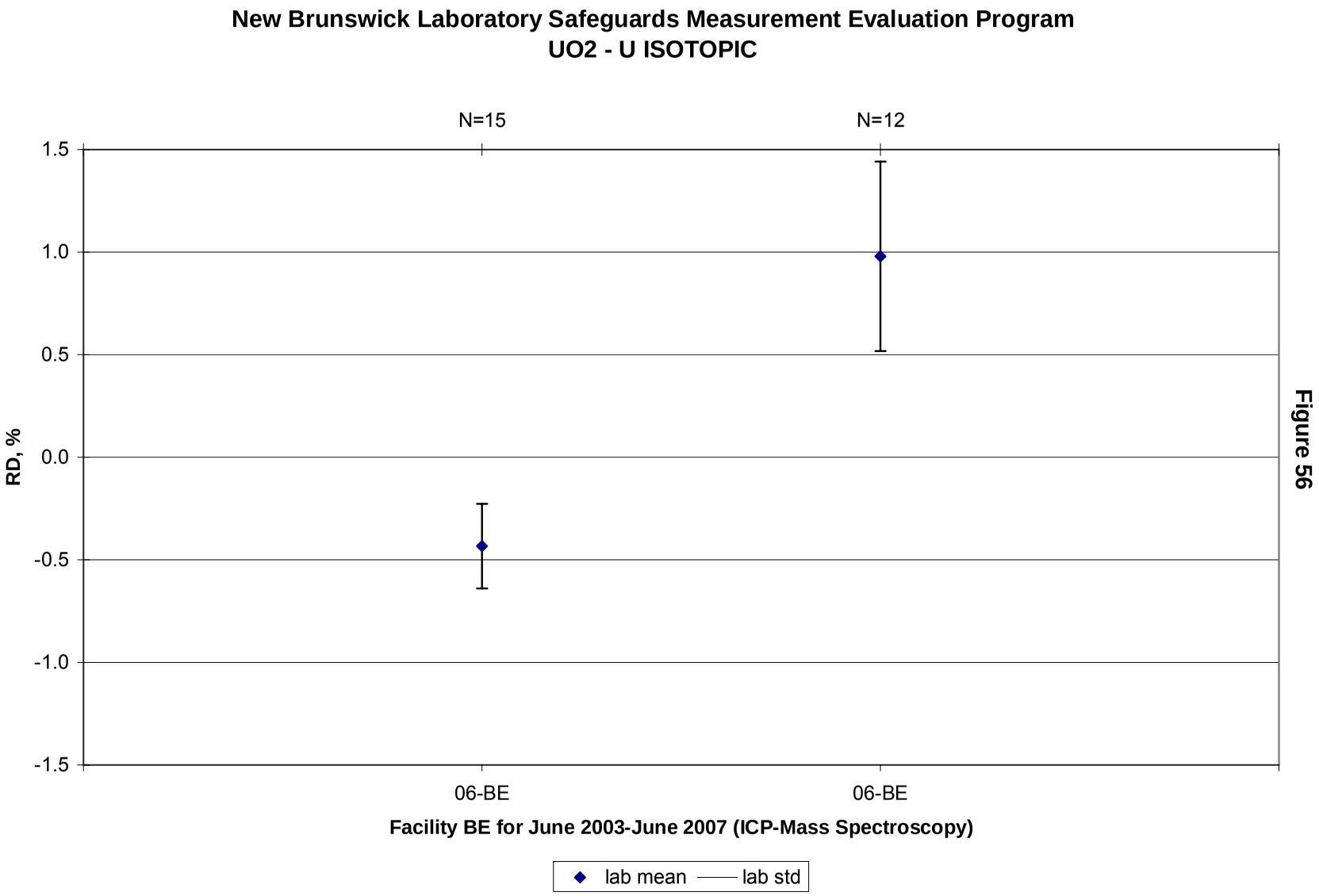

New Brunswick Laboratory Safeguards Measurement Evaluation Program
UO2 - U ISOTOPIC
N=15
N=12
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
RD, %
06-BE
06-BE
Facility BE for June 2003-June 2007 (ICP-Mass Spectroscopy)
lab mean
lab std

Figure 56

**New Brunswick Laboratory Safeguards Measurement Evaluation Program**
**LEU - U ISOTOPIC**

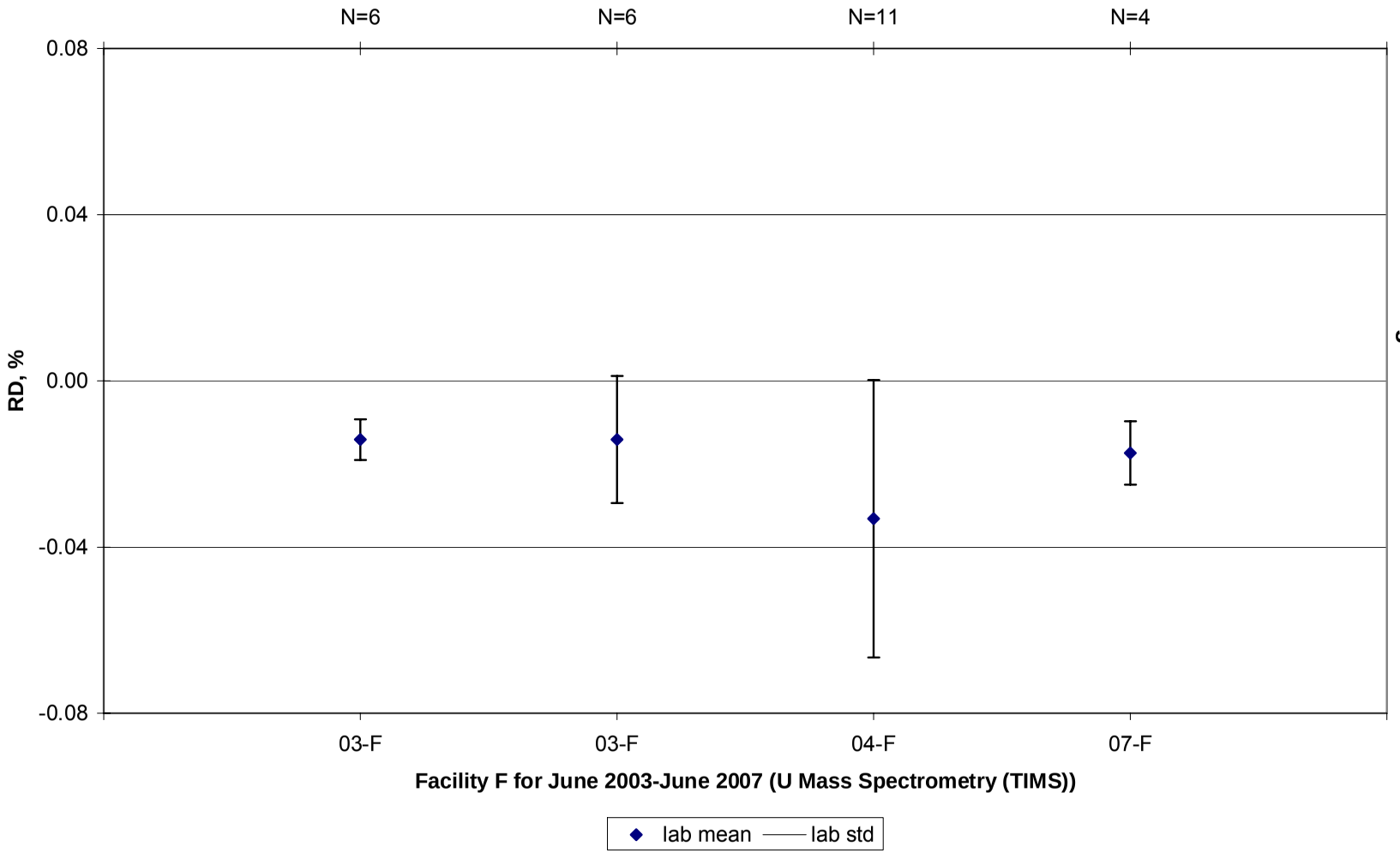



Figure 57

**Figure 58**

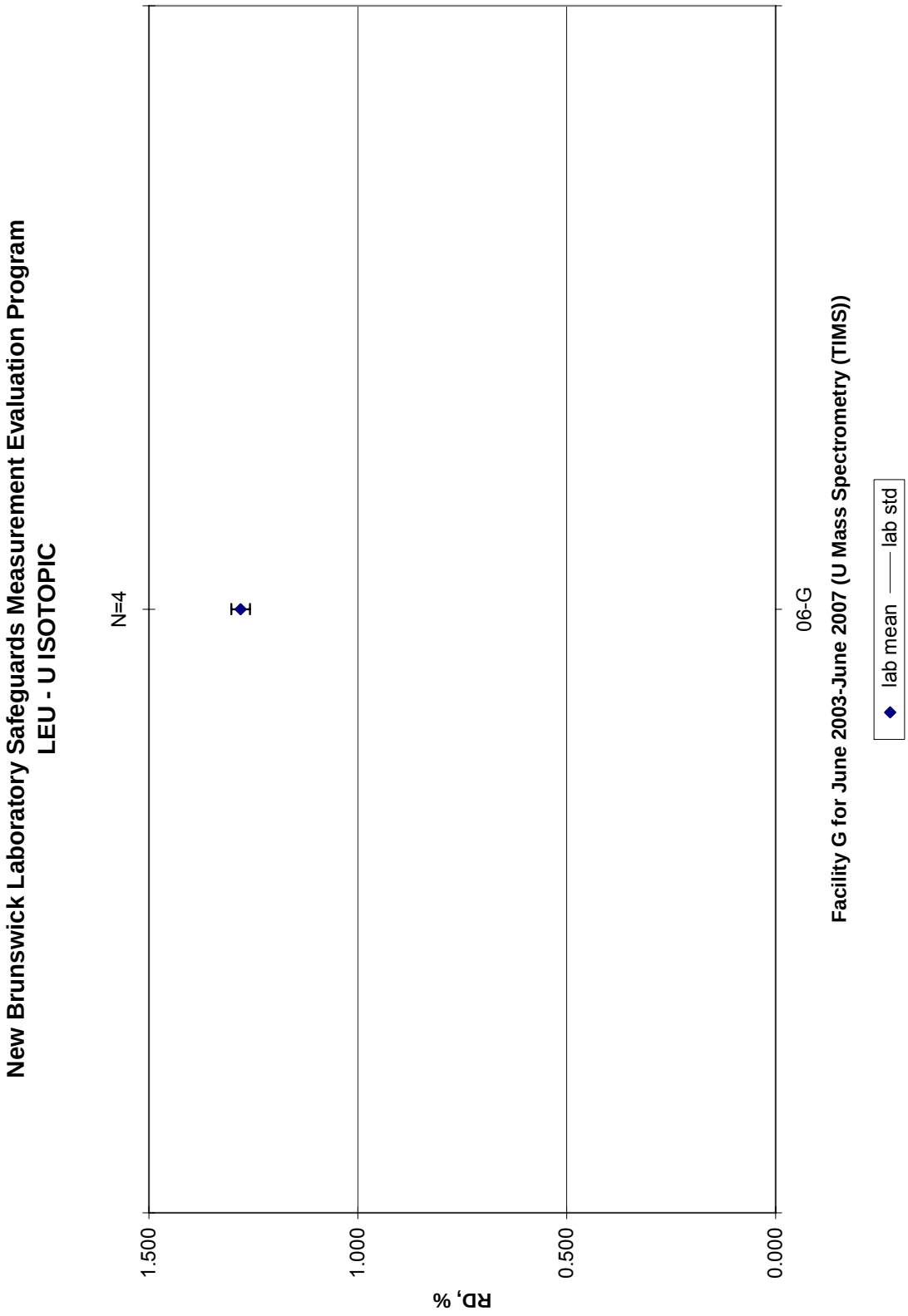
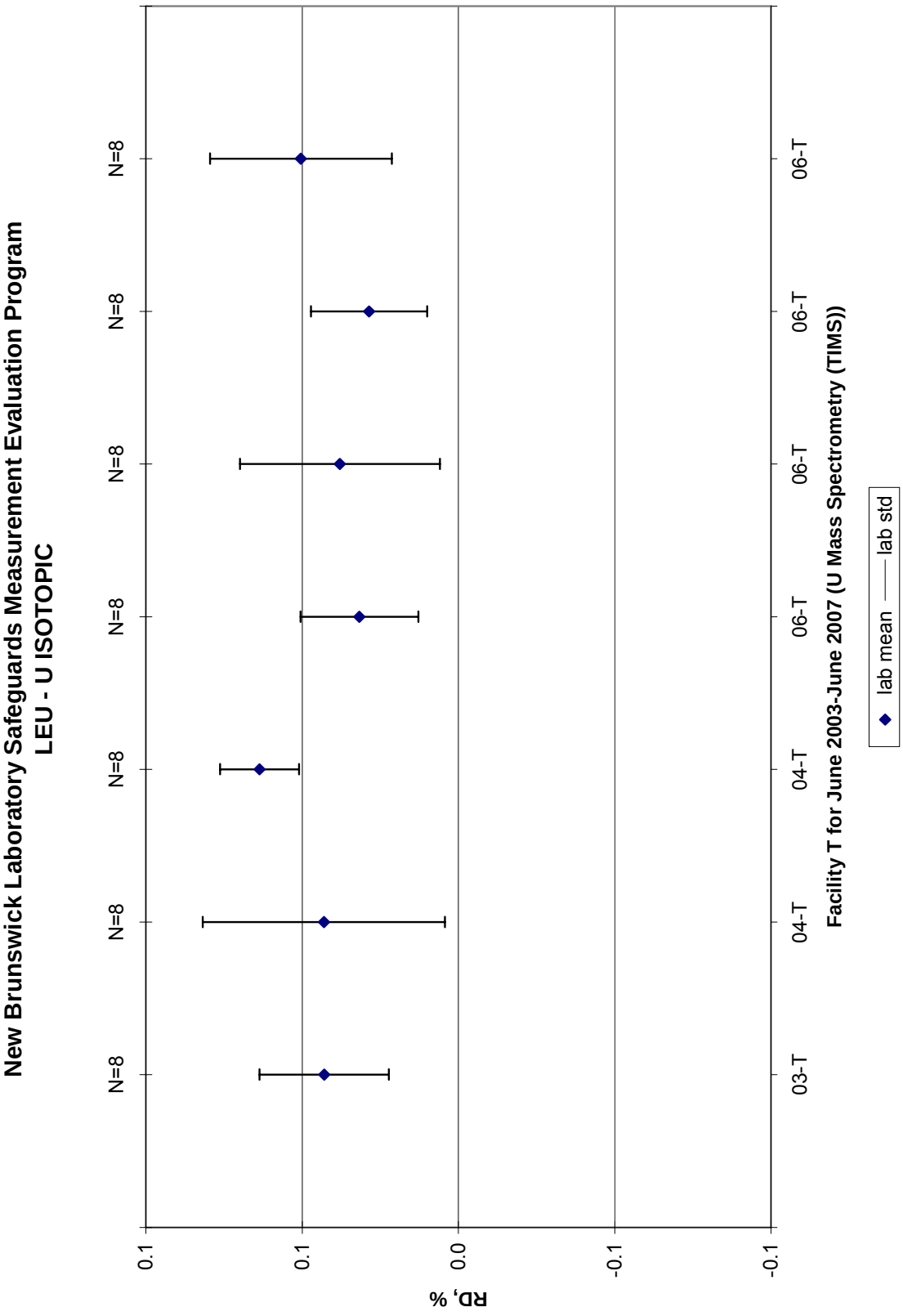

New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
RD, %
1.500
1.000
0.500
0.000
N=4
06-G
Facility G for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**Figure 59**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
N=8
N=8
N=8
N=8
N=8
N=8
0.1
0.1
0.0
-0.1
-0.1
RD, %
03-T
04-T
04-T
06-T
06-T
06-T
Facility T for June 2003-June 2007 (U Mass Spectrometry (TIMS))
lab mean
lab std

**New Brunswick Laboratory Safeguards Measurement Evaluation Program**
**LEU - U ISOTOPIC**

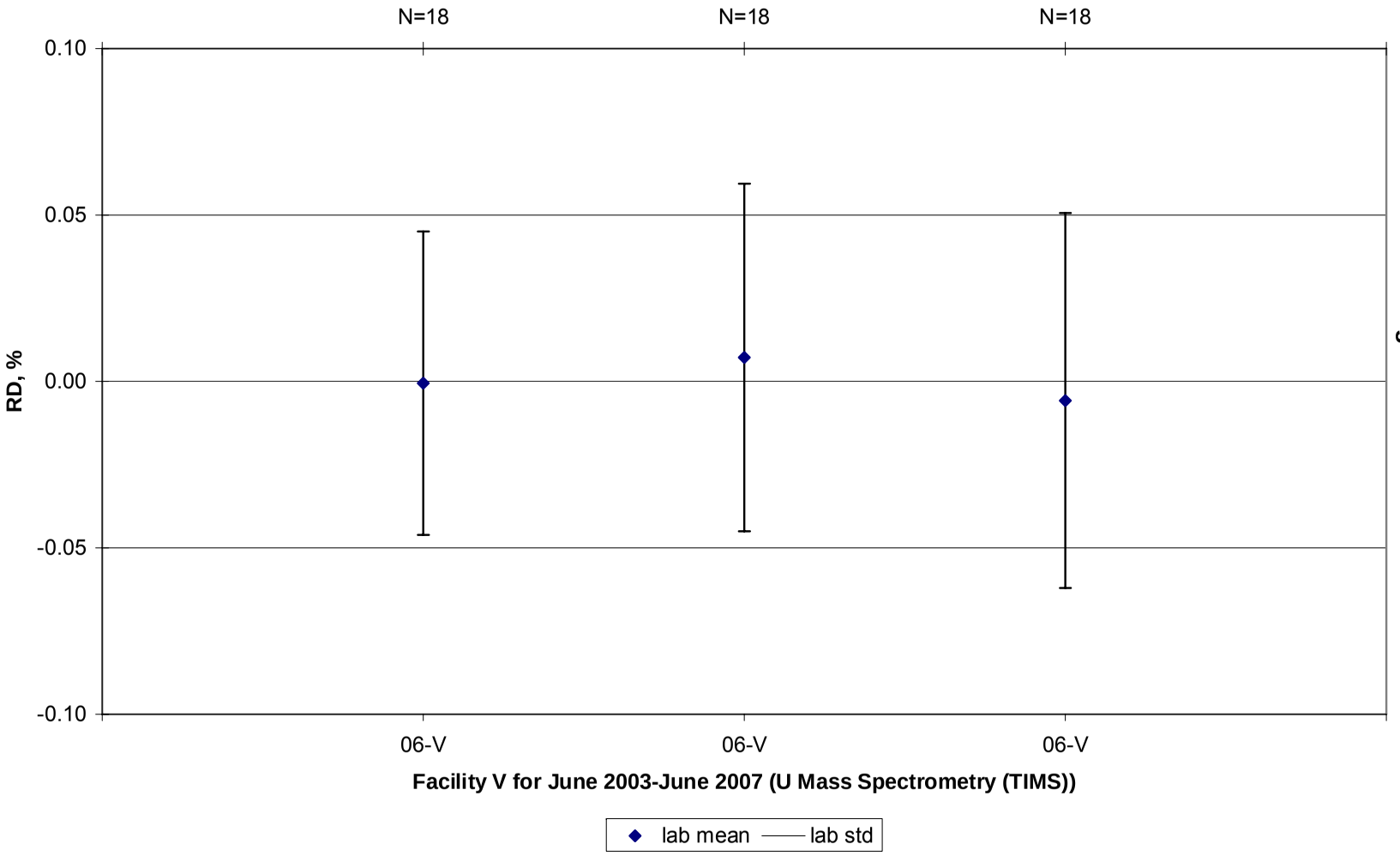
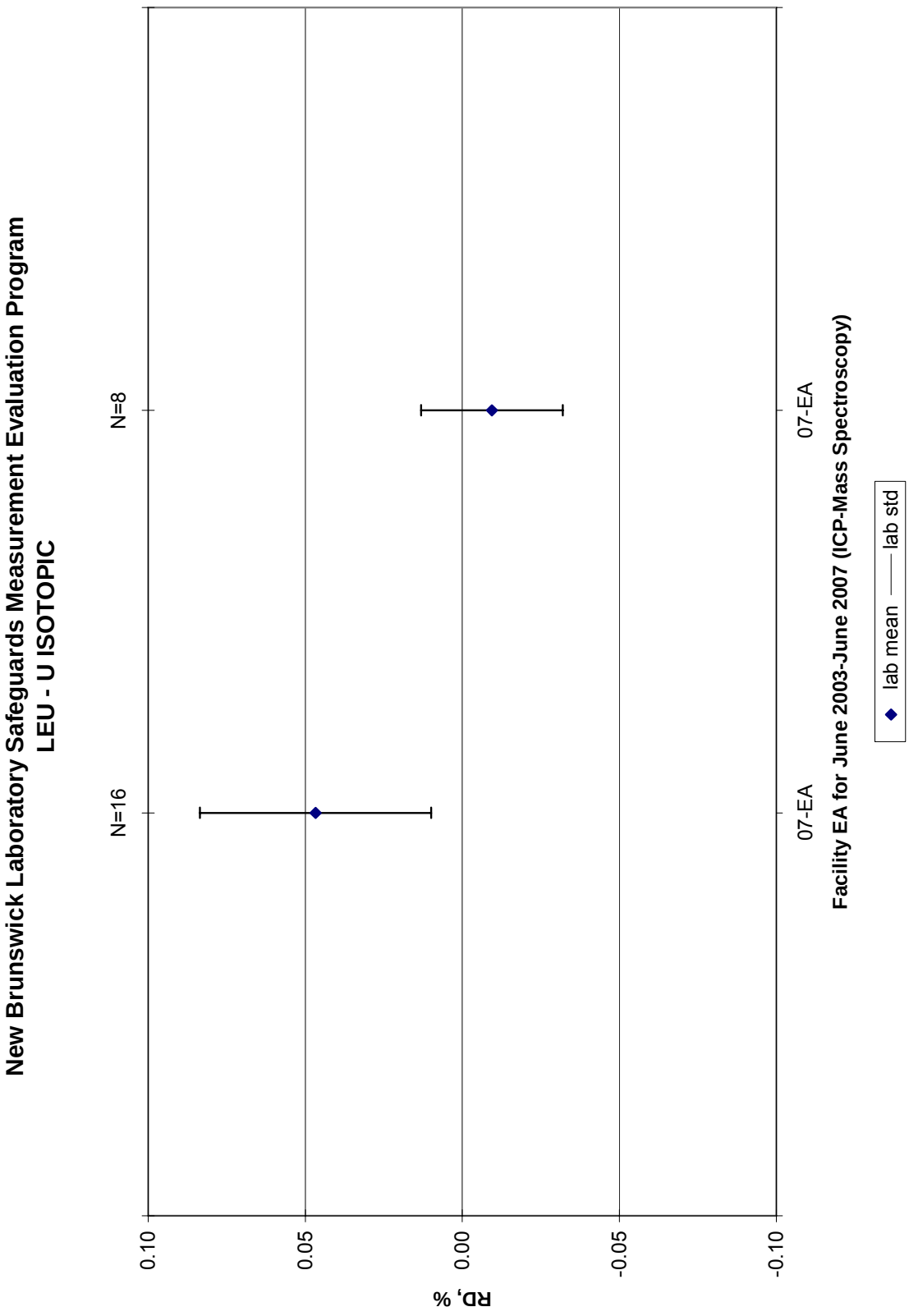



Figure 60

**Figure 61**


New Brunswick Laboratory Safeguards Measurement Evaluation Program
LEU - U ISOTOPIC
Facility EA for June 2003-June 2007 (ICP-Mass Spectroscopy)
RD, %
0.10
0.05
0.00
-0.05
-0.10
N=16
N=8
07-EA
07-EA
lab mean
lab std

**New Brunswick Laboratory Safeguards Measurement Evaluation Program**
**LEU - U ISOTOPIC**

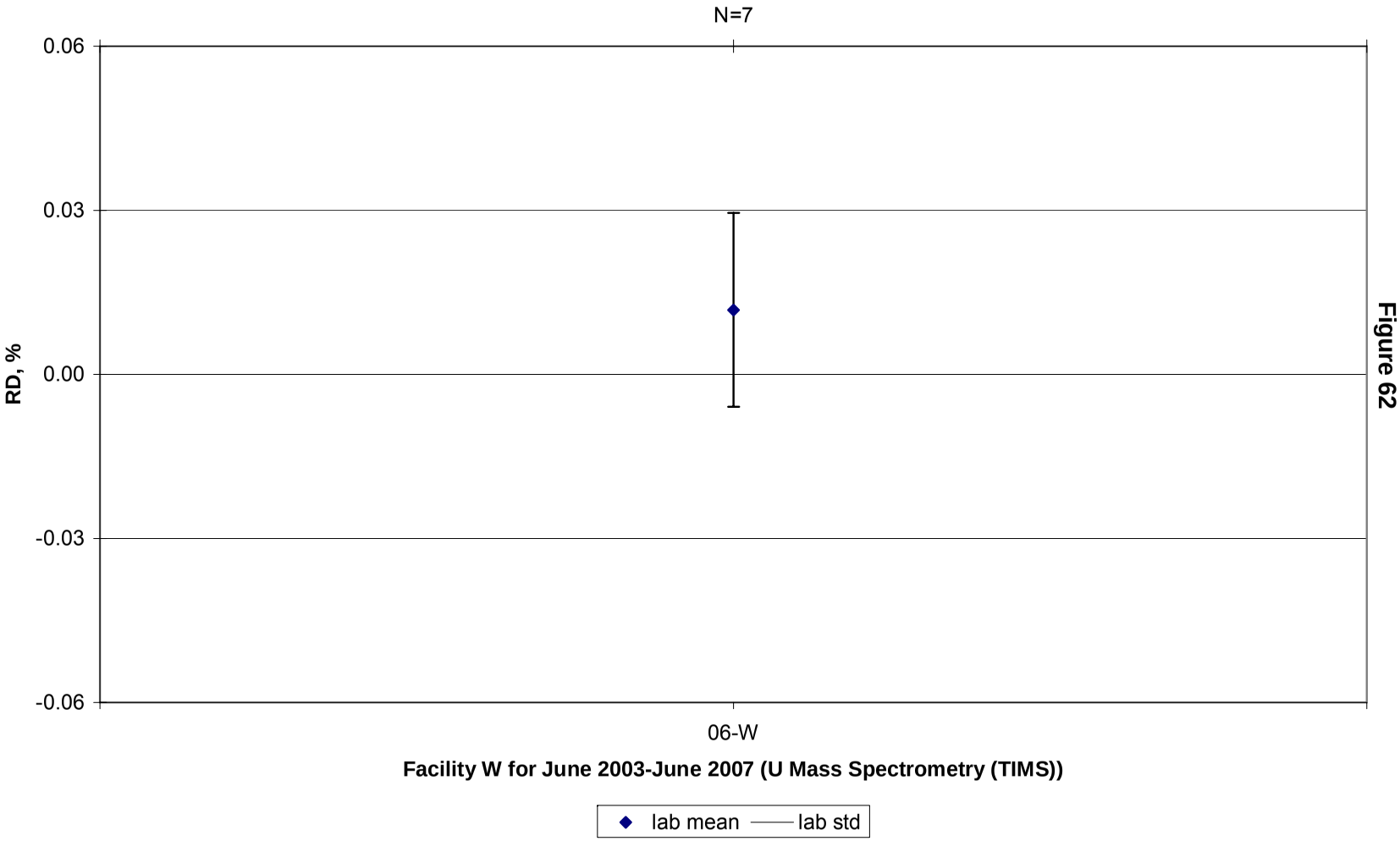



Figure 62

**New Brunswick Laboratory Safeguards Measurement Evaluation Program**
**LEU-UF6 - U ISOTOPIC**

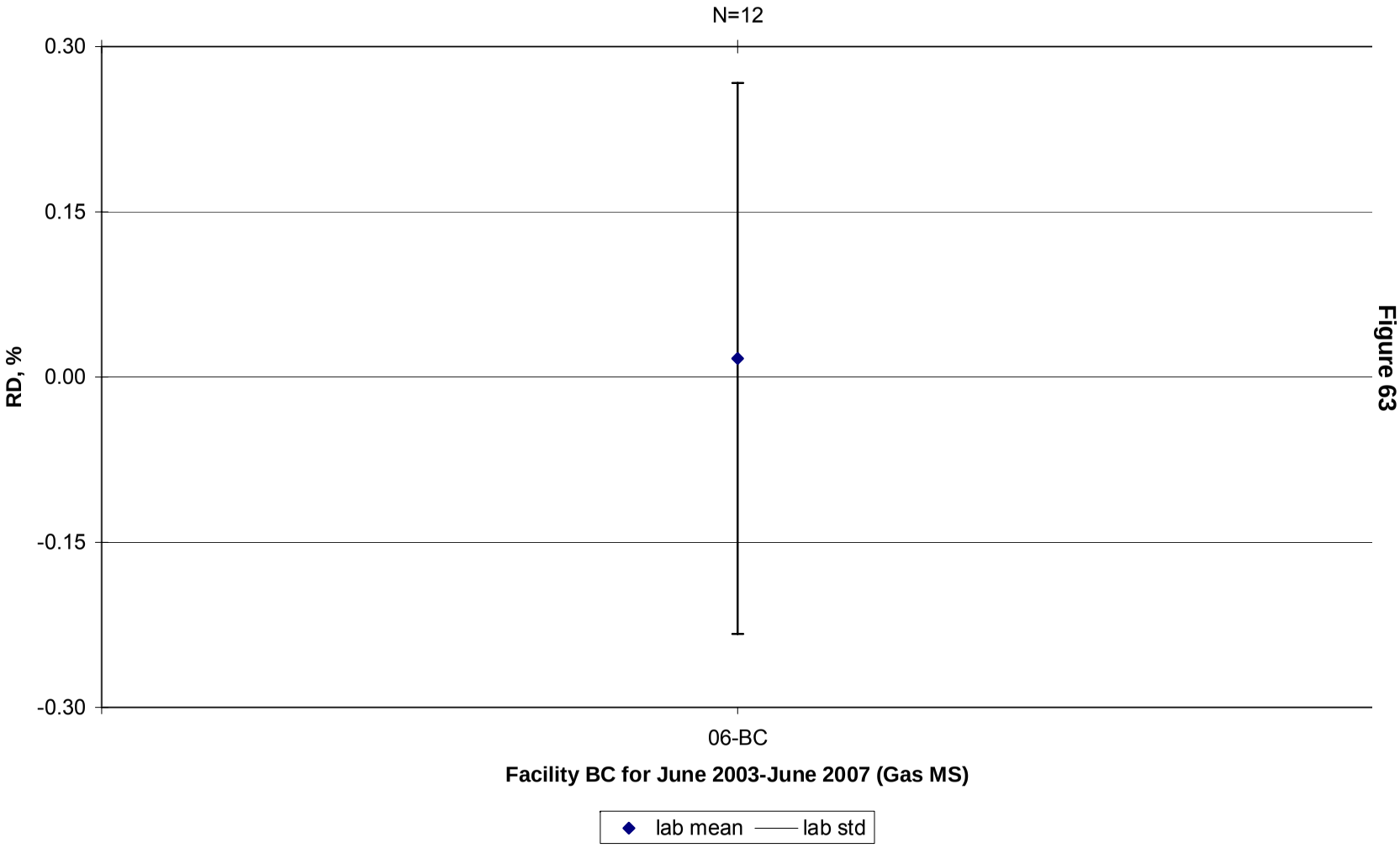



Figure 63

# APPENDICES

Appendix A: Uranium Assay Results

Appendix B: Uranium Isotopic Results

**Key to symbols in the tables in the appendices**

Material Symbols

| | |
|---|---|
| UNH | Uranyl Nitrate Solution |
| $UO_2$ | Uranium Dioxide Pellet |
| $UF_6$ | Uranium Hexafluoride |
| $UO_3$ | Uranium Trioxide Powder |
| HEU | Highly Enriched Uranium |
| LEU | Low Enriched Uranium |

Method Type Symbols

| | |
|---|---|
| DG | Davies-Gray Titration |
| IDMS | Isotope Dilution Mass Spectrometry |
| XRFL | X-Ray Fluorescence - Liquid |
| XRFS | X-Ray Fluorescence - Solid |
| TIMS | Thermal Ionization Mass Spectrometry |
| GSMS | Gas Source Mass Spectrometry |
| ICPMS | Inductively Coupled Plasma Mass Spectrometry |

## Appendix A: Uranium Assay Results

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| UNH | DG | B | 7/24/06 | 1.00015 | -0.215 | 796 |
| UNH | DG | B | 7/24/06 | 1.00225 | -0.005 | 796 |
| UNH | DG | B | 7/24/06 | 1.00024 | -0.031 | 796 |
| UNH | DG | B | 7/24/06 | 1.0014 | 0.085 | 796 |
| UNH | DG | B | 10/9/06 | 1.0043 | 0.200 | 374 |
| UNH | DG | B | 10/9/06 | 1.0046 | 0.229 | 374 |
| UNH | DG | B | 10/11/06 | 1.0018 | 0.125 | 374 |
| UNH | DG | B | 10/11/06 | 1.0021 | 0.155 | 374 |
| UNH | DG | G | 8/24/06 | 1.00045 | -0.010 | |
| UNH | DG | G | 8/24/06 | 1.00057 | 0.002 | |
| UNH | DG | G | 8/24/06 | 1.00211 | -0.019 | |
| UNH | DG | G | 8/24/06 | 1.00205 | -0.025 | |
| UNH | DG | G | 8/25/06 | 1.00047 | -0.008 | |
| UNH | DG | G | 8/25/06 | 1.0006 | 0.005 | |
| UNH | DG | G | 8/25/06 | 1.00217 | -0.013 | |
| UNH | DG | G | 8/25/06 | 1.00224 | -0.006 | |
| UNH | IDMS | B | 7/22/06 | 0.9955 | -0.678 | PWB |
| UNH | IDMS | B | 7/22/06 | 0.9981 | -0.419 | PWB |
| UNH | IDMS | B | 7/22/06 | 0.9975 | -0.305 | PWB |
| UNH | IDMS | B | 7/22/06 | 0.994 | -0.655 | PWB |
| UNH | IDMS | B | 7/31/06 | 1.0167 | 1.437 | DDB |
| UNH | IDMS | B | 7/31/06 | 1.0039 | 0.160 | DDB |
| UNH | IDMS | B | 8/1/06 | 0.9909 | -0.964 | DDB |
| UNH | IDMS | B | 8/1/06 | 0.9877 | -1.284 | DDB |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UO_2$ Pellet | DG | AC | 11/16/06 | 88.128 | -0.001 | AL |
| $UO_2$ Pellet | DG | AC | 11/16/06 | 88.137 | 0.009 | AL |
| $UO_2$ Pellet | DG | AC | 11/16/06 | 88.096 | -0.037 | NDS |
| $UO_2$ Pellet | DG | AC | 11/16/06 | 88.097 | -0.036 | NDS |
| $UO_2$ Pellet | DG | AC | 11/17/06 | 88.129 | 0.000 | NDS |
| $UO_2$ Pellet | DG | AC | 11/17/06 | 88.147 | 0.020 | NDS |
| $UO_2$ Pellet | DG | AC | 11/17/06 | 88.098 | -0.035 | AL |
| $UO_2$ Pellet | DG | AC | 11/17/06 | 88.11 | -0.022 | AL |
| $UO_2$ Pellet | DG | AD | 11/23/06 | 88.059 | -0.079 | EB |
| $UO_2$ Pellet | DG | AD | 11/23/06 | 88.069 | -0.068 | CD |
| $UO_2$ Pellet | DG | AD | 11/23/06 | 88.075 | -0.061 | EB |
| $UO_2$ Pellet | DG | AD | 11/23/06 | 88.064 | -0.074 | CD |
| $UO_2$ Pellet | DG | AD | 11/25/06 | 88.088 | -0.047 | EB |
| $UO_2$ Pellet | DG | AD | 11/25/06 | 88.065 | -0.073 | CD |
| $UO_2$ Pellet | DG | AD | 11/25/06 | 88.075 | -0.061 | EB |
| $UO_2$ Pellet | DG | AD | 11/25/06 | 88.07 | -0.067 | CD |
| $UO_2$ Pellet | DG | AE | 11/23/06 | 88.122 | -0.008 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/23/06 | 88.164 | 0.040 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/23/06 | 88.091 | -0.043 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/23/06 | 88.095 | -0.039 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/24/06 | 88.065 | -0.073 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/24/06 | 88.006 | -0.140 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/24/06 | 88.06 | -0.078 | JR-EL |
| $UO_2$ Pellet | DG | AE | 11/24/06 | 87.977 | -0.172 | JR-EL |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.055 | -0.084 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.15 | 0.024 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.114 | -0.017 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.094 | -0.040 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.131 | 0.002 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.099 | -0.034 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.137 | 0.009 | |
| $UO_2$ Pellet | DG | BA | 11/23/06 | 88.08 | -0.056 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.102 | -0.031 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.08 | -0.056 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.124 | -0.006 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.136 | 0.008 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.132 | 0.003 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.152 | 0.026 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.062 | -0.076 | |
| $UO_2$ Pellet | DG | BA | 11/24/06 | 88.113 | -0.018 | |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.07628 | -0.060 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.10536 | -0.027 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.11326 | -0.018 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.09782 | -0.035 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.07518 | -0.061 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.20877 | 0.091 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.13921 | 0.012 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.16356 | 0.039 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.19854 | 0.079 | ICO |
| $UO_2$ Pellet | DG | BC | 10/17/06 | 88.15852 | 0.033 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.05198 | -0.087 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.08551 | -0.049 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.05898 | -0.079 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.05865 | -0.080 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.05625 | -0.083 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.1391 | 0.011 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.15435 | 0.029 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.15698 | 0.0317 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.16761 | 0.0438 | ICO |
| $UO_2$ Pellet | DG | BC | 10/19/06 | 88.13891 | 0.011 | ICO |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 88.122 | -0.008 | ABC |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 88.121 | -0.009 | ABC |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 87.955 | -0.197 | ABC |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 87.998 | -0.149 | ABC |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 88.148 | 0.022 | ABC |
| $UO_2$ Pellet | DG | BF | 1/15/07 | 88.125 | -0.005 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.127 | -0.002 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.147 | 0.020 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.194 | 0.074 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.204 | 0.085 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.145 | 0.018 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.224 | 0.108 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.105 | -0.027 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.178 | 0.056 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.125 | -0.005 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.126 | -0.003 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.138 | 0.010 | ABC |
| $UO_2$ Pellet | DG | BF | 1/16/07 | 88.094 | -0.040 | ABC |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UO_2$ Pellet | DG | T | 8/23/06 | 88.09 | -0.044 | |
| $UO_2$ Pellet | DG | T | 8/23/06 | 88.16 | 0.035 | |
| $UO_2$ Pellet | DG | T | 8/23/06 | 88.16 | 0.035 | |
| $UO_2$ Pellet | DG | T | 8/23/06 | 88.1 | -0.033 | |
| $UO_2$ Pellet | DG | T | 8/25/06 | 88.1 | -0.033 | |
| $UO_2$ Pellet | DG | T | 8/25/06 | 88.12 | -0.010 | |
| $UO_2$ Pellet | DG | T | 8/25/06 | 88.19 | 0.069 | |
| $UO_2$ Pellet | DG | T | 8/25/06 | 88.16 | 0.035 | |
| $UO_2$ Pellet | DG | T | 10/16/06 | 88.15 | 0.024 | |
| $UO_2$ Pellet | DG | T | 10/16/06 | 88.15 | 0.024 | |
| $UO_2$ Pellet | DG | T | 10/16/06 | 88.1 | -0.033 | |
| $UO_2$ Pellet | DG | T | 10/16/06 | 88.12 | -0.010 | |
| $UO_2$ Pellet | DG | T | 10/24/06 | 88.03 | -0.112 | |
| $UO_2$ Pellet | DG | T | 10/24/06 | 88.18 | 0.058 | |
| $UO_2$ Pellet | DG | T | 10/24/06 | 88.03 | -0.112 | |
| $UO_2$ Pellet | DG | T | 10/24/06 | 88.18 | 0.058 | |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UF_6$ | DG | AE | 11/28/06 | 67.592 | -0.039 | JR-EL |
| $UF_6$ | DG | AE | 11/28/06 | 67.554 | -0.095 | JR-EL |
| $UF_6$ | DG | AE | 11/28/06 | 67.408 | -0.311 | JR-EL |
| $UF_6$ | DG | AE | 11/28/06 | 67.434 | -0.272 | JR-EL |
| $UF_6$ | DG | AE | 11/29/06 | 67.485 | -0.197 | JR-EL |
| $UF_6$ | DG | AE | 11/29/06 | 67.537 | -0.120 | JR-EL |
| $UF_6$ | DG | AE | 11/29/06 | 67.384 | -0.346 | JR-EL |
| $UF_6$ | DG | AE | 11/29/06 | 67.444 | -0.257 | JR-EL |

## Appendix B: Uranium Isotopic Results

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| UNH | TIMS | B | 7/22/06 | 0.7133 | 0.263696 | PWB |
| UNH | TIMS | B | 7/22/06 | 0.7122 | 0.109077 | PWB |
| UNH | TIMS | B | 7/22/06 | 0.7122 | 0.109077 | PWB |
| UNH | TIMS | B | 7/22/06 | 0.7135 | 0.291809 | PWB |
| UNH | TIMS | B | 7/25/06 | 90.346 | 0.009763 | PAM |
| UNH | TIMS | B | 7/25/06 | 90.3431 | 0.006553 | PAM |
| UNH | TIMS | B | 7/25/06 | 4.3886 | -0.066947 | PAM |
| UNH | TIMS | B | 7/25/06 | 4.3806 | -0.249115 | PAM |
| UNH | TIMS | B | 7/31/06 | 0.7121 | 0.095021 | DDB |
| UNH | TIMS | B | 7/31/06 | 0.7127 | 0.179359 | DDB |
| UNH | TIMS | B | 8/1/06 | 0.7126 | 0.165302 | DDB |
| UNH | TIMS | B | 8/1/06 | 0.7138 | 0.333978 | DDB |
| UNH | TIMS | B | 10/11/06 | 90.3263 | -0.012044 | LLB |
| UNH | TIMS | B | 10/11/06 | 90.334 | -0.00352 | LLB |
| UNH | TIMS | B | 10/11/06 | 4.3845 | -0.160308 | LLB |
| UNH | TIMS | B | 10/11/06 | 4.3855 | -0.137537 | LLB |
| UNH | TIMS | F | 1/12/07 | 89.68024 | 0.001583 | RE |
| UNH | TIMS | F | 1/12/07 | 89.68079 | 0.002197 | RE |
| UNH | TIMS | F | 1/12/07 | 90.33964 | 0.002723 | RE |
| UNH | TIMS | F | 1/12/07 | 90.33819 | 0.001118 | RE |
| UNH | TIMS | F | 1/13/07 | 89.68045 | 0.001818 | RE |
| UNH | TIMS | F | 1/13/07 | 89.68072 | 0.002119 | RE |
| UNH | TIMS | F | 1/13/07 | 90.34 | 0.003122 | RE |
| UNH | TIMS | F | 1/13/07 | 90.33858 | 0.00155 | RE |
| UNH | TIMS | F | 3/13/07 | 51.3386 | 0.027472 | RBT |
| UNH | TIMS | F | 3/13/07 | 51.3376 | 0.025524 | RBT |
| UNH | TIMS | F | 3/13/07 | 4.39049 | -0.02391 | RBT |
| UNH | TIMS | F | 3/13/07 | 4.39055 | -0.022543 | RBT |
| UNH | TIMS | F | 3/14/07 | 51.3381 | 0.026498 | RBT |
| UNH | TIMS | F | 3/14/07 | 51.3379 | 0.026108 | RBT |
| UNH | TIMS | F | 3/14/07 | 4.39122 | -0.007287 | RBT |
| UNH | TIMS | F | 3/14/07 | 4.39085 | -0.015712 | RBT |
| UNH | TIMS | W | 9/1/06 | 4.3933 | 0.040077 | KHN |
| UNH | TIMS | W | 9/1/06 | 4.392 | 0.010475 | KHN |
| UNH | TIMS | W | 9/2/06 | 4.3926 | 0.024137 | KHN |
| UNH | TIMS | W | 9/2/06 | 4.3908 | -0.016851 | KHN |
| UNH | TIMS | W | 9/3/06 | 4.392 | 0.010475 | KHN |
| UNH | TIMS | W | 9/4/06 | 4.3916 | 0.001366 | KHN |
| UNH | TIMS | W | 9/4/06 | 4.3921 | 0.012752 | KHN |
| UNH | TIMS | W | 9/5/06 | 90.3421 | 0.005446 | KHN |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| UNH | TIMS | W | 9/5/06 | 90.3435 | 0.006996 | KHN |
| UNH | TIMS | W | 9/6/06 | 90.3425 | 0.005889 | KHN |
| UNH | TIMS | W | 9/6/06 | 90.3415 | 0.004782 | KHN |
| UNH | TIMS | W | 9/7/06 | 90.3431 | 0.006553 | KHN |
| UNH | TIMS | W | 9/7/06 | 90.3425 | 0.005889 | KHN |
| UNH | TIMS | W | 9/8/06 | 90.343 | 0.006443 | KHN |
| UNH | TIMS | W | 9/8/06 | 90.3431 | 0.006553 | KHN |
| UNH | ICPMS | EA | 3/29/07 | 4.392 | 0.010 | |
| UNH | ICPMS | EA | 3/29/07 | 4.392 | 0.010 | |
| UNH | ICPMS | EA | 3/29/07 | 4.392 | 0.010 | |
| UNH | ICPMS | EA | 3/29/07 | 4.392 | 0.010 | |
| UNH | ICPMS | EA | 3/31/07 | 4.39 | -0.035 | |
| UNH | ICPMS | EA | 3/31/07 | 4.391 | -0.012 | |
| UNH | ICPMS | EA | 3/31/07 | 4.39 | -0.035 | |
| UNH | ICPMS | EA | 3/31/07 | 4.39 | -0.035 | |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UO_2$ | TIMS | AA | 11/30/06 | 4.0051 | -0.078 | AL/EG |
| $UO_2$ | TIMS | AA | 11/30/06 | 4.0027 | -0.138 | AL/EG |
| $UO_2$ | TIMS | AA | 11/30/06 | 4.0026 | -0.140461 | AL/EG |
| $UO_2$ | TIMS | AA | 11/30/06 | 4.0042 | -0.100543 | AL/EG |
| $UO_2$ | TIMS | AA | 12/1/06 | 4.0058 | -0.061 | AL/EG |
| $UO_2$ | TIMS | AA | 12/1/06 | 4.0009 | -0.183 | AL/EG |
| $UO_2$ | TIMS | AA | 12/1/06 | 4.0012 | -0.175 | AL/EG |
| $UO_2$ | TIMS | AA | 12/1/06 | 4.0023 | -0.148 | AL/EG |
| $UO_2$ | TIMS | BC | 10/9/06 | 4.0101 | 0.047 | MRPP |
| $UO_2$ | TIMS | BC | 10/9/06 | 4.0095 | 0.032 | MRPP |
| $UO_2$ | TIMS | BC | 10/9/06 | 4.0054 | -0.071 | MRPP |
| $UO_2$ | TIMS | BC | 10/9/06 | 4.0138 | 0.139 | MRPP |
| $UO_2$ | TIMS | BC | 10/16/06 | 4.0122 | 0.099 | MRPP |
| $UO_2$ | TIMS | BC | 10/16/06 | 4.0083 | 0.002 | MRPP |
| $UO_2$ | TIMS | BC | 10/16/06 | 4.0128 | 0.114 | MRPP |
| $UO_2$ | TIMS | BC | 10/16/06 | 4.0031 | -0.128 | MRPP |
| $UO_2$ | TIMS | T | 8/28/06 | 4.012 | 0.094 | |
| $UO_2$ | TIMS | T | 8/28/06 | 4.01 | 0.044159 | |
| $UO_2$ | TIMS | T | 8/28/06 | 4.01 | 0.044159 | |
| $UO_2$ | TIMS | T | 8/28/06 | 4.009 | 0.019 | |
| $UO_2$ | TIMS | T | 8/29/06 | 4.01 | 0.044 | |
| $UO_2$ | TIMS | T | 8/29/06 | 4.01 | 0.044 | |
| $UO_2$ | TIMS | T | 8/29/06 | 4.012 | 0.094 | |
| $UO_2$ | TIMS | T | 8/29/06 | 4.009 | 0.019 | |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.989 | -0.480 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.987 | -0.530 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.979 | -0.729 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.9830 | -0.629 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.9930 | -0.380 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.9840 | -0.605 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.9800 | -0.704 | MHK |
| $UO_2$ | ICPMS | BE | 10/3/06 | 3.9900 | -0.455 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 4.0210 | 0.319 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 4.0000 | -0.205 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 4.0020 | -0.155 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 3.9960 | -0.305 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 3.9940 | -0.355 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 3.9840 | -0.605 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 4.0070 | -0.031 | MHK |
| $UO_2$ | ICPMS | BE | 10/4/06 | 3.9950 | -0.330 | MHK |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| $UF_6$ | GSMS | BC | 10/24/06 | 3.1988 | 0.312 | ET |
| $UF_6$ | GSMS | BC | 10/24/06 | 3.2008 | 0.375 | ET |
| $UF_6$ | GSMS | BC | 10/24/06 | 3.1883 | -0.017 | ET |
| $UF_6$ | GSMS | BC | 10/24/06 | 3.1984 | 0.300 | ET |
| $UF_6$ | GSMS | BC | 10/24/06 | 3.1978 | 0.281 | ET |
| $UF_6$ | GSMS | BC | 10/24/06 | 3.1886 | -0.007 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1816 | -0.227 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1849 | -0.123 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1888 | -0.001 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1873 | -0.048 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1807 | -0.255 | ET |
| $UF_6$ | GSMS | BC | 10/27/06 | 3.1765 | -0.387 | ET |
| $UF_6$ | ICPMS | EA | 3/28/07 | 1.292 | 0.008 | |
| $UF_6$ | ICPMS | EA | 3/28/07 | 1.292 | 0.008 | |
| $UF_6$ | ICPMS | EA | 3/28/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/28/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/28/07 | 2.986 | 0.057 | |
| $UF_6$ | ICPMS | EA | 3/28/07 | 2.986 | 0.057 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 1.293 | 0.085 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 2.986 | 0.057 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 2.985 | 0.023 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 2.985 | 0.023 | |
| $UF_6$ | ICPMS | EA | 3/29/07 | 2.985 | 0.023 | |
| $UF_6$ | ICPMS | EA | 3/31/07 | 2.984 | -0.010 | |
| $UF_6$ | ICPMS | EA | 3/31/07 | 2.984 | -0.010 | |

| Material | Method Type | Facility | Analysis Date | Reported Result | % RD | Analyst |
|---|---|---|---|---|---|---|
| LEU | TIMS | T | 10/17/06 | 4.01 | 0.044 | |
| LEU | TIMS | T | 10/17/06 | 4.009 | 0.019 | |
| LEU | TIMS | T | 10/17/06 | 4.009 | 0.019 | |
| LEU | TIMS | T | 10/17/06 | 4.01 | 0.044 | |
| LEU | TIMS | T | 10/19/06 | 4.01 | 0.044 | |
| LEU | TIMS | T | 10/19/06 | 4.008 | -0.006 | |
| LEU | TIMS | T | 10/19/06 | 4.009 | 0.019 | |
| LEU | TIMS | T | 10/19/06 | 4.01 | 0.044 | |