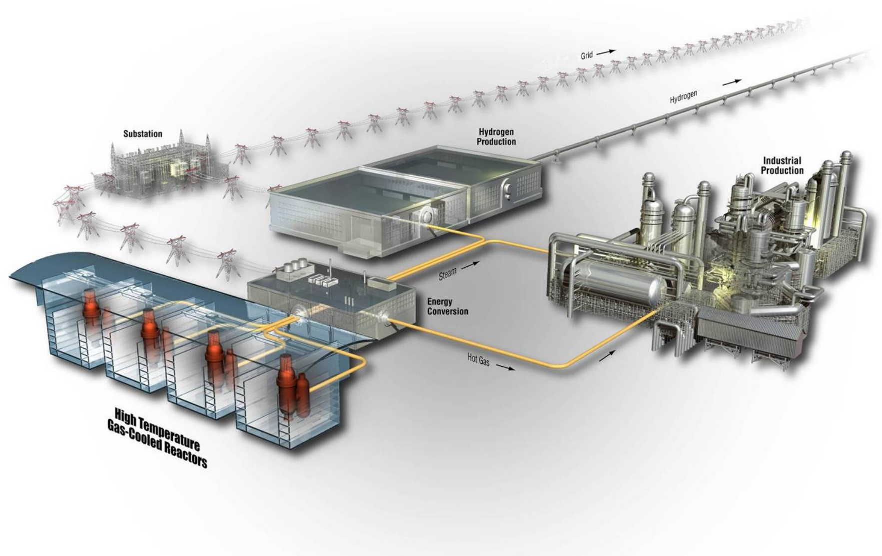
INL/EXT-14-31186
Revision 0

AGR-3/4 Data Qualification Report for ATR Cycles 151A, 151B, 152A, 152B, 154A, and 154B

Binh T. Pham

February 2014



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http://www.inl.gov

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Very High Temperature Reactor Technology Development Office

AGR-3/4 Data Qualification Report for ATR Cycles 151A, 151B, 152A, 152B, 154A, and 154B

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Revision 0

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SUMMARY

This data report provides the qualification status of Advanced Gas Reactor-3/4 (AGR-3/4) fuel irradiation experimental data from Advanced Test Reactor (ATR) Cycles 151A, 151B, 152A, 152B, 154A, and 154B, as recorded in the Nuclear Data Management and Analysis System (NDMAS). Of these cycles, ATR Cycle 152A is a low power cycle that occurred when the ATR core was briefly at low power. The irradiation data are not used for physics and thermal calculation, but the qualification status of these cycle data is still covered in this report. On the other hand, during ATR Cycles 153A (unplanned Outage cycle) and 153B (Power Axial Locator Mechanism [PALM] cycle), the AGR-3/4 was pulled out from the ATR core and stored in the canal to avoid being overheated. Therefore, qualification of the AGR-3/4 irradiation data from these 2 cycles was excluded in this report. By the end of ATR Cycle 154B, AGR-3/4 was irradiated for a total of 264.1 effective full power days.

The AGR-3/4 data streams addressed in this report include thermocouple (TC) temperatures, sweep gas data (flow rates, pressure, and moisture content), and Fission Product Monitoring System (FPMS) data (release rates and release-to-birth rate ratios [R/Bs]) for each of the twelve capsules in the AGR-3/4 experiment. The final data qualification status for these data streams is determined by a Data Review Committee (DRC) composed of AGR technical leads, Sitewide Quality Assurance (QA), and NDMAS analysts. The DRC convened on February 12, 2014, reviewed the data acquisition process, and considered whether the data met the requirements for data collection as specified in QA-approved Very High Temperature Reactor (VHTR) Technology Development Office (TDO) data collection plans. The DRC also examined the results of NDMAS data testing and statistical analyses, and confirmed the qualification status of the data as given in this report.

A total of 29,863,811 TC temperature and sweep gas data records were received and processed by NDMAS for this period. Of these records, 26,934,862 (90.2% of the total) met data collection and accuracy requirements and are labeled as *Qualified*. Data records for ATR Cycles 151A and 151B are 5-minute averaged values and are instantaneous (every minute) measurements for the remaining cycles. For TC readings, 940,233 TC records (8.0% of the total of 11,721,025 TC records) were *Failed* mostly because of TC instrument failures (TC2 in Capsule 2 and TC1/2 in Capsule 3). For sweep gas flow rates, 1,988,716 gas flow records (11.0% of the total of 18,142,786 gas flow records) were *Failed* mostly because of missing values. However, 800,420 slightly negative flow rate records were reexamined and found to be valid measurements. They were replaced with 0 standard cubic centimeters per minute in the database and labeled as *Qualified.*

For FPMS data, NDMAS received and processed preliminary release and R/B data for five ATR cycles (151A, 151B, 152B, 154A, and 154B). These data consist of 196,512 release rate records and 196,512 R/B records for the 12 radionuclides reported for 12 AGR-3/4 capsules. There are equivalent numbers of error (%) records associated with these records. The qualification status of these data has been set to *Qualified* based on receipt of QA-approved Engineering Calculations and Analysis Reports submitted by the FPMS staff.

All the above data have been processed and tested using a SAS-based enterprise application software system, stored in a secure Structured Query Language database, made available on the NDMAS Web portal (http://ndmas.inl.gov), and approved by the Idaho National Laboratory Scientific and Technical Information Management System for release to both internal and external VHTR TDO program participants.

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ACRONYMS

AGC	Advanced Graphite Creep
AGR	Advanced Gas Reactor
ASME	American Society of Mechanical Engineers
ATR	Advanced Test Reactor
CDCS	Capsule Distributed Control System
CRADA	Cooperative Research and Development Agreement
DRC	Data Review Committee
DTF	design to fail
ECAR	Engineering Calculations and Analysis Report
EDMS	Electronic Data Management System
FPM	Fission Production Monitoring
FPMS	Fission Production Monitoring System
INL	Idaho National Laboratory
MST	Mountain Standard Time
NDMAS	Nuclear Data Management and Analysis System
NEFT	northeast flux trap
PALM	Powered Axial Locator Mechanism
PIE	post-irradiation examination
QA	Quality Assurance
R/B	release rate to birth rate ratio
RDAS	Reactor Data Acquisition System
SQL	Structured Query Language
TC	thermocouple
TDO	Technology Development Office
TFR	Technical and Functional Requirements
TRISO	tristructural isotropic
VHTR	very high temperature reactor

AGR-3/4 Data Qualification Report for ATR Cycles 151A, 151B, 152A, 152B, 154A, and 154B

1. INTRODUCTION

This report presents the data qualification status of fuel irradiation monitoring data from the first six Advanced Test Reactor (ATR) cycles (151A, 151B, 152A, 152B, 154A, and 154B) of the Advanced Gas Reactor -3/4 (AGR-3/4) experiment being conducted in the ATR at Idaho National Laboratory (INL). AGR-3/4 is the third in a series of planned irradiation experiments for the AGR Fuel Development and Qualification Program, which supports development of the very high temperature reactor (VHTR) under the VHTR Technology Development Office (TDO). The experiment primary objectives are: (1) irradiate tristructural isotropic (TRISO) UCO (uranium oxycarbide) fuel particles including designed to fail (DTF) fuel particles that will provide a known source of fission products for subsequent transport through compact matrix and structural graphite materials; and (2) assess the effects of sweep gas impurities, such as CO, H_2O, and H_2 typically found in the primary circuit of high temperature gas-cooled reactors, on fuel performance and subsequent fission product transport (PLN-3636, SPC-1345, and PLN-3867).

All aspects of AGR-3/4 experimental data are captured and processed by the Nuclear Data Management and Analysis System (NDMAS). NDMAS processes AGR data into a secure Structured Query Language (SQL) Server database, performs testing on and analysis of the data for anomalies identification, presents the data via an access-controlled Web portal, and documents the qualification status of the data. The AGR-3/4 data streams addressed in this report include thermocouple (TC) temperatures, sweep gas data (flow rates, pressure, and moisture content), and fission product monitoring system (FPMS) data (release rates and release-to-birth rate ratios [R/Bs]) for each of the 12 capsules in the AGR-3/4 experiment.

AGR-3/4 irradiation was first at full power on December 14, 2011, and was planned to continue for approximately 450 effective full power days (EFPDs) (PLN-3867). Among the first six cycles, ATR Cycles 151A through 154B, there was one low power cycle, ATR Cycle 152A, when the ATR power was slightly up for a few short periods of time resulting in the averaged effective power of 0.209 MW for 89.6 hours. From a physics point of view, this cycle can be considered as extended power outage for the test fuel depletion calculation. During this time, the experiment was run on pure helium for both capsule and leadout gas flows. During the unplanned outage cycle, ATR Cycle 153A, the experiment was removed from the ATR northeast flux trap (NEFT) location and stored in the ATR canal. This was to prevent overheating of fuel compacts due to higher than normal ATR power during the subsequent Powered Axial Locator Mechanism (PALM) cycle, ATR Cycle 153B. Therefore, qualification of the AGR-3/4 data received from these two cycles was excluded from this report and they should be deleted from NDMAS database. By the end of ATR Cycle 154B, 3 of the 27 total installed TCs in the AGR-3/4 experiment failed: TC1/2 in Capsule 3 and TC2 in Capsule 2. This report covers the period from December 12, 2011, through October 16, 2013, when AGR-3/4 had been irradiated for a total of 264.1 EFPDs.

1.1 Purpose and Scope

The AGR-3/4 fuel irradiation monitoring data streams examined in this report include capsule TC temperatures, sweep gas measurements (gas flows, pressure, and moisture), and fission product monitoring data. The evidence of questionable data revealed by NDMAS data analysts was presented to the Data Review Committee (DRC). The DRC is comprised of project technical leads, Quality Assurance (QA), NDMAS analysts, and an independent technical reviewer (Appendix A). Final data qualification status for these data streams is determined by the DRC. The DRC considers: (1) whether the data meet the requirements for data collection as specified in Test Plans, Test Specifications, Technical and Functional Requirements (TFR), and QA plans; (2) the results of data testing and statistical analyses as performed by the NDMAS; (3) other QA-approved data reports submitted by data generators such as Engineering Calculations and Analysis Reports (ECARs); and (4) whether the data support applications to the defined intended use (MCP-2691, “Data Qualification”). All of the above information is summarized in this report. The final DRC findings on data qualification status are documented using FRM-1073, “Data Evaluation Report,” which is stored as a record in the Idaho National Laboratory (INL) Electronic Data Management System (EDMS).

This report describes (1) data handling procedures within NDMAS after receipt of the data from data generators; (2) the data structure, including data packages, components, attributes, and response variables; (3) NDMAS testing and statistical methods used to help identify possible data anomalies; (4) summarized information on test results and resolutions; and (5) the qualification status of the AGR-3/4 data records received by NDMAS during this period.

Fuel irradiation monitoring data reported herein include the following for each of 12 independently controlled and monitored capsules in the AGR-3/4 experiment:

- TC temperatures (3 in each of capsules 5, 10, and 12; and 2 in remaining capsules)
- Sweep gas (helium, neon, impure, outlet) measurements (mass flow rates, pressure, and moisture content)
- Krypton and xenon radionuclide (12 isotopes) release rates measured by the FPMS detectors and subsequently calculated krypton and xenon radionuclide R/Bs.

The basis for the qualification status of FPMS data is QA-approved ECARs submitted by the FPMS technical staff. These ECARs provide independent verification that the FPMS data submitted to NDMAS meet data collection requirements and conform to NQA-1 (ASME NQA-1-2008 with 1a 2009 addenda) requirements. No similar ECARs exist for the TC and sweep gas data, so the basis for their data qualification is the DRC review of the data, data testing and analysis results, and data collection documentation as presented in this report.

This document does not address the qualification status of three additional AGR-3/4 data streams stored in the NDMAS database: fuel fabrication data, thermal/neutronics simulation data, and post-irradiation examination (PIE) data. All AGR-3/4 fuel fabrication data were qualified based on INL receipt and review of hard-copy vendor Data Certification Packages. These data have been stored in the NDMAS database and made available on the NDMAS Web portal (http://ndmas.inl.gov). AGR-3/4 thermal/neutronics simulation data are available up to the end of Cycle 154B and used for analysis only. They will be entered into the NDMAS database after the ECAR is issued by the modeler. AGR-3/4 PIE has not yet begun.

ATR operating conditions data, including lobe powers, outer shim control cylinder positions, neck shim positions, and control rod positions, are stored in the NDMAS database and presented with AGR irradiation data on the NDMAS Web portal to help experimental interpretation and to provide input for physics calculations. Because ATR data are generated outside of the VHTR TDO program, NDMAS does not formally qualify these data on a routine basis. However, to verify QA program execution for use as an NDMAS data stream, the Sitewide QA organization performed an inspection of the ATR data acquisition systems and data collection processes (IAS121679 2012). This inspection confirmed implementation of the INL QA program (PDD-13000, “Quality Assurance Program Description”) for the ATR data used by NDMAS in the VHTR TDO program. In addition, NDMAS also performed several simple tests to exclude obvious failed lobe power data preventing their use in physics calculations.

1.2 Overview of NDMAS Data Qualification

NDMAS roles and responsibilities regarding data qualification are provided in PLN-2709, “Very High Temperature Reactor Program Data Management and Analysis Plan,” and MCP-2691.

Some of the primary tasks performed by NDMAS related to data qualification are:

- Archiving submitted data in native file format on a secure SAS® server under version control.
- Processing the data into standardized electronic data sets, storing the data in a secure electronic database compliant with the VHTR TDO quality assurance program plan (PLN-2690), and the records management plan (PLN-3319), and testing the data to ensure accuracy. NDMAS is currently using SAS® Enterprise Guide and a secure Microsoft SQL server (the “Vault”) for these purposes.
- Analyzing irradiation monitoring data to identify possible data anomalies and trends using various SAS® statistical tools such as range testing, control charts, correlation analyses, and regression analyses. These results are included in data qualification reports (such as this one) that are considered by the DRC in their determination of final data *Qualification State*.
- Documenting the receipt of QA-approved data reports (e.g., ECARs) for FPMS and fuel fabrication data, which provide the basis for their data qualification status.
- Providing secure and appropriate Web access to the data (http://ndmas.inl.gov), information on the data qualification status, and requested data analyses to end users, including external research partners.

All the AGR-3/4 data currently being collected at INL are considered to be *Type A*—data obtained within an NQA-1 QA program that must meet specific requirements for data collection with independent verification that those requirements were met (MCP-2691). The final results of this process are one of three data *Qualification States* applied to each data record:

- *Qualified*. Independent verification documenting that the data meet the requirements for a specific end use as defined in a data collection plan and were collected within an NQA-1 or equivalent QA program. Any nonconformances are concluded to not affect the usability of the data.
- *Trend*. Independent verification identifying minor flaws or gaps in meeting requirements for data use. Even so, the data still provide information that can be used by the program. Data were collected within an NQA-1 or equivalent QA program.
- *Failed*. Independent verification identifies major flaws in meeting data collection requirements. Data do not provide information about the system or object. Data are not useable by the program as intended.

While the data are being processed by NDMAS and prior to the data receiving a final Qualification State, NDMAS sets the data Qualification State to *In Process*. Time-critical data, such as the fuel irradiation data, are made available on the NDMAS Web portal while *In Process* to facilitate near real-time monitoring of experimental results by project staff to improve control of the test condition predefined in the test specification plan (SPC-1345, “AGR-3/4 Irradiation Test Specification”).

2. AGR–3/4 EXPERIMENT

The primary objectives of the AGR-3/4 experiment are defined in PLN-3636, "Technical Program Plan for the Next Generation Nuclear Plant/Advanced Gas Reactor Fuel Development and Qualification Program." A detailed description of the experiment is provided in PLN-3867, "AGR-3/4 Irradiation Experiment Test Plan." The fuel to be irradiated in AGR-3/4 contains conventional TRISO fuel particles with UCO kernel similar to the baseline fuel used in the AGR-1 experiment and DTF fuel particles whose kernels are identical to the driver fuel kernels but whose coatings are designed to fail under irradiation, leaving fission products to migrate through the surrounding materials (PLN-3867). The AGR-3/4 test train was inserted in the NEFT location of the ATR core as shown in Figure 1 during outage portion of ATR Cycle 151A in December 2011.

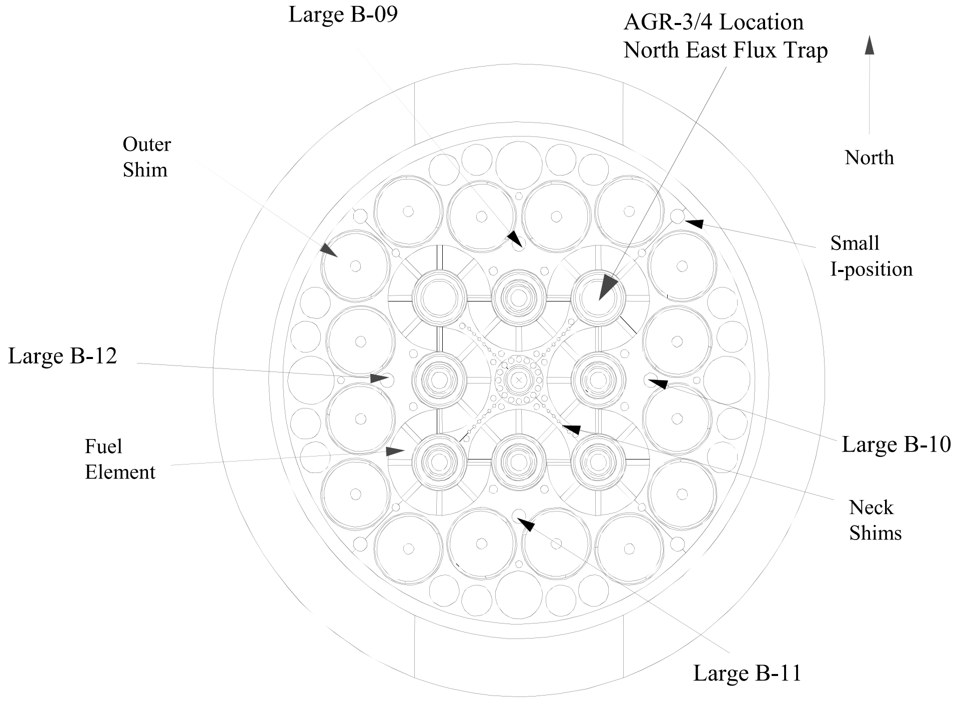


Figure 1. AGR-3/4 NEFT location in ATR core cross section.

AGR-3/4 is comprised of 12 independently controlled and monitored capsules stacked on top of each other to form the test train using the full 4-ft active core height (

Figure 2).). Each capsule contains four 1 ½-in.-long compacts. A leadout tube holds the experiment in position and contains and protects the gas lines and TC wiring extending from the test train to the reactor penetration. Three TCs are located in Capsules 5, 10 and 12; and 2 TCs in the remaining capsules, as shown in Figure 2 on the right. TC data received in NDMAS are instantaneous measurements every minute, except ATR Cycles 151A and 151B that are 5-min average temperatures.

Each capsule has an independent gas line to route a helium/neon gas mixture, which has variable thermal conductivities to control test fuel temperatures during irradiation and to transport any fission products released from the capsules to the corresponding FPMS detector by the gas outlet line (Figure 3). The FPMS detector is capable of detecting individual fuel particle failures and providing release rates for the 12 radionuclides as specified in SPC-1345. In order to assess the effects of sweep gas impurities on fuel performance and subsequent fission product transport the impure gas was injected into any of the capsules 7–12 using additional flow controllers. This impure gas consists of 98% or 99% helium contaminated with CO, H_2O, and H_2, which are typically found in the primary circuit of high temperature gas-cooled reactors. Thus, each capsule would have combined helium/neon flow from a mass flow controller and any additional impure gas flow.

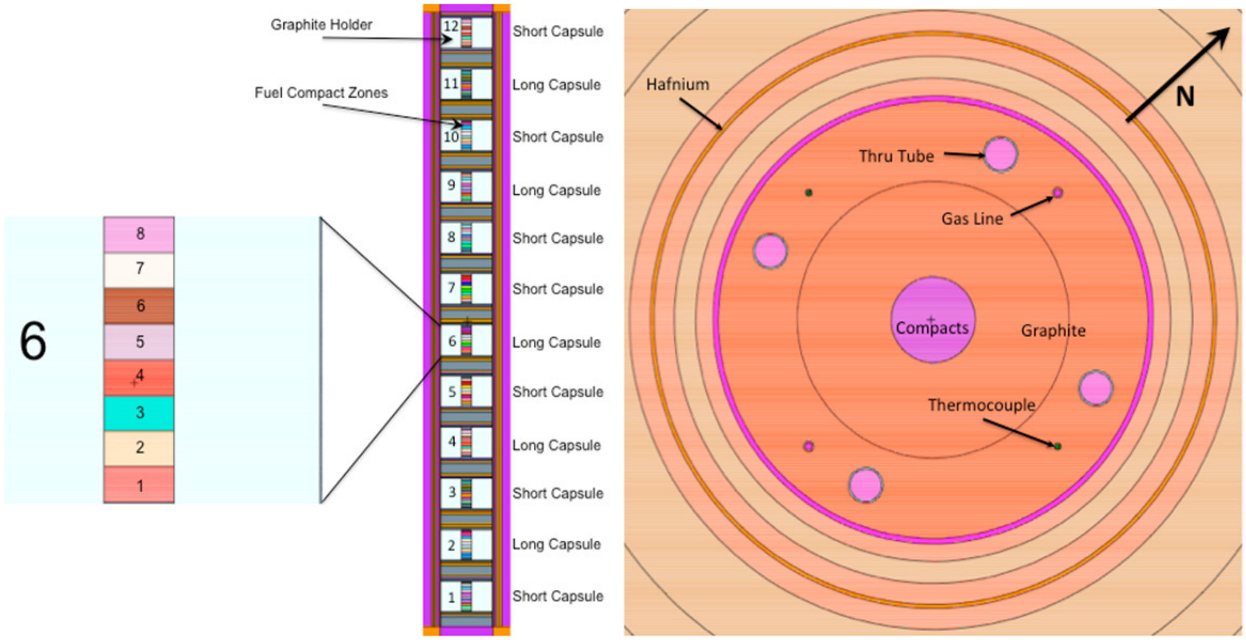


Figure 2. Axial (left) and radial (right) cross-section view of AGR-3/4 capsules.

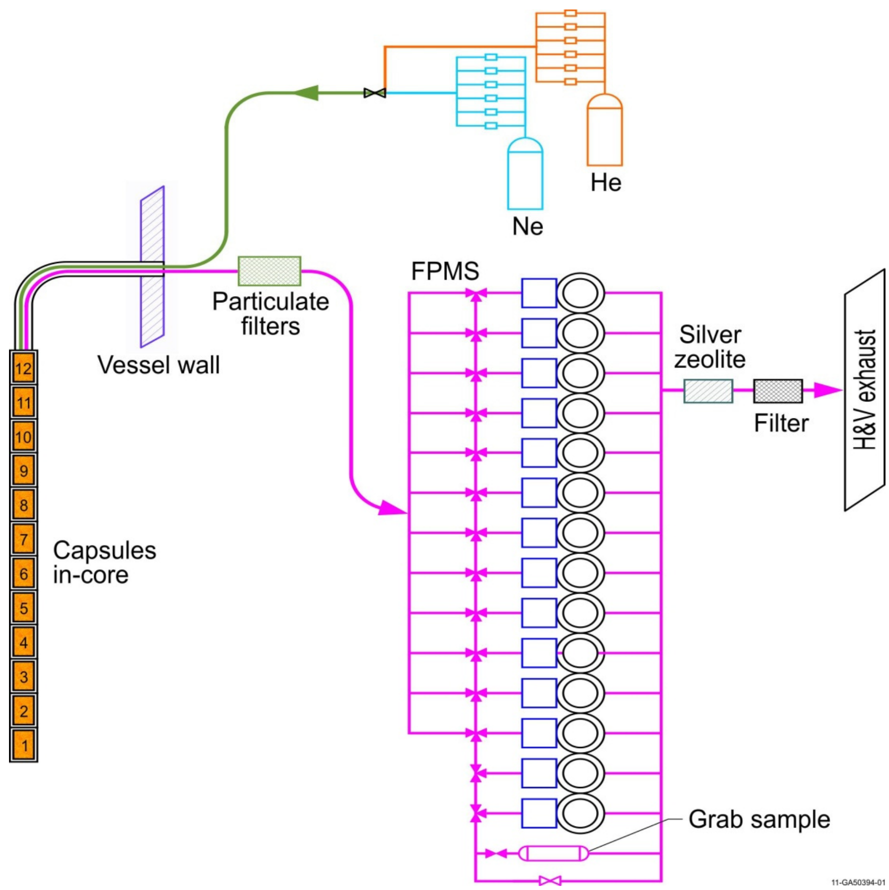


Figure 3. Simplified flow path for AGR-3/4 sweep gas.

2.1 Data Requirements

Requirements and specifications for the AGR-3/4 irradiation test are contained in SPC-1345, and TFR-656, "Temperature Control and Off Gas Monitoring Systems for Advanced Gas Reactor Experiment AGR-3/4." Significant features of the test train are presented in the Technical and Functional Requirements documents (TFR-630 2011 and TFR-729 2011). In addition, from the start of Cycle 152A, the automated feed was implemented to provide to NDMAS both ATR operating data (Reactor Data Acquisition System [RDAS]) and capsule irradiation data (Capsule Distributed Control System [CDCS] for Advanced Graphite Creep [AGC] and AGR experiments) every 2 hours as described in TFR-747, "RDAS-CDCS Data Transfer to NDMAS," Revision 3.

The following requirements include only those related to the measured data provided to NDMAS during the AGR-3/4 experiment (TC temperatures; sweep gas flow rates including impure gas, pressure, and moisture content; and FPMS data). They do not include requirements related to process or instrument parameters not reported to NDMAS, requirements specifying as-installed instrument accuracy that cannot be verified during the experiment (e.g., sweep gas flow rate accuracy of ±2%), as-installed materials specifications (e.g., hafnium shield purity), or requirements that can only be evaluated by simulation modeling or PIE activities (e.g., fast neutron fluence and burnup).

The requirements given in the following sections are requirements of the irradiation test conditions. Actual data may not meet some of these requirements but still be flagged as qualified data. Data are qualified based on compliance with NQA-1, passing statistical tests, and confirmation by the Data Review Committee.

2.1.1 Temperature

The irradiation test condition requirements relating to capsule temperature are summarized in (SPC 1345). Fuel temperature performance can only be evaluated using thermal simulation modeling. The requirements listed below are for reference only. TC temperature data cannot be rigorously compared to these requirements because they represent graphite sink for 12 capsules and matrix for 3 capsules (5, 10, and 12) ring temperatures outside the fuel compacts (see Figure 2). The AGR-3/4 temperature specification listed is as follows:

- The instantaneous peak fuel temperature for each capsule shall be ≤1800°C.
- The time average, peak temperature shall be 900 ± 50°C for one capsule, 1100 ± 50°C for up to six capsules, 1200 ± 50°C for up to four capsules, and 1300 ± 50°C for one capsule.
- The instantaneous peak temperature for the sink material in each capsule shall be ≤650°C.
- Readings from each TC shall be recorded at least every 5 minutes during irradiation, and each TC shall have an as-installed accuracy of ±2% of reading irradiation (measurement requirement in SPC-1345).

2.1.2 Sweep Gas

The irradiation test condition requirements relating to sweep gas (helium, neon, combined outlet) are summarized as follows (SPC-1345, TFR-656, and PLN-3867):

- The moisture content of inlet sweep gas on the inlet side of the capsule shall be <5 parts-per-million (ppm) H_2O, measured at least once after each gas cylinder change at a dew point of −100 ± 2.5°C (SPC-1345).
- The moisture content of the sweep gas on the outlet side of the capsule shall be measured at least every hour at a dew point of −100 ± 2.5°C and shall be indicated in volumetric water concentration in

ppm (SPC-1345). There is no published ppm limit or specification for moisture content on the capsule outlet side; values are monitored to ensure they do not exceed the inlet specification (<5 ppm), which may indicate a leak (J. Maki, personal communication).

- Flow rate of each sweep gas constituent shall be measured with an accuracy of ±2% and shall be recorded at least every hour during irradiation and continuing for at least 2 days after each reactor shutdown (SPC-1345).
- Before reactor startup, the gas flow will be set at 100% helium. One or a combination of several thermocouples in the experiment will be selected for temperature control. After the ATR reaches full power and all startup activities are complete, the control system will be initialized and will adjust the helium/neon mixture to control test temperature to meet the experiment's temperature requirement.
- Gas flow rates will be ≤50 sccm (standard cubic centimeters per minute) at a pressure of about 15 psia or 0.103 MPa (PLN-3867).
- Before reactor startup, the gas flow will be set at 100% helium. One or a combination of several thermocouples in the experiment will be selected for temperature control. After the ATR reaches full power and all startup activities are complete, the control system will be initialized and will adjust the helium/neon mixture to control test temperature to meet the experiment's temperature requirement (TFR-656).
- Flow to the capsules will be monitored and controlled by the Distributed Control System using mass flow controllers with an accuracy of ± 2% and the system will allow flow rates from 0-100 sccm (TFR-656).

2.1.3 Fission Product Monitoring System

The irradiation test condition requirements relating to the FPMS are as follows (SPC-1345):

- Able to detect every individual particle failure from each capsule, up to and including the first 250 failures, and able to identify in which capsule each failure had occurred (operation requirement in SPC-1345).
- Transit time of sweep gas <25 minutes from each capsule to the FPMS (operation requirement in SPC-1345).
- Continuous measurements of total radiation level of the sweep gas from each capsule (measurement requirement in SPC-1345).
- Concentrations of at least Kr-85m, Kr-87, Kr-88, Xe-131m, Xe-133, and Xe-135 shall be measured in the sweep gas from each capsule and recorded at least daily during irradiation. If possible, the concentrations of Kr-89, Kr-90, Xe-135m, Xe-137, Xe-138, and Xe-139 should also be measured in the sweep gas from each capsule and recorded at least daily during irradiation (measurement requirement in SPC-1345).
- Concentrations of at least Xe-133, Xe-135, and Xe-135m shall be measured in the sweep gas from each capsule and recorded daily for at least 2 days following each reactor shutdown (measurement requirement in SPC-1345).

2.2 Qualification Requirements and NQA-1 Conformance

All electronically recorded *Type A* data are to be validated and qualified to confirm conformance with data collection requirements. For the irradiation monitoring data streams, this includes the following types of data for each capsule:

- TC temperatures (three in Capsules 5, 10, and 13; and two for the remaining nine capsules)

- Sweep gas measurements (mass flow rates [helium inlet, neon inlet, total outlet, impure], pressure, and moisture content)
- FPMS krypton and xenon radionuclide release rates and associated error
- FPMS R/Bs and associated error for krypton and xenon radionuclides.

Qualified data must be collected in accordance with data collection plans that are NQA-1 compliant. Compliance of the irradiation monitoring data addressed in this report was independently verified on February 12, 2014, by a DRC comprised of AGR technical leads, Sitewide QA, an independent peer reviewer, and NDMAS analysts.

The data collection requirements are documented in the following QA-approved plans, procedures, specifications, and software user guides, which implement NQA-1 requirements for the VHTR TDO program:

- Program Documents
  - MCP-2691, "Data Qualification"
  - MCP-3058, "VHTR TDO Software Quality Assurance"
  - PLN-2690, "VHTR TDO Quality Assurance Project Plan"
  - PLN-3319, "Records Management Plan for the VHTR Technology Development Office Program"
- AGR Experiment Documents
  - PLN-3636, "Technical Program Plan for the Next Generation Nuclear Plant/Advanced Gas Reactor Fuel Development and Qualification Program"
  - PLN-3867, "AGR-3/4 Irradiation Experiment Test Plan"
  - SPC-1345, "AGR-3/4 Irradiation Test Specification"
  - TFR-630, "Advanced Gas Reactor AGR-3/4 Experiment Test Train", Technical and Functional Requirements
  - TFR-656, "Temperature Control and Off Gas Monitoring Systems for Advanced Gas Reactor Experiment AGR-3/4"
  - TFR-747, "Technical and Functional Requirements: RDAS-CDCS Data Transfer to NDMAS"
- FPMS Documents (all approved by Sitewide QA)
  - GDE-503, "Users' Guide for the Fission Product Monitoring System"
  - PLN-3551, "Fission Product Monitoring System Operability Test Plan for the AGR Experiment Series."

2.3 NDMAS Database 2.0

As the number of data records and their complexity grows, the new data structure in the Vault was implemented in the NDMAS database version 2.0 (Hull 2012) applying the best practiced database technology. This structure allows storing a large amount of data and all aspects of associated information (Meta data) for reduced storage space. The systematic table structure in this relational database also speeds up the retrieval of a large amount of data via the predefined views and customized tables in the Vault. This section explains the data flow to NDMAS and describes data specific to the AGR-3/4 irradiation experiment.

2.3.1 Database Structure

The new design of the NDMAS relational database is described in detail in (Hull 2012). The data storage structure is based on a hierarchy of:

Project → Experiment → Data stream → Data package → Data value

AGR-3/4 *Experiment* belongs to AGR *project* within the VHTR program. A *Data stream* is particular work flow pathway along with related data flow into NDMAS. A *Data package* is a batch of data provided to NDMAS from the data generator. The number of data packages ranges from one to dozens, depending on the data stream. *A data value* is a single variable value recorded that provides information about the system or object being measured. Data values include response elements, usually numeric values that describe the response of the object or system (e.g., pressure or temperature) and attribute elements that generally describe the object or system being measured, or provide categorical or spatial information about the object such as thermocouple composition, graphite grade, or capsule position. When applicable (e.g., NQA-1 requirements for AGR experiments data) each data value also includes data state and qualification state representing data quality.

AGR-3/4 experiment has two time series data streams: irradiation monitoring and FPMS. Figure 4 shows general data schema for time series data adopted for the NDMAS database design. The use of common "key" tables sharing between multiple data streams increases the flexibility for storing various types of data associated information and reduces storage space by using unique numeric identification (EID) instead of descriptive text data. The data retrieval from the NDMAS Vault is achieved by the use of views associating data with metadata and context information such as location, instrument, measurement units, and data stream information. To further speed up the data retrieval, several customized tables were created and are automatically updated with new data as they received using SAS store processes on the server.

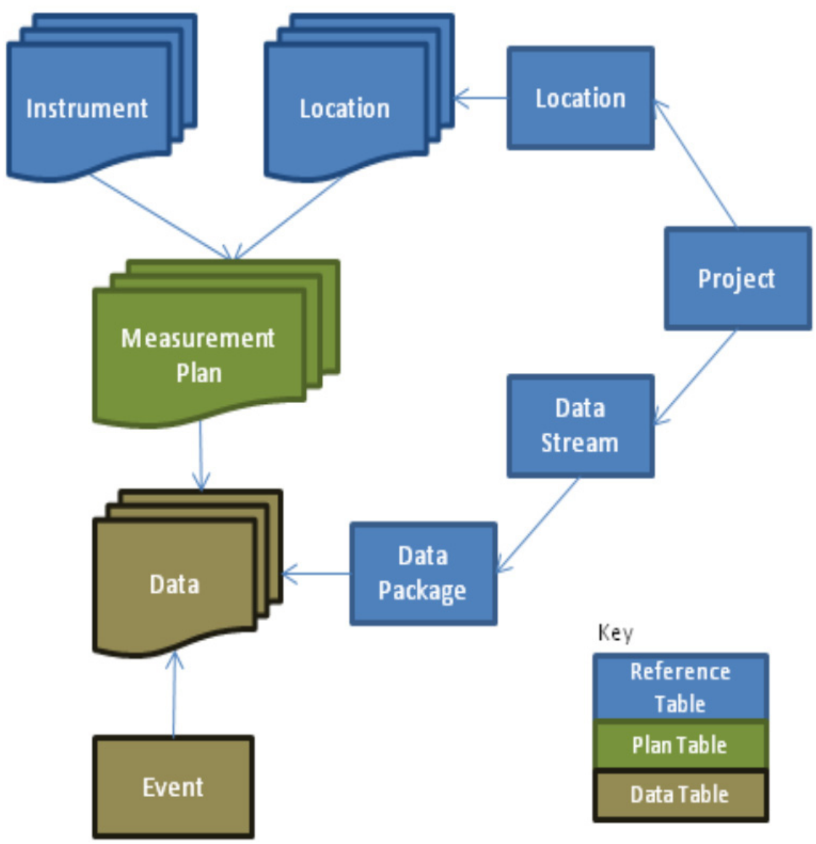


Figure 4. Data schema for time series data (Hull 2012)

2.3.2 Data Values for AGR Experiments

The *data values* in the new design of NDMAS database include response elements and attribute elements as described in Section 2.3.1. Figure 5 shows the diagram for TC temperature values and Figure 6 shows the diagram for gas flow values for AGR experiments. The reference tables contain unique hardware IDs associated with actual domain hardware components such as measurement instruments (e.g., rThermocouple on top left of Figure 5 and Figure 6) or test train components (e.g., rAGR_Capsule on bottom left) used in the experiments. The plan tables (e.g., bAGR_Temperature_Plan in the middle) contain plan ID associated with the detailed description about the measured parameter to be stored in the database and hardware domain IDs to serve as a link between actual data records and experimental hardware. The data tables (e.g., dAGR_Temperature in top right), the largest tables in the database, contain data values (or records) and multiple associated integer IDs. These ID numbers correspond to unique attributes and descriptions in the reference tables and plan tables to link the data records with their metadata information. Because AGR irradiation data consisted of several serial data streams, each data value is also associated with a unique event ID, AGRIrrEvent_ID, corresponding to a time stamp stored in the event table (e.g., dAGR_IrrEvent on bottom right). Besides domain data, each data value is assigned with a certain data state (e.g., raw, in-process, or capture passed), Data_State_ID, and qualification state (e.g., qualified, failed, or trend), Qual_State_ID, as required by NQA-1 quality data.

In order to pull necessary information associated with a data value from various tables for data users (e.g., data analysts) numerous SQL views were created in the database. A view is an SQL query used to store data IDs to link a data value with all associated attributes from all supporting tables. For example, each temperature response in the database will be connected with its metadata such as TC description and capsule location as well as data state and qualification state. This data structure allows pulling the data state and qualification state individually for each measured temperature value as required (Hull 2012).

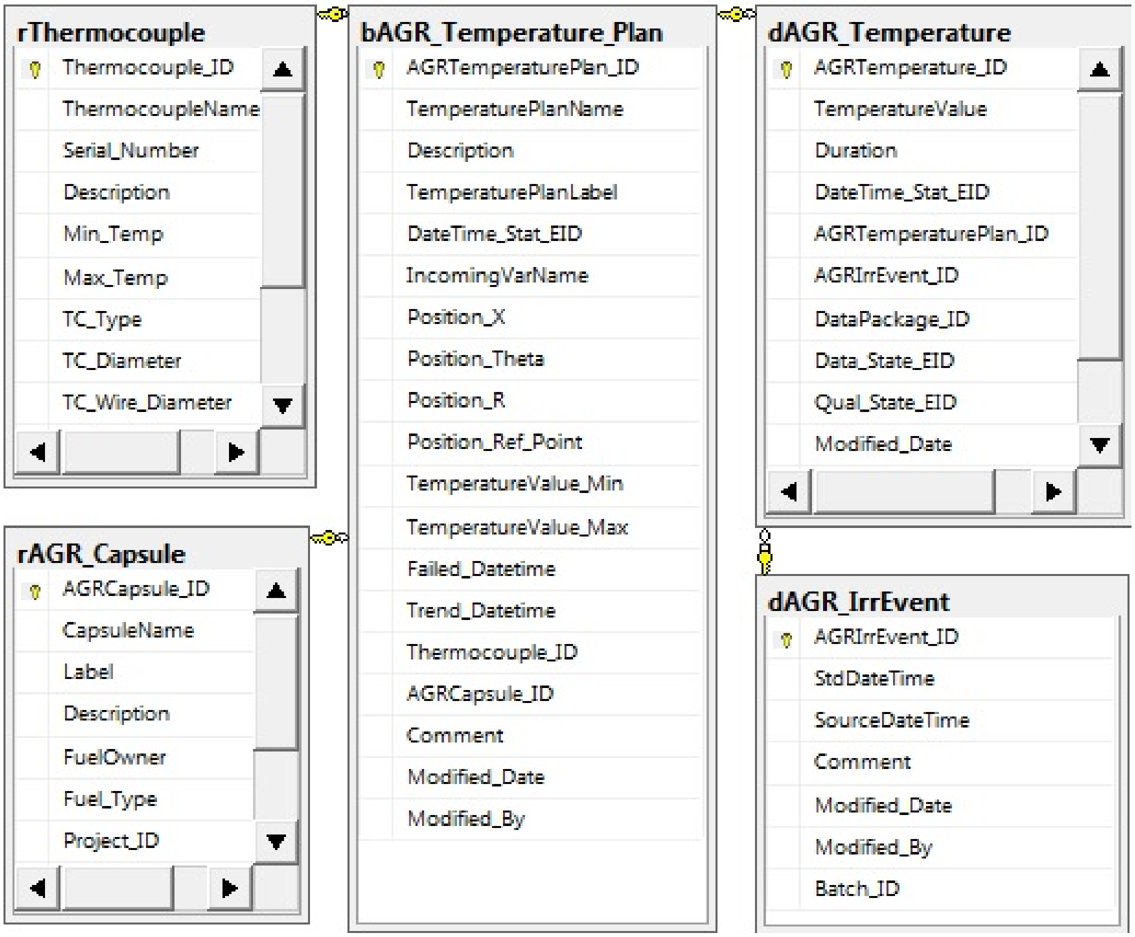


Figure 5. TC temperature value diagram of AGR experiment

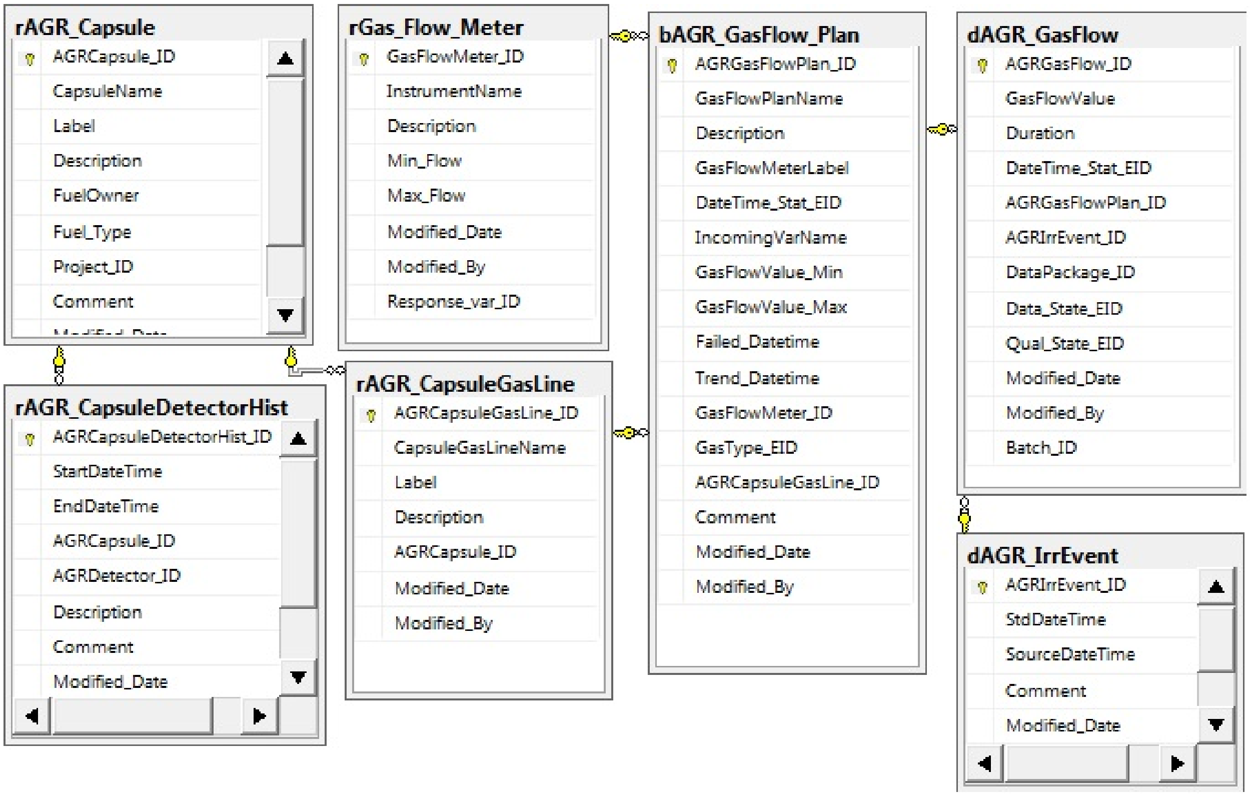


Figure 6. Gas flow value diagram of AGR experiment

Table 1. NDMAS data values for the AGR-3/4 irradiation monitoring and FPMS data.

Response Element	Attribute Element	
Response Plan Name	**Component Name**	**Response Description**
Irradiation Monitoring:		
TC-xx -1	AGR3_Cxx_TC1	TC1 Temperature in Capsule xx (ºC) [xx=01-12]
TC-xx -2	AGR3_Cxx_TC2	TC2 Temperature in Capsule xx (ºC) [xx=01-12]
TC-xx -3	AGR3_Cxx_TC3	TC3 Temperature in Capsule xx (ºC) [xx=01-12]
Cxx_out_MI	AGR3_C[01–12, LO]	Humidity in Capsules 1–12 and leadout gas flow (ppmv) [xx=01-12, LO]
Cxx_in_PI	AGR3_C[01–12, LO]	Pressure in Capsules 1–12 and leadout gas flow (psia)
Cxx_in_Q_He	AGR3_C[01–12, LO]	Helium flow to Capsules 1–12 and leadout (sccm)
Cxx_in_Q_Ne	AGR3_C[01–12, LO]	Neon flow to Capsules 1–12 and leadout (sccm)
Cxx_out_Q_Total	AGR3_C[01–12]	Outflow from Capsules 1–12 (sccm) [xx=01-12]
Gxx_in_Q_Contam	AGR3_G[07–12]	Impure gas flow to Capsules 7–12 (sccm) [xx=07-12]
FPMS:		
Kr_[A]_Rel	AGR3 Capsule [1–12]	Release rate for five krypton isotopes (atoms/s) (A = 85m, 87, 88, 89, 90) for each capsule
Kr_[A]_Rat	AGR3 Capsule [1–12]	R/B for five krypton isotopes (unitless)
Xe_[A]_Rel	AGR3 Capsule [1–12]	Release rate for seven xenon isotopes (atoms/s) (A = 131m, 133, 135, 135m, 137, 138, 139)
Xe_[A]_Rat	AGR3 Capsule [1–12]	R/B for seven xenon isotopes (unitless)
Kr_[A]_Err	AGR3 Capsule [1–12]	Release rate error for five krypton isotopes (%)
Kr_[A]_REr	AGR3 Capsule [1–12]	R/B error for five krypton isotopes (%)
Xe_[A]_Err	AGR3 Capsule [1–12]	Release rate error for seven xenon isotopes (%)
Xe_[A]_REr	AGR3 Capsule [1–12]	R/B error for seven xenon isotopes (%)

2.3.3 Data Delivery

For NDMAS to reach its maximum utility in support of the temperature control of experiments, ATR operating data (RDAS) and irradiation monitoring data (CDCS) are delivered to NDMAS automatically and in near real-time every 2 hours in a readily accessible .csc format starting with ATR Cycle 152A in May 2012. Each batch of data received is a text file either from RDAS (e.g., 2013-03-19-05-13.csc) containing ATR operating condition data or from CDCS (e.g., 2013-03-19-10_cap.csc) containing irradiation monitoring data for both AGR and AGC current experiments. The automatic data transfer includes instantaneous values at 1 minute intervals for the following AGR-3/4 irradiation monitoring data:

- TC temperatures (tag name, AGR2TIxy)
- Outlet flow (tag name, AGR2FIOUTx)
- Impure gas inlet flow (tag name, AGR2FIGIINz)
- Neon inlet flow (tag name, ITVNE2FINESHF2z and ITVNE2FINESHF3z)

- Helium inlet flow (tag name, ITVHE2FINESHF2z and ITVHE2FINESHF3z)
- Leadout neon flow (tag name, ITVNE2FINESHF27)
- Leadout helium flow (tag name, ITVHE2FIHESHF27)
- Inlet pressure (tag name, AGR2PIINx)
- Outlet moisture (tag name, AGR2MIOUTx).

Where x is a capsule number 1 – 12; y is a TC number in that capsule 1 – 3; and z is gas flow controller number 1 – 6: for impure flow z is corresponding to capsules 7 – 12; and for neon/helium inlet flow, 2z is corresponding to capsules 1 – 6; and 3z is corresponding to capsules 7 – 12.

FPMS release rate and R/B data are provided by FPMS technical staff to NDMAS at the end of each reactor cycle. Twelve capsule-specific release rate and 12 R/B text (.csv) files are placed in the NDMAS data archive location with subversion configuration control. Data are generally provided as 8-hour averages. The first three columns of data contain SPEC_ID (sample name containing the detector number, date/time, and instrument reset index), date, and time. Columns 4 and 5 contain parameters used by the FPMS technical staff to calculate radionuclide concentrations. The remaining 24 columns contain the release rates (or R/B values) and percent error for the 12 gaseous fission products.

2.3.4 Irradiation Monitoring Data Capture and Testing

Upon automatic data transfer from the ATR servers, these raw data files are automatically processed into the NDMAS database by the following steps:

1. Extract data according to the tags described in the TFR-747
2. Assign appropriate descriptive IDs for each response value and unique event ID for associated time stamp
3. Assign data state flag either to "Capture Passed" or "Accuracy Failed" as resulting from the initial range test and instrument failure time tests to identify any clear anomalies
4. Assign the data qualification flag to "In-process" until qualification flags are updated according to the qualification decisions from the DRC after its meeting
5. Push response value and associated integer IDs into appropriate data tables (e.g., dAGR_Temperature for TC readings) and push time stamp with unique ID into event table (e.g., dAGR_IrrEvent) into the NDMAS production database
6. Copy raw data files to NDMAS archive folder.

The automation of this data processing step uses stored procedures written in the C# language on the .Net Application Version 1.0 framework of the Microsoft Studio 2012 development tool. All processing codes to push data to the Vault and views to pull desired data from the Vault are subject to rigorous review and testing procedures in compliance with software QA requirements described in MCP-3058 and PLN-2690.

2.3.4.1 Range Test

Range tests evaluate whether instrument readings fall within an expected range of values, given what is known about experimental operating conditions or instrument range specifications. Range tests are used as a simple screening tool to identify data records that could potentially be bad, or they can be used to identify and reexamine extreme, but valid, data. For example, all the TCs terminated in the graphite holders will read the graphite temperatures, which are less than the fuel compact temperature. Therefore, the time average peak fuel temperature specifications given in Section 2.1.1 can be used as a "coarse" upper test limit for a TC temperature range test. Range tests are currently only applied to the TC and sweep gas (flow rates, pressure, and moisture) data that NDMAS receives. The range test limits selected for these response variables are listed in Table 2.

Table 2. Range test limits applied to AGR-3/4 irradiation monitoring data (see Section 2.1).

Response Variable	Range Test Limits[a]	Comments
Capsule TC Temperature	0 to 1400ºC	Capsules 1–12. Time average, peak fuel temperature requirement for UCO fuel (SPC-1345). TC temperatures are expected to be lower than this fuel temperature requirement, which can only be evaluated by simulated modeling.
helium/neon inlet gas flow	-0.5 to 102 sccm	Capsules 1–12 and leadout. Nominal flow rates are 0-30 sccm, but short-term peaks in helium flow up to and exceeding 100 sccm are assumed to be valid (TFR-656).
Capsule gas mixture outlet flow	-0.5 to 102 sccm	Capsules 1–12 (TFR-656).
Impure gas flow	-0.5 to 102 sccm	Capsules 1–12. Nominal flow rates are 0.5 sccm,
Gas pressure—capsule inlet	0 to 90 psia	Capsules 1–12 and leadout. Pressure relief valve setting (TFR-656).
Moisture—capsule outlet	0 to 5 ppm	Capsules 1–12 and leadout. No published limit for capsule outlet moisture level. Limit is set to the gas inlet specification in SPC-1345, the exceedance of which may indicate a leak.

[a] A missing value is counted as a *failed* record in the range test because it is not a valid representation of a measurement.

2.3.5 FPMS Data Capture and Testing

Upon receiving the FPMS data files after the end of each cycle, SAS Enterprise Guide projects were used to capture the data from the *.csv* files into AGR-3/4 SAS datasets. The database required description and appropriate IDs are assigned to each response value. Then, FPMS SAS data sets are pushed into four separate tables in NDMAS database as follow: (1) date and time data inserted into “dAGR_FPMEvent” table, (2) R/B data inserted into “dAGR_FPMRatio” table, (3) release data inserted into “dAGR_FPMRelease” table, and (4) flow data inserted into “dAGR_FPMFlow” table.

For quality purposes, NDMAS does not perform any accuracy testing for FPMS data, although data analysis (e.g., regressions of R/B data with temperature) by NDMAS may be performed. Data states for FPMS records are assigned to *Capture passed* after matching verification between data captured to NDMAS database and *raw* data files. Data quality for this data stream is documented in an ECAR, which is currently submitted by FPMS staff after each reactor cycle. When a QA-approved ECAR is received by NDMAS, a certification test is recorded in the vault for that data package, and the qualification status of the data is set to *Qualified*. If the FPMS data transmittal and its associated ECAR are designated as *Preliminary* data (as is currently the practice), it is assumed that this qualification status is subject to change if revisions to the data and revised ECARs are submitted later by the FPMS staff (as was done for AGR-1). Only the latest version of FPMS data will be used for Web page display and data download. Data from older versions are still stored in the database as *Obsolete* for qualification status and are available on special request.

3. DATA ANALYSIS AND TESTING RESULTS

NDMAS provides a controlled and secure electronic data storage environment, supports data qualification, identifies the qualification status of data, provides data analysis and modeling products, and makes data available for use by the program (PLN-2709). The data delivery portal (http://ndmas.inl.gov) is Web-based so both internal and external VHTR TDO program participants can access the system and review data, obtain analysis results (including statistics and graphics), and download data. By performing these roles, NDMAS ensures the correct data are used by the project, and data of known quality are available to support future licensing. Figure 7 summarizes the stages of data processing within NDMAS.

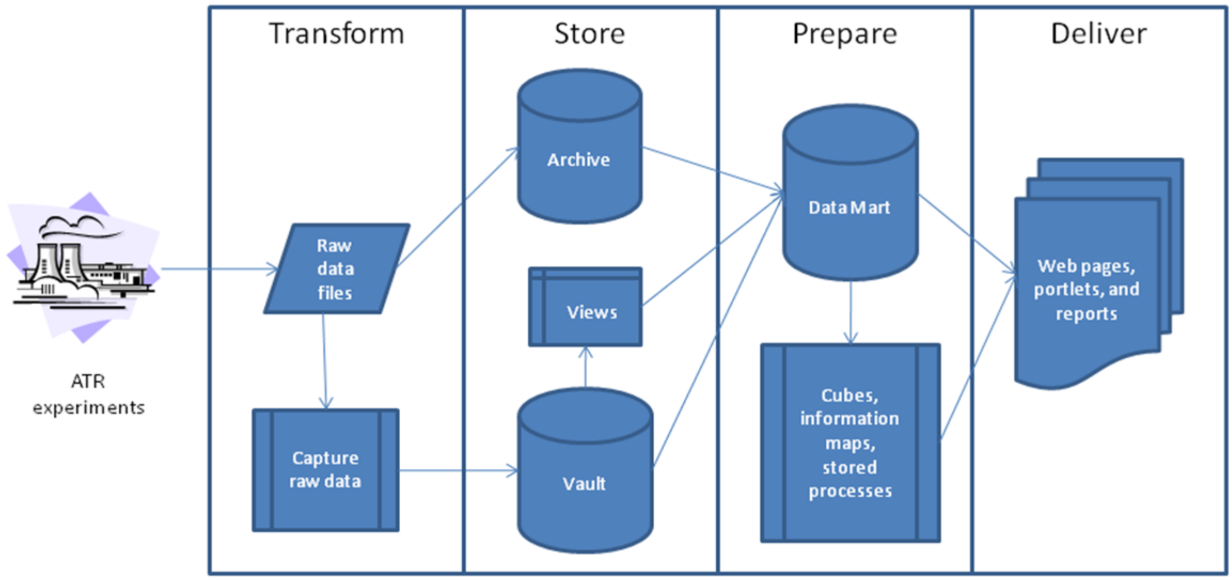


Figure 7. Stages of data processing in NDMAS.

3.1 Data Overview

This section provides overview plots of the data captured and processed by NDMAS for the first six ATR cycles evaluated in this report (151A through 154B, including the low power cycle, 152A). The qualification status of these data is presented in Section 4 of this report.

3.1.1 Reporting Cycles

This report provides the qualification status of AGR-3/4 fuel irradiation experimental data during the first six ATR fuel cycles, 151A, 151B, 152A, 152B, 154A, and 154B, as recorded in NDMAS. During Cycle 152A the ATR power was raised to low level for a few short periods of time resulting in the averaged effective power of 0.209 MW for 89.6 hours for Cycle 152A. During this time, the AGR-3/4 experiment was run on pure helium in all capsules and leadout. It was decided that for the test fuel depletion calculation this cycle was considered as an extended power outage. There are no thermal calculations for AGR-3/4 capsules during this time. But AGR-3/4 irradiation data are still captured and stored in the NDMAS database, and their qualification statuses are documented in this report. Table 3 provides summary of AGR-3/4 irradiation data by cycle examined in this data qualification report covering the period from December 12, 2011, through October 16, 2013.

ATR Cycles 153A and 153B were not included in Table 3 because during the outage portion of ATR Cycle 153A the AGR-3/4 test train was removed from the ATR core and stored in the canal to prevent overheating of fuel compacts because of high ATR lobe powers of the subsequent ATR PALM Cycle 153B. The AGR-3/4 test was inserted back into the ATR NEFT location during the outage of ATR Cycle 154A on April 26, 2013, so for this cycle the AGR-3/4 irradiation data are valid only after that date.

DRC Recommendation: Delete all AGR-3/4 irradiation data (gas flow rates, TC readings, inlet gas moisture, and pressures) recorded during periods January 20, 2013, at 10:10 (2 days after 152B power-down) to April 26, 2013, at 23:59 (when AGR-3/4 inserted back to ATR core) because the test train was removed from the reactor core.

Table 3. Overview of AGR-3/4 cycles for this reporting period.

ATR Cycle	Record Start	Power Up	Record End	No. of EFPDs	Total # Records	Cycle Comment
151A	12DEC11:01:00	14DEC11:01:00	11FEB12:11:00	56.1	1,248,251	Normal
151B	11FEB12:11:00	01MAR12:06:00	05MAY12:11:00	51.3	1,673,341	Normal
152A	05MAY12:15:00	n/a	30OCT12:00:00	0	6,614,715	Low power
152B	30OCT12:00:30	27NOV12:04:00	18JAN13:10:10	51.0	5,102,632	Normal
154A	26APR13:23:59	19MAY13:03:00	13JUL13:09:30	52.3	7,414,477	Normal
154B	13JUL13:09:30	23AUG13:15:00	16OCT13:11:00	53.4	8,146,189	Normal
			Total =	264.1	30,199,605	

3.1.2 Temperature Data

Figure 8 and Figure 9 show the hourly TC temperature data averaged from instantaneous measurements for all twelve AGR-3/4 capsules. Gaps in TC plots represent periods with missing irradiation data, which happened only during ATR power outages due to equipment maintenance. TC readings in all 12 capsules were largely low ranging from ~30 to 50 °C during low power cycle, 152A, except for 89.6 hours around the beginning of October 2012 when all TC readings raised to more than 450 °C (Figure 8 and Figure 9). Plots are empty during Cycles 153A and 153B because AGR-3/4 was not in the ATR core. Also, Figure 9 shows that TC2 in Capsule 2 and TC1 in Capsule 3 failed before ATR powered up in Cycle 154A and TC2 in Capsule 3 failed near the end of ATR Cycle 154B (Panels 4 and 5 from the top). Details on evidences of these TC failures are presented in Section 3.2.1

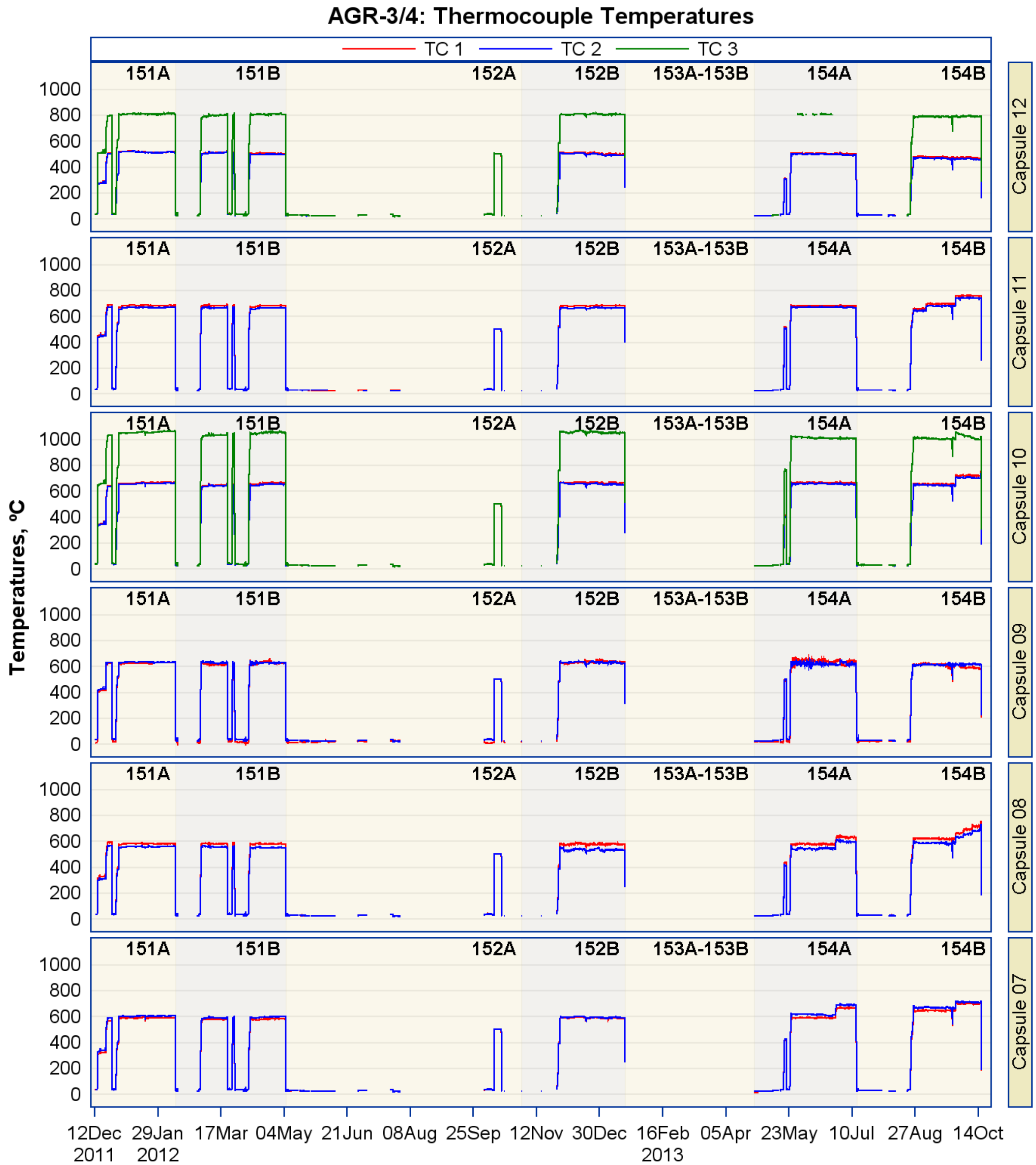


Figure 8. Capsules 7-12 TC temperature data for Cycles 151A through 154B.

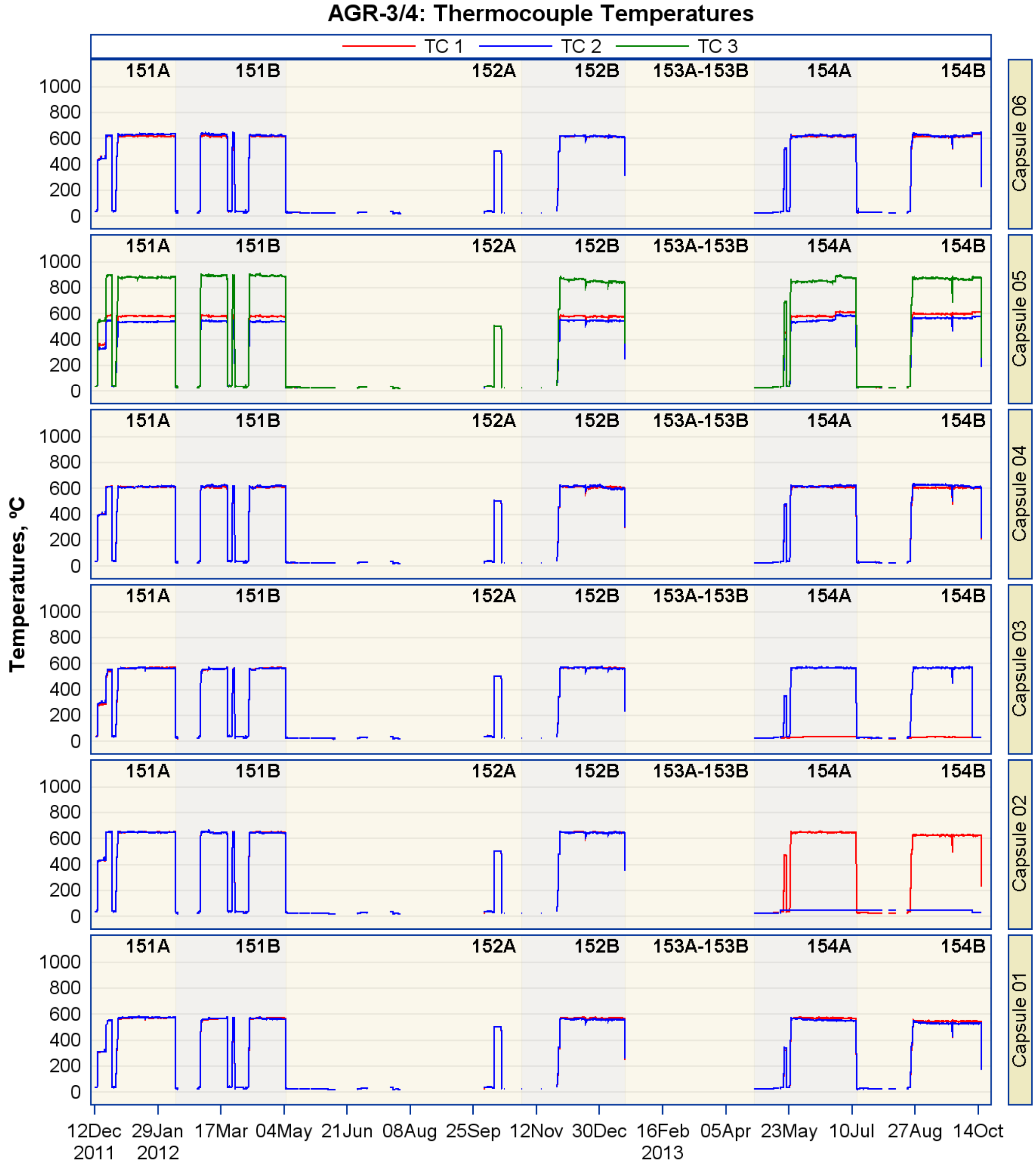


Figure 9. Capsules 1-6 TC temperature data for Cycles 151A through 154B.

3.1.3 Sweep Gas Data

Figure 10 and Figure 11 show the hourly sweep gas flow rates averaged from instantaneous measurements for each capsule including helium inlet, neon inlet, and total outlet. Leadout gas flow (both helium and neon) are shown at the bottom panel of Figure 10 (same for all capsules). As in the TC plots in Figure 8 and Figure 9, gaps in gas flow plots represent periods with missing irradiation data during cycle outages, during which AGR-3/4 usually runs on the same level of pure helium in all six capsules and the leadout except for a few short flow meter testing periods when gas flow rate can be abnormally high (see vertical lines out of normal boundary in Figure 10). Therefore, these unusually high flow rates are still valid unless they are greater than the flow controller limit of 102 sccm as stated in Table 2. Figure 12 shows impure gas flow rates in Capsules 7 through 12, as 0.5 sccm of impure gas was mixed into the Capsule 11 gas flow using an additional flow controller starting shortly after ATR Cycle 154B powered up. The impure gas consists of more than 98% helium and gas impurities such as CO, H_2O, and H_2. A discussion on gas flow rate anomalies as they relate to data qualification is presented in Section 3.3.

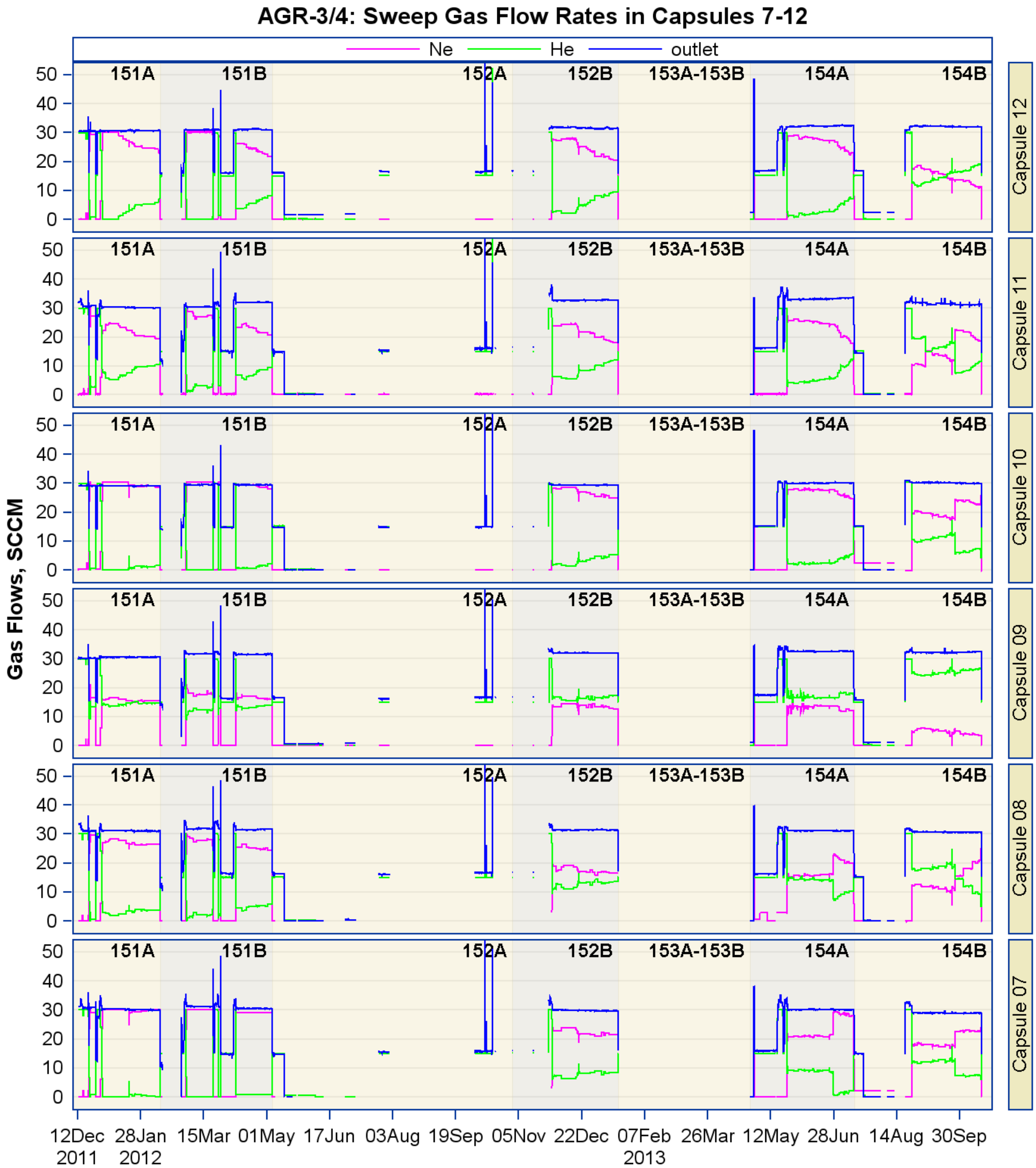


Figure 10. Capsules 7-12 sweep gas flow rates (sccm).

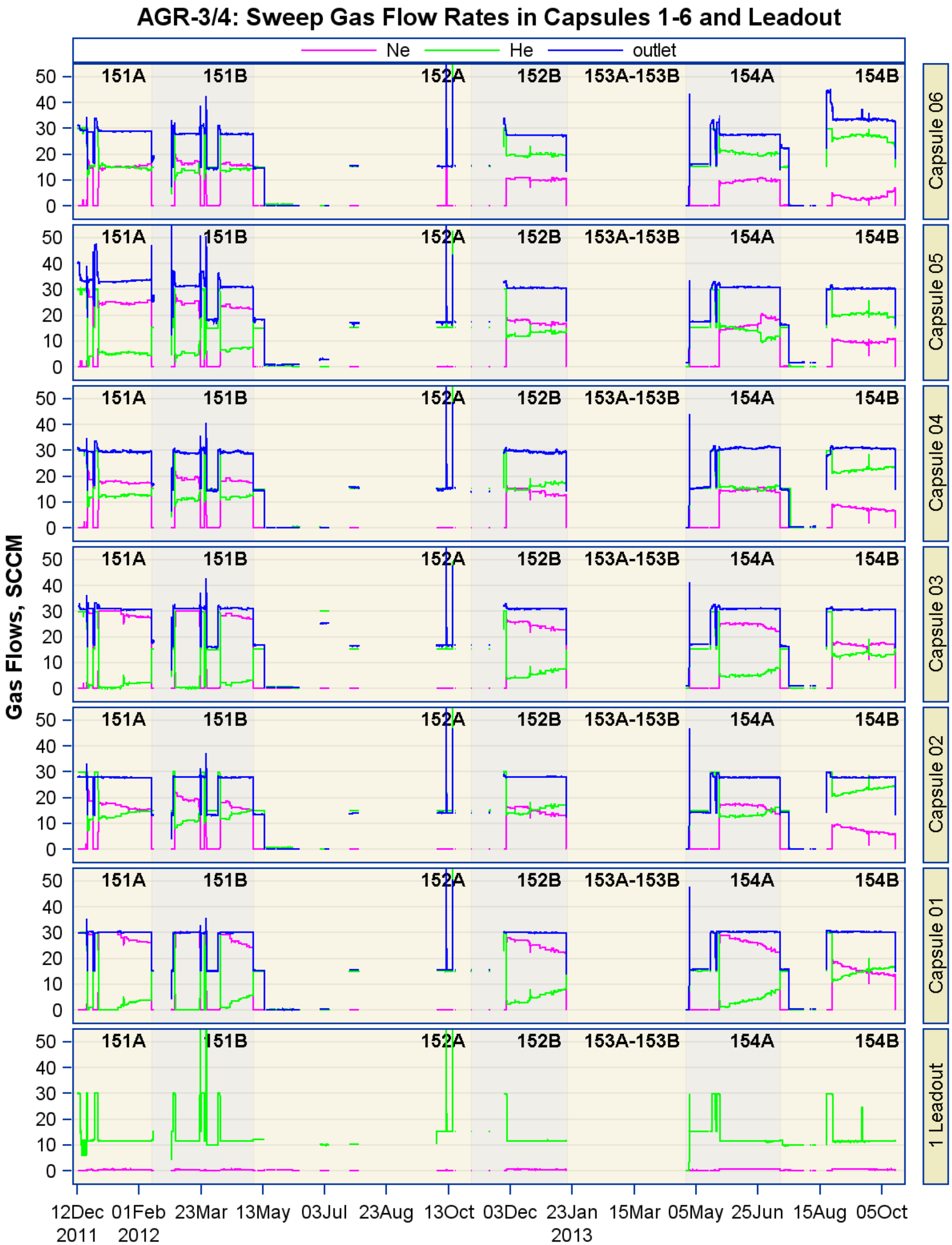


Figure 11. Capsules 1-6 and the Leadout sweep gas flow rates (sccm).

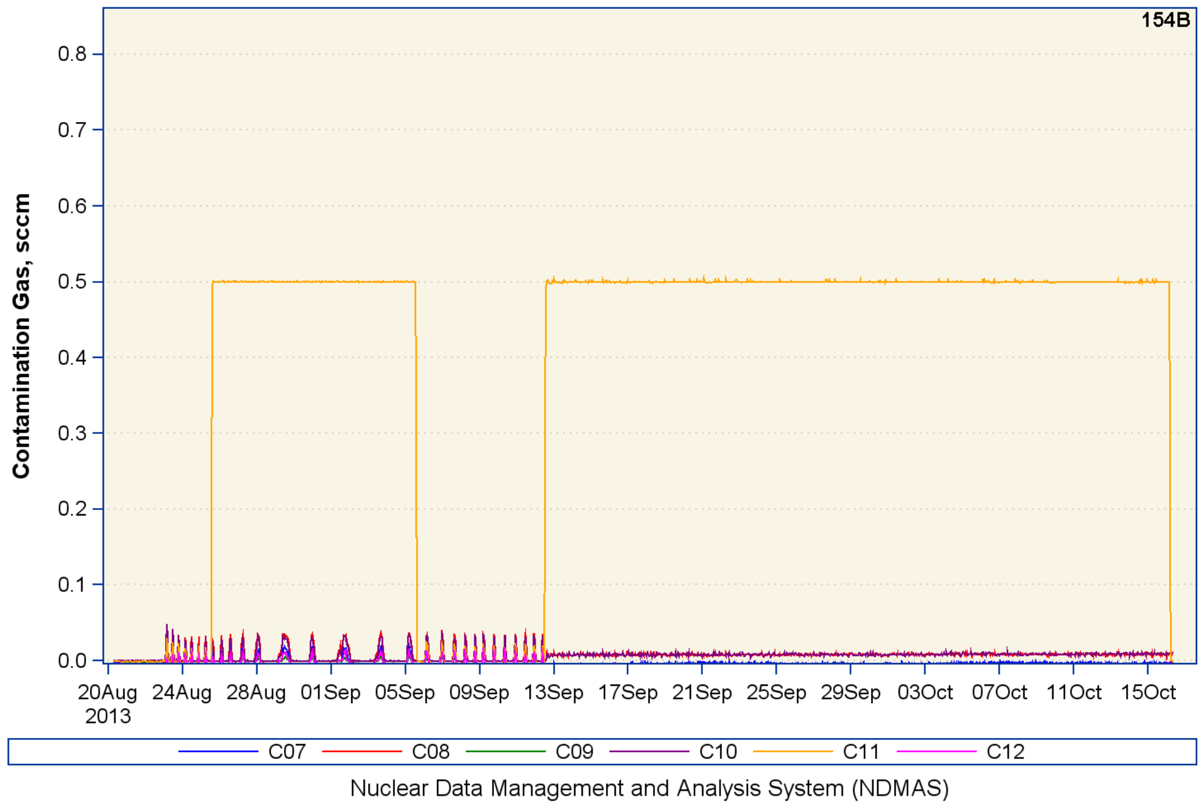


Figure 12. Capsules 7-12 impure gas flow rates (sccm).

3.1.4 FPMS Data

Figure 13 through Figure 16 plot fission product release rate and R/B data (nominal 8-hour count times) for five ATR cycles that have been submitted to NDMAS for this reporting period (151A, 151B, 152B, 154A, and 154B). The fission product R/B data in these plots were calculated using the four points per cycle radionuclide birth rates. Detailed documentation of the FPMS measurement and processing methods is contained in an ECAR written by FPMS staff (ECAR-2457) for these five cycles. This ECAR also provide the basis for FPMS data qualification.

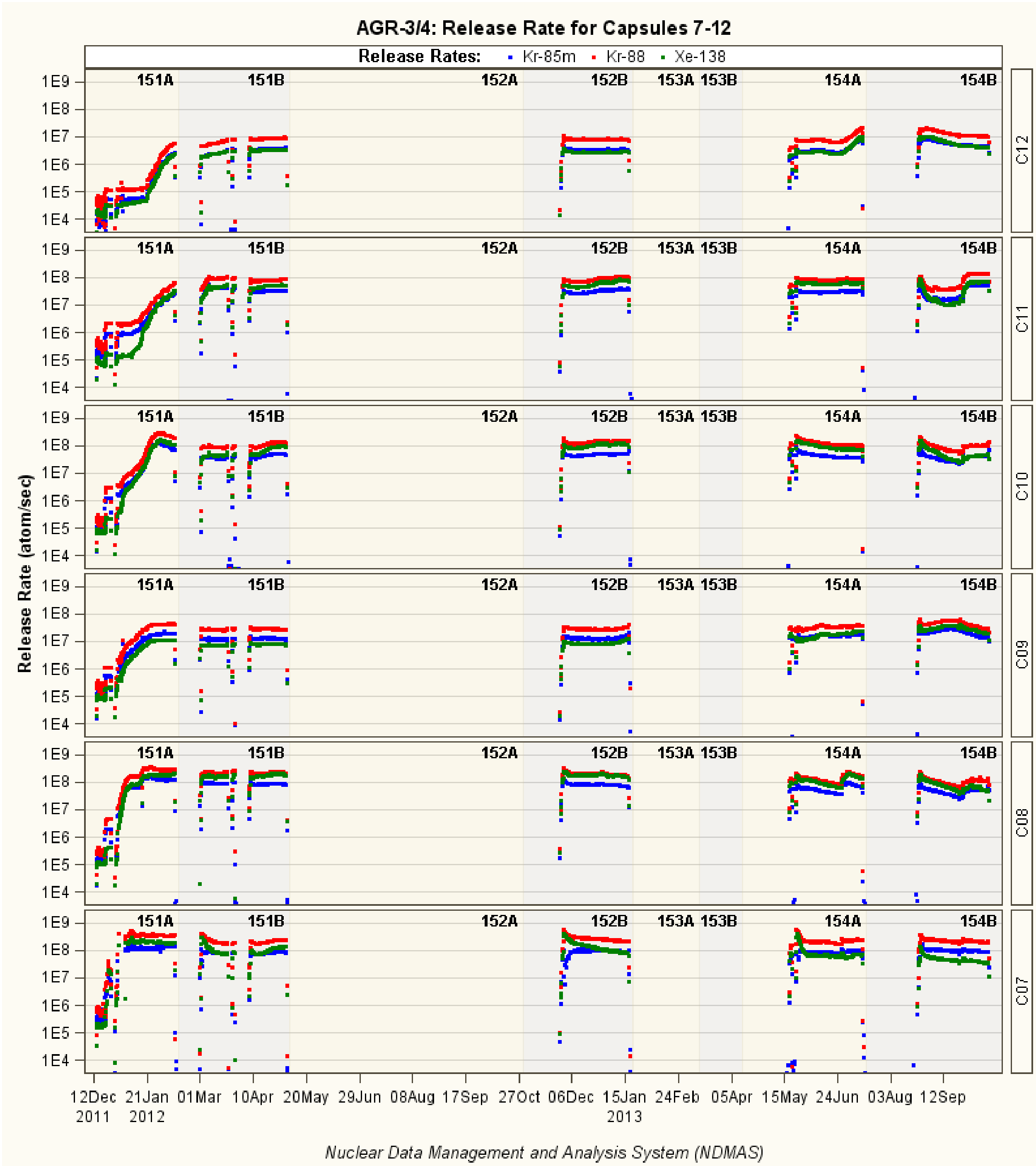


Figure 13. Fission product release rates for Kr-85m, Kr-88, and Xe-138 for ATR Cycles 151A, 151B, 152B, 154A, and 154B for the AGR-3/4 Capsules 7 to 12.

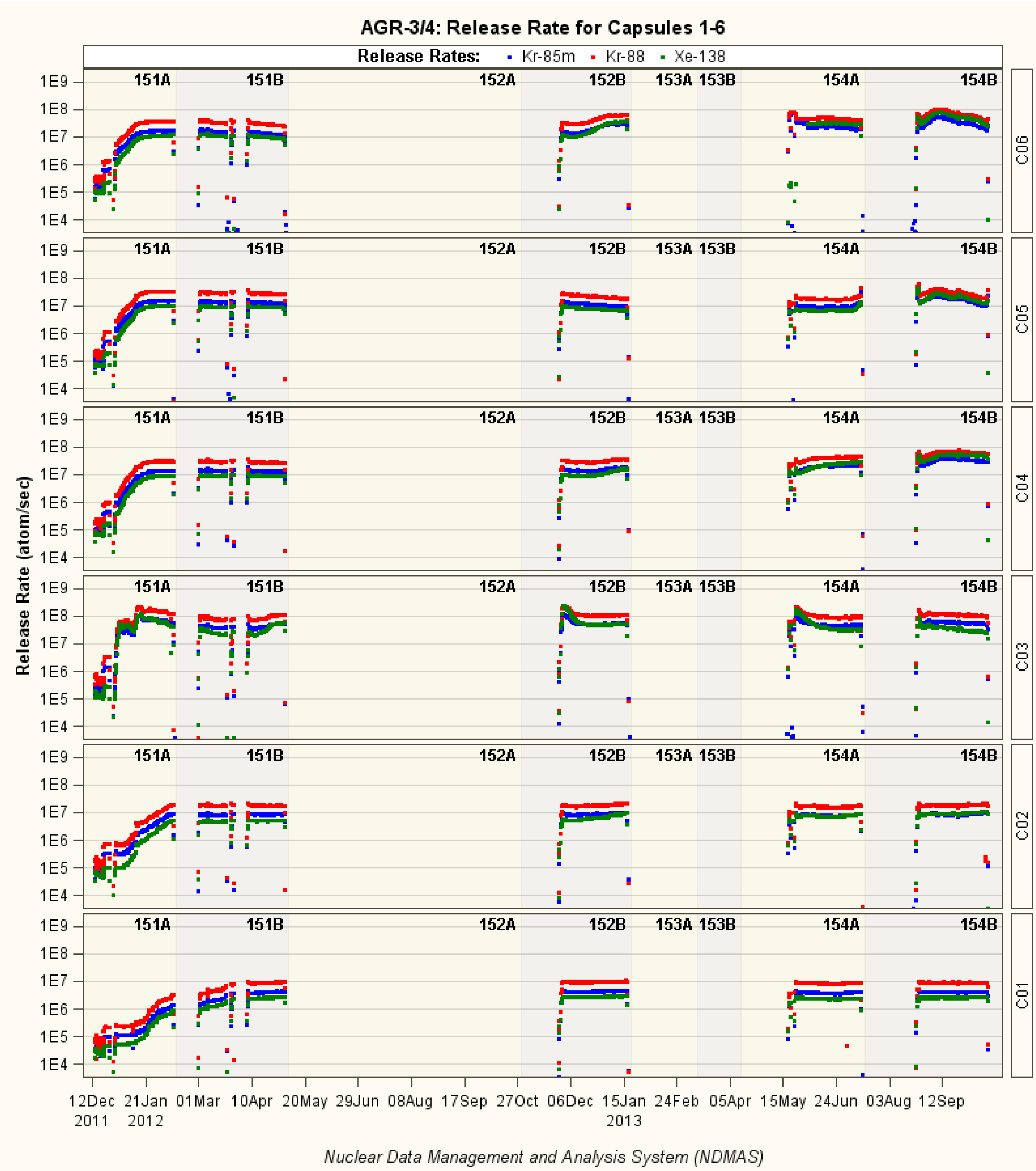


Figure 14. Fission product release rates for Kr-85m, Kr-88, and Xe-138 for ATR Cycles 151A, 151B, 152B, 154A, and 154B for the AGR-3/4 Capsules 1 to 6.

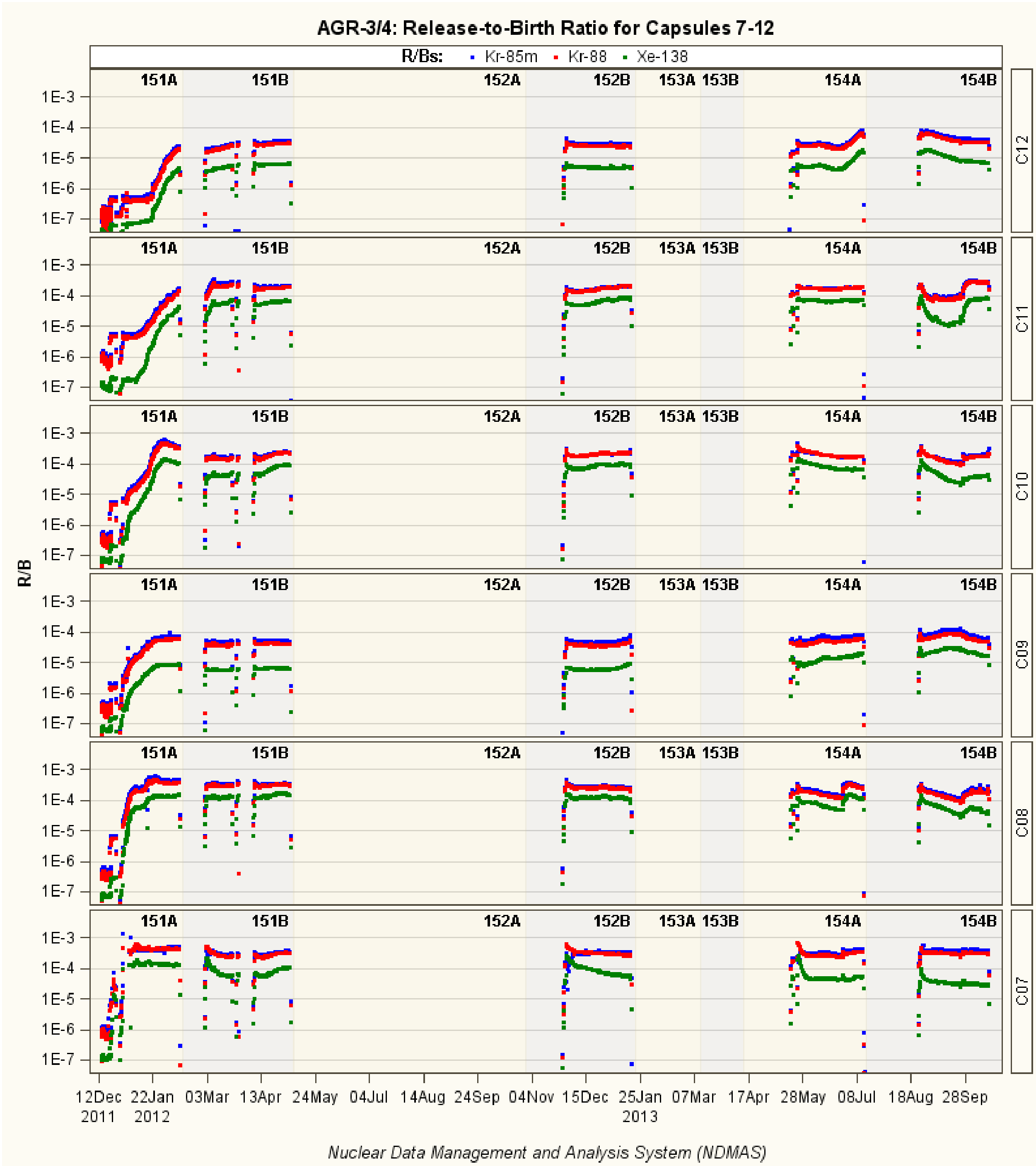


Figure 15. Fission product R/B ratios for Kr-85m, Kr-88, and Xe-138 for ATR Cycles 151A, 151B, 152B, 154A, and 154B for the AGR-3/4 Capsules 7 to 12.

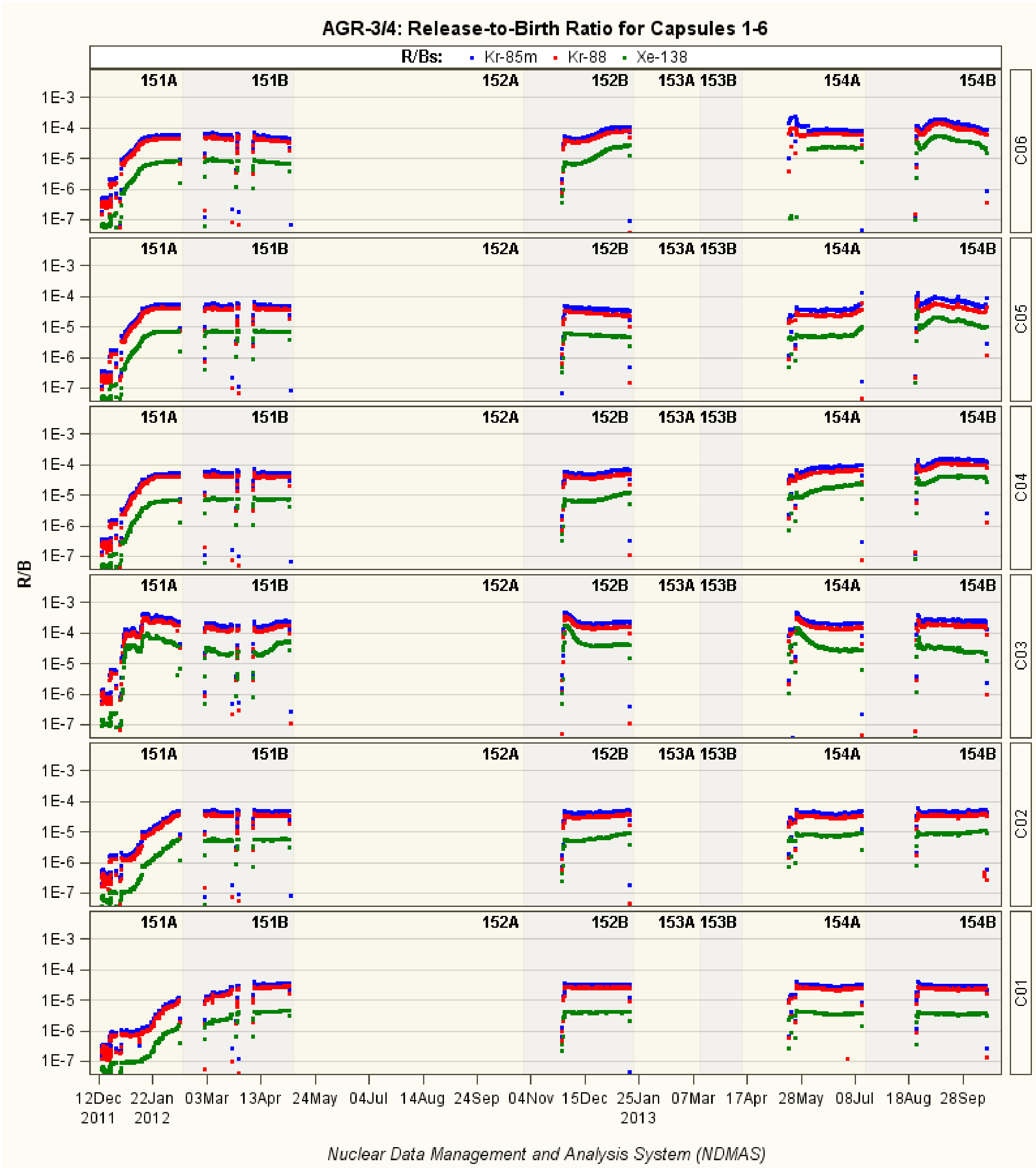


Figure 16. Fission product R/B ratios for Kr-85m, Kr-88, and Xe-138 for ATR Cycles 151A, 151B, 152B, 154A, and 154B for the AGR-3/4 Capsules 1 to 6.

3.2 Testing for Data Anomalies of TC Temperatures

NDMAS runs a number of tests for TC temperature data to identify potential anomalies (Table 4). Anomalies are data with values outside the range of expected behaviors. Some of these may reflect bad data (e.g., as a result of instrument failure), but some may reflect transient events that produced correctly measured data outside of normal operating ranges. The anomalies are reviewed as part of the data qualification process to determine their quality (valid or failed) for future use. The accuracy range test is discussed in Section 2.3.4 as part of the NDMAS database activity. This section discusses the range and analytical tests, the basis for the tests, and presents the test results. Qualification decisions based on the results of these tests are presented in Section 4.

Table 4. NDMAS tests performed for AGR-3/4 irradiation monitoring data.

Test Type	Test Name	Test Description
Capture	Range	Used range test limits applied to AGR-3/4 TC data
Analysis	Instrument Failure	Used to fail data collected from an instrument that has been deemed to no longer be providing reliable data.
Analysis	TC Difference Control Charts	Anomaly testing for TC drift: The temperature difference between TCs in the same capsule should be similar over time. Trends and discontinuities in the data suggest that one of the TCs is drifting.
Analysis	TC Spatial Correlations	Anomaly testing for TC junction failure: A TC should be most highly correlated with one in the same (or nearby) capsule. Higher correlation with a distant TC suggests a TC junction failure.

3.2.1 NDMAS Capture and Range Testing

This section discusses data anomalies of TC readings resulting from data capture and range testing. A total of 11,721,025 TC records captured in NDMAS database during this reporting period are discussed here. The three failure modes of TC measurements considered in the capture and range testing are: (1) missing, (2) out-of-range, and (3) irrelevant. Modes (1) and (2) are identified by range testing within the NDMAS data capture process. Mode (3), irrelevant data, is defined as data that are clearly not represented by the actual measurements in the capsules. Table 5 shows that during this reporting period, there are 503,043 TC readings that failed the capture and range test out of a total of 11,721,025 TC records (or 6.4% of the TC readings total).

Table 5. Number of TC readings that failed capture and range tests during ATR Cycles 151A through 154B.

ATR Cycle	Total # Records	Negative	Missing	Irrelevant	Total # Failed	%Failed
151A	474,687	0	0	0	0	0.0%
151B	635,337	26	19	0	45	0.0%
152A	2,515,455	5	15,252	0	15,257	0.6%
152B	2,068,686	0	61	0	61	0.0%
154A	2,868,987	0	1,116	486,564	487,680	17.0%
154B	3,157,873	0	0	0	0	0.0%
Total =	**11,721,025**	**31**	**16,448**	**486,564**	**503,043**	**6.4%**

3.2.1.1 Missing Data

Data are classified as missing only if there is no record present for an existing time stamp in the raw data files provided by the data generators. There are 16,448 missing TC readings out of a total of 11,721,025 TC records (or 0.14% of the total). Most of the missing TC data were received during the ATR low power cycle 152A. They were not critical to the test objectives because this cycle was largely outage period. There are 1,116 missing values of TC3 in Capsule 12 during ATR Cycle 154A because of a mistake in the automated data output script, which was fixed for subsequent cycles.

DRC recommendation: Fail 16,448 missing TC records.

3.2.1.2 Out-of-Range Data

Because the TC readings range from 0 to 1,400ºC, the negative and "too high" TC records (>1400ºC) are assigned "failed" data status as a result of the NDMAS capture range testing. There are 0 "too high" TC readings and only 31 negative TC readings out of a total of 11,721,025 TC records.

DRC recommendation: Fail 31 negative TC readings.

3.2.1.3 Irrelevant Data

The AGR-3/4 test was inserted back into the ATR NEFT location during the outage of ATR Cycle 154A on April 26, 2013, after its removal during ATR Cycle 153A. However, as seen in Figure 17 for Capsule 10, the TCs did not respond to actual capsule temperatures until 08:50 on April 29, 2013. (All other TCs show similar behavior.) So, the TC readings before April 29, 2013, 08:50 are not relevant and should be deleted.

DRC Recommendation: Delete all TC data recorded during period between January 20, 2013 at 10:00 and April 29, 2013 at 08:50 because the test train was removed from the reactor core.

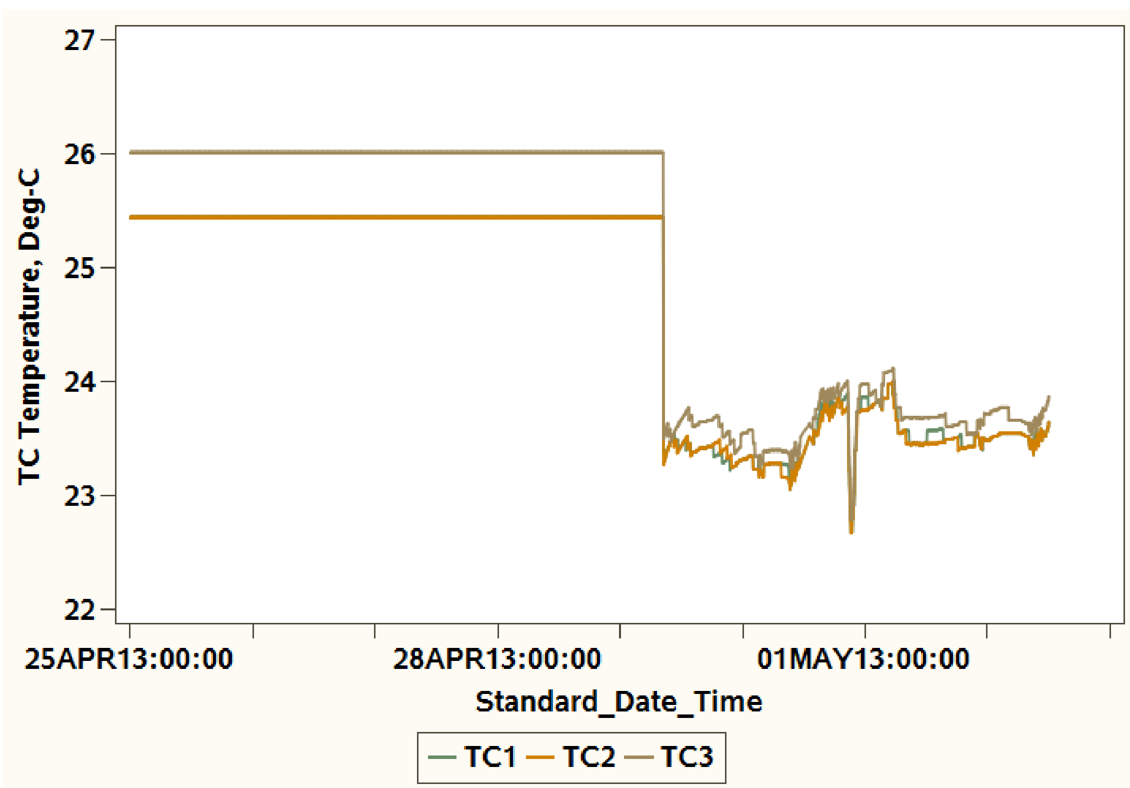


Figure 17. Capsule 10 TC temperatures around the time when AGR-3/4 was inserted back into the ATR core.

3.2.2 Instrument Failure Testing

AGR TCs deteriorate and sometimes fail because of the high irradiation and temperature conditions that occur during test reactor cycles. Failures are likely caused by deterioration or damage to the TC sheath and/or dielectric insulating material that separates the TC thermal elements. This produces an electrical path ("virtual junction") at some location along the TC wire other than at the terminal tip. Failure is exhibited when the temperature reading drops to or near zero during full power conditions, does not respond during reactor power-up, or responds in a way that is inconsistent with reactor power conditions, gas mixture inlet flows, or other TC responses. The three TC failures with failure date/time and corresponding ATR cycle during this reporting period are presented in Table 6. Evidence of these TC failures is shown using plots and discussions in the following subsections. These failures were visually identified by both VHTR TDO program leads and NDMAS analysts over the course of the experiment. The date/time of the failures were confirmed by the DRC during the data qualification process. After DRC verification, the Data State and Qualification State flags are set to "*Failed*" in the NDMAS database for all temperature records from the failed TC after the failure date. These failure flags ensure the data are managed and used appropriately (e.g., are not used in any plots or downloads and are identified as *Failed* in the data tables). The decisions of the DRC will be reported in the final version after the meeting.

Table 6. TC failure times for AGR-3/4 capsules during this reporting time

Capsule #	TC #	Failure Time	ATR Cycle
2	2	2013-04-29 08:45:00	154A
3	1	2013-05-17 03:15:00	154A
3	2	2013-10-09 12:15:00	154B

3.2.2.1 TC2 in Capsule 2

<u>DRC Recommendation</u>: Failure on April 29, 2013, at 08:45 (Cycle 154A)

AGR-3/4 was inserted back into the NEFT location during the outage portion of ATR Cycle 154A on April 26, 2013, from the ATR canal. So the AGR-3/4 irradiation data for ATR Cycle 154A recorded before April 26 are invalid data. Readings of TC1 and TC2 in Capsule 2 during the beginning of ATR Cycle 154A presented in Figure 18 show that TC2 (orange line) was unresponsive right from the moment when the AGR-3/4 resumed data recording as compared to the small fluctuations of TC1 readings (blue line). Further, TC2 readings remained at a very low level even as the ATR reached its fully powered-up phase as shown in Panel 5 from the top of Figure 9. Based on this response, TC2 is assumed to have failed on April 26, 2013, at 08:45, and all data from this TC are *Failed* after this date/time.

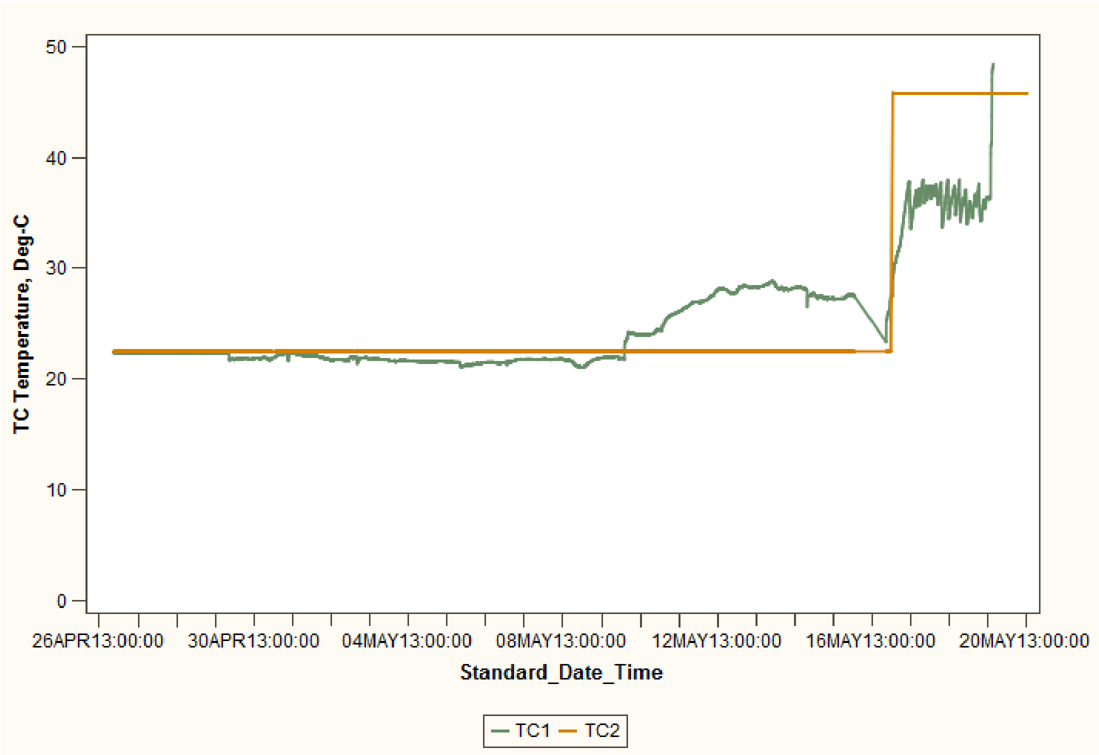


Figure 18. TC2 in Capsule 2 failed right at the beginning of Cycle 154A on 29 April, 2013 at 08:45.

3.2.2.2 TC1 in Capsule 3

<u>DRC Recommendation</u>: Failure on May 17, 2013, at 03:15 (Cycle 154A)

Figure 19 shows that TC1 in Capsule 3 also failed during the outage portion of the ATR Cycle 154A, but a later than TC2 in Capsule 2. At first, TC1 and TC2 readings in Capsule 3 followed each other perfectly, but from May 17, 2013, at 03:15 TC1 readings (blue line) dropped lower and stayed at that low level even when ATR powered up as shown on Panel 4 from the top of Figure 9. Based on this response, TC1 is assumed to have failed on May 17, 2013, at 03:15, and all data from this TC are *Failed* after this date/time.

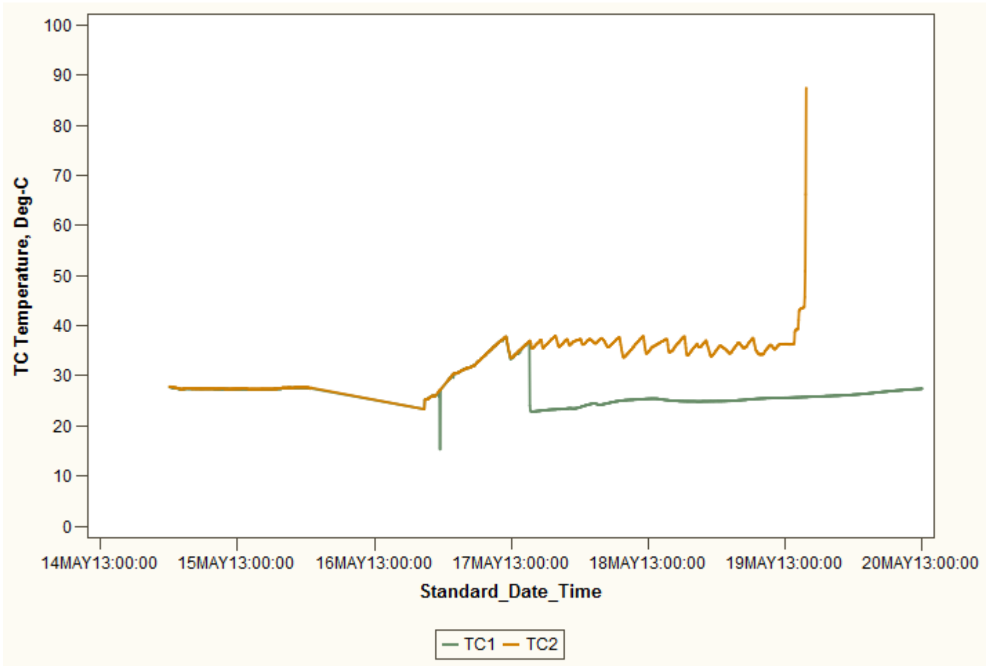


Figure 19. TC1 in Capsule 3 failed on May 17, 2013, at 03:15 (based on actual data).

3.2.2.3 TC2 in Capsule 3

DRC Recommendation: Failure on October 9, 2013, at 12:15 (Cycle 154B)

Figure 20 shows that TC2 in Capsule 3 failed on October 9, 2013 at 12:15 when its readings dropped to about 30 °C during ATR full power, and all data from this TC are failed after this date/time.

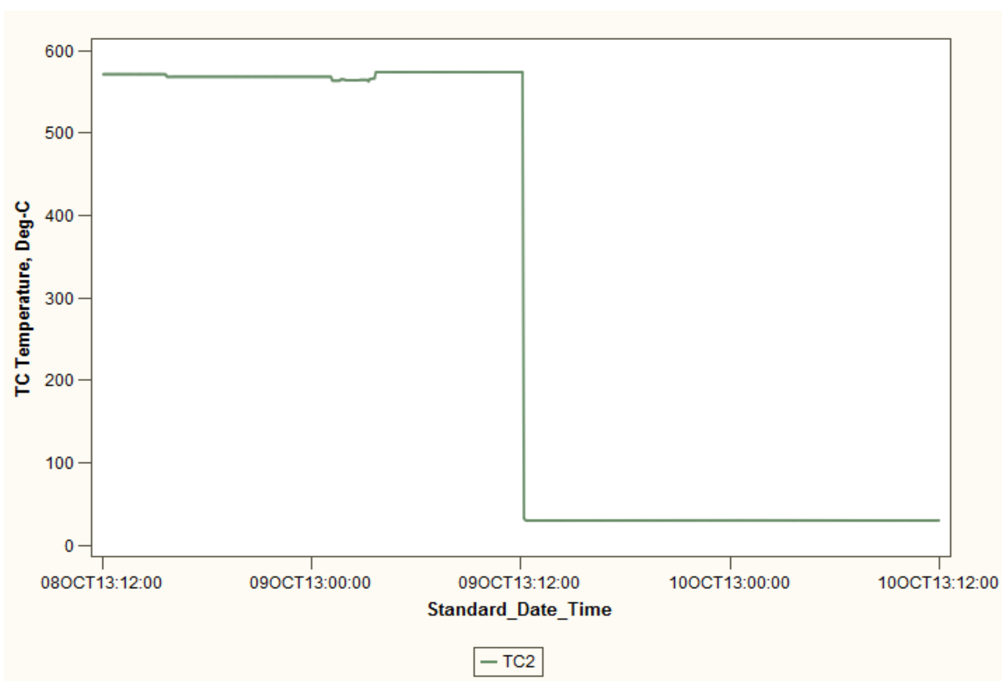


Figure 20. TC2 in Capsule 3 failed on October 9, 2013 at 12:15 (based on actual data).

3.2.3 TC Drift

The term *TC drift* refers to the differences in TC readings over time that are the result of a malfunctioning TC rather than changes in experimental conditions. NDMAS uses control charts to help visualize and identify unacceptable TC drift over the course of the experiment. A control chart uses an initial "baseline" period of data to calculate typical operating conditions and then evaluates a subsequent "monitoring period" of data relative to the baseline conditions. A control chart centerline is calculated for a given capsule using the mean of the differences between TC pairs in that capsule during the baseline period. Upper and lower control limits for the TC differences are then calculated as three standard deviations above and below the control chart mean difference.

TC drift monitoring is based on measurement and simulation data of a TC pair in the same capsule and looks at four panels of plots as functions of time as shown in Figure 21 through Figure 35: Panel 1: control charts of TC pair temperature differences for both measurement and simulation; Panel 2: TC residuals (measured minus simulated); Panel 3: daily correlation coefficients and actual measured and simulated TC values; and Panel 4: TC measurements. These monitoring plots provide complementary indications of potential TC drift and help define the failure mode. The TC drift criteria are determined as follows:

1. *Control charts of TC pair temperature differences*: For a stable TC pair located in thermally similar locations, the temperature differences in the monitoring period should stay within the established control limits of three standard deviations around the mean value. When consistently out-of-control instances in a monitoring period are apparent, two scenarios should be considered:
   a. The measured TC differences follow the simulated TC differences (the two plots are parallel); and the out-of-control instances are justified and the TC pair is deemed stable.
   b. Otherwise, at least one of the TCs in the pair might be drifting.
2. *TC residuals*: The TC is deemed stable in relation to simulation when its residuals, as a function of time, lie around a horizontal line. Therefore, a consistent slope of TC residuals indicates a TC drift (either downward or upward depending on slope direction).
3. *Daily correlation coefficients*: The correlation coefficients between within-capsule TC pairs should be close to 1. Therefore, decreasing daily correlation coefficients indicate that at least one TC of the subject TC pair is deteriorating.
4. *Actual measured TC data plots*: These plots are used to confirm the drift indication identified in items (1) through (3) by the departure of the actual readings of a drifting TC from being parallel to readings of the other TC.

A key control chart assumption is that there is a constant mean and standard deviation between TC pairs within a capsule over both the baseline and monitoring periods. This assumption may not always be valid because of differential heating across TC pairs that may occur as the experiment progresses. Thus, interpretation of data responses relative to control chart limits cannot be strictly defined with regard to data qualification status. Although NDMAS provides control chart results and statistical interpretations, the final determination of whether there is unacceptable TC drift is made by AGR project leads during the DRC process using multiple performance indicators, including control charts, simulated fuel temperatures, and engineering judgment. All these plots for valid TC temperature data are available on the NDMAS Web portal (http://ndmas.inl.gov) under AGR-34/Analysis/Temperatures.

For AGR-3/4, three capsules (5, 10, and 12) have three TCs, TC1 and TC2 located in the graphite heat sink, and TC3 is located in the graphite matrix. The remaining capsules have both TCs located in the graphite heat sink. So, TC1/2 pairs are expected to be more consistent with each other than TC1/3 pairs. Therefore, the calculated TCs are useful for assessing TC1/3 pairs as shown in Figure 22, Figure 25, and Figure 31. The results show only TC3 in Capsule 10 was drifted during this reporting period.

3.2.3.1 Control Chart Results – TC1, TC2, and TC3 in Capsule 12

Figure 21 and Figure 22 show the control chart results for the TC1/2 and TC1/3 pairs in Capsule 12 indicating that all three TCs in this capsule are stable relative to each other because readings of three TCs are consistent according to the four above listed criteria: TC differences are within the control bound and similar to calculation, both TC residuals are flat over time, and fairly high correlation coefficients, especially for TC1/2 pair.

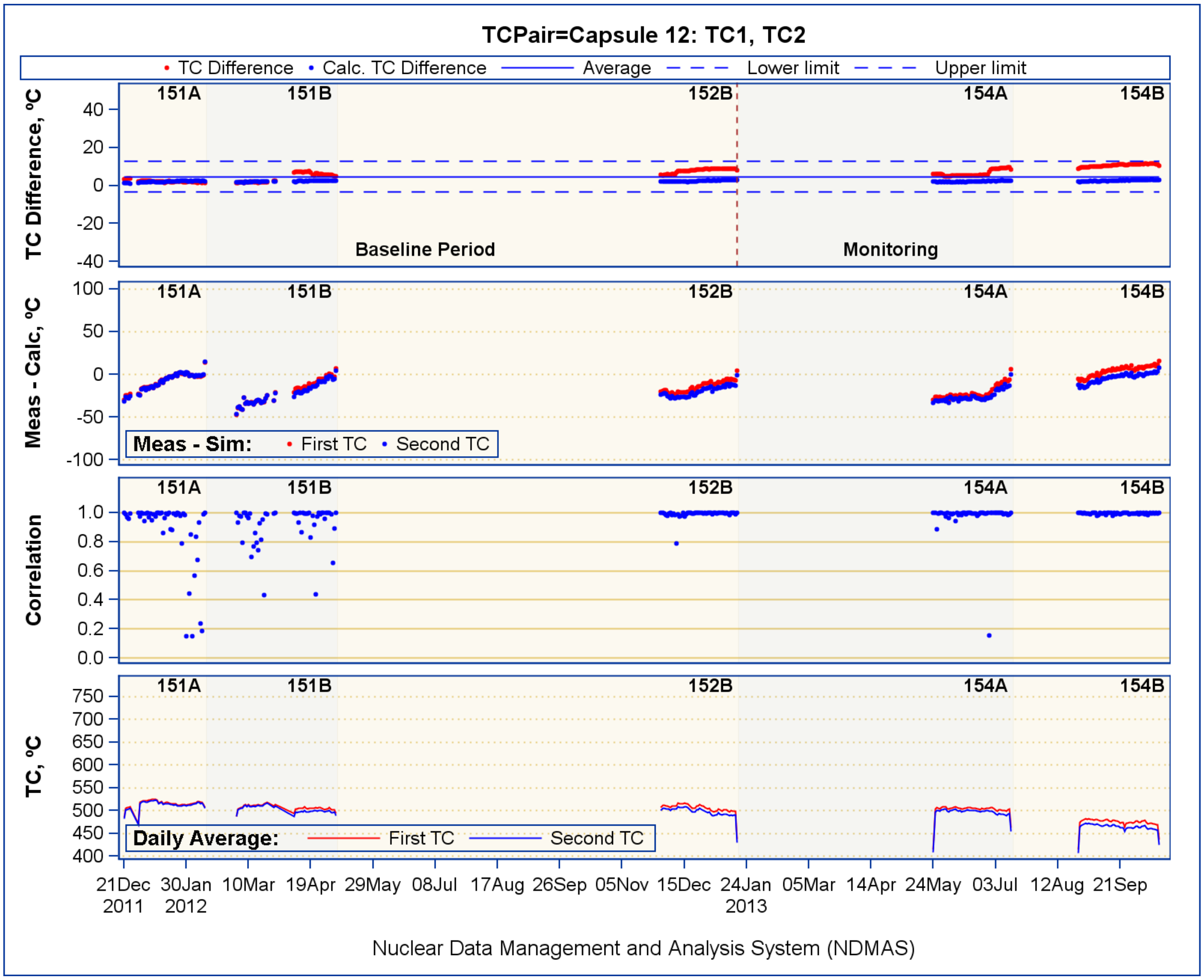


Figure 21. Control chart for the TC1/2 pair in Capsule 12.

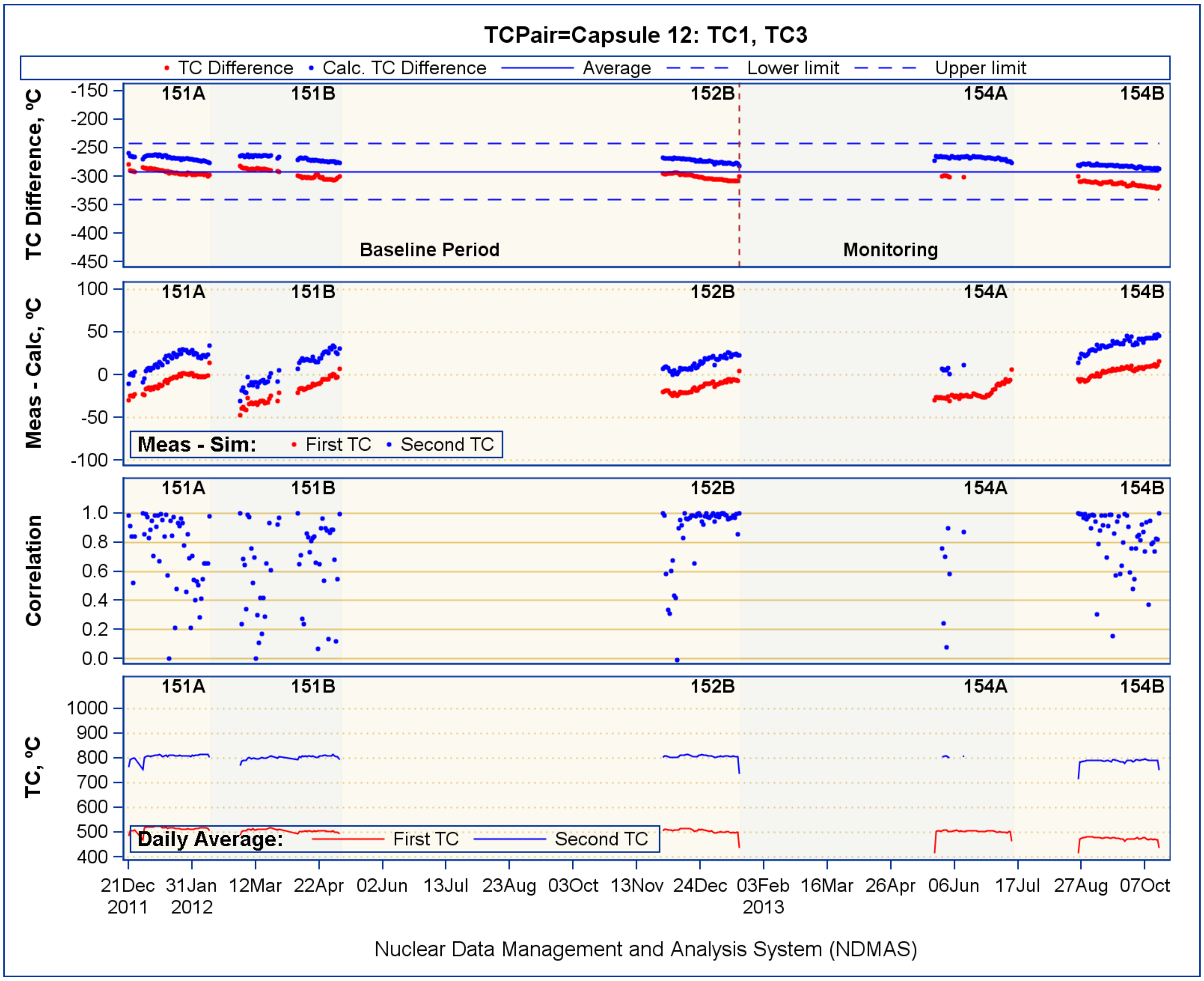


Figure 22. Control chart for the TC1/3 pair in Capsule 12.

3.2.3.2 Control Chart Results – TC1 and TC2 in Capsule 11

Control charts of temperature differences between TC1 and TC2 in Capsule 11 in Figure 23 indicate that these two TCs were stable relative to each other.

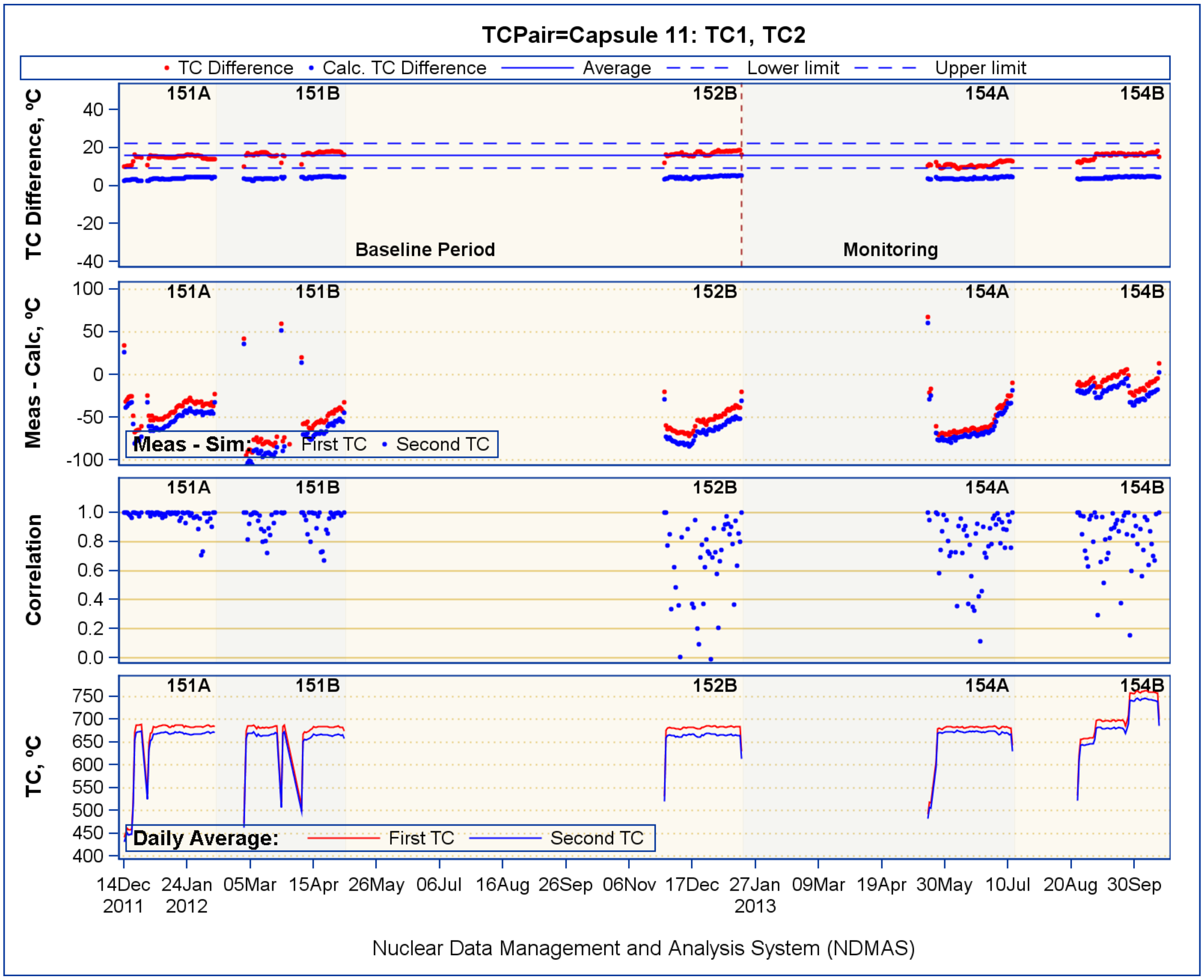


Figure 23. Drift monitoring for TC1 and TC2 in Capsule 11.

3.2.3.3 Control Chart Results – TC1, TC2, and TC3 in Capsule 10

Control charts of temperature differences between TC1 and TC2 in Capsule 10 in Figure 24 indicate that these two TCs were not perfectly stable relative to each other because the TC differences started to cross the upper limit of control chart by the end of ATR Cycle 154B. However, the TC difference increased only less than 10 °C, so this can serve as warning for further observation.

On other hand, control charts of temperature differences between TC1 and TC3 in Capsule 10 in Figure 25 indicate that TC3 was drifting starting by the middle of ATR Cycle 154B. The TC differences (Panel 1) rapidly increased and TC3 residuals (measured – calculated in Panel 2) rapidly decreased. In addition, around the same time the pair correlation coefficients (Panel 3) started to drop, and their actual TC readings (Panel 4) were not parallel over time.

<u>DRC recommendation</u>: Confirmed TC3 in Capsule 10 drifted starting from the middle of ATR Cycle 154B and its readings are *Trend* data after September 20, 2013.

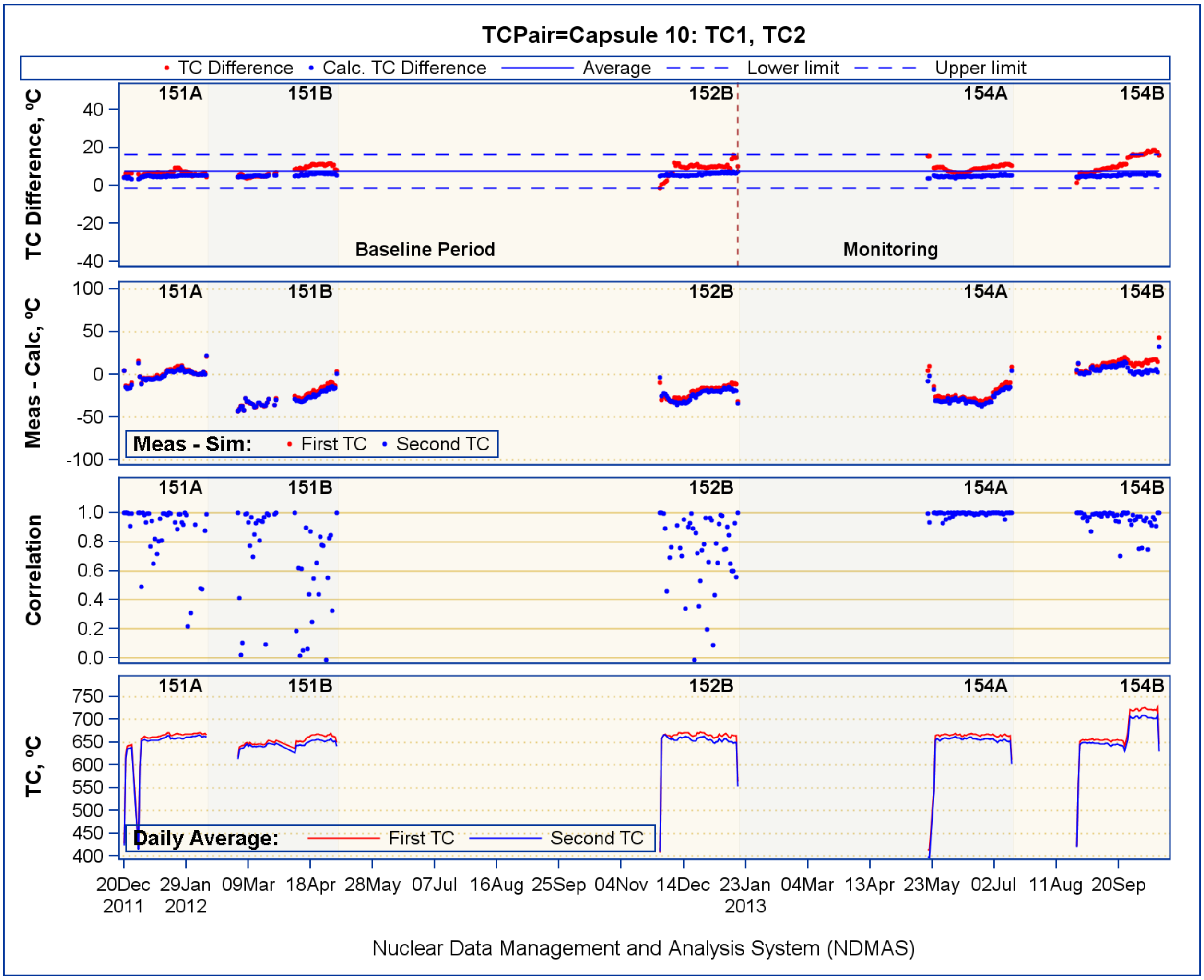


Figure 24. Drift monitoring for TC1 and TC2 in Capsule 10.

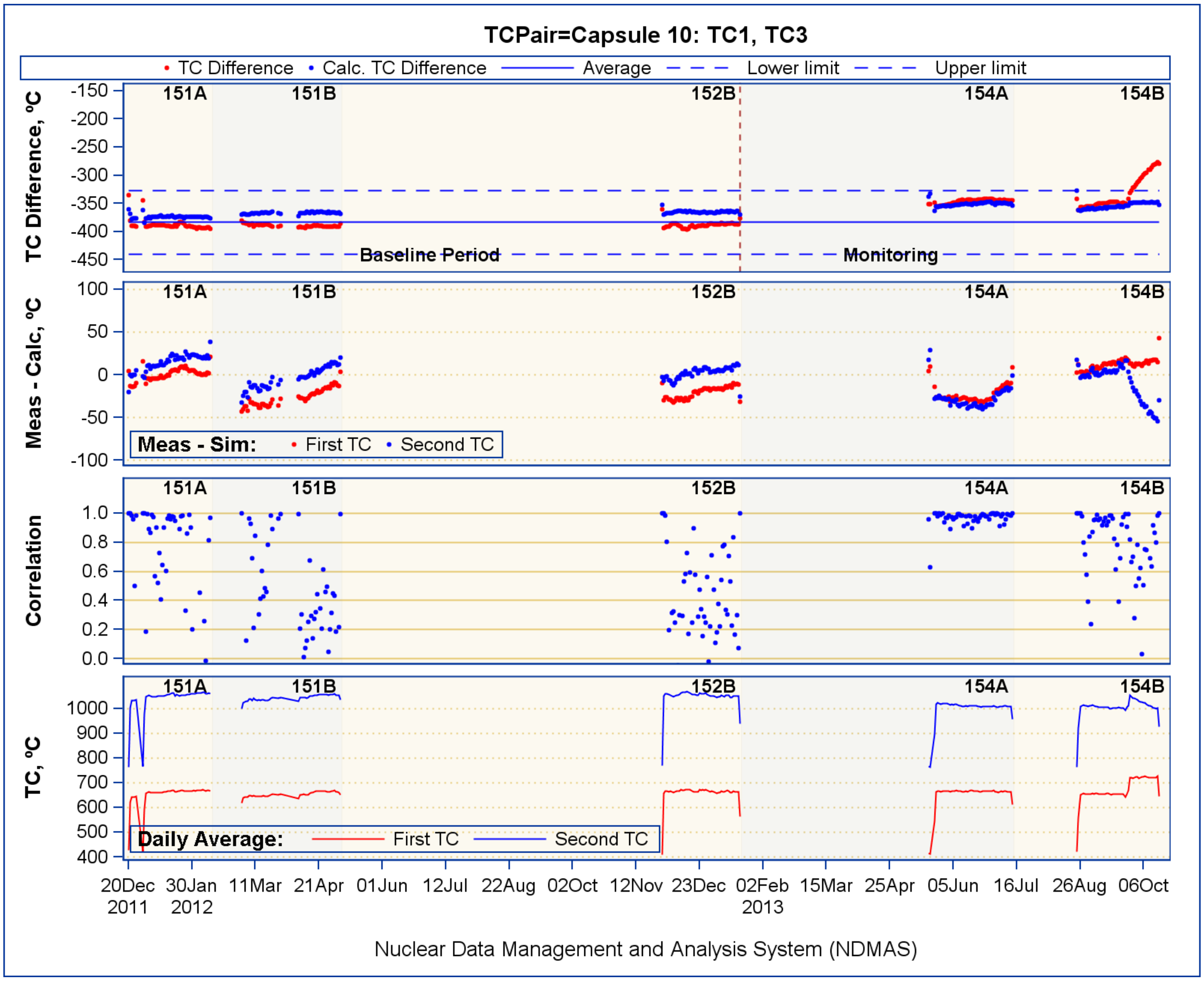


Figure 25. Drift monitoring for TC1 and TC3 in Capsule 10.

3.2.3.4 Control Chart Results – TC1 and TC2 in Capsule 9

Control charts of temperature differences between TC1 and TC2 in Capsule 9 in Figure 26 indicate that these two TCs were not drifting, but their readings were not stable relative to each other. Readings of TC1 and TC2 seemed to be mirroring each other, but they are generally still maintaining similar time-averaged values. One possible explanation for this behavior is the fact that TC1 in Capsule 9 was found to have reversed polarity in the potting cup during the heat up test. Then, the leads of TC1 had to be switched back at the connector at the top of the test. This resulted in a temperature offset for TC1 based on the temperature difference between the potting location, which is well above the core region and therefore runs at the reactor water inlet temperature (50 °C) and the connector location, which is right above the reactor vessel head and runs at about 30 °C, (Q15807901 – "Engineering Work Instructions for Assembling the AGR-3/4 Experiment"). Therefore, TC1 temperature values are offset from the actual TC1 temperatures by about 20 °C. This temperature offset has a 5 °C or 10 °C variability because of the variation of temperature above the reactor top head while the reactor inlet temperature is fairly stable.

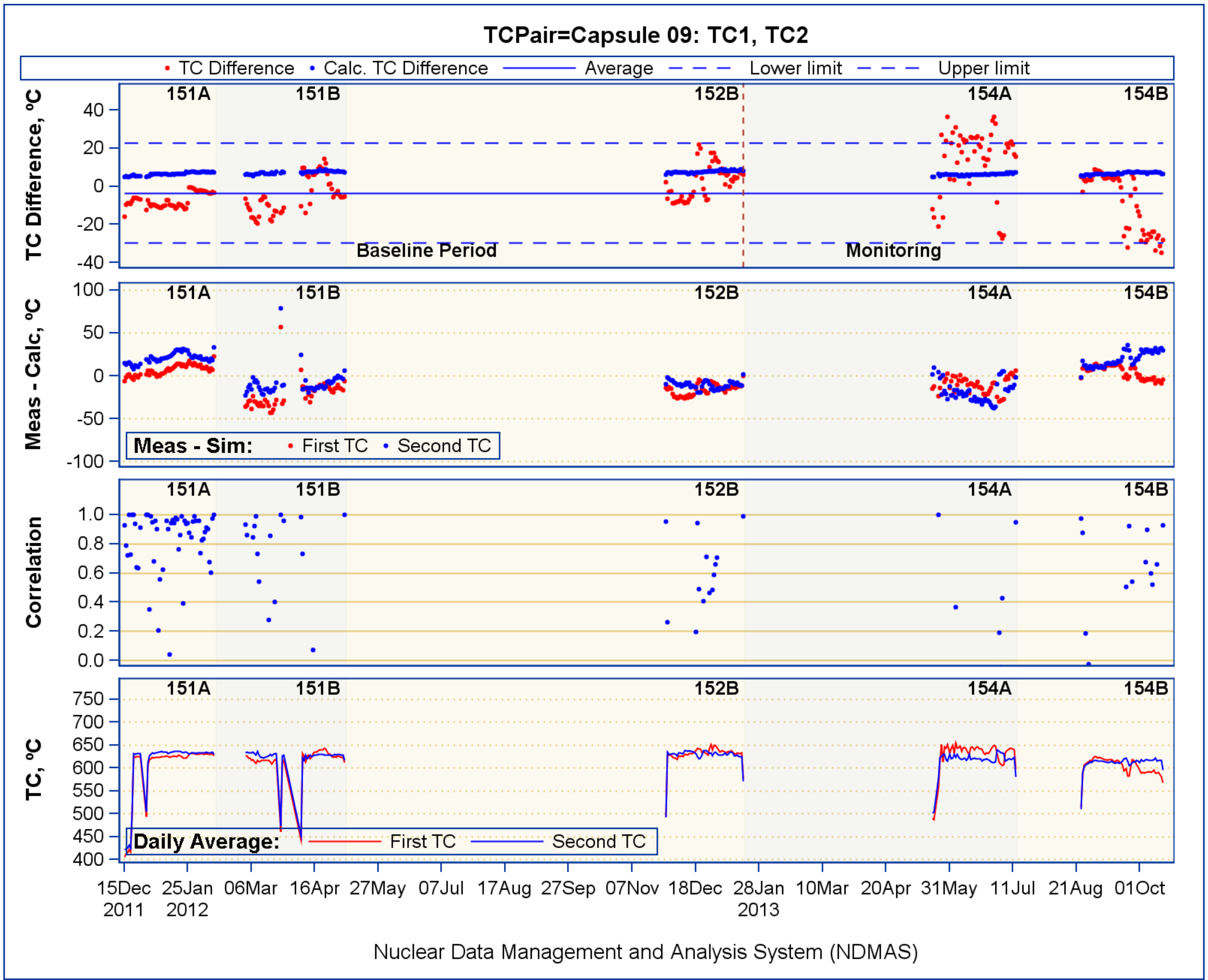


Figure 26. Drift monitoring for TC1 and TC2 in Capsule 9.

3.2.3.5 *Control Chart Results – TC1 and TC2 in Capsule 8*

Control charts of temperature differences between TC1 and TC2 in Capsule 8 in Figure 27 indicate that these two TCs were stable relative to each other. According to calculated TCs, one TC in this pair is biased relative to the other by the same amount during all cycles. This known bias does not affect fuel temperature control in Capsule 8, because it can be accounted for by appropriate TC set point.

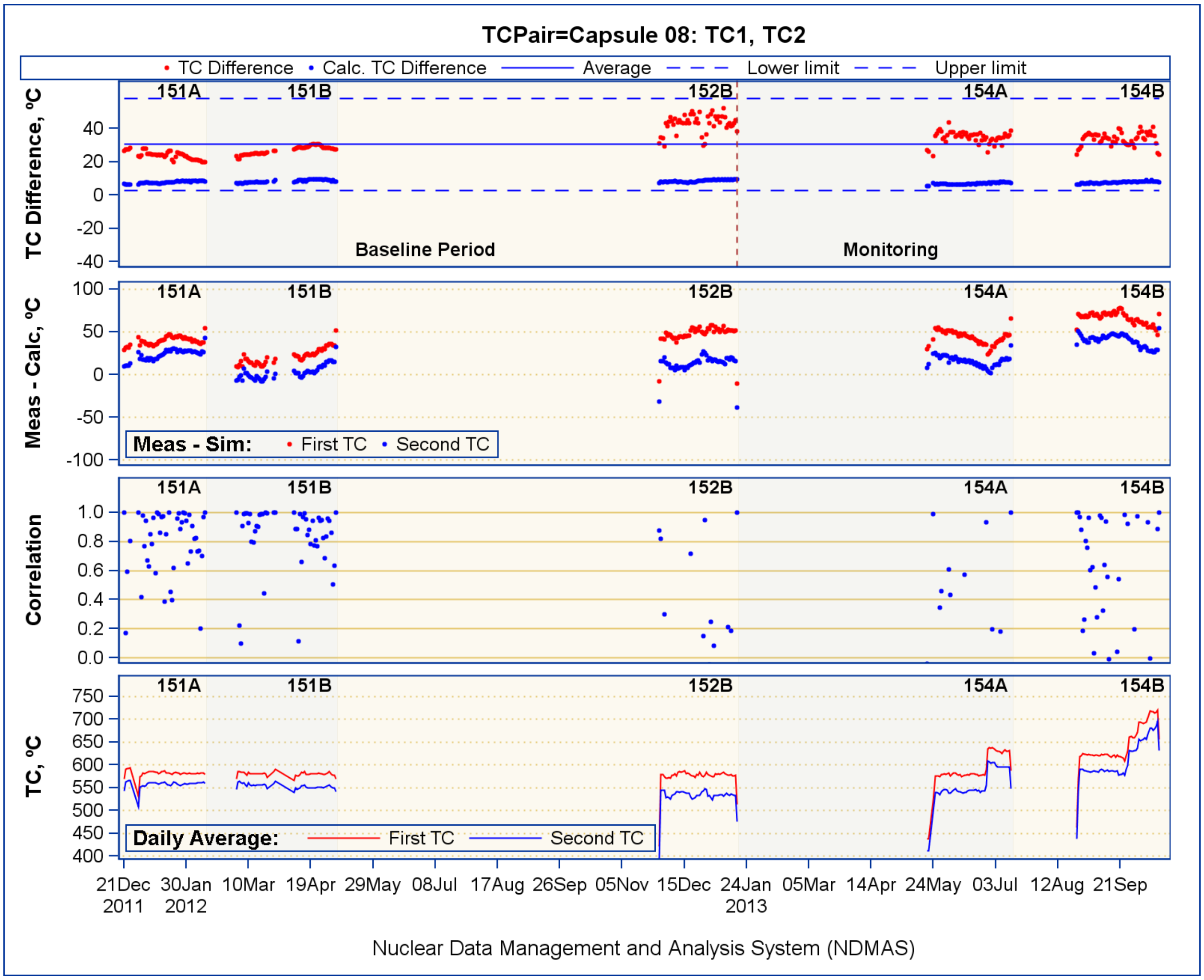


Figure 27. Drift monitoring for TC1 and TC2 in Capsule 8.

3.2.3.6 Control Chart Results – TC1 and TC2 in Capsule 7

Control charts of temperature differences between TC1 and TC2 in Capsule 7 in Figure 28 indicate that these two TCs were not drifting, but they were not stable relative to each other because a drift of 20 °C during ATR Cycle 154A was recovered during ATR Cycle 154B. Their correlation coefficients were low during ATR Cycles 154A and 154B.

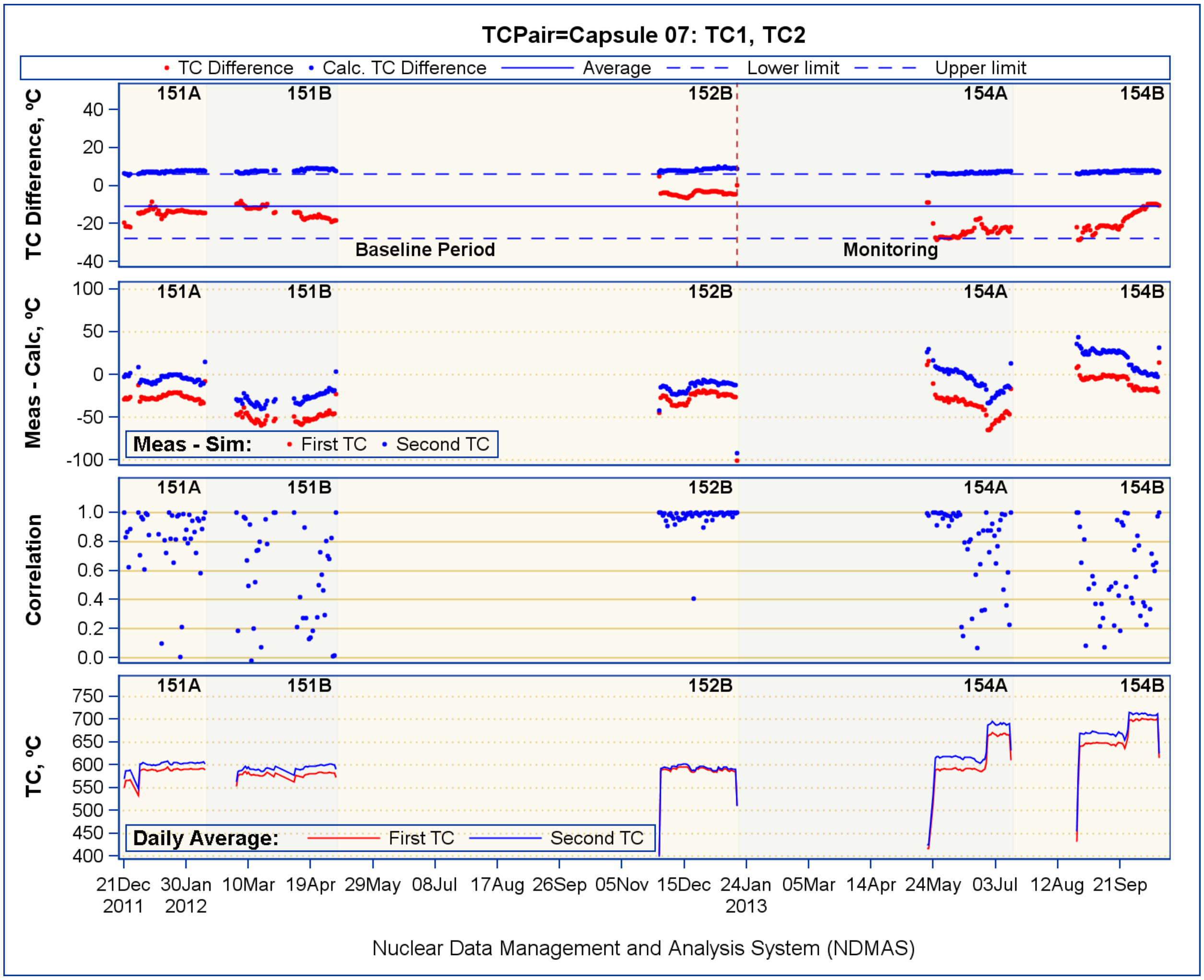


Figure 28. Drift monitoring for TC1 and TC2 in Capsule 7.

3.2.3.7 Control Chart Results – TC1 and TC2 in Capsule 6

Control charts of temperature differences between TC1 and TC2 in Capsule 6 in Figure 29 indicate that these two TCs were not drifting, but they are not exactly stable relative to each other.

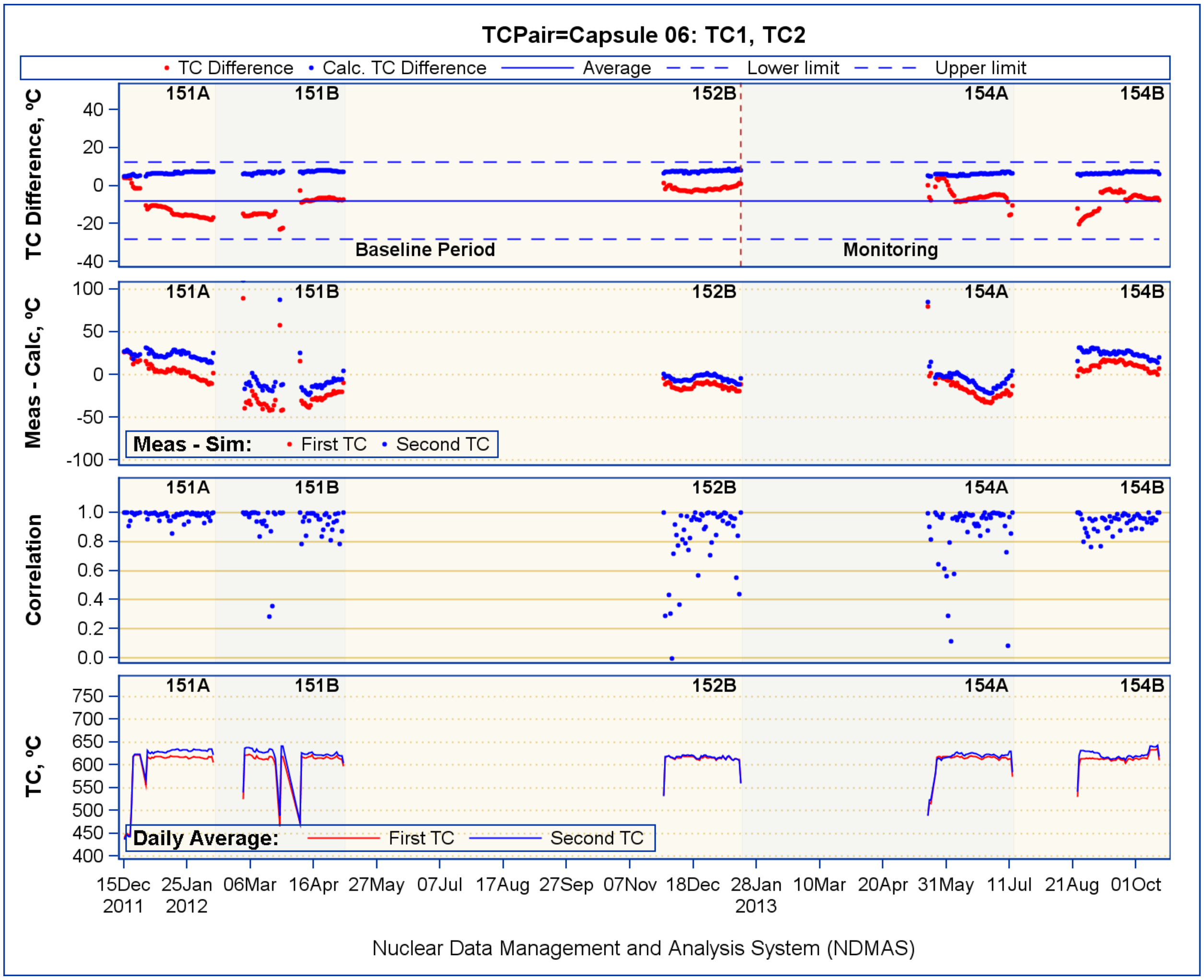


Figure 29. Drift monitoring for TC1 and TC2 in Capsule 6.

3.2.3.8 Control Chart Results – TC1, TC2, and TC3 in Capsule 5

Figure 30 and Figure 31 show the control chart results for the TC1/2 and TC1/3 pairs in Capsule 5 indicating that all three TCs in this capsule are stable relative to each other because readings of all three TCs are consistent according to the four above listed criteria: TC differences are within the control bounds and largely similar to calculation, both TC residuals are flat over time, and fairly high correlation coefficients for both TC pairs.

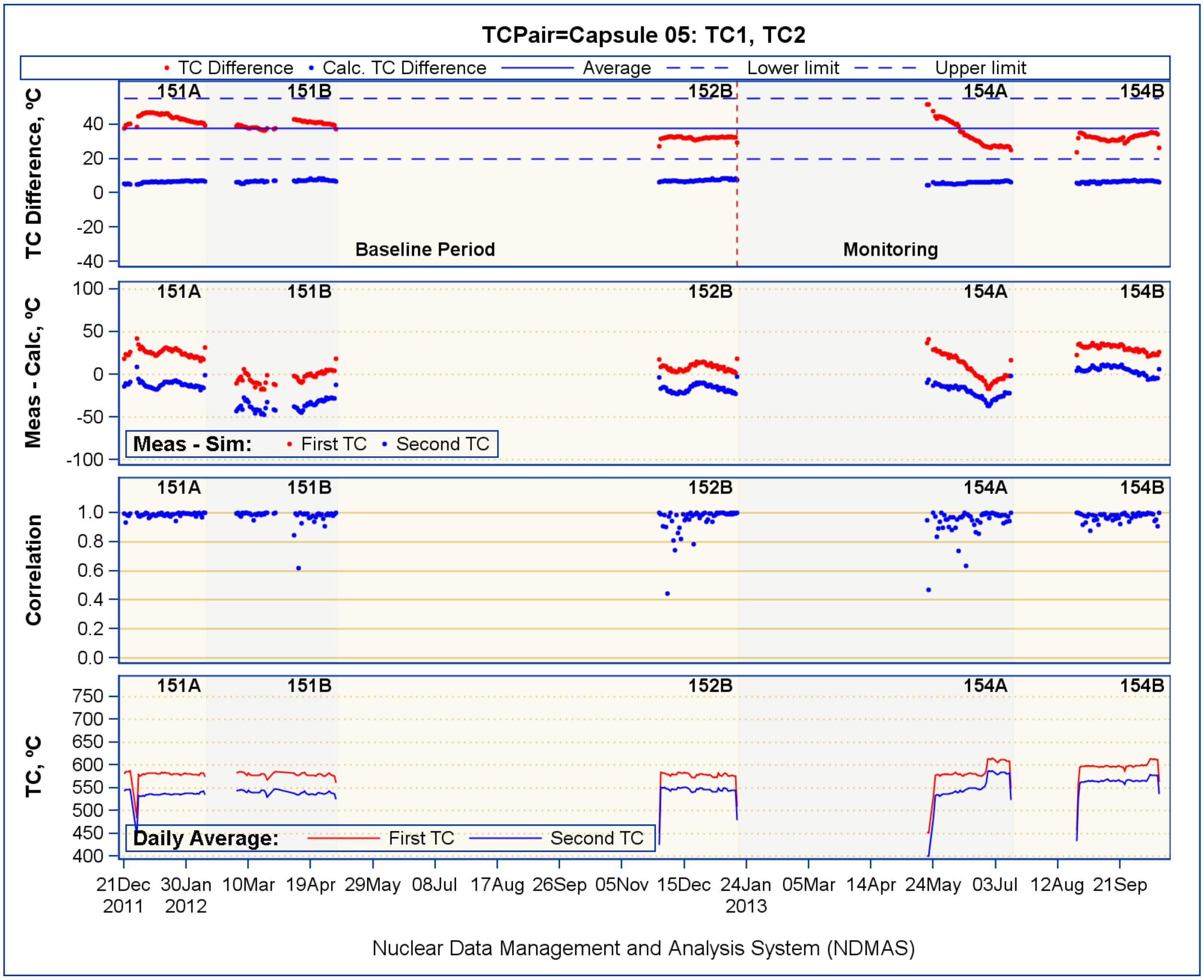


Figure 30. Drift monitoring for TC1 and TC2 in Capsule 5.

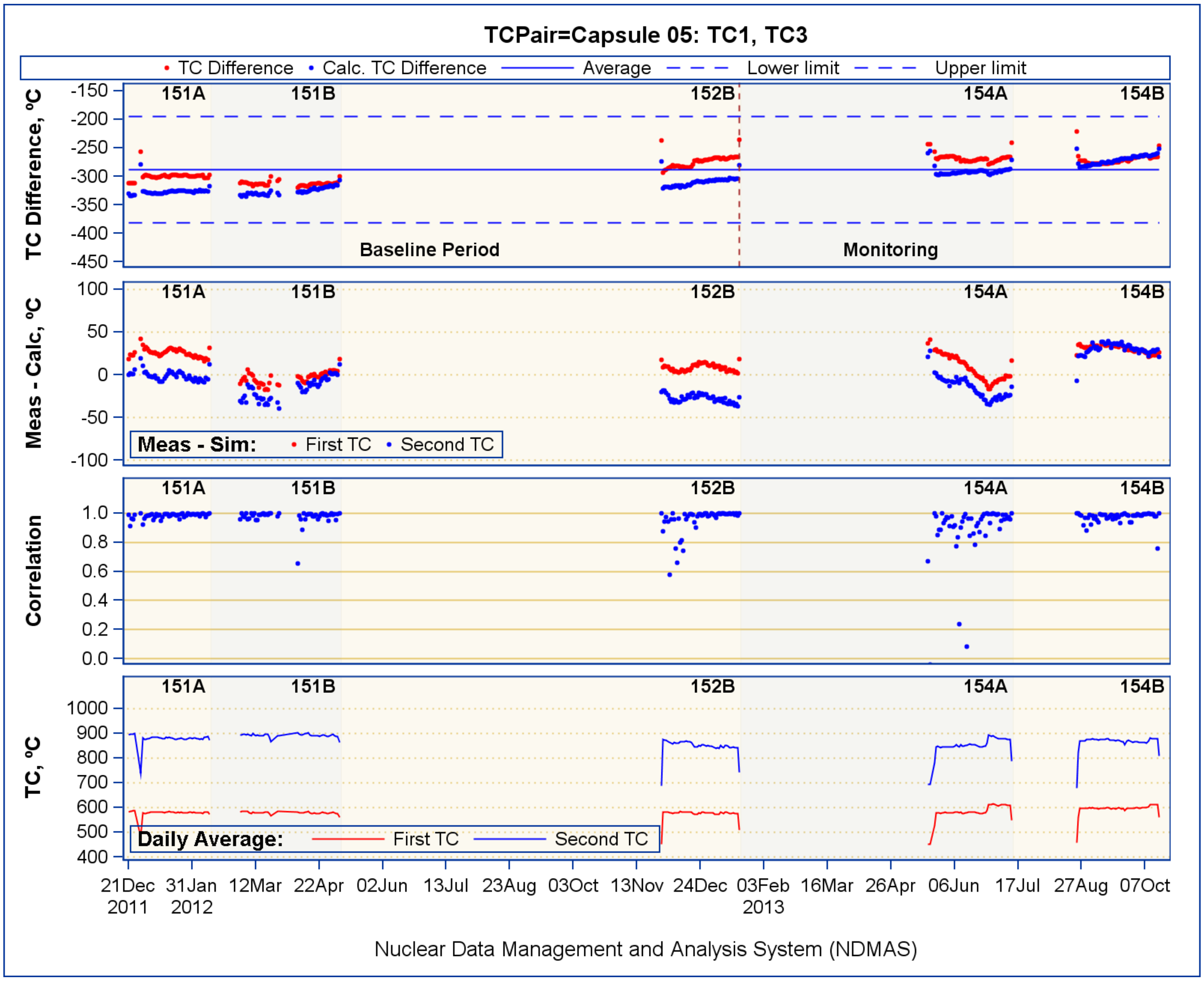


Figure 31. Drift monitoring for TC1 and TC3 in Capsule 5.

3.2.3.9 Control Chart Results – TC1 and TC2 in Capsule 4

Control charts of temperature differences between TC1 and TC2 in Capsule 4 in Figure 32 indicate that these two TCs were not drifting, but their readings were not stable relative to each other similar to the TC pair in Capsule 9.

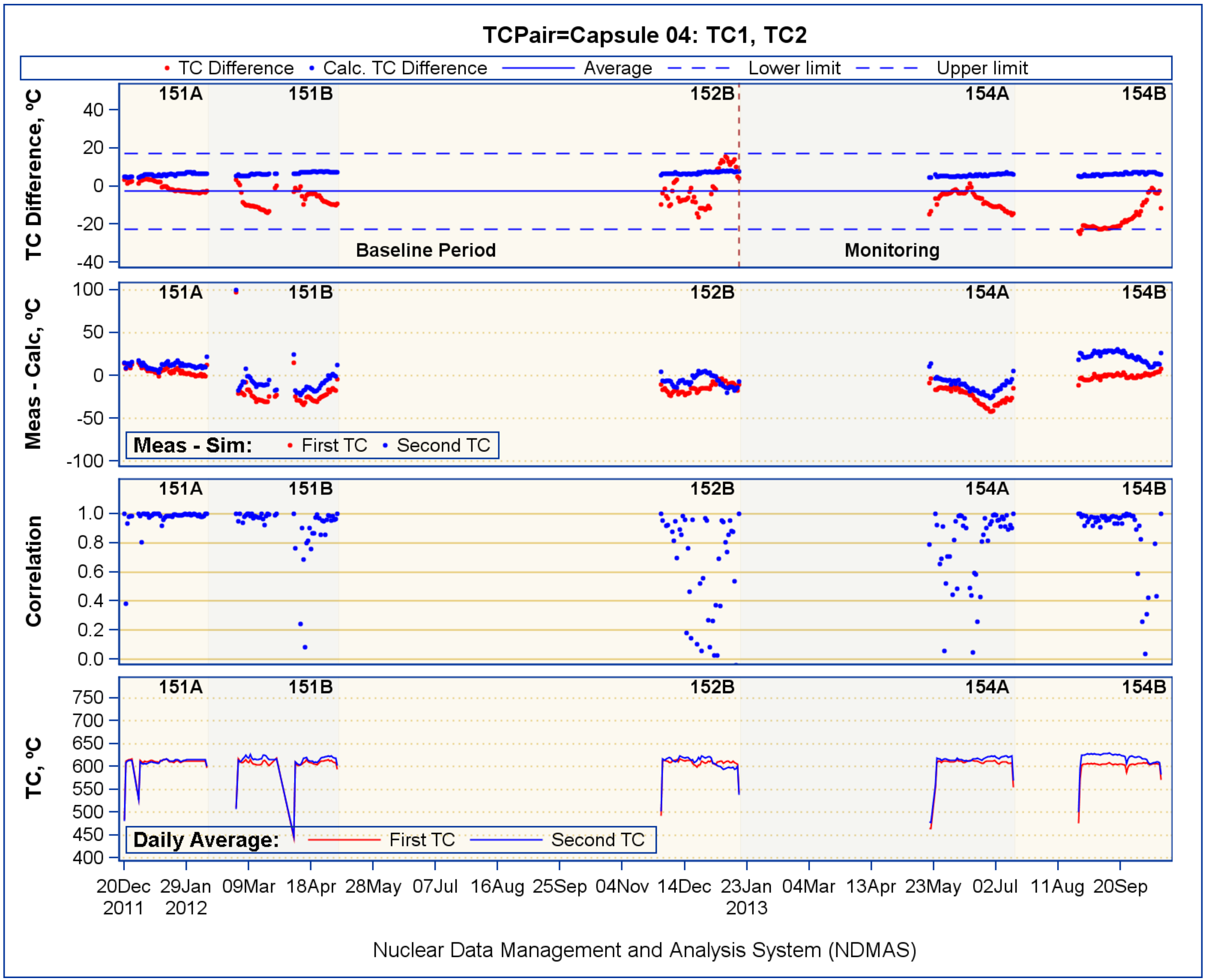


Figure 32. Drift monitoring for TC1 and TC2 in Capsule 4.

3.2.3.10 Control Chart Results – TC1 and TC2 in Capsule 3

Control charts of temperature differences between TC1 and TC2 in Capsule 3 in Figure 33 indicate that these two TCs were stable relative to each other until TC2 failure after ATR Cycle 152B.

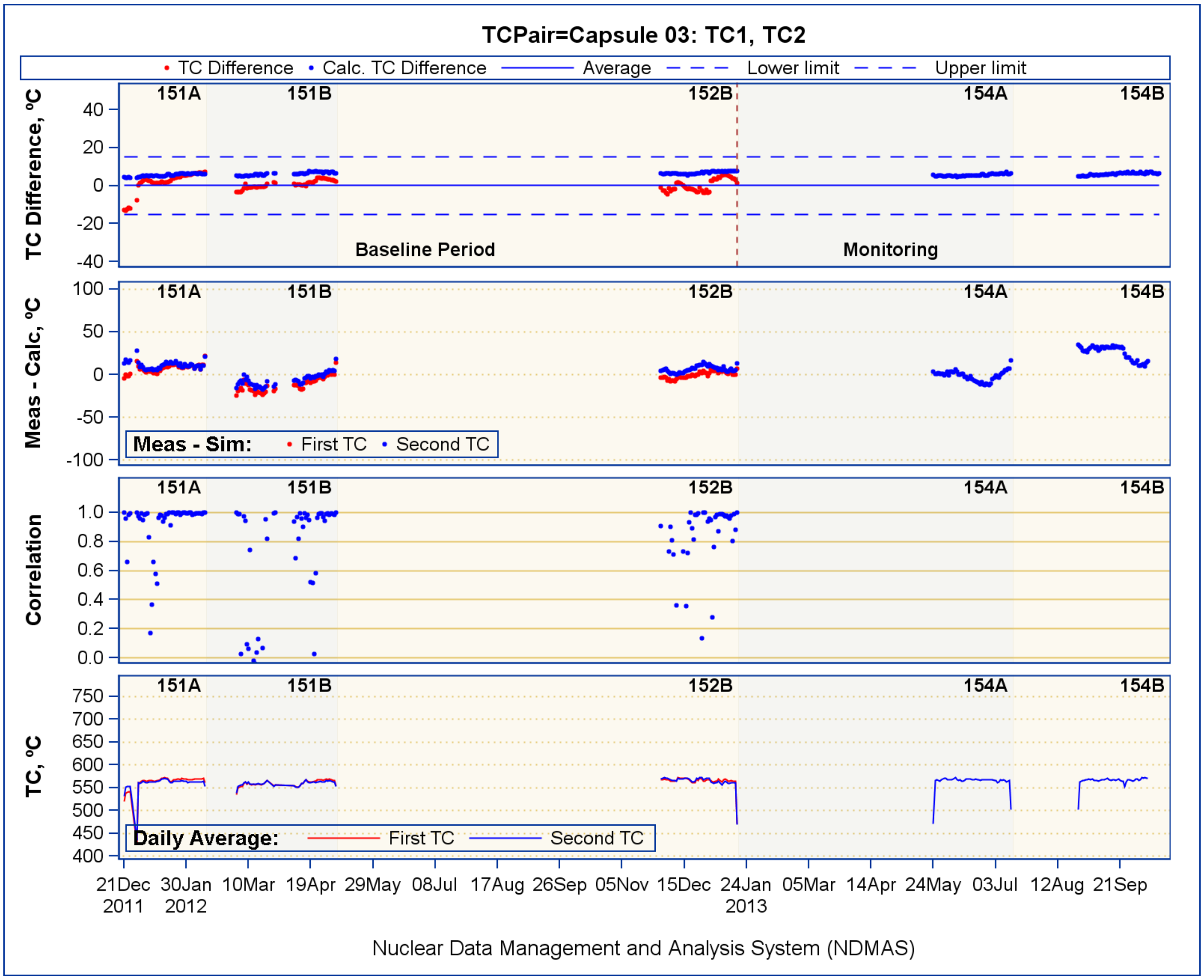


Figure 33. Drift monitoring for TC1 and TC2 in Capsule 3.

3.2.3.11 Control Chart Results – TC1 and TC2 in Capsule 2

Control charts of temperature differences between TC1 and TC2 in Capsule 2 in Figure 34 indicate that these two TCs were stable relative to each other until TC2 failed after ATR Cycle 152B.

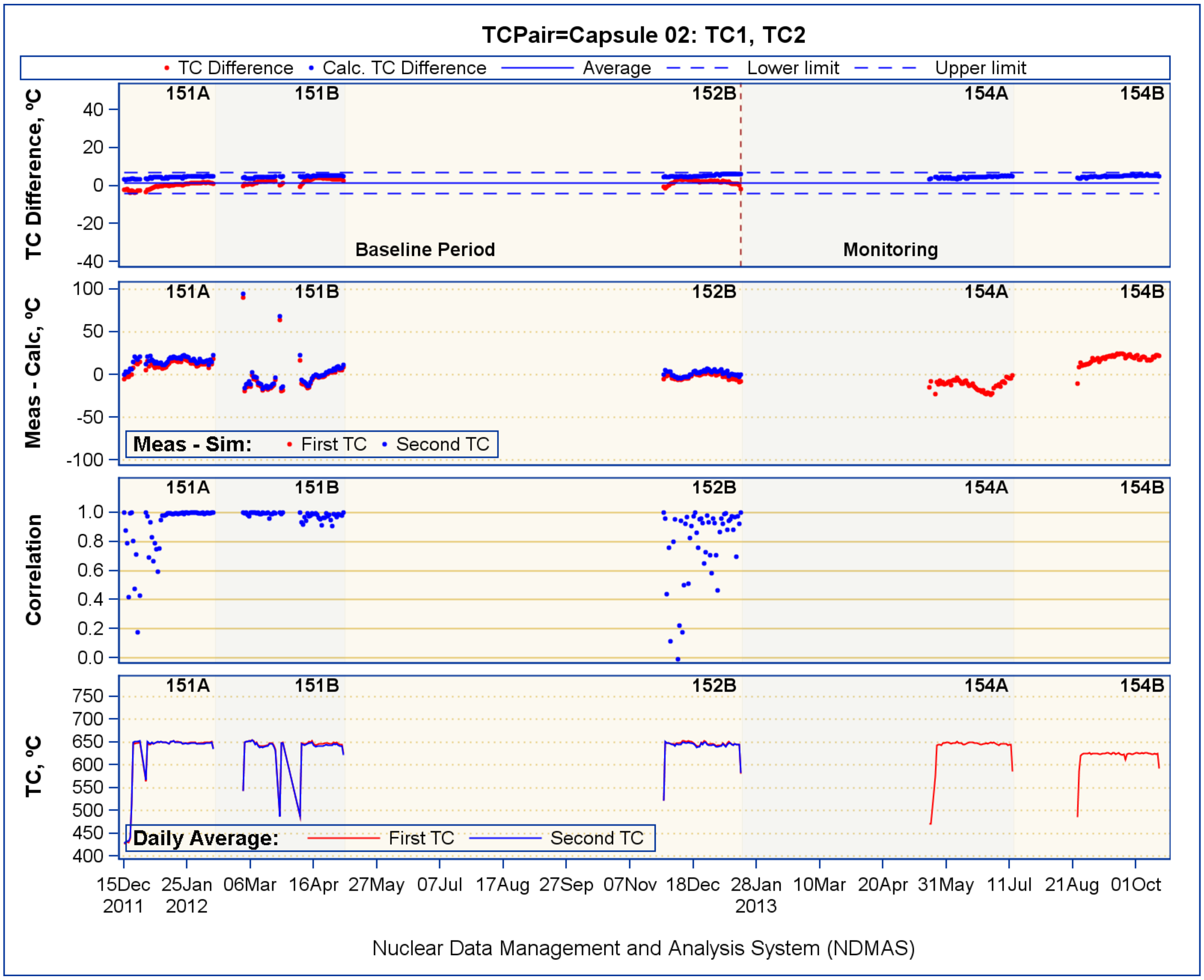


Figure 34. Drift monitoring for TC1 and TC2 in Capsule 2.

3.2.3.12 Control Chart Results – TC1 and TC2 in Capsule 1

Control charts of temperature differences between TC1 and TC2 in Capsule 1 in Figure 35 indicate that these two TCs had still not drifted, but they are not perfectly stable relative to each other. The TC differences were within the control limits, but they were trending up all the time from the start of AGR-3/4 irradiation. Their TC residuals in Panel 2 and the actual TC measurements in Panel 4 also indicate small possible drift of at least one TC. Finally, their correlation coefficients are low the whole time. Based on increasing TC1 residuals, TC1 might be insignificantly drifting upward relative to TC2.

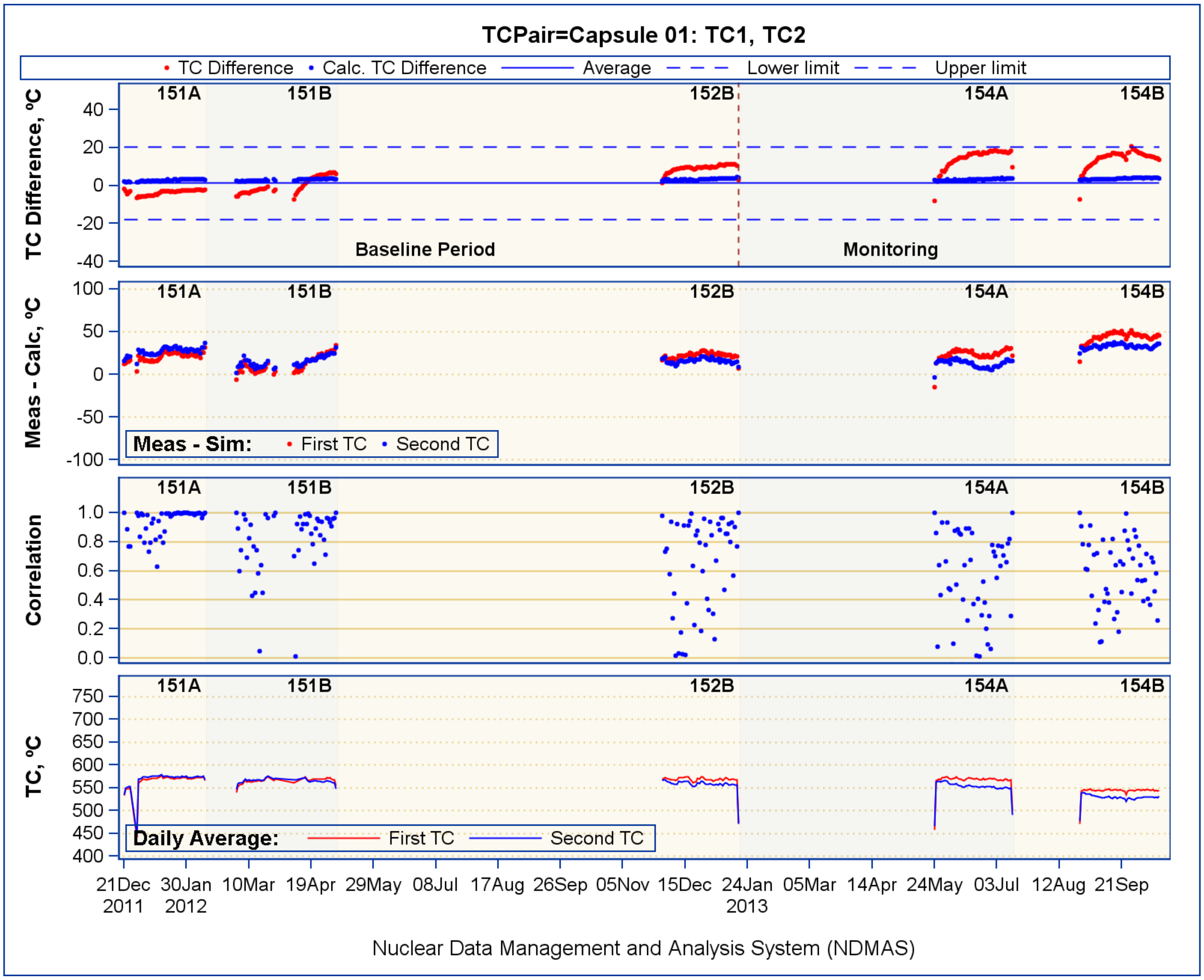


Figure 35. Drift monitoring for TC1 and TC2 in Capsule 1.

3.2.4 TC Virtual Junctions

NDMAS developed a simple correlation test to help identify virtual junction failures in TCs. A virtual junction occurs when a TC starts to measure temperature at a different location than at its installed terminal location (e.g., in a higher elevation capsule where the TC wire traverses).

When functioning properly, TC readings for a given capsule should be most highly correlated with other TCs in the same capsule. If a virtual junction occurs, the highest correlation will switch to a TC reading in a different capsule (where the junction occurs). To do this test for a given capsule, there needs to be at least two functioning TCs located in that capsule, and comparisons can only be made with other capsules that have functioning TCs. Figure 36 shows an example of the correlation coefficients for the TCs in Capsule 12. This plot shows that, for the majority of the time, all these TCs are most highly correlated with some other TC in Capsule 12, indicating no virtual junctions. On other hand, the most highly correlated capsules were randomly scattered over time as shown in Figure 37 also indicating no virtual junction, because TC readings were not consistently correlated with any particular capsule. TCs in all remaining capsules have these same patterns indicating no TC virtual junction failure for AGR-3/4.

Figure 36. Example of a correlation plot for the TC1, TC2, and TC3 installed in Capsule 12.

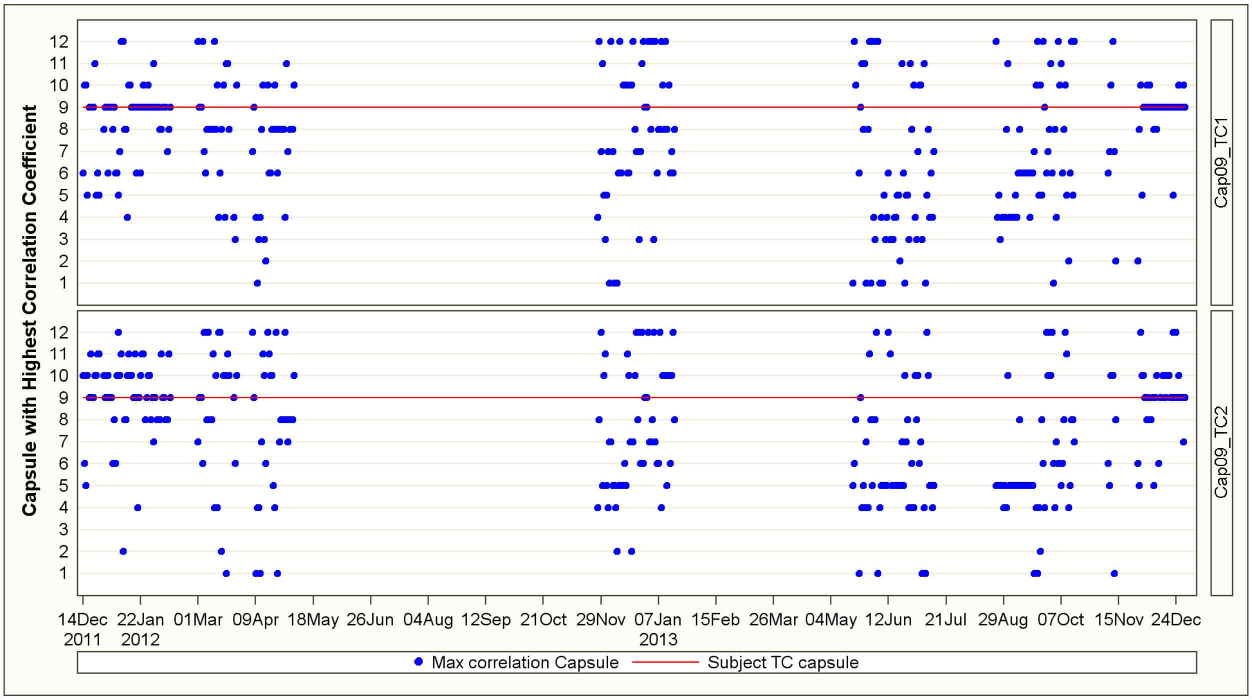


Figure 37. Example of a correlation plot for the TC1 and TC2 installed in Capsule 9.

3.3 Testing for Data Anomalies of Gas Flow Rate Data

This section discusses data anomalies of gas flow rates resulting from data testing and DRC data qualification decisions along with their impacts to program objectives. A total of 18,080,676 flow data records captured in NDMAS database during this reporting period are discussed here. The three failure modes of gas flow rate measurements are: (1) out-of-range, (2) missing, and (3) irrelevant. Modes (1) and (2) are identified by range testing within the NDMAS data capture process. Mode (3), irrelevant data, is identified by data overview in Section 3.1.1. The irrelevant data are defined as data that are clearly not representing the actual conditions in capsules. The data analysis and testing efforts were performed to make sure that the failed gas flow rates do not affect exact calculation of the capsule gas composition (e.g., neon fraction) needed in the thermal calculations for AGR-3/4 capsules. Details of the data analysis and testing results are presented in the following subsections.

3.3.1 NDMAS Capture Range Testing

In this section only neon, helium, impure, and outlet sweep gas flow data testing results are discussed. Table 7 shows that during this reporting period there were 1,988,716 gas flow records (or 11.0% of the total) that failed the capture and range test out of a total of 18,142,786 gas flow records. Note that the total failed data does not include slightly negative gas flow rates as discussed in subsection 3.2.1.2.

Table 7. Number of gas flow rates failed capture and range tests during ATR Cycles 151A through 154B.

ATR Cycle	Total # Records	Negative	Failed Records			Total # Failed	%Failed
			Too High	Missing	Irrelevant		
151A	773,564	104,838	0	0		0	0.0%
151B	1,038,048	118,468	2	20,588		20,590	2.0%
152A	4,099,304	188,210	274	1,057,295		1,057,569	25.8%
152B	3,095,924	0	0	198,531		198,531	6.4%
154A	4,147,586	10,645	0	894	711,132	712,026	17.2%
154B	4,988,360	378,259	0	0		0	0.0%
Total =	**18,142,786**	**800,420**	**276**	**1,277,308**	**711,132**	**1,988,716**	**11.0%**

3.3.1.1 Out-of-Range Data

Because the gas flow rates range from 0 to 102 sccm, the negative flow rates and “too high” flow rates (> 102 sccm) are assigned *Failed* data status as a result of the NDMAS capture range testing. According to Table 7, there are 800,420 negative flow rates and only 276 “too high” flow rates (274 during low power Cycle 152A and 2 during the ATR Cycle 151B) out of a total of 18,080,676 gas flow data records.

DRC recommendation: Trend 276 “*Too high*” sweep gas flow rate records.

Negative Gas Flow Rates: Except for ATR Cycle 152B, all other cycles have negative flow rates as shown in Table 7. However, all negative gas flow records are slightly less than zero ranging between -0.00289 sccm and -0.0206 sccm.

DRC recommendation: Qualify 800,420 negative sweep gas flow data and replace them with 0 sccm.

3.3.1.2 Missing Data

Data are classified as missing only if there is no record present for an existing time stamp in the raw data files provided by the data generators. There are 1,277,308 missing flow rates out of a total of 18,080,676 flow data records representing 64.2% of all the failed flow data. Table 7 breaks down the number of missing data into cycles showing that most of the missing data are during the ATR low power cycle 152A, followed by ATR Cycles 152B. The majority of the missing values occurred during the ATR outage periods, when the impact of bad flow data is not critical to the test objectives. However, there are missing neon flow rate records in Capsules 7 and 8 for the period November 27, 2013 12:00 to November 29, 2013 22:35, immediately after power-up for Cycle 152B, as shown by the pink lines in Panels 5 and 6 in Figure 38. These missing neon flow rates prevent capsule neon fraction calculation, which are crucial inputs to the thermal models used for fuel temperature prediction. Figure 38 also shows that during that time helium flows in all capsules (including Capsules 7 and 8) were mostly the same 30 sccm (pure helium flow). Therefore, the missing neon gas flow data for Capsules 7 and 8 can be filled in with whatever is higher of 0 scm or differences between helium flow rate and 30 sccm.

DRC recommendation: (1) Fill-in missing neon flow records in Capsules 7 and 8 for the periods November 27, 2013 12:00 to November 29, 2013 22:35 (152B) with whatever is higher of 0 sccm or differences between 30 sccm and helium flow rate and (2) fail all other missing records.

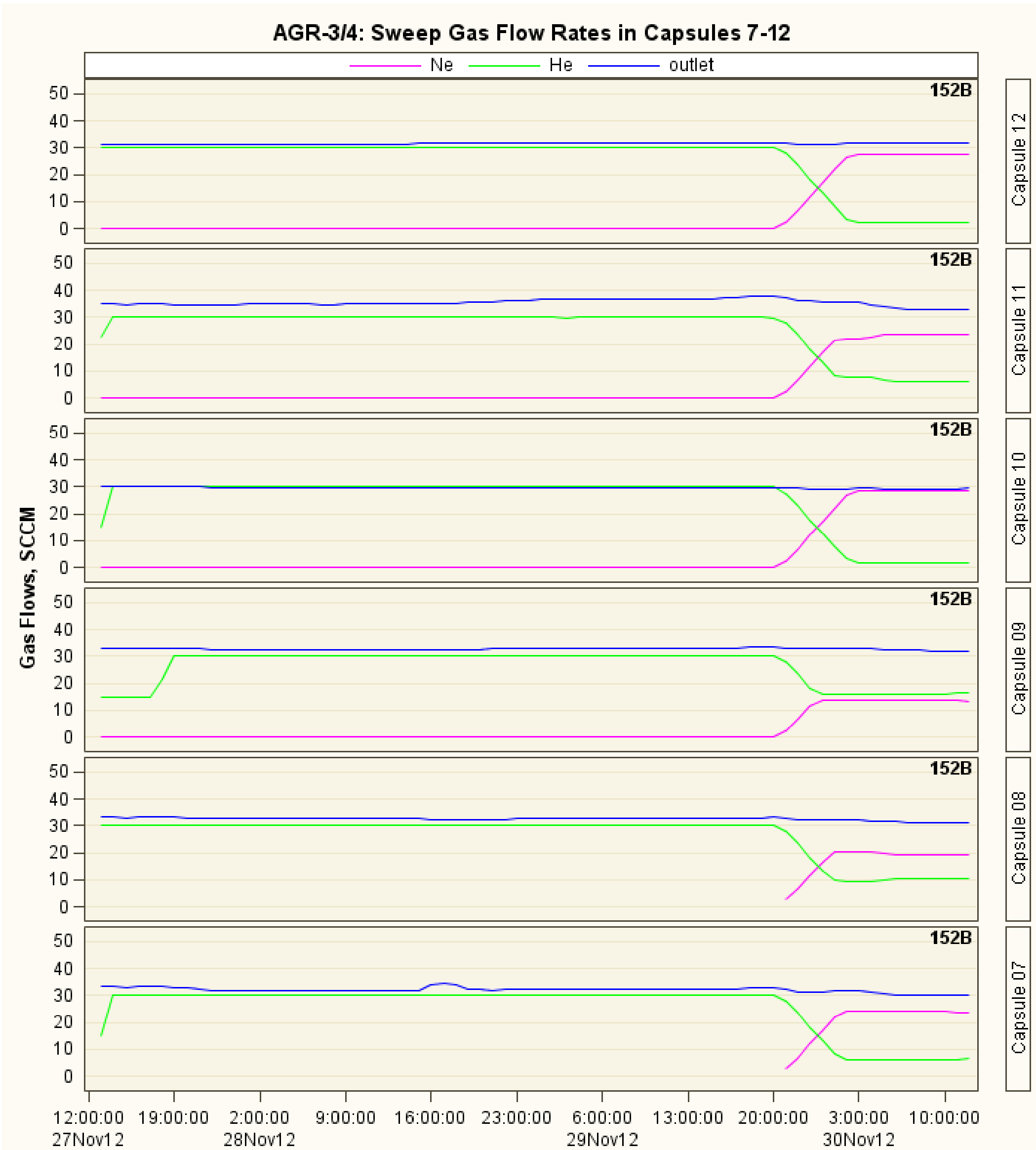


Figure 38. Capsules 7 - 12 gas flow rates for the period November 27, 2013, 12:00 to November 29, 2013, 22:35.

3.3.1.3 Irrelevant Data

The AGR-3/4 test was inserted back into the ATR NEFT location during the outage of ATR Cycle 154A on April 26, 2013 after its removal during ATR Cycle 153A. However, Figure 39 shows that only after April 29, 2013, 08:50 the gas flow records seemed to be responsive to actual flow measurement. Therefore, gas flow rates recorded before April 29, 2013, 08:50 are not the actual (or meaningful) measurements from capsules and should be disqualified.

DRC Recommendation: Delete all gas flow data recorded during period between January 20, 2013 at 10:00 and April 29, 2013 at 08:50 (ATR Cycle 154A) because the test train was removed from the reactor core.

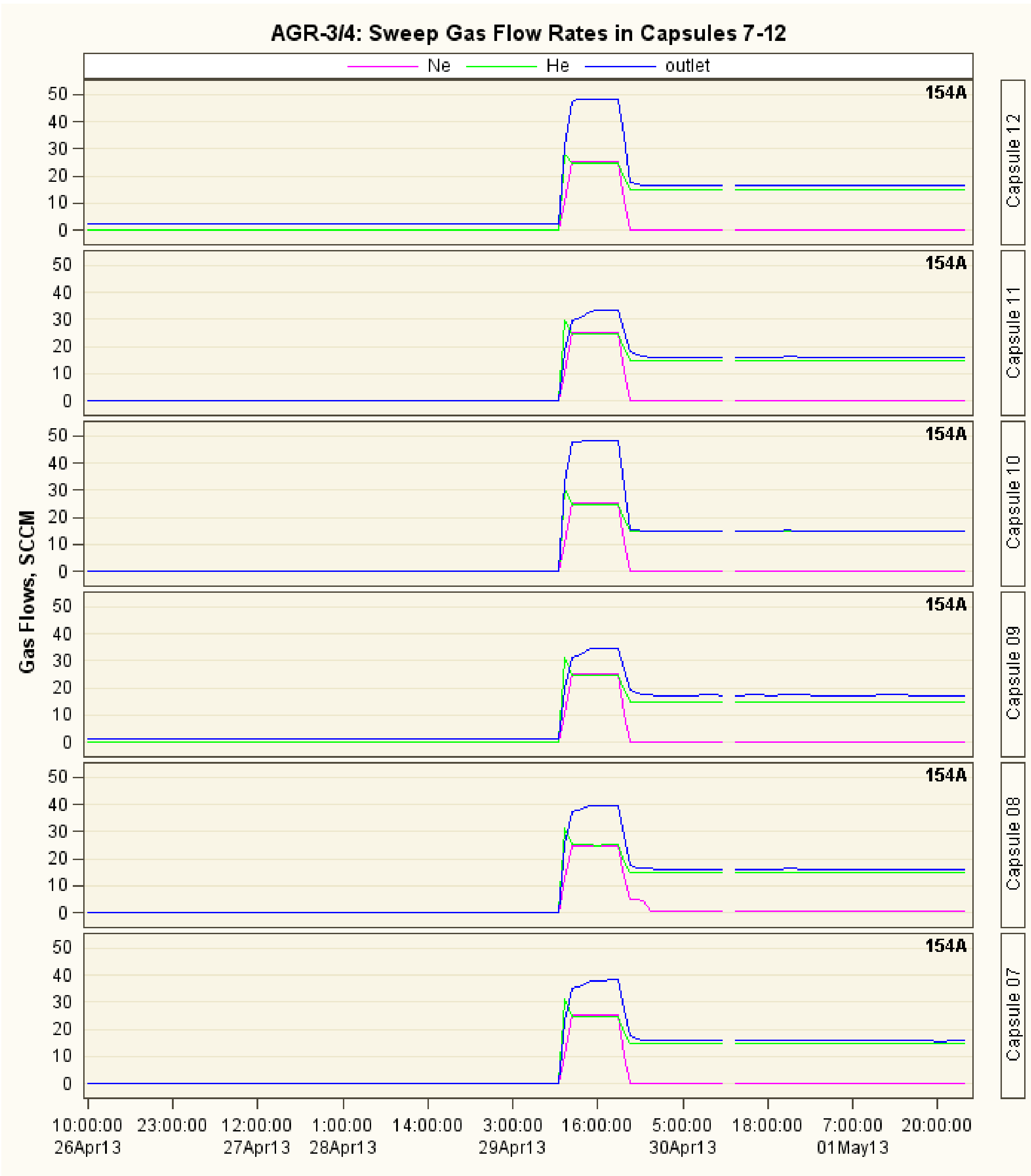


Figure 39. Capsules 7 - 12 gas flow rates around the time when AGR-3/4 inserted back to ATR core.

3.3.2 Sweep Gas Flow Data Analysis for Neon Fraction Calculation

As designed, the variation of neon fraction in the sweep gas mixture is used to maintain target fuel temperature. So the accuracy of calculated neon fraction is critical for the capsule thermal model to correctly predict test fuel temperature. This section examines the actual neon/helium gas flow rates passing through each capsule taking into account portion from the leadout flow and measurement bias of the outlet flow meter. For each AGR-3/4 capsule, the inlet flow consists of neon, helium, and impure gas (for Capsules 7 – 12) administered by individual mass flow controllers. When ATR is at full power, the Irradiation Test Vehicle controller delivers at a flow rate of 30 sccm of combined neon and helium and an additional controller delivers 0.5 sccm of impure gas whenever needed to the selected capsule (currently to Capsule 11). In addition to the inlet flows, an unknown portion of the flow in the leadout might also pass through a capsule. The total flow at the capsule outlet is measured by a flow meter. The gas flow rate in the leadout is usually maintained at the same level (12 sccm for ATR Cycles 151A through 154B) and the leadout gas can be pure helium, or pure neon, or a mix of neon/helium. Ideally, the total outlet flow in one capsule exactly equals the sum of all inlet flows (Eq. 1) as in Eq. 2:

$$Q_{inlet} = Q_{Ne} + Q_{He} + Q_{contam} \quad (1)$$

$$Q_{outlet} = Q_{inlet} + Q_{lo_{portion}} = Q_{Ne} + Q_{He} + Q_{contam} + Q_{lo_{portion}} \quad (2)$$

where Q are the gas flow rates in (sccm) unit: outlet, inlet, neon, helium, impure, and portion of leadout gas flows. Thus, the unknown portion of the leadout flow passing through capsule can be expressed as:

$$Q_{lo_{portion}} = Q_{outlet} - Q_{inlet} = Q_{outlet} - (Q_{Ne} + Q_{He} + Q_{contam}) \quad (3)$$

However, Figure 40 shows that the total outlet flows (blue line) are consistently lower than the sum of inlet flows from the 12 capsules and the leadout (red line) indicating some measurement biases of the outlet flows because the total inlet flows are maintained stable at 30 sccm for all 12 capsules. The possible existence of the outlet flow measurement bias prevents exact determination of that portion of leadout gas flows passing through each capsule using Eq. 3, which is needed in capsule neon fraction calculation. Thus a series of two tests were performed to experimentally determine the amounts of the leadout flow passing through each capsule and the bias of outlet flow measurement.

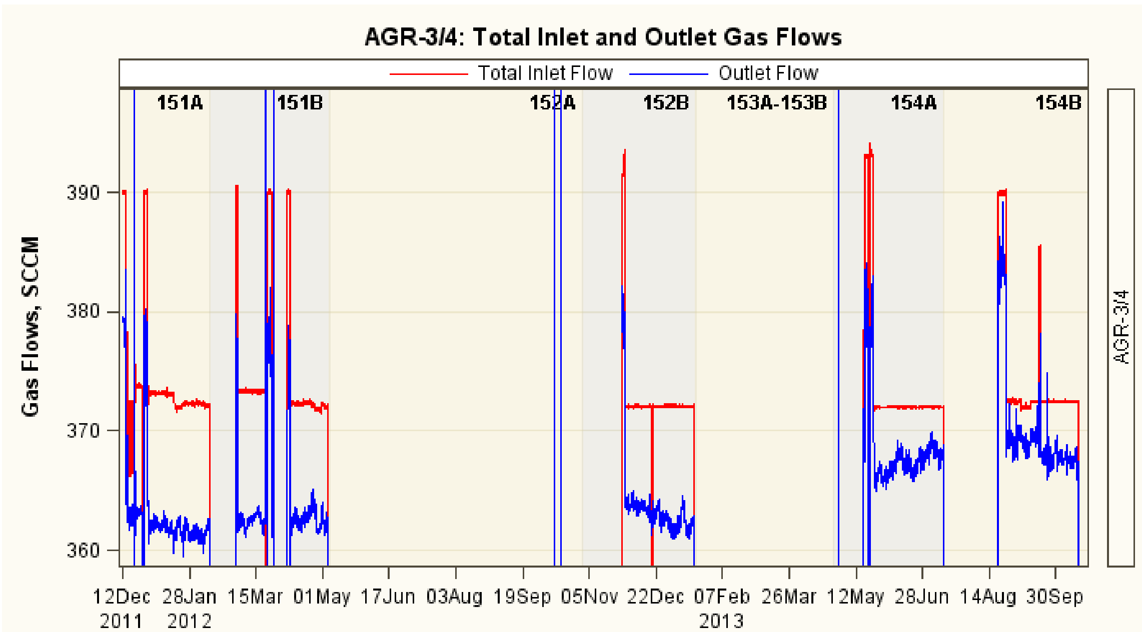


Figure 40. Total inlet and outlet gas flows of the whole AGR-3/4 test train.

3.3.2.1 Leadout flow tests

Two leadout flow tests were performed in September and December 2013 to determine the amount of leadout flow passing through each of the 12 capsules. During these tests, the flow rate in the leadout was increased to double its normal rate while maintaining the same levels of inlet flows in all capsules. In the first test in September, the leadout flow was increased from 12 to 24 sccm for 24 hours, and in the second test in December the leadout flow was increased from 20 to 40 sccm for 48 hours. As a result, the outlet flows in 8 out of 12 capsules increased as shown in Figure 41 (plot of the differences between inlet and outlet flow rates).

Amounts of the leadout flow passing through AGR-3/4 capsules.

Table 8 shows the estimated amount of the leadout flow passing through each capsule equal to the increase in outlet flow when the leadout flow increased from 20 sccm to 40 sccm (Eq. 3) as example.

Outlet flow measurement bias

After the amount of the leadout flow portion is experimentally determined, the biases of the outlet flows relative to their inlet flows can be calculated as equal to the difference between inlet including leadout portion and outlet flow. The outlet measurement bias relative to inlet is calculated as:

$$B_{outlet} = Q_{outlet} - (Q_{inlet} + Q_{lo_{portion}}) \qquad (4)$$

Only three capsules (2, 7, and 12) had significant outlet measurement bias (~ 2 sccm).

Table 8. Summary of the leadout flow portions and the outlet flow measurement biases for all capsules.

Capsule	1	2	3	4	5	6	7	8	9	10	11	12
Portion of leadout flow (sccm)	0	0	0.5	0.5	0.5	8.5	1	0.5	1.5	0	1.5	0
Outlet bias relative to inlet (sccm)	0	-2	0	~0	0	0	-2	0	~0	0	0	+2

3.3.2.2 Neon fractions for AGR-3/4 capsules including portion of leadout flow

According to Table 8, the twelve AGR-3/4 capsules can be divided into three categories: (1) capsule with added flow from the leadout and significant outlet measurement bias, which is Capsule 7 with -2 sccm outlet flow bias (purple column); (2) capsules with added flow from the leadout but negligible outlet measurement bias, which are Capsules 3, 4, 5, 6, 8, 9, and 11 (black columns); and (3) tight capsule (0 sccm portion of leadout flow), which are Capsule 1, 2, 10, and 12 (red columns). Neon fraction (Fr_{Ne}) formula for each category is expressed as:

- For Category 1, capsule with added flow from the leadout and outlet measurement bias:

$$Fr_{Ne} = \frac{Q_{Ne} + (Q_{outlet} - B_{outlet} - Q_{inlet}) * \frac{Q_{Ne\ leadout}}{Q_{Ne+He\ leadout}}}{Q_{outlet} - B_{outlet}} \qquad (5)$$

- For Category 2, capsules with added flow from leadout but negligible outlet measurement bias ($B_{outlet} = 0$):

$$Fr_{Ne} = \frac{Q_{Ne} + (Q_{outlet} - Q_{inlet}) * \frac{Q_{Ne\ leadout}}{Q_{Ne+He\ leadout}}}{Q_{outlet}} \qquad (6)$$

- For Category 3, tight capsules ($Q_{lo_{portion}} = 0$), neon fraction is equal to inlet neon fraction:

$$Fr_{Ne} = \frac{Q_{Ne}}{Q_{inlet}} \qquad (7)$$

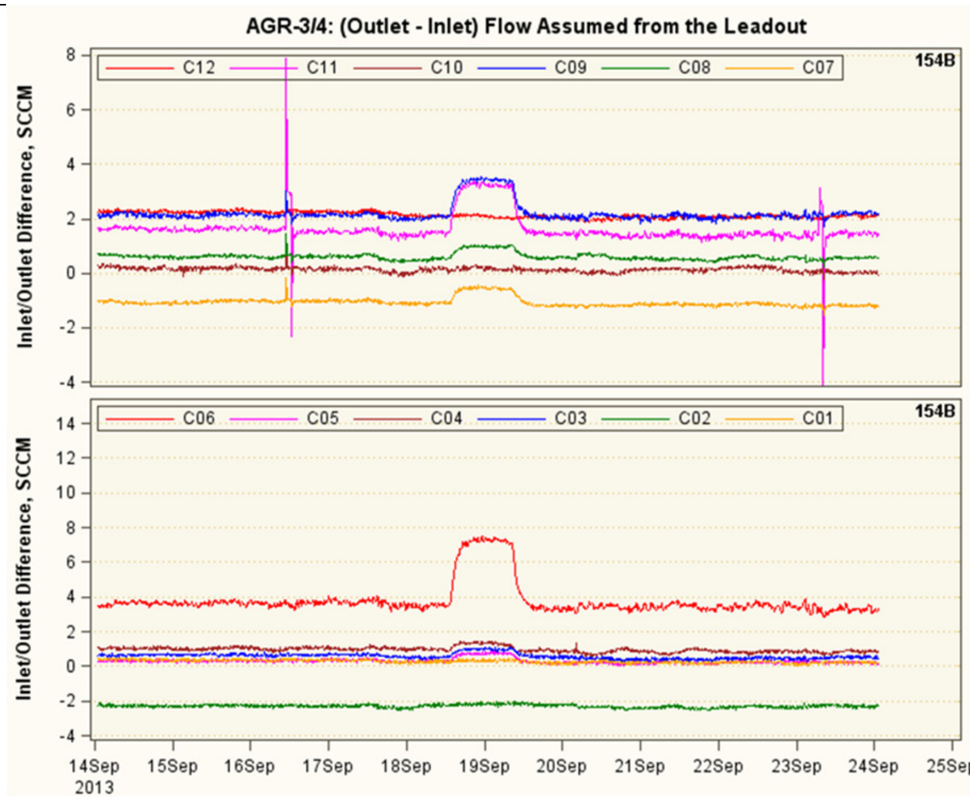
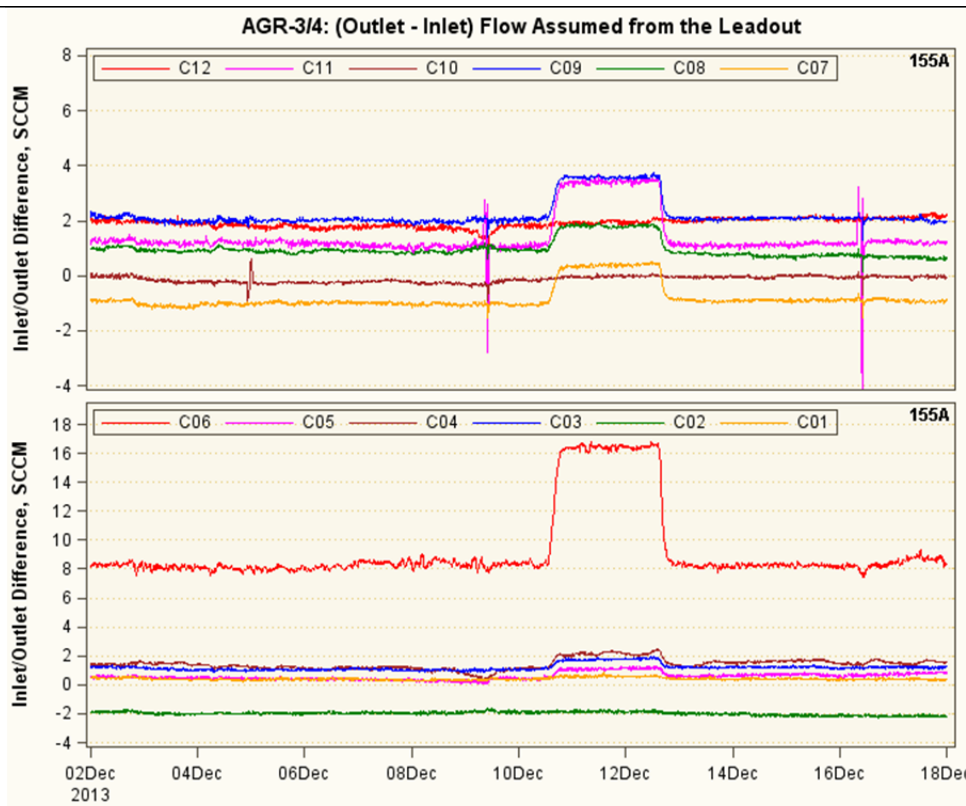
ATR Cycle 154B: September 19-20, 2013 **Leadout flow increased from 12 to 24 sccm**	
ATR Cycle 155A: December 11-13, 2013 **Leadout flow increased from 20 to 40 sccm**	

Figure 41. Differences between outlet and inlet flows increased in response to the leadout flow increase.

4. DATA RECORD QUALIFICATION SUMMARY

This section summarizes the data qualification decisions made by the DRC for the AGR-3/4 irradiation data received by NDMAS from December 12, 2012 (start of ATR Cycle 151A) through October 16, 2013 (end of ATR Cycle 154B). Detailed information on the data and the technical basis for data record qualification can be found in Sections 2 and 3.

4.1 Irradiation Monitoring Data

From the beginning of ATR Cycle 152A, the new automatic data transfer from the CDCS provides NDMAS with 1-minute instantaneous irradiation monitoring data every 2 hours instead of the weekly 5-minute averaged data provided during earlier cycles (ATR Cycles 151A and 151B). The new data delivery method provides NDMAS with significantly more irradiation data and, therefore, requires implementation of a more flexible data structure and online database testing.

4.1.1 Data Qualification Results

This section presents qualification statuses of irradiation data as the result of NDMAS database online testing and analysis. Except for a few missing values, there are no *Failed* gas pressure or moisture measurements. Therefore, results of the database testing presented in the following subsections are only for TC readings and sweep gas flow measurements.

4.1.1.1 TC Readings

Table 9 lists the number of TC records failed based on the DRC decisions resulting from the database testing and analysis as described in Section 3.2. There are 16,448 missing records from operational TCs that are counted as *Failed missing* records. The majority of failed TC records were due to the three TC failures within this reporting period as described in Section 3.2.1 and the irrelevant TC records at the beginning of ATR Cycle 154A. There are only 31 *Failed negative* TC readings and no TC readings exceeded the upper limit of 1400 °C during this time. In total, there were 940,233 *Failed* TC records (8.0% of the total TC records).

Table 9. Summary of TC reading failures during ATR Cycles 151A through 154B.

		No. of Failed Records							
ATR Cycle	Total # Records	Negative	Missing	TC Failures	Irrelevant	Total Failed	% Failed	% Qualified	Notes
151A	474,687	0	0	0	0	0	0.0%	100%	
151B	635,337	26	19	0	0	45	0.0%	100%	
152A	2,515,455	5	15,252	0	0	15,257	0.6%	99.4%	
152B	2,068,686	0	61	0	0	61	0.0%	100%	
154A	2,868,987	0	1,116	190,703	486,564	678,383	23.6%	76.4%	a,c
154B	3,157,873	0	0	246,487	0	246,487	7.8%	92.2%	a,b
Total =	**11,721,025**	**31**	**16,448**	**437,190**	**486,564**	**940,233**	**8.0%**	**92.0%**	

a. ATR Cycles 154A TC failures: C2 TC2 (starting 2013-04-26 08:45) and C3 TC1 (starting 2013-05-17 03:15).
b. ATR Cycles 154B TC failure: C3 TC2 (starting 2013-10-09 12:15).
c. ATR Cycle 154A: total number of failed data included 486,564 irrelevant TC records, which will be deleted from NDMAS database.

The decisions of the DRC meeting on February 12, 2014, on qualification statuses of TC readings during this reporting period are summarized as:

1. Delete all TC readings recorded between January 20, 2013, at 10:00 and April 29, 2013, at 23:59 due to irrelevant values
2. Fail 16,448 missing and 31 negative TC records
3. Confirm three TC failures: TC2 in Capsule 2 (starting 2013-04-26 08:45), TC1 in Capsule 3 (starting 2013-05-17 03:15), and TC2 in Capsule 3 (starting 2013-10-09 12:15)
4. Confirmed TC3 in Capsule 10 drifted starting from the middle of ATR Cycle 154B and its readings are *Trend* data after September 20, 2013.

4.1.1.2 Sweep Gas Data

Table 10 lists the number of gas flow records failed from the database testing as described in Section 2.3.4 for neon, helium, and outlet flow rates. The percentage of *Failed* gas flow records is unexpectedly high for the low power cycle (152A). During this cycle, AGR-3/4 was run on pure helium; therefore, the neon flow responses should be zero or close to zero. However, there are 1,988,716 sweep gas flow records (11.0% of the total gas flow records) that were *Failed* due to negative values or missing values.

Table 10. Summary of neon, helium, impure, and outlet gas flow rates failures during ATR Cycles 151A through 154B.

		No. of Failed Records						
			No. of out-of-range					
ATR Cycle	Total # Records	Missing	Negative	Too high[a]	Irrelevan[b]	Total of Failed[c]	% Failed	% Qualified
151A	773,564	0	0	0	0	0	0.0%	100.0%
151B	1,038,048	20,588	0	2	0	20,588	2.0%	98.0%
152A	4,099,304	1,057,295	0	274	0	1,057,295	25.8%	74.2%
152B	3,095,924	198,531	0	0	0	198,531	6.4%	93.6%
154A	4,147,586	894	0	0	711,132	712,026	17.2%	82.8%
154B	4,988,360	0	0	0	0	0	0.0%	100.0%
Total =	**18,142,786**	**1,277,308**	**0**	**276**	**711,132**	**1,988,716**	**11.0%**	**89.0%**

a. 276 "too high" gas flow rates are *Trend* records.

b. All irrelevant data will be deleted from NDMAS database.

c. Failed gas flow data do not include 276 "too high" *Trend* gas flow rates and 800,420 slightly negative flow rates recommended to be replaced with 0 sccm.

The decisions of the DRC meeting on February 12, 2014, on qualification statuses of sweep gas flow rates are summarized as:

1. Delete all sweep gas flow rates recorded between January 20, 2013 at 10:00 and April 29, 2013 at 23:59 due to irrelevant values because AGR-3/4 was outside the reactor core
2. Qualify and replace 800,420 slightly negative sweep gas flow rates with 0 sccm
3. Trend 276 "too high" sweep gas flow rates

4. Fill-in missing neon flow records in Capsules 7 and 8 for the period November 27, 2013 12:00 to November 29, 2013 22:35 (152B) with whatever is higher of 0 sccm or differences between 30 sccm and helium flow rate as stated in Section 3.3.1.2.
5. Fail all the remaining missing records.

4.1.2 Data Qualification Summary

NDMAS received a total of 29,863,811 irradiation monitoring data records for the six ATR cycles evaluated in this report (Table 11). Of these data, 90.2% met the requirements for *Qualified* data and 9.8% were *Failed* data. For TC readings, there were 940,233 TC records (8.0% of the total TC records) that were *Failed* mostly because of TC instrument failures (see Section 3.2.1 for details).). For sweep gas flow rates, there were 1,988,716 gas flow records (11.0% of the total gas flow records) that were *Failed* mostly because of the missing values. The DRC recommended that all irrelevant AGR-3/4 irradiation data recorded during periods January 20, 2013, at 10:10 (2 days after 152B power-down) to April 26, 2013, at 23:59 (when AGR-3/4 inserted back to ATR core) are *Failed* (or deleted) because the test train was removed from the reactor core. They include gas flow rates, TC readings, inlet gas moisture, and pressures. All the pressure and moisture (humidity) sweep gas data were classified as *Qualified* by the DRC.

Table 11. Summary of the qualification status of the irradiation monitoring data (TC temperature and sweep gas flow rate) received by NDMAS during Cycles 151A, 151B, 152A, 152B, 154A, and 154B.

ATR Cycle	Record Start	Total # Records	No. of Failed Records		% Failed	% Qualified	Notes
			TC	Gas Flow[c]			
151A	12DEC11:01:00	1,248,251	0	0	0.00%	100.00%	
151B	11FEB12:11:00	1,673,385	45	20,590	1.23%	98.77%	
152A	05MAY12:15:00	6,614,759	15,257	1,057,569	16.22%	83.78%	
152B	30OCT12:00:30	5,164,610	61	198,531	3.85%	96.15%	
154A	26APR13:23:59	7,016,573	678,383	712,026	19.82%	80.18%	a,d
154B	13JUL13:09:30	8,146,233	246,487	0	3.03%	96.97%	a,b
	Total =	**29,863,811**	**940,233**	**1,988,716**	**9.81%**	**90.19%**	

a. Cycles 154A TC failures: C2_TC2 (starting 2013-04-26 08:45), C3_TC1 (starting 2013-05-17 03:15).
b. Cycles 154B TC failure: C3_TC1 (starting 2013-10-09 12:15).
c. Failed gas flow data do not include 800,420 slightly negative flow rates
d. At the beginning of ATR Cycle 154A: 1,197,696 irrelevant TC and gas flow records

4.2 FPMS Data

As of this report publication, NDMAS has received and processed into its database preliminary release rate and R/B data for reactor Cycles 151A, 151B, 152B, 154A, and 154B (see

Figure 13 through Figure 15). This consists of 196,512 (nominal 8-hour) release rate records and 196,512 R/B records for 12 reported radionuclides (Kr-85m, Kr-87, Kr-88, Kr-89, Kr-90, Xe-131m, Xe-133, Xe-135, Xe-135m, Xe-137, Xe-138, and Xe-139). All these data have been capture passed, stored in the NDMAS database, and made available on the NDMAS Web portal (see

Figure 13 through Figure 15). The qualification status of these data has been set to *In Process* until appropriate documentation is received from the data generator.

5. DATA ACCESS

The irradiation monitoring data and data qualification status are available on the NDMAS Web portal (http://ndmas.inl.gov) for secure access by VHTR TDO Program participants as shown in Figure 42. The website is organized by experiment (e.g., AGR-3/4) and data stream (e.g., IRR for irradiation data). These Web pages (blue bar on left in Figure 42) have multiple portlets with different data type content, including plots and tabular data that can be interactively queried (e.g., sorted or filtered by capsule or date) or expanded ("drill-down") by date. The tabular data (_DATA reports below) can be downloaded to a .csv file or opened directly in Excel.

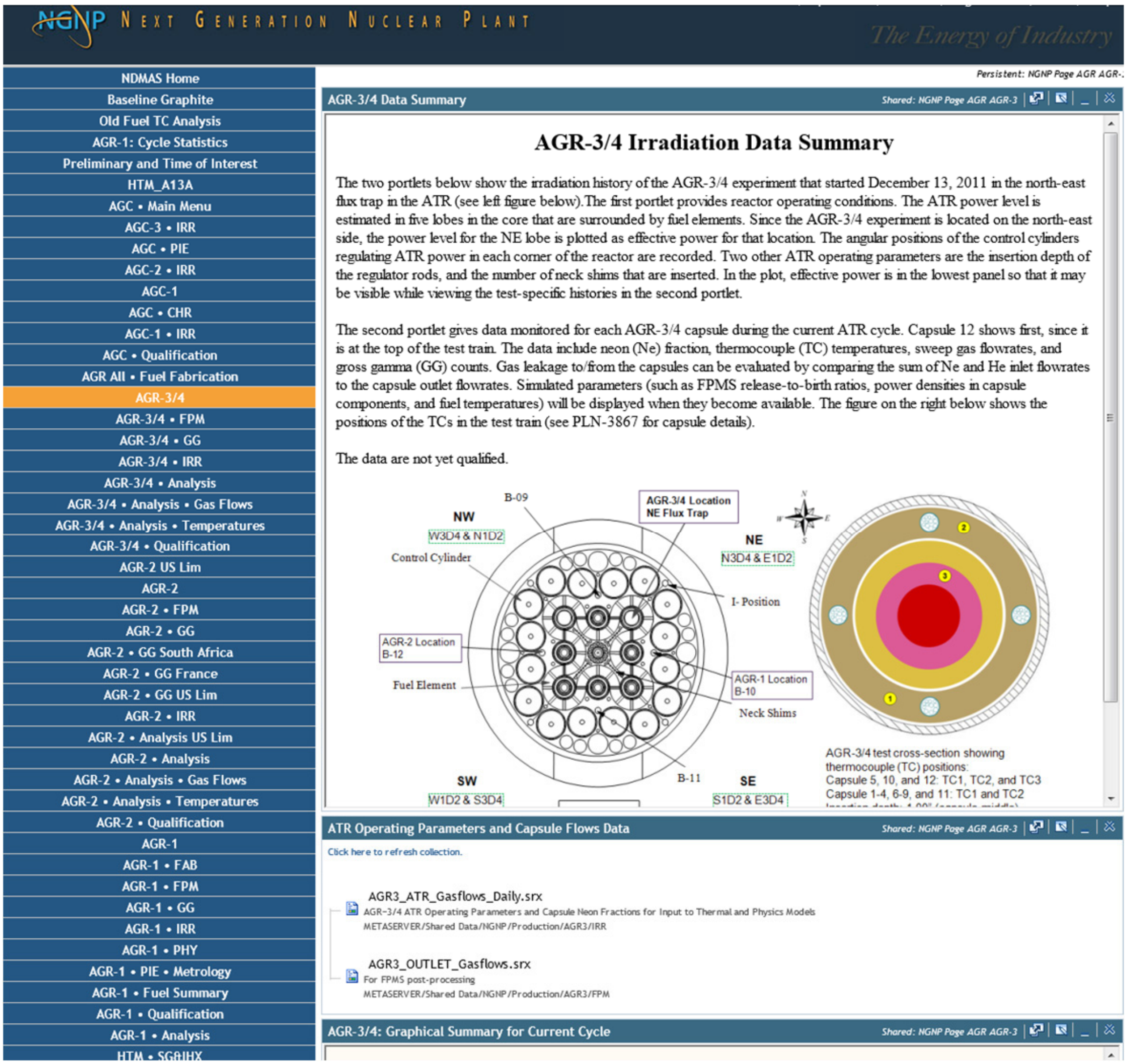


Figure 42. The AGR-3/4 Web page (in blue bar on left) on the NDMAS Web portal provides access to numerous types of data reports, graphs, and images.

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APPENDIX A

Credentials of Technical Reviewer

Credentials for Blaise Collin

Blaise Collin is a senior nuclear physicist and engineer with more than 10 years of experience in modeling, simulation, and data analysis. His past fields of interest and expertise include intermediate energy nuclear physics, particle astrophysics, neutronics and nuclear reactor core physics. His current focus is on the modeling and assessment of TRISO fuel performance, especially for its use in the AGR experiments. In his different activities, he performed experimental modeling, ran simulations, and analyzed the subsequent results and output data. As a member of the AGR Fuel Development and Qualification Program team, he has a sound knowledge of the AGR-3/4 experiment, for which he wrote the Irradiation Experiment Test Plan.