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AGR-2 Final Data Qualification Report for U.S. Capsules - ATR Cycles 147A through 154B

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July 2014

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SUMMARY

This report provides the data qualification status of Advanced Gas Reactor-2 (AGR-2) fuel irradiation experimental data in four U.S. capsules from all 15 Advanced Test Reactor (ATR) Cycles 147A, 148A, 148B, 149A, 149B, 150A, 150B, 151A, 151B, 152A, 152B, 153A, 153B, 154A, and 154B, as recorded in the Nuclear Data Management and Analysis System (NDMAS). Thus, this report covers data qualification status for the entire AGR-2 irradiation and will replace four previously issued AGR-2 data qualification reports (i.e., INL/EXT-11-22798, INL/EXT-12-26184, INL/EXT-13-29701, and INL/EXT-13-30750). During AGR-2 irradiation, two cycles, 152A and 153A, occurred when the ATR core was briefly at low power; therefore, irradiation data from these two cycles are not used for physics and thermal calculations. Also, two cycles, 150A and 153B, are Power Axial Locator Mechanism (PALM) cycles, which is when the ATR power is higher than during normal cycles. During the first PALM cycle, 150A, the experiment was temporarily moved from the B-12 location to the ATR water canal, and during the second PALM cycle, 153B, the experiment was temporarily moved from the B-12 location to the I-24 location to avoid being overheated. During "Outage" Cycle 153A, seven flow meters were installed downstream from seven Fission Product Monitoring System (FPMS) monitors to measure flows from the monitors; these data are included in the NDMAS database.

The AGR-2 data streams addressed in this report include thermocouple (TC) temperatures, sweep gas data (flow rates, including new fission product monitoring downstream flows, pressure, and moisture content), and FPMS data (release rates and release-to-birth rate ratios) for each of the four U.S. capsules in the AGR-2 experiment (Capsules 2, 3, 5, and 6). The final data qualification status for these data streams is determined by a Data Review Committee comprised of AGR technical leads, Very High-Temperature Reactor Program Quality Assurance, and NDMAS analysts. The Data Review Committee, which convened just before each data qualification report was issued, reviewed the data acquisition process, considered whether the data met the requirements for data collection as specified in quality assurance approved very high-temperature reactor data collection plans, examined the results of NDMAS data testing and statistical analyses, and confirmed the qualification status of the data as given in each report. This report serves the following purposes: (1) combines existing qualification status of all AGR-2 data; (2) provides an FPMS data qualification update and new release-to-birth ratio data calculated using daily calculated birthrates; and (3) revises data qualification status of TC readings for some TCs in Capsule 6 based on their differences relative to calculated temperatures at TC locations.

A total of 17,001,695 TC temperature and sweep gas data records were received and processed by NDMAS for the four U.S. capsules during AGR-2 irradiation. Of these records, 9,655,474 (56.8% of the total) were determined to be *Qualified;* 5,792,052 (34.1% of the total) were determined to be *Failed;* and 1,554,169 (9.1% of the total) were determined to be *Trend*. For the first nine cycles, from ATR Cycle 147A to 151B, data records are 5-minute or 10-minute averaged values provided on a weekly basis in EXCEL spreadsheets. For the last six cycles, ATR Cycle 152A through 154B, data records are instantaneous measurements recorded every minute and provided by *.csv* text files automatically every 2 hours. Therefore, the number of processed irradiation data increased substantially from ATR Cycle 152A on.

For TC temperature data, there were 6,857,675 records and of these data 5,288,249 records (77.1% of the total TC data) were *Failed* due to TC instrument failures and 418,569 records (6.1% of the total TC data) were *Trend* due to large differences between TC readings and calculated values. By the end of Cycle 154A, all TCs in the AGR-2 test train failed. The overall percentage of *Failed* TC records is high, to some extent, because TCs failed toward the end of AGR-2 irradiation when the recording frequency was much higher.

For sweep gas data, there were 10,144,020 gas flow records and of these data records only 503,803 gas flow records (5.0% of the gas flow data) were *Failed* and 1,135,600 gas flow records (11.2% of the gas flow data) were *Trend.* The *Failed* gas flow records are mostly missing values and when the number

was reduced by repairing some missing and negative neon and helium flow rates. *Trend* flow rate records are the fission product monitoring flow rates during ATR Cycles 153A and 153B. Because of capsule gas cross-talk and leakage problems that occurred after Cycle 150A, a procedure was implemented by AGR-2 operations staff on January 17, 2012, (Cycle 151A) that used uniform neon fraction of gas mixtures in all six capsules and the leadout so the capsules' actual gas mixture can be accurately defined. Use of the capsule outlet gas flow data in calculating FPMS release rate and release-to-birth ratio data after Cycle 150A should take into account the possibilities of fission product cross-talk between capsules. The downstream flow meters help in detection of the capsule relief valves lifting.

For FPMS data, NDMAS received and processed release and release-to-birth ratio data for all "full power" reactor cycles. This data consists of 190,416 release rate records and 190,416 release-to-birth ratio records for the 12 radionuclides reported. The release-to-birth ratio data are calculated using the isotope daily birthrates. According to FPMS data qualification status reported in ECAR-2420 (Scates 2014), due to the relief valve failure during Cycles 149A and 149B and the capsule flow cross-talk failure that began during Cycle 150B, the FPMS data will not be *Qualified* after the end of Cycle 148B. However, the data still provide useful information for identifying particle failures and performing additional analyses and will be flagged as *Trend.*

All of 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 Very High-Temperature Reactor Program participants.

CONTENTS

FIGURES

TABLES

ACRONYMS

AGR	advanced gas reactor
ATR	Advanced Test Reactor
CDCS	Capsule Distributed Control System
CRADA	Cooperative Research and Development Agreement
DRC	Data Review Committee
ECAR	engineering calculations and analysis report
EFPD	effective full power days
FPM	fission production monitoring
FPMS	Fission Production Monitoring System
INL	Idaho National Laboratory
NDMAS	Nuclear Data Management and Analysis System
PALM	powered axial locator mechanism
QA	quality assurance
R/B	release-rate-to-birth-rate ratio
RDAS	Reactor Data Acquisition System
TC	thermocouple
TFR	technical and functional requirements
VHTR	very high-temperature reactor

AGR-2 Final Data Qualification Report for U.S. Capsules – ATR Cycles 147A through 154B

1. INTRODUCTION

This report presents the data qualification status of fuel irradiation monitoring data from the Advanced Gas Reactor-2 (AGR-2) experiment conducted in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL). AGR-2 is the second 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. The experiment is intended to demonstrate performance of U.S. TRISO fuel particles containing UCO (uranium oxycarbide) and UO_2 (uranium dioxide) fuel produced in a large (i.e., 6-inch) coater.

AGR-2 irradiation was first at full power on June 23, 2010 (ATR Cycle 147A), and completed irradiation when it was removed from ATR in October 2013 (outage of ATR Cycle 155A), which resulted in 559.2 effective full power days (EFPDs) during approximately 3.3 calendar years. Qualification of data from all AGR-2 cycles was presented in four previously issued AGR-2 data qualification reports (i.e., INL/EXT-11-22798, INL/EXT-12-26184, INL/EXT-13-29701, and INL/EXT-13-30750). However, in order to address some data updates arising after completion of the last AGR-2 data qualification report, this AGR-2 final data qualification report is necessary to (1) combine qualification status of all AGR-2 irradiation data in one place for easy reference; (2) provide update to Fission Production Monitoring System (FPMS) data qualification and new release-to-birth rate ratio (R/B) data calculated using daily calculated birthrates; and (3) revise data qualification status of thermocouple (TC) readings for one TC in Capsule 6 based on the differences between measured and calculated temperatures at TC locations.

AGR-2 irradiation lasted for a total of fifteen ATR cycles, including eleven normal cycles, two Power Axial Locator Mechanism (PALM) cycles, one low power cycle, and one unplanned outage cycle. The ATR Cycles 150A and 153B are the PALM cycles when the ATR power is substantially higher than during normal cycles. During the first PALM cycle, 150A, the experiment was temporarily moved from the B-12 location to the ATR water canal, and during the second PALM cycle, 153B, the experiment was temporarily moved from the B-12 location to the I-24 location (next to the northwest lobe) to prevent overheating of fuel compacts. During the lower power cycle, 152A, and unplanned outage cycle, 153A, the ATR core raised up to low power for a short time. For Cycle 152A, the averaged effective power is 0.209 MW for 89.6 hours and for Cycle 153A, the average effective power is 1.082 MW for only 0.25 hours. During this time, the experiment was run on pure helium for both capsule and leadout gas flows. These two cycles can be considered as extended power outages for the test fuel depletion calculation and thermal analysis. Subsequently, AGR-2 irradiation data during this time are not used for physics and thermal calculations.

All aspects of AGR-2 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 server database, performs testing on and analysis of the data for identification of anomalies, presents the data via an access-controlled web portal, and documents the qualification status of the data. The data examined in this report cover the period from June 19, 2010, through October 23, 2013.

1.1 Purpose and Scope

The AGR-2 fuel irradiation monitoring data streams examined in this report include capsule TC temperatures, sweep gas measurements (i.e., 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 NDMAS; (3) other QA-approved data reports submitted by data generators such as engineering calculations and analysis reports; and (4) whether the data support applications to the defined intended use (MCP-2691). 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 INL Electronic Data Management System.

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 entire AGR-2 data records received by NDMAS.

Fuel irradiation monitoring data reported herein include the following for each of the independently controlled and monitored capsules in the AGR-2 experiment:

- TC temperatures (two in each capsule except for Capsule 6, which has five)
- Sweep gas (i.e., helium, neon, outlet, and downstream) measurements (i.e., mass flow rates, pressure, and moisture content)
- Krypton and xenon radionuclide (12 isotopes) release rates measured by the FPMS and subsequently calculated krypton and xenon radionuclide R/Bs.

The basis for the qualification status of FPMS data is QA-approved ECAR-2420, which is submitted by the FPMS technical staff (Scates 2014). This ECAR provides 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. The FPMS data from ATR Cycle 149A are flagged as *Trend* due to the relief valve failures during ATR Cycles 149A and 149B and the fission product cross talk between capsules that started with ATR Cycle 150B. No similar ECARs exist for the TC and sweep gas data; therefore, 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-2 data streams stored in the NDMAS database: fuel fabrication data, thermal/neutronics simulation data, and post-irradiation examination data. All 4,395 records of AGR-2 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-2 thermal/neutronics simulation data are available for all cycles and the data status is qualified based on ECAR-2066 (Sterbentz 2014) for neutronics data and ECAR-2476 (Hawkes 2014) for thermal data. AGR-2 post-irradiation examination 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 the VHTR 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, VHTR Program QA performed an inspection of the ATR data acquisition systems and data collection processes (IAS121679, 2/10/2012). 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 Program. Additionally, 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, "Data Qualification."

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

- 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 QA 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 structured query language server (i.e., 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. In this instance with AGR-2, this includes secure limited data access to external research partners in France and South Africa.

All AGR-2 data currently being collected at INL are considered to be *Type A*, which are data obtained within an NQA-1 QA program that must meet the 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 an equivalent QA Program. Any non-conformances 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 an 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 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-1064).

2. AGR–2 EXPERIMENT

The primary objectives of the AGR-2 experiment are defined in PLN-3636, "Technical Program Plan for the Next Generation Nuclear Plant/Advanced Gas Reactor Fuel Development and Qualification Program," and a detailed description of the experiment is provided in PLN-3798, "AGR-2 Irradiation Experiment Test Plan." The AGR-2 was inserted into the large B-12 location of the ATR core in June 2010 (as shown in Figure 1). AGR-2 is comprised of six individual capsules, approximately 3.49 cm diameter and 15.24 cm long, stacked on top of each other to form the test train. 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. Each AGR-2 capsule contains only one type of TRISO-coated fuel particles. U.S. UCO fuel particles are in Capsules 2, 5, and 6; U.S. UO_2 fuel particles are in Capsule 3; French UO_2 fuel particles are in Capsule 1; and South African UO_2 fuel particles are in Capsule 4. These assignments are listed in Table 1, where the capsules are numbered consecutively from the bottom (Capsule 1) to the top (Capsule 6). The French and South African capsule data are not presented or discussed in this report because of Cooperative Research and Development Agreement (CRADA) restrictions.

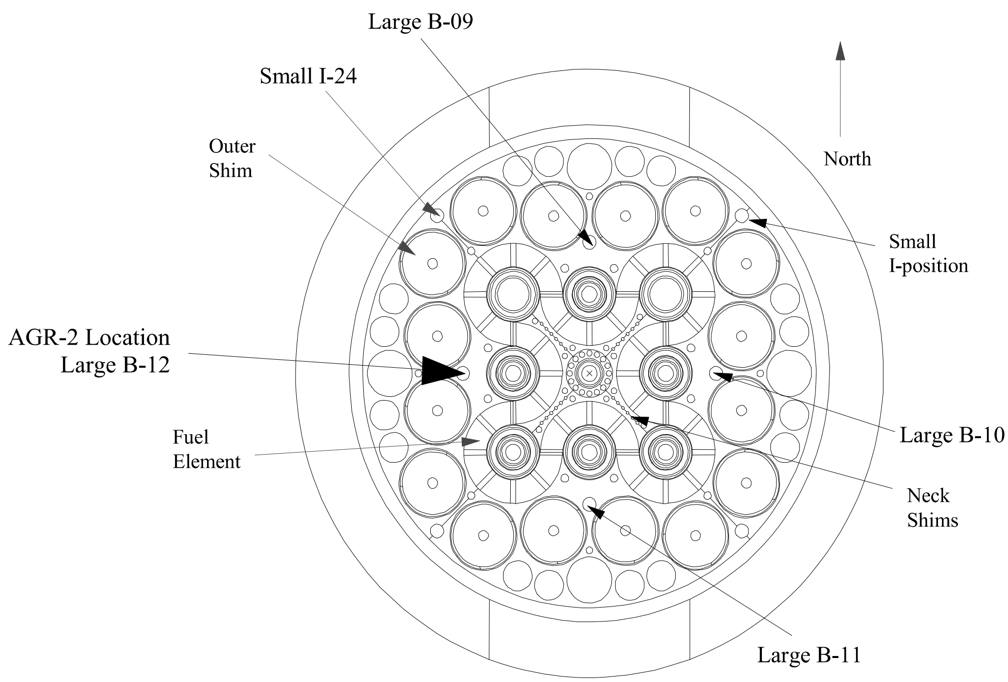

Figure 1. AGR-2 location in the ATR core cross section.

Table 1. Fuel types in the six AGR-2 capsules (PLN-3798).

Location	Coated Particle Composite	Fuel Designation
Capsule 6 (top)	G73J-14-93073A	UCO
Capsule 5	G73J-14-93073A	UCO
Capsule 4	—	South African UO_2
Capsule 3	G73H-10-93085B	UO_2
Capsule 2	G73J-14-93073A	UCO
Capsule 1 (bottom)	—	French UO_2

A total of 15 TCs are installed in the AGR-2 experiment; five TCs are located in Capsule 6 and two TCs in each of the remaining capsules (as shown in Figure 3). Each capsule has independently controlled helium and neon gas flows, which have different thermal conductivities to control capsule fuel temperatures by maintaining the control TC readings at the set point temperature. The mixed gas outlet lines transport any fission products released from the capsules to the corresponding FPMS detectors, which are capable of measuring fission product release activities of six krypton and six xenon isotopes and detecting individual in-pile fuel particle failures using gross gamma spectra.

Figure 2 shows the simplified flow path for AGR-2 sweep gas. Normally, gas mixtures from Capsules 1 through 6 flow to corresponding detectors 1 through 6 and 7 is a spare detector for replacement of a potentially failed detector. Because of the relief valve issues that occurred since Cycle 149A, seven additional gas flow meters were installed at the outlets of seven FPMS detectors to measure downstream gas flow rates from these detectors during Cycle 153A. These flow rates help determine actual flow rates through the FPMS detectors used for essential fission product release rate calculation. Ideally, the downstream flow rates are comparable to the capsule outlet flow rates measured at capsule outlets, indicating tightness of the gas lines from the capsules to FPMS detectors.

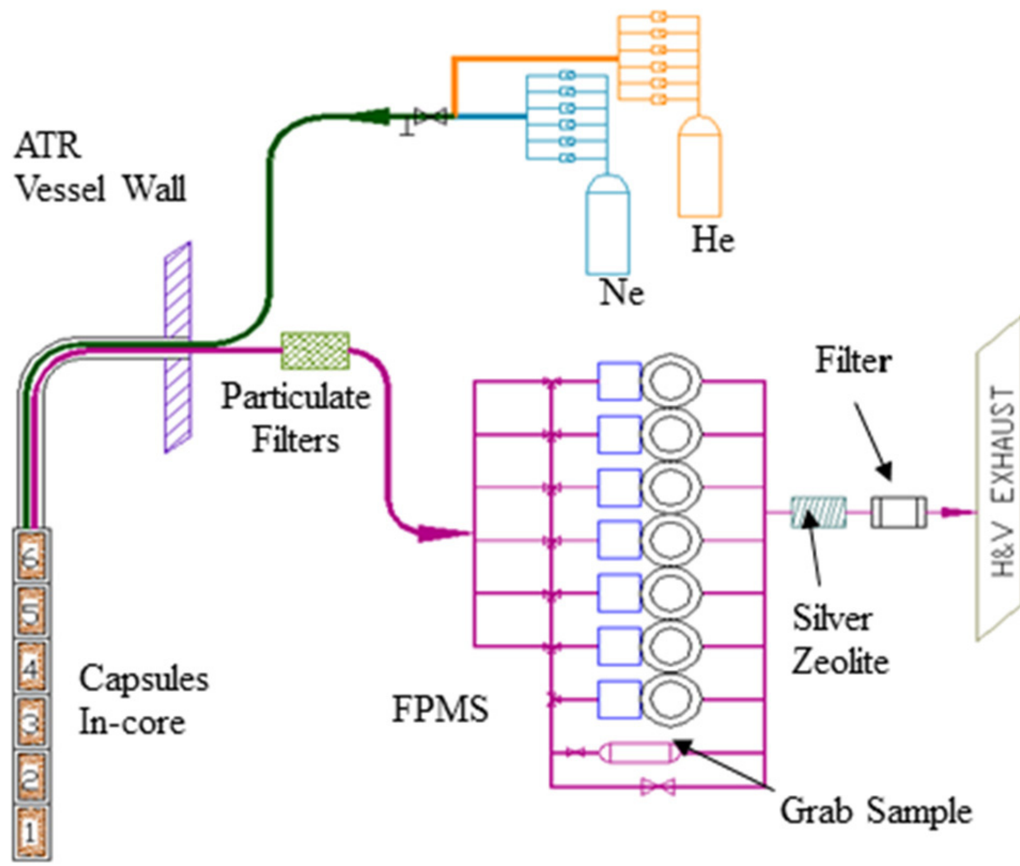

Figure 2. Simplified flow path for AGR-2 sweep gas.

The AGR-2 irradiation data streams covered in this report include TC temperatures, sweep gas data (flow rates, including new fission production monitoring [FPM] downstream flows, pressure, and moisture content), and FPMS data (release rates and R/Bs) for each of the four U.S. capsules (Capsules 2, 3, 5, and 6). By the end of Cycle 154A, all TCs in the AGR-2 test train failed, which will be described in detail in subsequent sections. Temperature data captured after TC failure date will be flagged as *Failed* records. Also, the gas relief valves for some capsules were lifted some time during ATR Cycles 149A and 149B and then the gas line cross-talk failure occurred during ATR Cycle 150B due to experiment handling during PALM Cycle 150A. These events lead to inaccurate fission product release rate calculation in all capsules; consequently, the FPMS data will be flagged as "*Trend*" records from Cycle 148A on.

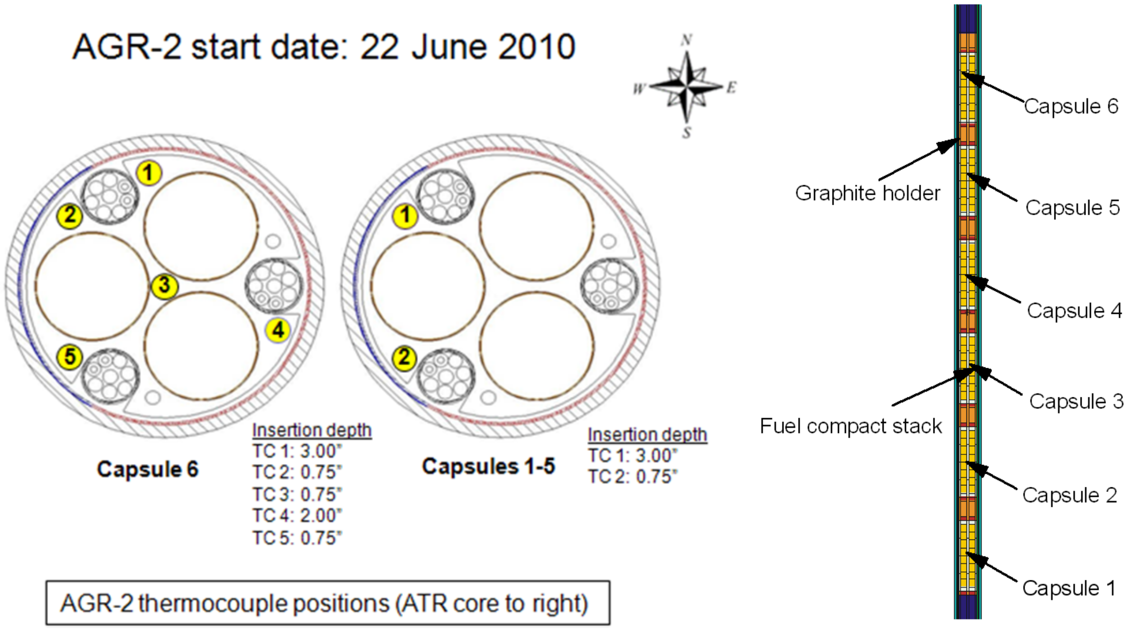

Figure 3. Radial (left) and axial (right) views of the AGR-2 capsules with TC locations (yellow circles).

2.1 Data Requirements

Requirements and specifications for the AGR-2 irradiation test are contained in TFR-559, "Requirements for the Design of the Advanced Gas Reactor Experiment AGR-2 for Irradiation in the ATR," SPC-1064, "AGR-2 Irradiation Test Specification," and TFR-248, "Temperature Control and Off Gas Monitoring Systems for Advanced Gas Reactor Experiment AGR-1." TFR-248 applies because the AGR-2 experiment is using the same temperature control and off-gas monitoring system as used in AGR-1. Since the start of Cycle 152A, the automated feed provides to NDMAS both ATR operating data (RDAS) and capsule irradiation data (CDCS for advanced graphite creep 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-2 experiment (e.g., TC temperatures; sweep gas flow rates, pressure, and moisture content; and FPMS data). They do not include requirements related to process or instrument parameters not reported to NDMAS (e.g., sweep gas purity), 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 post-irradiation activities (e.g., fast neutron fluence and burnup).

2.1.1 Temperature

The irradiation test condition requirements relating to fuel temperature are summarized below (SPC-1064). 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 holder temperatures outside the fuel compacts (see Figure 3) and are instantaneous measurements every 1 minute. The fuel temperature specification listed is as follows:

- The instantaneous peak fuel temperature for each capsule shall be ≤1800°C
- The time average peak fuel temperature shall be ≤1400°C for one capsule containing UCO fuel (Capsule 2), ≤1250°C for each remaining capsule containing UCO fuel (Capsules 5 and 6), and ≤1150°C for each capsule containing UO_2 fuel (e.g., Capsule 3)
- The time average, volume average fuel temperature goal is ≥1150°C for the highest temperature capsule containing UCO fuel, ≥1000°C for each remaining capsule containing UCO fuel, and ≥900°C for each capsule containing UO_2 fuel.

2.1.2 Sweep Gas

The irradiation test condition requirements relating to sweep gas (i.e., helium, neon, or combined outlet) are summarized as follows (SPC-1064, TFR-559, and TFR-248):

- The moisture content of inlet sweep gas on the inlet side of the capsule shall be <5 ppm H_2O, measured at least once after each gas cylinder change at a dew point of −100 ± 2.5°C (SPC-1064 and TFR-248).
- 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 parts-per-million (ppm; SPC-1064). 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).
- Gas flow rates will be ≤50 sccm (standard cubic centimeters per minute) at a pressure of about 15 psia or 0.103 MPa (PLN-3798).
- Test gas mixture maximum flow rate shall be between 50 and 100 sccm (Condition 1 Normal Operations; TFR-559).
- Failure of mass flow controller or computer (Condition 2 Fault; TFR-559):
  - 100% helium 0 to 100 sccm gas flow to 100% neon 0 to 100 sccm gas flow
  - TFR-559 states "Flow rates up to or exceeding 100 sccm (the maximum output of the controllers) will not adversely affect the heat transfer rate from the test or invalidate the analyses."
- Failure of pressure regulator (Condition 2 Fault; TFR-559):
  - 100% helium relief valve setting—90 psig
  - 100% neon relief valve setting—90 psig.

2.1.3 Fission Product Monitoring System

The irradiation test condition requirements relating to the FPMS are as follows (SPC-1064):

- Able to detect every individual particle failure from each capsule, up to and including the first 250 particle failures, and able to identify in which capsule each failure had occurred (operation requirement in SPC-1064).
- Transit time of sweep gas less than 25 minutes from each capsule to the FPMS (operation requirement in SPC-1064).
- Continuous measurements of total radiation level of the sweep gas from each capsule (measurement requirement in SPC-1064).
- At least daily measurements of concentrations of at least Kr-85m, Kr-87, Kr-88, Xe-131m, Xe-133, and Xe-135 in the sweep gas from each capsule. Optional isotopes to also measure include Kr-89, Kr-90, Xe-135m, Xe-137, Xe-138, and Xe-139 (measurement requirement in SPC-1064).

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 (two in each capsule, except for Capsule 6, which has five)
- Sweep gas measurements (i.e., mass flow rates [helium inlet, neon inlet, total outlet], 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 August 21, 2013, by a DRC comprised of AGR technical leads, VHTR 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 Project:

- 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-3798, "AGR-2 Irradiation Experiment Test Plan"
  - SPC-1064, "AGR-2 Irradiation Test Specification"
  - TFR-559, "Requirements for the Design of the Advanced Gas Reactor Experiment AGR-2 for Irradiation in the ATR"
  - TFR-248, "Temperature Control and Off Gas Monitoring Systems for Advanced Gas Reactor Experiment AGR-1"
  - TFR-747, "Technical and Functional Requirements: RDAS-CDCS Data Transfer to NDMAS"
- FPMS Documents (all approved by VHTR Technology Development Office QA Lead)
  - 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 practice" database technology. This structure allows storing a large amount of data and all aspects of associated information (metadata) 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 in the Vault. This section explains the data flow to NDMAS and describes data specific to the AGR-2 irradiation experiment.

2.3.1 Database Structure

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

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

AGR-2 *Experiment* belongs to AGR *project* within the VHTR Program. A *Data stream* is a 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.

The AGR-2 experiment has two time series data streams, which are irradiation monitoring and FPMS. Figure 4 shows a general data schema for the 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 (ID) instead of descriptive text data. Data retrieval from the NDMAS Vault is achieved through use of views associating data with metadata and context information (such as location, instrument, measurement units, and data stream information).

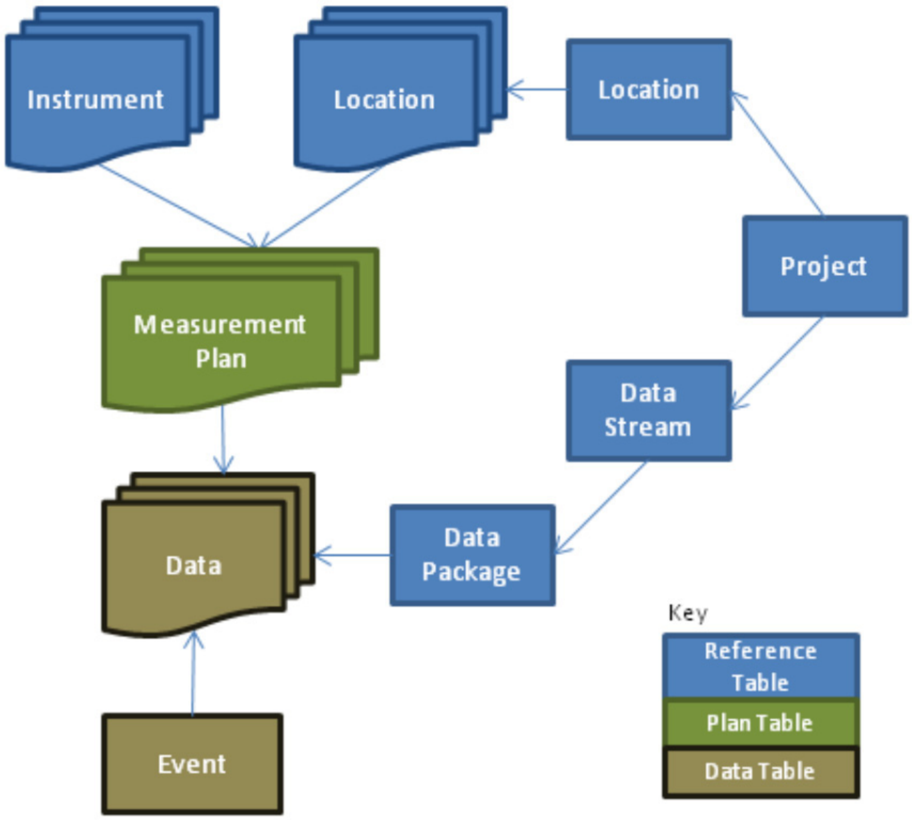

Figure 4. Data schema for time series data (Hull 2012).

2.3.2 Data Values for AGR Experiments

The *data values* in the new design of the 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 the 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), which are 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.

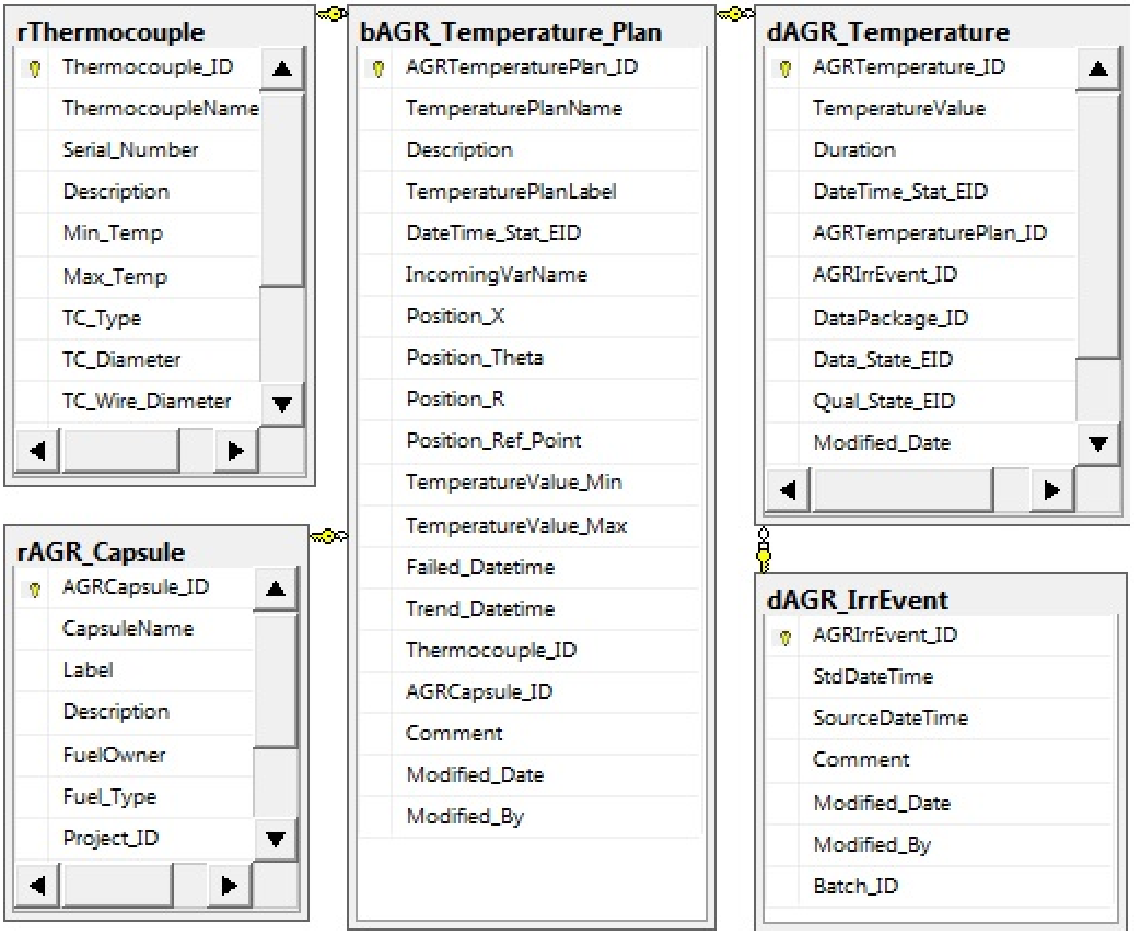

Figure 5. TC temperature value diagram of AGR experiment.

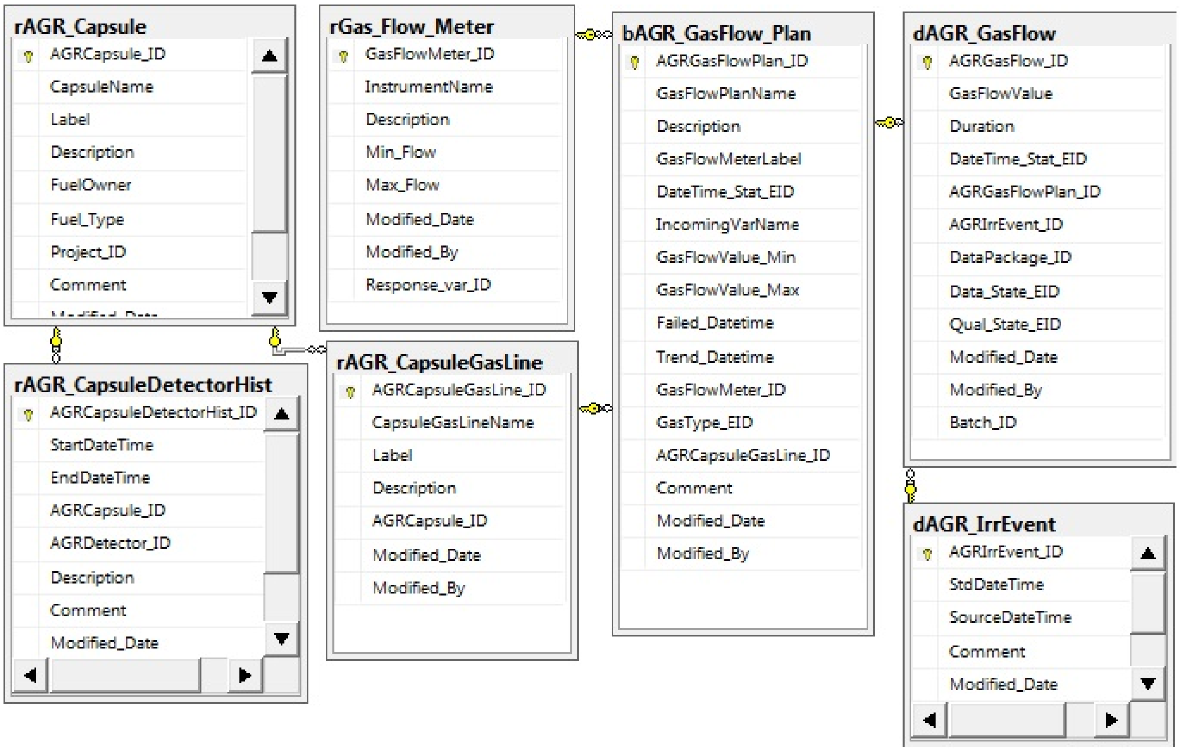

Figure 6. Gas flow value diagram of AGR experiment.

The new downstream flow data were also added to the NDMAS database (TFR-747), which stored the first flow record on February 26, 2013, at 10:40 (Cycle 153A). This data stream is associated with the FPMS detectors as described in the reference table rAGR_DetectorGasLine and the plan table bAGR_DetectorGasFlow_Plan. Then the AGR-2 FPMS detectors are connected with the AGR-2 capsule through the rAGR_CapsuleDetectorHist reference table. Generally, the detector numbers are the same as capsule numbers when all detectors are in good working condition. Any failed detector will be replaced with the spare detector number 7 and that information will be recorded in the rAGR_CapsuleDetectorHist reference table. The data variables stored for the AGR-2 irradiation monitoring data streams are listed in Table 2.

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 structured query language 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) and 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).

Table 2. NDMAS data values for the AGR-2 irradiation monitoring and FPMS data.

Response Element	Attribute Element	
Response Plan Name	Component Name	Response Description
Irradiation Monitoring:		
TC-1-x	AGR2_C1_TC[1,2]	TC1, TC2 Temperature in Capsule 1 (ºC) [x=1,2]
TC-2-x	AGR2_C2_TC[1,2]	TC1, TC2 Temperature in Capsule 2 (ºC)
TC-3-x	AGR2_C3_TC[1,2]	TC1, TC2 Temperature in Capsule 3 (ºC)

Response Element Response Plan Name	Attribute Element Component Name	Response Description
TC-4-x	AGR2_C4_TC[1,2]	TC1, TC2 Temperature in Capsule 4 (ºC)
TC-5-x	AGR2_C5_TC[1,2]	TC1, TC2 Temperature in Capsule 5 (ºC)
TC-6-x	AGR2_C6_TC[1–5]	TC1–TC5 Temperature in Capsule 6 (ºC) [x=1-5]
Cxx_out_MI	AGR2_C[01–06, LO]	Humidity in Capsules 1 through 6 and leadout gas flow (ppmv) [xx=01-06, LO]
Cxx_in_PI	AGR2_C[01–06, LO]	Pressure in Capsules 1 through 6 and leadout gas flow (psia)
Cxx_in_Q_He	AGR2_C[01–06, LO]	Helium flow to Capsules 1 through 6 and leadout (sccm)
Cxx_in_Q_Ne	AGR2_C[01–06, LO]	Neon gas flow to Capsules 1 through 6 and leadout (sccm)
Cxx_out_Q_Total	AGR2_C[01–06]	Gas outflow from Capsules 1 through 6 (sccm) [xx=01-06]
GSpecxx_QTotal_out	AGR2_G[01–07*]	Gas outflow from Detectors 1 through 6 (sccm) [xx=01-07*] **07 is a spare detector.*
FPMS:		
Kr_[A]_Rel	AGR2 Capsule [1–6]	Release rate for five krypton isotopes (atoms/s) (A = 85m, 87, 88, 89, 90) for each capsule
Kr_[A]_Rat	AGR2 Capsule [1–6]	R/B for five krypton isotopes (unitless)
Xe_[A]_Rel	AGR2 Capsule [1–6]	Release rate for seven xenon isotopes (atoms/s) (A = 131m, 133, 135, 135m, 137, 138, 139)
Xe_[A]_Rat	AGR2 Capsule [1–6]	R/B for seven xenon isotopes (unitless)
Kr_[A]_Err	AGR2 Capsule [1–6]	Release rate error for five krypton isotopes (%)
Kr_[A]_REr	AGR2 Capsule [1–6]	R/B error for five krypton isotopes (%)
Xe_[A]_Err	AGR2 Capsule [1–6]	Release rate error for seven xenon isotopes (%)
Xe_[A]_REr	AGR2 Capsule [1–6]	R/B error for seven xenon isotopes (%)

2.3.3 Data Delivery

For the first nine cycles, from ATR Cycle 147A to 151B, data records are 5-minute or 10-minute averaged values provided on a weekly basis in EXCEL spreadsheets. In order 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 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 advanced graphite creep current experiments. The automatic data transfer includes instantaneous values at 1- minute intervals for the following AGR-2 irradiation monitoring data:

- TC temperatures (tag name, AGR1TIxy [x=capsule no., y = TC number in that capsule])
- Outlet flow (tag name, AGR1FIOUTx)
- Downstream flow (tag name, AGR1FIFPMx)
- Neon flow rate (tag name, ITVNE1FINESHF1x)

- Helium flow rate (tag name, ITVHE1FINESHF1x)
- Inlet pressure (tag name, AGR1PIINx)
- Outlet moisture (tag name, AGR1MIOUTx).

FPMS release rate and R/B data are currently provided by FPMS technical staff to NDMAS at the end of each reactor cycle. Six capsule-specific release rates and six 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 (i.e., 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

2.3.4.1 Data Capture. 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 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 a result of 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 into the NDMAS archive folder.

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.

2.3.4.2 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 could be used to identify and reexamine extreme, but valid, data. For example, all 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 currently are only applied to the TC and sweep gas (e.g., flow rates, pressure, and moisture) data that NDMAS receives. The range test limits selected for these response variables are listed in Table 3. The lower limit for gas flow rate is set to 0 sccm; however, sometimes the gas flow meters can give slightly negative values at the factual zero flow rates. Thus, these valid negative flow rates, because of instrument measurement uncertainty, are replaced with 0 sccm as necessary in the NDMAS database.

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

Response Variable	Range Test Limits[a]	Comments
Capsule TC temperature	0 to 1400ºC	Capsules 1 through 6. Time-average, peak fuel temperature requirement for UCO fuel (SPC-1064). 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 to 102 sccm	Capsules 1 through 6 and leadout. Nominal flow rates are 0 to 30 sccm, but short-term peaks in helium flow up to and exceeding 100 sccm are assumed to be valid (TFR-259).
Capsule gas mixture outlet flow	0 to 102 sccm	Capsules 1 through 6 (TFR-559).
Downstream gas mixture flow	0 to 102 sccm	Flow from seven FPM detectors: 1 through 6 corresponding to 6 capsules and 7 is a spare detector (TFR-747). Downstream flow rates are expected to be comparable to capsule outlet flow rates.
Gas pressure—capsule inlet	0 to 90 psia	Capsules 1through 6 and leadout. Pressure relief valve setting (TFR-559).
Moisture—capsule outlet	0 to 5 ppm	Capsules 1 through 6 and leadout. No published limit for capsule outlet moisture level. Limit is set to the gas inlet specification in SPC-1064, 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-2 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 the NDMAS database as follows: (1) date and time data inserted into the "dAGR_FPMEvent" table; (2) R/B data inserted into the "dAGR_FPMRatio" table; (3) release data inserted into the "dAGR_FPMRelease" table; and (4) flow data inserted into the "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 status for this data stream is documented in an ECAR. 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 according to status reported in the ECAR. The qualification status will 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 webpage display and data download. Data from older versions are still stored in the database as *Obsolete* for qualification status and are available upon 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 Program participants can access the system and review data, obtain analysis results (including statistics and graphics), and download data. By performing these roles, NDMAS assures 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.

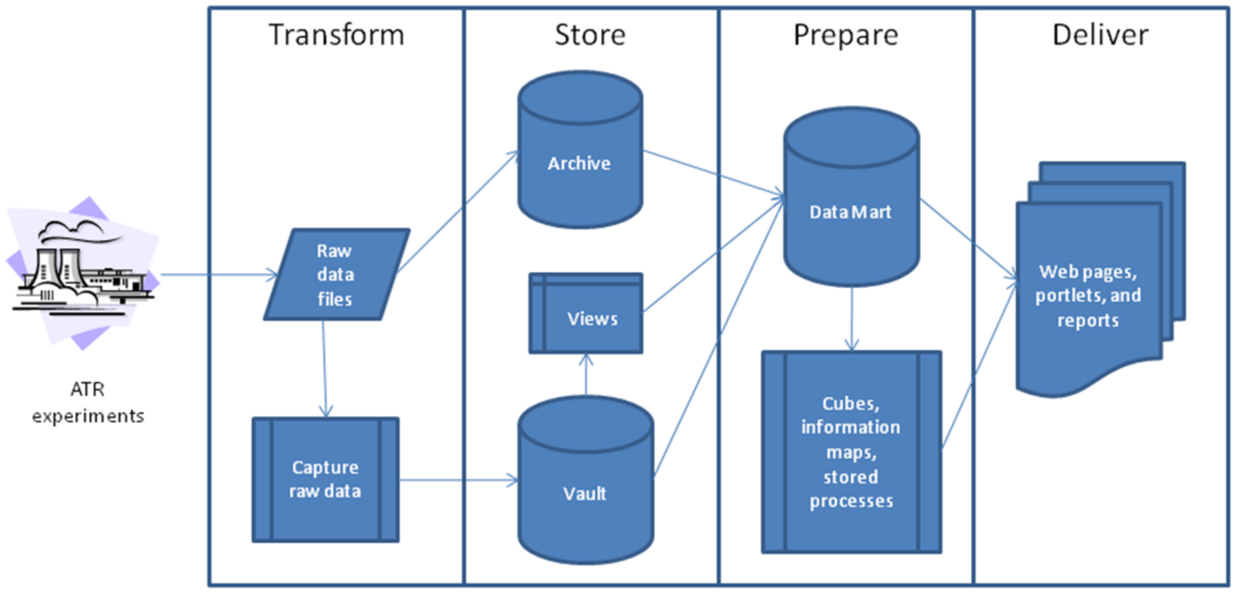

Figure 7. Stages of data processing in NDMAS.

3.1 Data Overview

This section provides a data summary and overview plots of the data captured and processed by NDMAS for the entire AGR-2 irradiation period. The qualification status of these data is presented in Section 4 of this report.

3.1.1 Reporting Cycles

AGR-2 test fuel was irradiated in the ATR core for a total of 559.2 EFPD spanning over fifteen ATR cycles, from Cycle 147A through 154B. Table 4 provides a summary of AGR-2 irradiation data captured in the NDMAS database for each of the ATR cycles, covering the period from June 22, 2010, through October 16, 2013. The summary of the ATR operating parameters during the AGR-2 irradiation presented in Figure 8 provides an overview of the ATR operating history and helps interpret AGR-2 experimental data. Because the AGR-2 experiment is located on the west side, the average of the power levels for the center, northwest, and southwest lobes is plotted as effective power (Panel 4). The angular positions of the outer shim control cylinders regulating the ATR power distribution in each corner of the reactor are presented in Panel 3. Two other ATR operating parameters are the insertion depth of the regulator rods (Panel 2) and the number of neck shims that are inserted (Panel 1).

Table 4. Overview of cycles for AGR-2 irradiation (PALM cycles are in blue rows and outage cycles are in gray rows).

ATR Cycle	Record Start	Power Up	Power Down/ Record End	No. of EFPDs	Total No. Records	Cycle Comment
147A	19JUN10 05:00	22JUN10 14:28	14AUG10 8:59	50.2	202,225	Normal
148A	14AUG10 9:09	31AUG10 17:53	23OCT10 9:00	47.5	252,000	Normal
148B	23OCT10 9:10	17NOV10 14:40	08JAN11 10:00	51.5	277,350	Normal
149A	08JAN11 10:10	14APR11 02:00	21MAY11 9:00	36.8	295,425	Normal
149B	21MAY11 9:20	06JUN11 13:20	30JUL11 9:00	53.6	403,750	Normal
150A	AGR-2 moved to the water canal			0	15,850	PALM
150B	01SEP11 3:00	14OCT11 23:15	26NOV11 10:00	41.9	310,575	Normal
151A	26NOV11 10:15	14DEC11 00:10	11FEB12 9:59	56.1	453,850	Normal
151B	11FEB12 10:05	01MAR12 5:30	05MAY12 9:06	51.3	588,275	Normal
152A	05MAY12:15:00	N/A	30OCT12 00:00	0	2,329,125	Low power outage
152B	30OCT12:00:30	27NOV12 04:00	18JAN13 10:10	51.0	1,915,450	Normal
153A	18JAN13:10:10	N/A	11MAR13 13:07	0	1,005,625	Unplanned outage
153B	11MAR13:13:10	29MAR1313:00	12APR13 19:00	13.5	1,363,770	PALM/I-24
154A	10APR13:01:05	19MAY13 03:00	13JUL13 9:05	52.3	3,863,430	Normal
154B	13JUL13 9:10	23AUG13 15:00	23OCT13 13:32	53.5	3,724,995	Normal
			Total:	**559.2**	**17,001,695**	

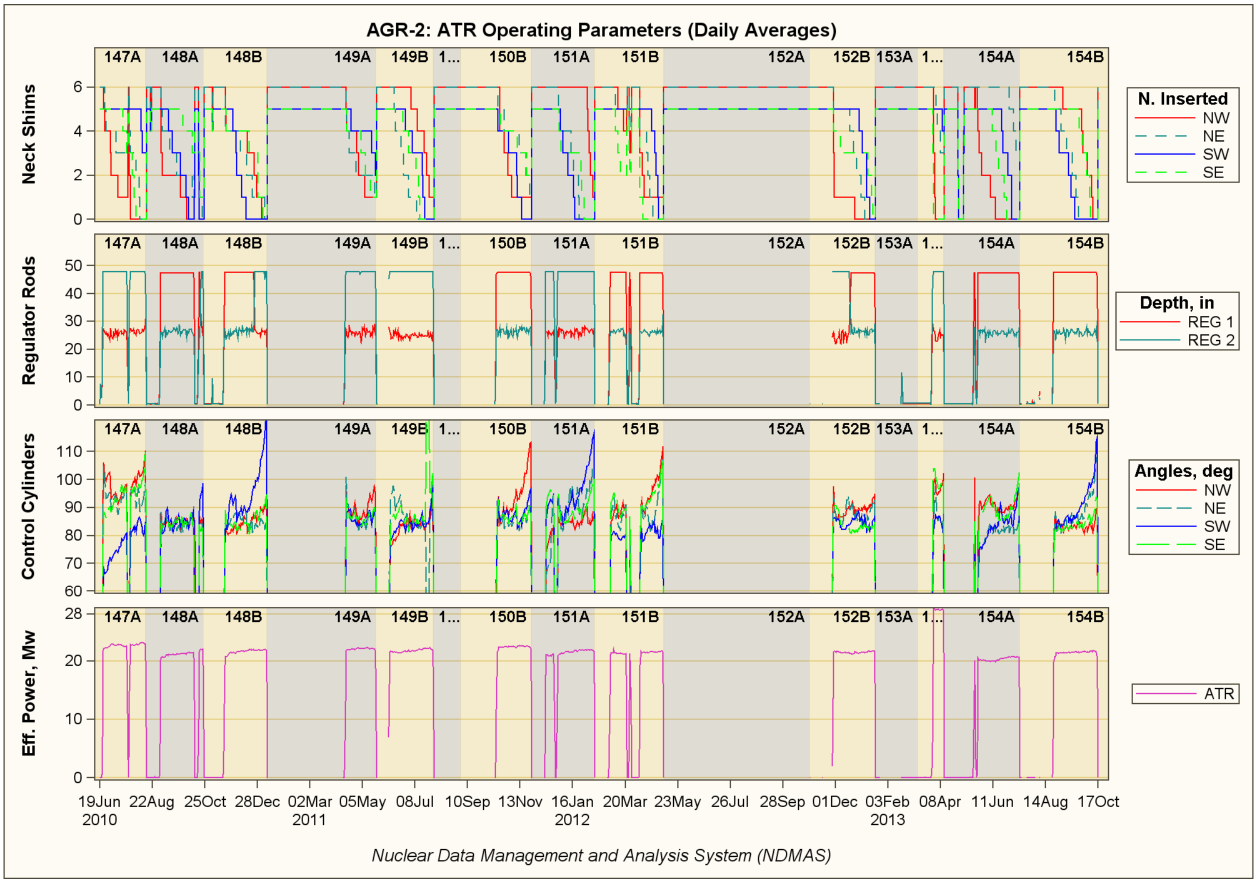

Figure 8. ATR operating parameters during AGR-2 irradiation.

For Cycles 152A and 153A, the ATR core was raised to a low power level for a few short periods of time, resulting in the averaged effective power of 0.209 MW for 89.6 hours for the low power Cycle 152A and 1.082 MW for 0.25 hours for the outage Cycle 153A. Thus, ATR operating data during these two cycles are not shown in Figure 8. During this time, the AGR-2 experiment was run on pure helium for both capsule and leadout gas flows as during all outage periods of other normal cycles. It was decided that for the test fuel depletion calculation, these cycles were considered as extended power outages (0 EFPD as shown on gray-shaded rows in Table 4) and there are no thermal calculations for AGR-2 capsules during these periods. However, AGR-2 irradiation data are still captured and stored in the NDMAS database. Also, during the outage Cycle 153A, seven flow meters were installed downstream from seven FPMS monitors to measure flows from them; their data was included in the NDMAS database.

In addition, there are two other untypical cycles, PALM Cycles 150A and 153B, when the ATR power is significantly higher than during normal cycles. During the first PALM cycle, 150A, the experiment was temporarily moved from the B-12 location to the ATR water canal and during the second PALM cycle, 153B, the experiment was temporarily moved from the B-12 location to the I-24 location (next to the northwest lobe) to prevent over-heating of fuel compacts due to high ATR lobe power. As a result, the AGR-2 irradiation had 0 EFPD for ATR Cycle 150A and any irradiation data captured during this time were mostly not useful or not valid (when AGR-2 was in the water canal); therefore, they should be removed or flagged as “*Failed*” records.

3.1.2 Temperature Data

The hourly TC temperature data averaged from instantaneous measurements are shown in Figure 9 for all AGR-2 U.S. capsules. Capsules 1 and 4 are not shown because of CRADA restrictions. Gaps in TC plots represent periods with missing irradiation data, which happened only during ATR power outages due to equipment maintenance. As shown in Table 4, there are eleven normal cycles when ATR was up to usual power level and readings from operational TCs can reach their pre-defined set points, except for a few short periods when AGR-2 was run on pure helium due to the sweep gas line and valve issues. During PALM Cycle 153B, the ATR power level increased by as much as 50% above that during a normal cycle; therefore, AGR-2 was moved to the peripheral location I-24 and run on full helium to avoid overheating. As a result, TC readings are lower than during typical cycles, such as ~600°C for TC3 in Capsule 6 (green line in a short section of time after Cycle 153A in Panel 1 of Figure 9) instead of ~950ºC during the earlier cycles. TC readings during low power Cycle 152A and outage Cycle 153A were largely low ranging from ~30 to 50°C. During 1 hour and 15 minutes on October 4, 2012, from 19:15 to 20:30 (ATR Cycle 152A), TC1 and TC2 in Capsule 3 increased to 431°C and 432°C, respectively, and TC2 and TC3 in Capsule 6 increased to 461°C and 463°C, respectively.

A discussion on TC temperature anomalies as they relate to data qualification is presented in Section 3.2. With the exception of TC2 in Capsule 2, which failed at fabrication, the failed TCs failed during irradiation when their readings did not respond as the ATR core rose to full power (Figure 9). Soon after the ATR power was up during ATR Cycle 154A, the last TC in the U.S. capsules, TC3 in Capsule 6, failed as its readings dropped to ~30ºC for the rest of the power-up period.

3.1.3 Sweep Gas Data

Figure 10 shows the hourly sweep gas flow rates averaged from detailed measurements for each capsule, including helium inlet, neon inlet, and total outlet. Leadout gas flows (both helium and neon) are shown at the bottom panel of Figure 10 (same for all capsules). As in the above TC plots, gaps in the gas flow plots represent periods with missing irradiation data during cycle outages. Fortunately, during that time, AGR-2 usually ran 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 rates 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 3. A discussion on gas flow rate anomalies as they relate to data qualification is presented in Section 3.3. The quality assessment of the flow rates from the downstream meters at FPMS detector outlets are discussed separately in Section 3.3.3.

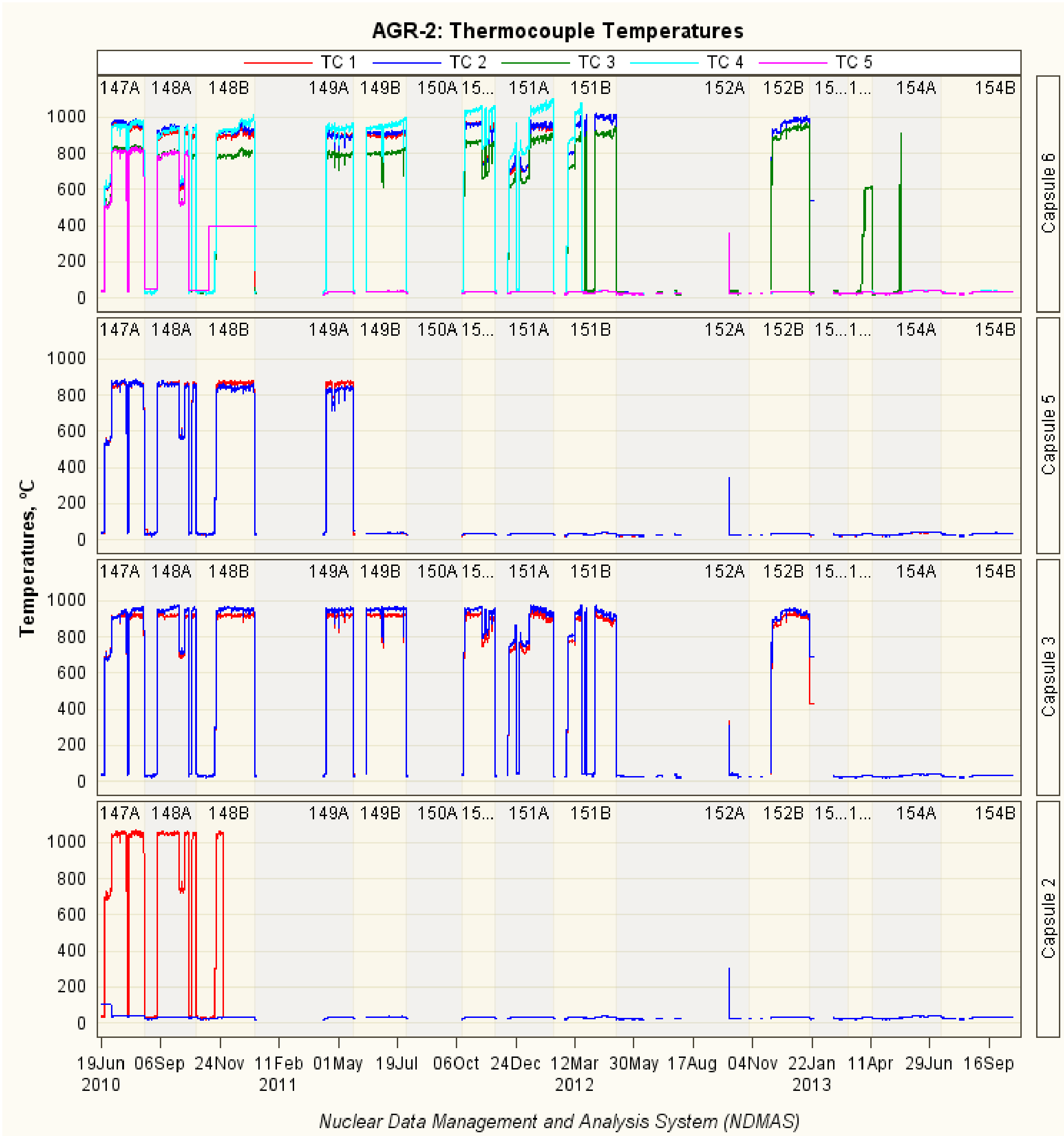

Figure 9. AGR-2 TC temperature data in four U.S. capsules for all cycles.

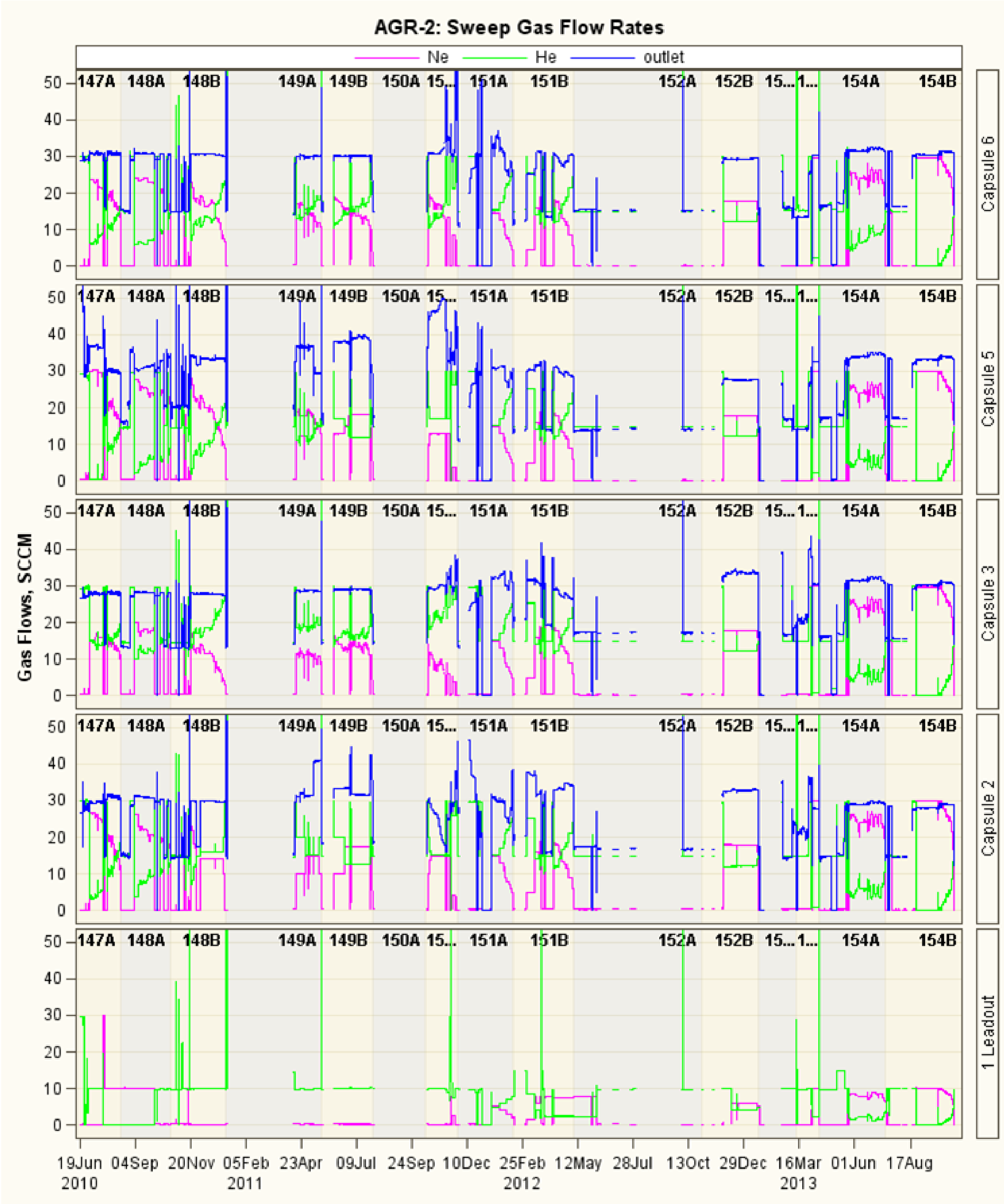

Figure 10. AGR-2 capsule and leadout sweep gas flow rates (sccm) for all cycles.

3.1.4 FPMS Data

Detailed documentation of the FPMS measurement and processing methods for the AGR-2 FPMS data is contained in ECAR-2420 written by FPMS staff (Scates 2014). This ECAR also provides the basis for qualification of the FPMS data for the entire AGR-2 irradiation. According to this ECAR, because of the relief valve issues during ATR Cycles 149A and 149B and the cross-talk between capsule gas lines that began during Cycle 150B, fission product from one capsule was suspected of entering other capsules' detectors. Therefore, the FPMS release rates are not representing the actual fission product in each capsule, thus the FPMS data after ATR Cycle 148B will not be qualified. However, the data still provide useful information for identifying particle failures and performing additional analyses and will be flagged as *Trend.* Additionally, the FPMS team provides the requirements for storage and display of FPMS data within the NDMAS database. These requirements prevent the use of data with high measurement uncertainty in fission product release data analysis. Therefore, there are two data sets available for all FPMS data in the NDMAS database: the original data set and a clean data set and is described as follows:

- Original data set – Contains all data passed from the FPM team to the NDMAS server. All data passed to NDMAS is qualified because of the acceptance testing performed within the measurement system and operability test plans. However, the data quality in terms of representing the intended measured quantity is discussed in the corresponding ECAR for FPMS data (e.g., ECAR-2420 for AGR-2 data). The original data set is fully captured into the NDMAS data tables (Vault) and all raw data files are also archived in NDMAS storage.
- Clean data set – Contains all meaningful data that can be used in fission product release analysis. In the clean data set, the negative values and values where uncertainties of greater that 50% are omitted. These data filters remove data from the "short" leadout flow runs or measurements that were incomplete, while leaving other runs that have enough counting statistics unaffected.

Figure 11 and Figure 12 plot the original data set of fission product release rate and R/B data (nominal 8-hour count times) for all AGR-2 cycles that have been submitted to NDMAS to-date. The R/B data in Figure 12 are the latest version of calculated R/B using the isotope daily birthrate; therefore, these R/Bs are named daily R/B to differentiate with the earlier version of R/B. The daily R/B data replace the earlier version of R/B data calculated using a four-point isotope birthrate. Currently, the four-point FPMS data are flagged as "*Obsolete*" data in NDMAS database and they are available upon special request. The daily FPMS data are used for display on the NDMAS web pages and are ready for data download.

3.2 Testing Results for TC Temperatures

NDMAS runs a number of tests for TC temperature data to identify potential anomalies (Table 5). 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 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.

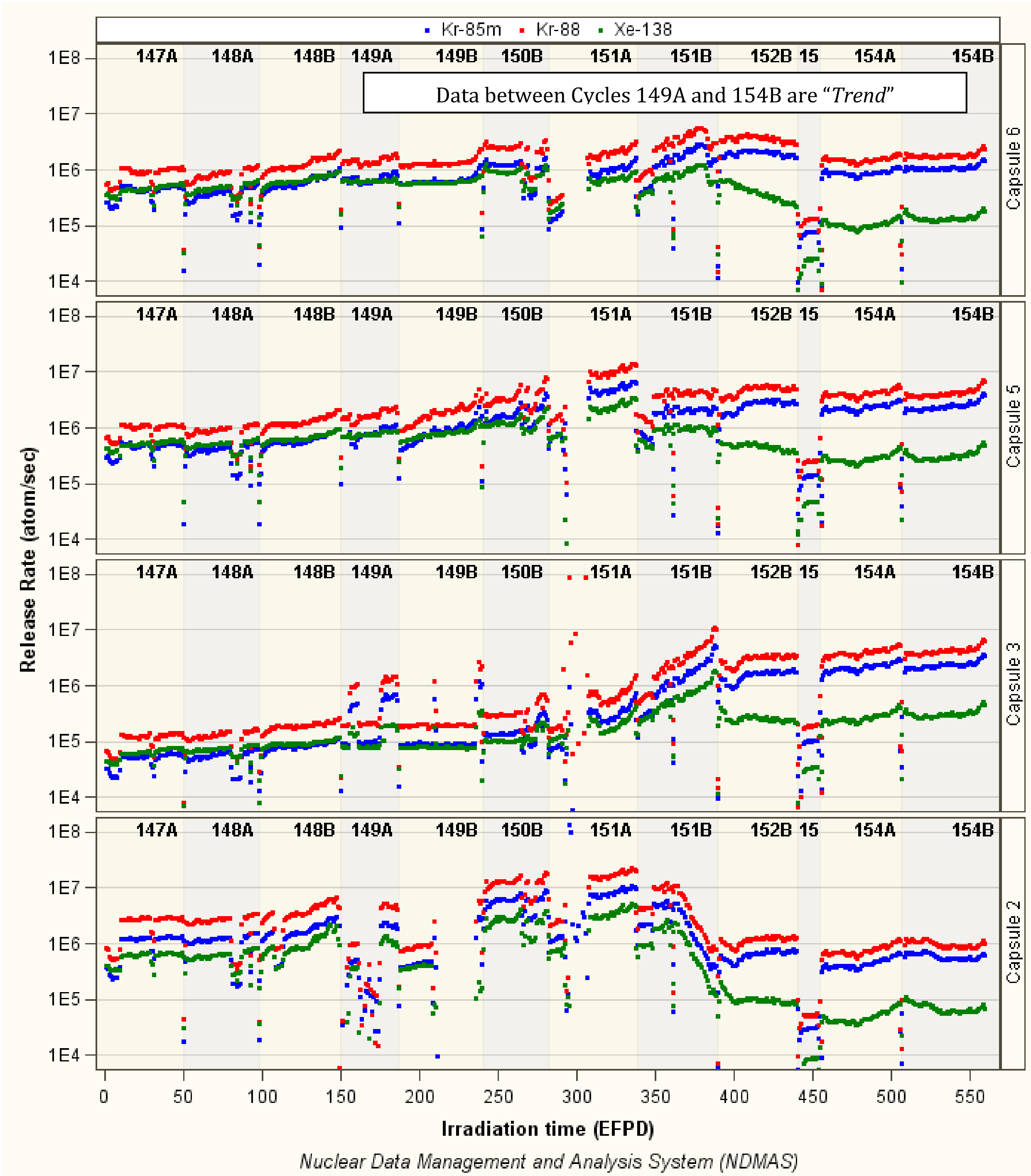

Figure 11. AGR-2 fission product release rates for Kr-85m, Kr-88, and Xe-138 for all cycles.

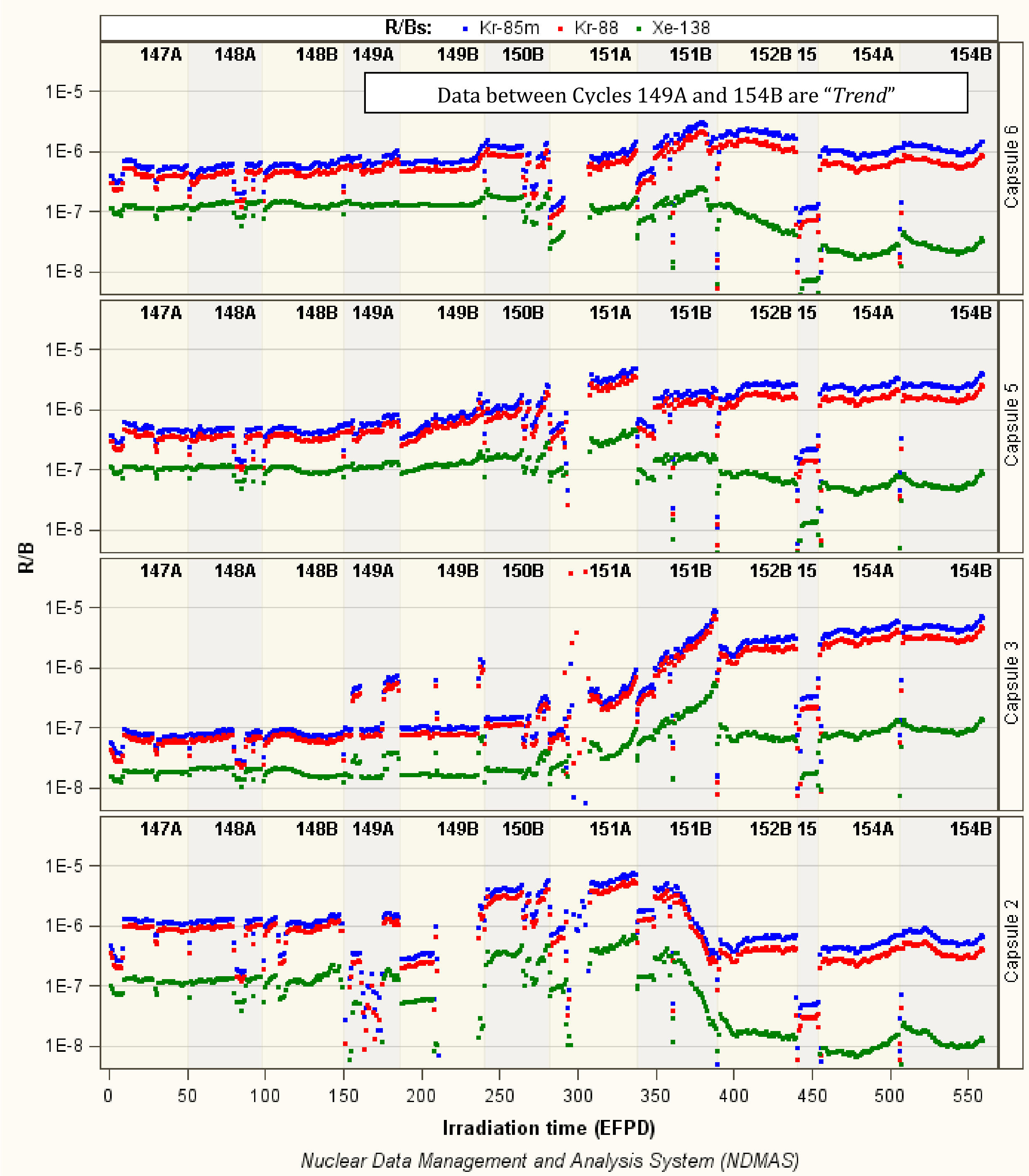

Figure 12. AGR-2 fission product R/B ratios for Kr-85m, Kr-88, and Xe-138 for all cycles.

Table 5. NDMAS tests performed for AGR-2 irradiation monitoring data.

Test Type	Test Name	Test Description
Accuracy	Range	Compares response values to anticipated/nominal ranges for the experiment (0 to 1400ºC). Identifies anomalous values that fall outside the expected range.
Analysis	Physics	Compares response values to thermal analysis predictions for the experiment. Identifies anomalous values that are deviated from the temperature prediction for more than 200°C.
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 Capture Range Testing

The NDMAS range testing results for TC readings reveal only six *negative* TC readings, 3,321 missing records, and no TC readings exceeded the upper limit of 1400°C during the entire AGR-2 irradiation. Six temperature measurements fell well outside the range test criteria (0 to 1400°C) as shown in Table 6. The magnitude of these values indicates that they do not represent actual temperatures in the AGR-2 capsules and are likely due to a data acquisition error. All of these values are flagged as *Failed* data.

Table 6. Temperature values (°C) that exceeded test range criteria.

ATR Cycle	Value	Component Name	Standard Date:Time
147A	-161,062	C6_TC1	24Jun2010:13:00
147A	-321,431	C2_TC2	01Jul2010:11:50
148B	-168,168.60	C2_TC1	09Nov2010:14:20
149A	-3,999,966	C5_TC1	13Apr2011:07:38
152A	-0.351822	C5_TC2	06JUN2012:14:22
154A	-44.84634	C6_TC3	02MAY2013:10:03

3.2.2 Instrument Failure Testing

AGR-2 TCs deteriorate and sometimes fail because of the high irradiation and temperature conditions that occur during test reactor cycles. The two common failure mechanisms for TCs are the formation of virtual junctions and open circuit failures, where the signal ceases altogether. Open circuit failures occur when the entire TC breaks in two, causing a break of the thermo-elements, and hence an open circuit. Failures from virtual junctions are 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. Virtual junctions are detected by perturbing the temperature in a single capsule using gas flow, then observing the TC readings from capsules below this one to see if they respond. If a capsule TC responds to temperature changes in a capsule above it, it is likely that a virtual junction has formed and the TC can be considered failed. No evidence of virtual junction was found during the operating lifetime of the AGR-2 TCs; therefore, all TC failures were attributed to open circuit failure.

All fifteen TCs in the AGR-2 experiment were failed by the end of ATR Cycle 154A. The DRC, which convened just before each data qualification report was issued, reviewed the data acquisition process, considered whether the data met the requirements for data collection as specified in QA-approved VHTR data collection plans, examined the results of NDMAS data testing and statistical analyses, and confirmed the qualification status of the data as given in each report. The DRC reviewed the data on the TC failure dates using plots and discussions in the following subsections and confirmed all TC failures.

The failure date/times of TCs in four U.S. capsules are presented in Table 7. Capsules 1 and 4 discussions are CRADA-restricted and excluded from this report. 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 data tables). Figure 13 shows readings of all functioning TCs as a function of EFPDs, thus the plots discontinued after TC failure dates.

Table 7. TC failure times for AGR-2 U.S. capsules.

Capsule No.	TC No.	Failure Time	ATR Cycle
2	1	2010-11-27 16:11	During 148B
2	2	At fabrication	Start of 147A
3	1	2013-01-18 10:05	End of 152B
3	2	2013-01-18 10:05	End of 152B
5	1	2011-05-21 06:00	End of 149A
5	2	2011-05-21 06:00	End of 149A
6	1	2012-02-29 11:25	End of 151A
6	2	2013-01-18 10:05	End of 152B
6	3	2013-05-21 04:45	Start of 154A
6	4	2012-03-22 15:35	Middle of 151B
6	5	2010-10-12 20:00	End of 148A

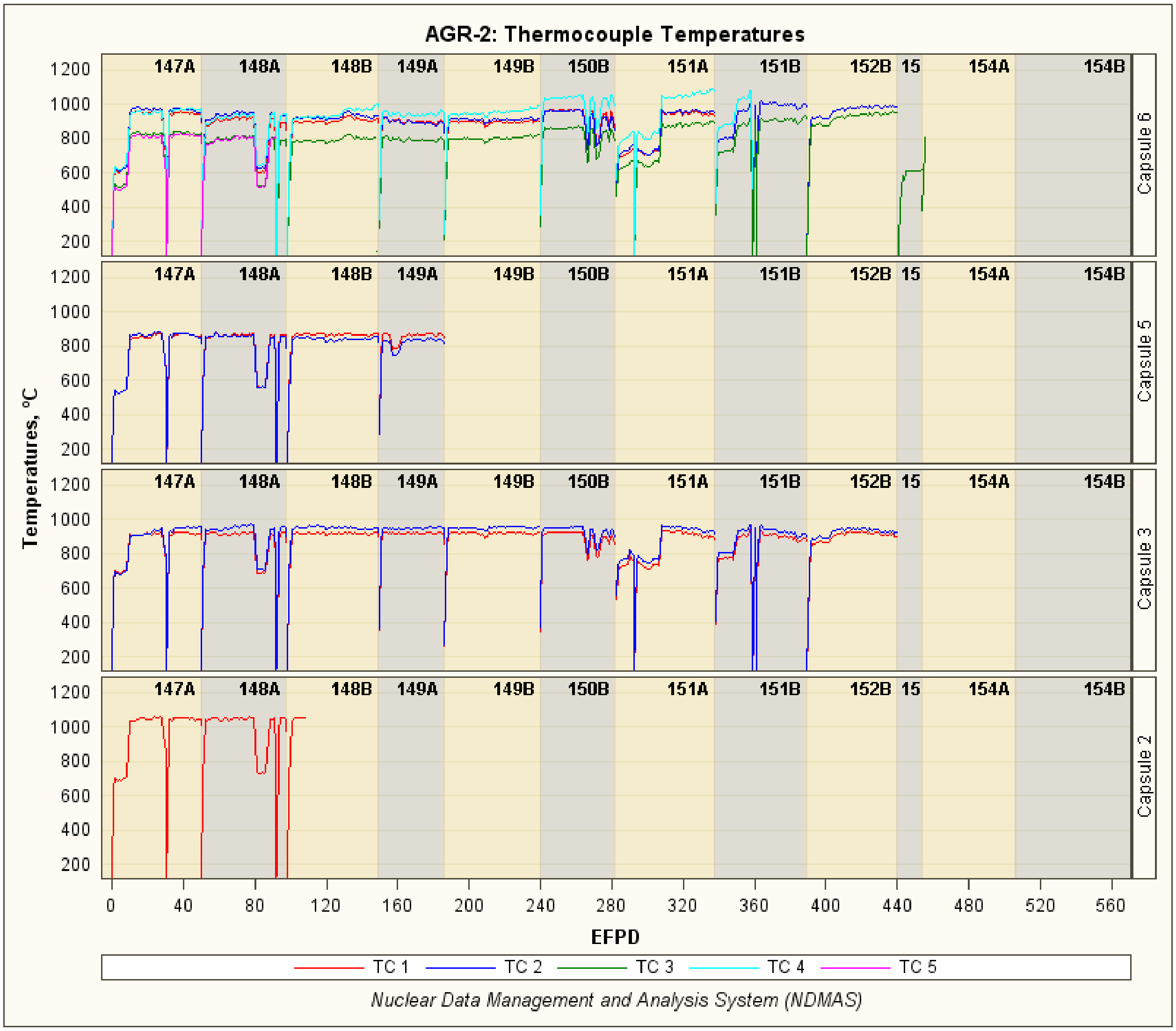

Figure 13. Temperature readings from operational TCs as function of EFPDs.

3.2.2.1 TC1 and TC2 in Capsule 2. DRC Recommendation: TC 1 Failed on November 27, 2010, at 16:11 (ATR Cycle 148B) and TC 2 failed during installation.

TC 1 failed on November 27, 2010, during reactor Cycle 148B as shown in Figure 14 (red line), leaving Capsule 2 with no functioning TCs. The last valid reading for this TC is assumed to have occurred at 1610 MST on November 27, 2010, based on review of the raw data files. After this reading, the indicated temperature values dropped rapidly to approximately 29°C when the ATR core was at full power. All data after this time are considered to be *Failed*.

TC 2 in Capsule 2 never responded to high temperature in Capsule 2 during the time the ATR core was at full power (blue line in Figure 14); therefore, it is assumed to have failed during installation (no readings from TC 2 in Capsule 2 existed as shown on the bottom panel in Figure 13). All data from this TC during the AGR-2 irradiation are considered *Failed*.

3.2.2.2 TC1 and TC2 in Capsule 3. DRC Recommendation: TC1 and TC2 failed on January 18, 2013, at 10:05 (end of ATR Cycle 152B).

Both TC1 and TC2 in Capsule 3 failed at exactly the same time on January 18, 2013, at 10:05. TC1 dropped to 430°C and TC2 dropped to 693°C instead of decreasing to about 40°C as expected when ATR powered down to zero at the end of ATR Cycle 152B (Figure 15). They did not respond to the power-up phase during the next cycle, 153B, which are the discontinued red and blue lines after ATR Cycle 152B on Panel 3 of Figure 13. Based on this response, TC1 and TC2 are assumed to have failed on January 18, 2013, at 10:05 and all data from these TCs are "*Failed*" after this date/time.

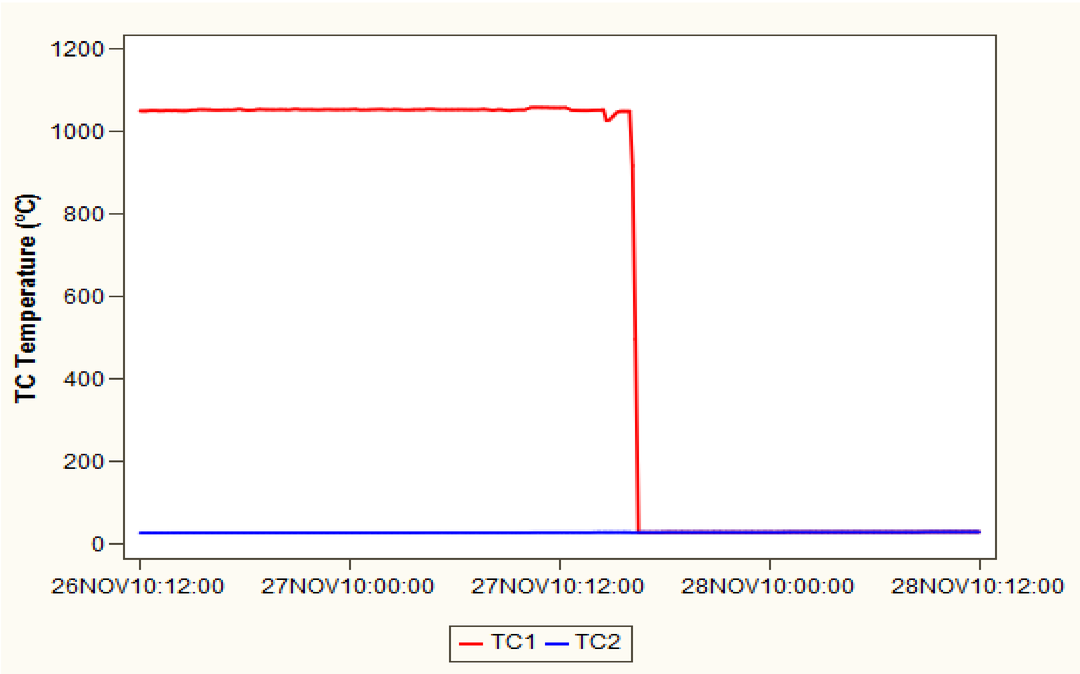

Figure 14. TC1 in Capsule 2 failed on November 27, 2010, at 16:11 (based on actual data).

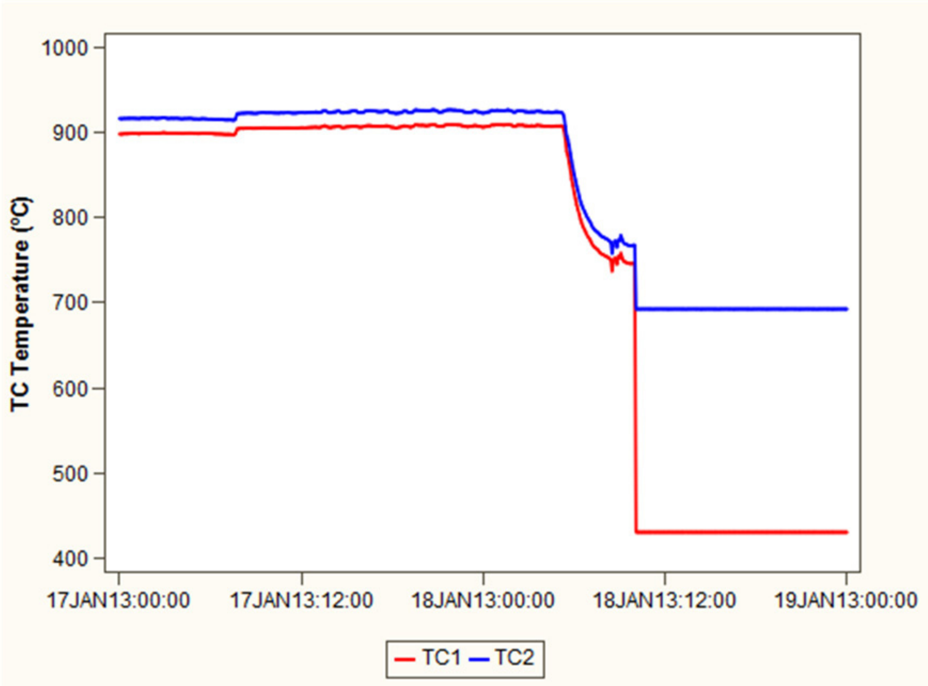

Figure 15. TC1 and TC2 in Capsule 3 failed on January 18, 2013, at 10:05 (based on actual data).

3.2.2.3 TC1 and TC2 in Capsule 5. <u>DRC Recommendation</u>: TC1 and TC2 failed on May 21, 2011, at 6:00 (end of ATR Cycle 149A).

Both TC1 and TC2 in Capsule 5 appear to have failed just before reactor shutdown on May 21, 2010, (ATR Cycle 149A) as shown in Figure 16. The last valid readings for these TCs are assumed to have occurred at 06:00 on May 21, after which the temperatures started to drop below 800°C when the ATR core was still at full power and temperature readings from other functional TCs were unchanged. Neither of these TCs responded to the power-up phase during the next cycle, 149B, as shown in Panel 3 of Figure 13. Based on this response, TC1 and TC2 are assumed to have failed on May 21, 2011, at 6:00 hours and all data from these TCs are failed after this date/time.

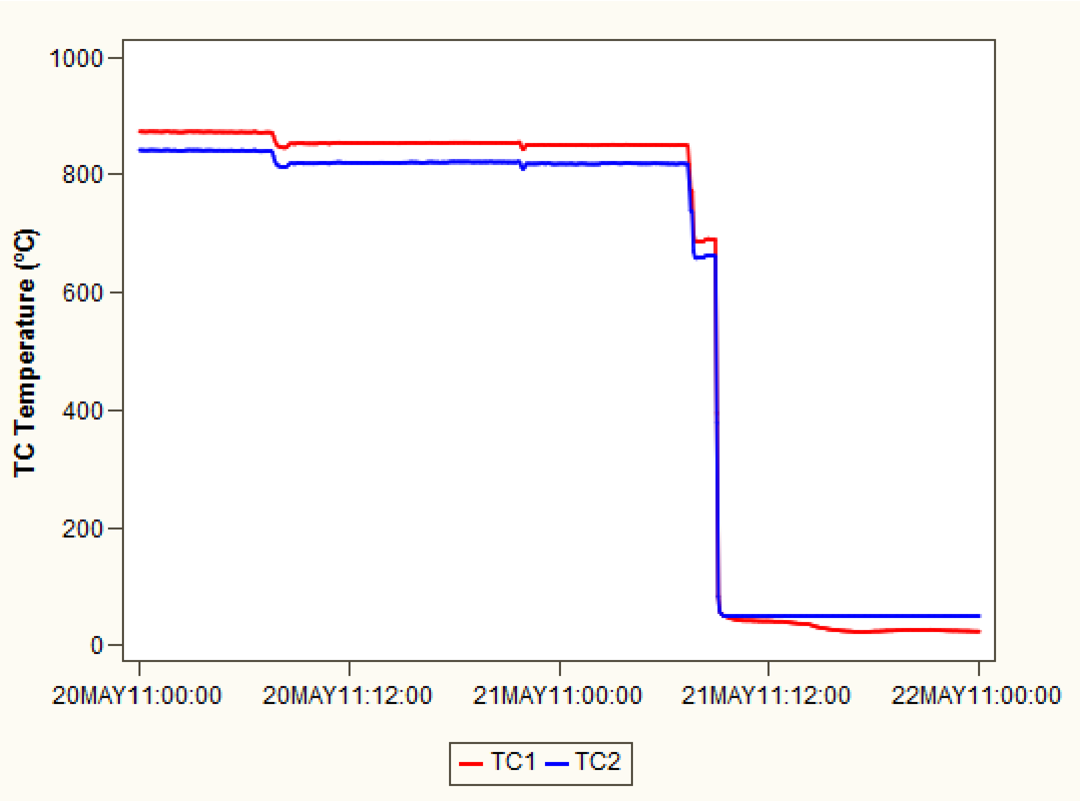

Figure 16. TC1 and TC2 in Capsule 5 failed on May 21, 2011, at 6:00 (based on actual data).

3.2.2.4 TC1 in Capsule 6. <u>DRC Recommendation</u>: TC1 failed on February 29, 2012, at 11:25 (end of ATR Cycle 151A)

TC1 readings (red line in Figure 17) dropped below readings from the other operating TCs in Capsule 6 (TCs 2, 3, and 4) when ATR core power was down to zero after the end of Cycle 151B (Figure 17). TC1 did not respond to the power-up phase during the next cycle, ATR Cycle 151B (discontinued red line in Panel 1 of Figure 13). Based on this response, TC1 is assumed to have failed on February 29, 2012, at 11:25 and all data from this TC are "*Failed*" after this date/time.

3.2.2.5 TC2 in Capsule 6. <u>DRC Recommendation</u>: TC2 failed on January 18, 2013, at 10:05 (end of Cycle 152B).

TC2 in Capsule 6 first dropped to 540°C and stayed at that same level for an extended period, while the other operating TC (TC3 in Capsule 6) dropped to about 40°C as expected when the ATR core powered down to zero at the end of Cycle 152B (Figure 18). TC2 did not respond to the power-up phase during the next cycle, 153B (discontinued blue line in Panel 1 of Figure 13). Based on this response, TC2 is assumed to have failed on January 18, 2013, at 10:05 and all data from this TC are "*Failed*" after this date/time.

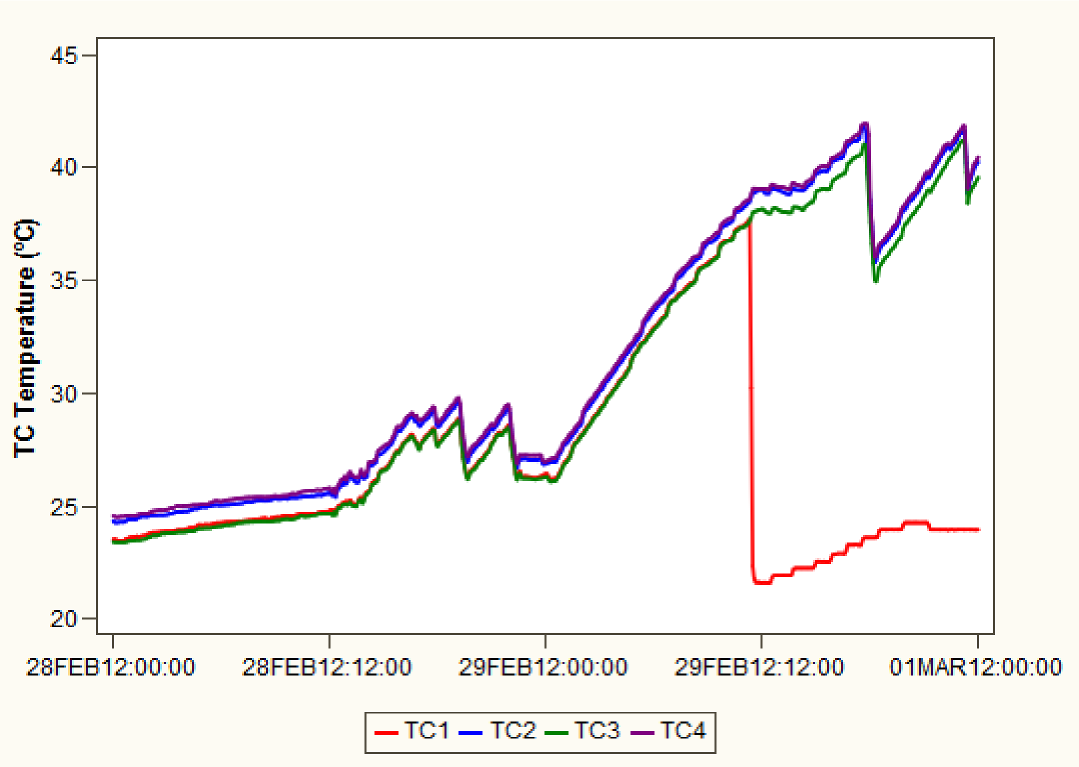

Figure 17. TC1 in Capsule 6 failed on February 29, 2012, at 11:25 (based on actual data).

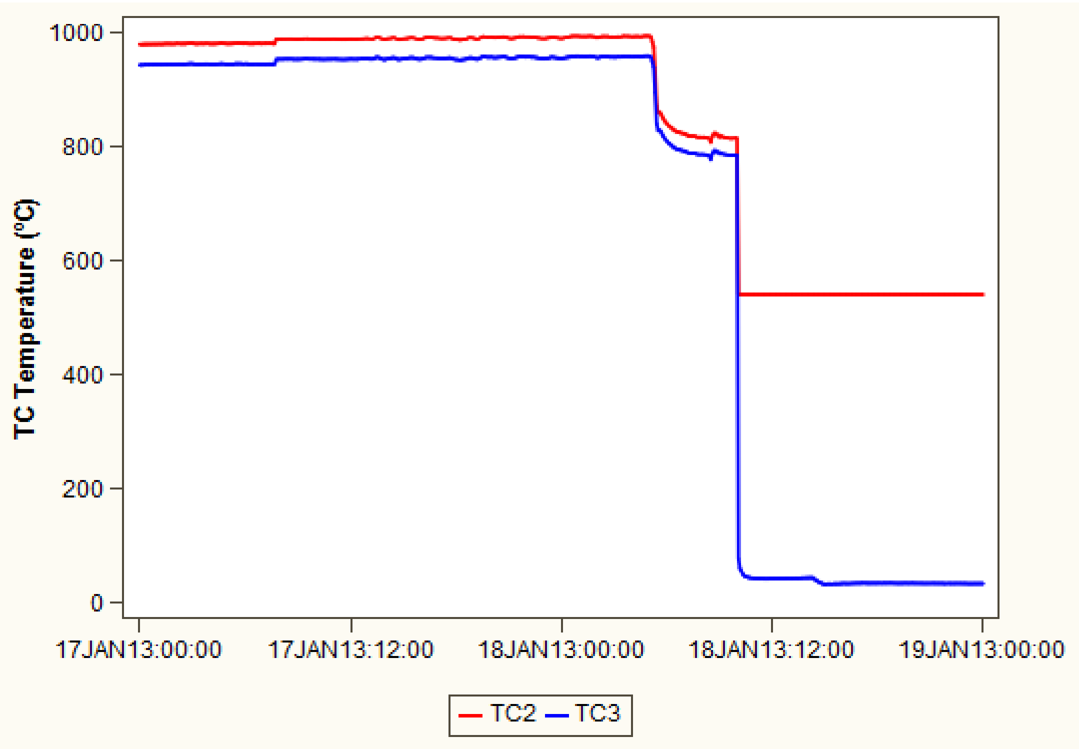

Figure 18. TC2 in Capsule 6 failed on January 18, 2013, at 10:05 (based on actual data).

3.2.2.6 TC3 in Capsule 6. DRC Recommendation: TC3 failed on May 21, 2013, at 04:45 (near the start of ATR Cycle 154A).

TC 3 was the last functional TC in Capsule 6 because four other TCs failed during earlier cycles. During ATR Cycle 154A, TC3 readings first dropped to 48.7°C and stuck at that same level for an extended period (Figure 19), when the ATR core was unexpectedly scrammed after only a few days into this cycle. Then TC3 readings did not increase when ATR restarted during that same cycle (discontinued green line in Panel 1 of Figure 13). Based on this response, TC3 is assumed to have failed on May 21, 2013, at 04:45 hours and all data from this TC are "*Failed*" after this date/time.

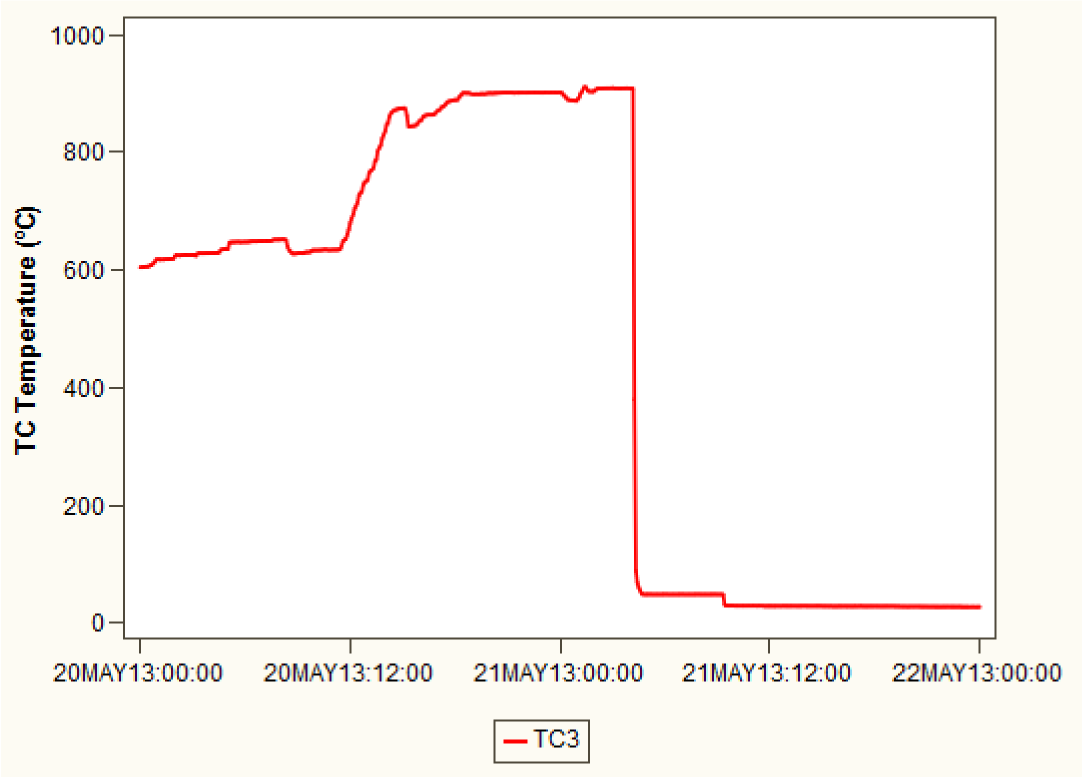

Figure 19. TC3 in Capsule 6 failed on May 21, 2013, at 04:45 (based on actual data).

3.2.2.7 TC4 in Capsule 6. DRC Recommendation: TC4 failed on March 22, 2012, at 15:35 (middle of Cycle 151B).

TC4 in Capsule 6 appears to have failed on March 22, 2012, right after the start of an unplanned outage in Cycle 151B as shown in Figure 20 (red line). At this time, two other operational TCs (TC2 and TC3) in Capsule 6 dropped to and varied around 42°C, while TC4 dropped and remained fixed at 29°C. After that, TC4 never again responded to increases in reactor power (discontinued cyan line in Panel 1 of Figure 13). Based on this performance history, TC4 was assumed to have failed on March 22, 2012, at 15:35 (middle of Cycle 151B) and all data after that time are considered to be *"Failed"*.

3.2.2.8 TC5 in Capsule 6. DRC Recommendation: TC5 failed on October 12, 2010, at 20:00 (near the end of ATR Cycle 148A).

TC5 in Capsule 6 appears to have failed on October 12, 2010, at the start of an unplanned outage in Cycle 148A, as shown in Figure 21 (red line). At this time, all other TCs in Capsule 6 dropped to and varied around 35°C, while TC5 dropped and remained fixed at exactly 41.44659°C. After that, TC5 never again responded to increases in reactor power (discontinued pink line in Panel 1 of Figure 13). Based on this performance history, TC5 was assumed to have failed on October 12, 2010, at 20:00 and all data after that time are considered to be *"Failed"*.

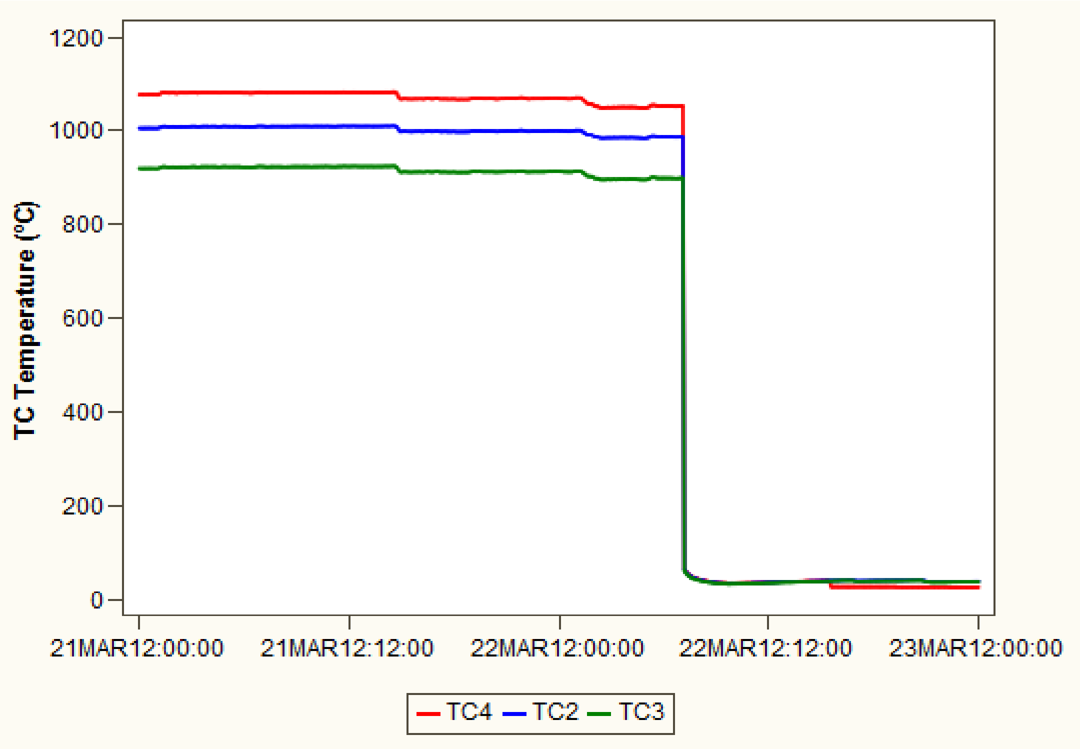

Figure 20. TC4 in Capsule 6 failed on March 22, 2012, at 15:35 (based on actual data).

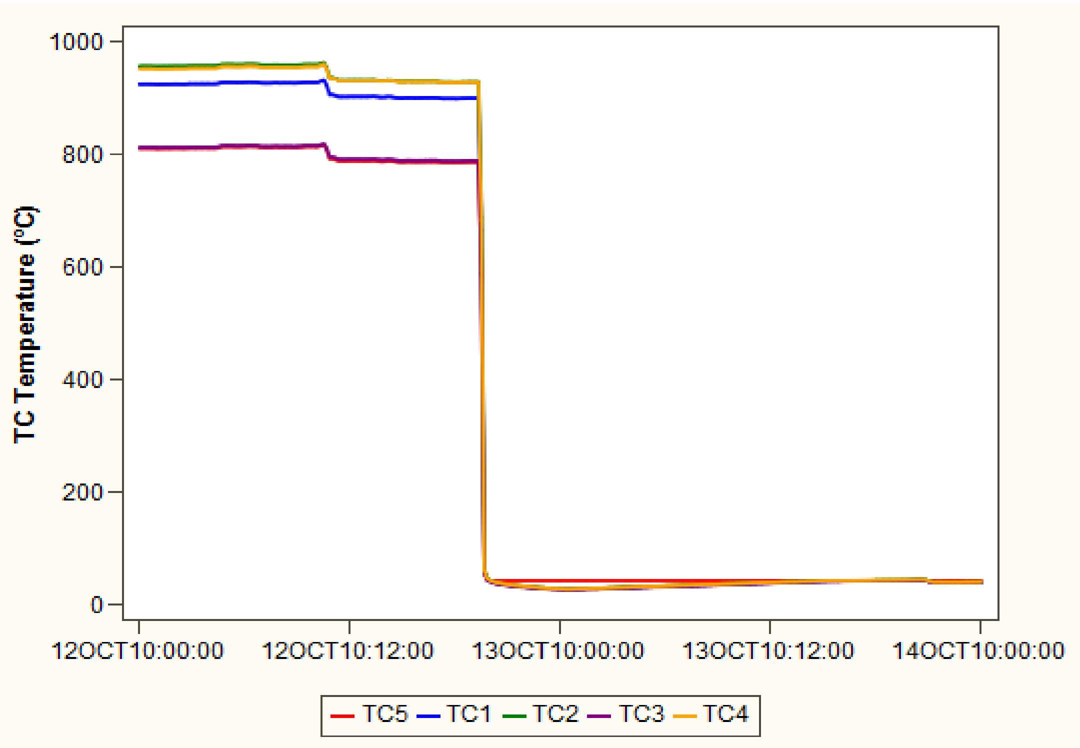

Figure 21. TC5 in Capsule 6 failed on October 12, 2010, at 20:00 (based on actual data).

3.2.3 TC Performance Based on Thermal Model Predictions

The ABAQUS-based thermal models were created for each of six AGR-2 capsules (as described in detail in [Hawkes 2014]). Even through TC readings are used for these models' calibration, the calculated temperatures at TC locations also can be useful in TC performance assessment. For the four U.S capsules, comparison between measured and calculated TC temperatures reveals that predicted temperatures were within 20 to 50°C of the measured thermocouple temperatures for six of the ten working TCs, while three of the other four were within 50 to 100°C and only one had a deviation above 100°C (and its deviation was almost 200°C). There seems to be an inconsistency between the Capsule 6 TC readings and the model prediction, with one TC having a residual above 100°C. This inconsistency is discussed in more detail in Appendix B.

In spite of the apparent inconsistency between measured and calculated TC temperatures described in Appendix B, there is not clear enough evidence to indicate that mislabeling of TCs occurred during AGR-2 installation. Thus, relabeling of TCs in Capsule 6 is not done, but the discussion of Capsule 6 TC readings relative to model predictions (Appendix B) serves as a precaution for calibration of the Capsule 6 thermal model. As a rule, if the differences between measured and calculated TC temperatures are equal to or more than 200°C as for TC3, then the TC readings cannot be qualified. However, readings from this TC are still useful for Capsule 6 temperature temporal profiling, especially because it was the last TC to fail (at the start of ATR Cycle 154A) in Capsule 6. Therefore, temperature readings from TC3 in Capsule 6 are flagged as "*Trend*" records.

DRC Recommendation: Temperature records from TC3 in Capsule 6 before its failure are "*Trend*" records due to large differences with thermal model predictions.

3.2.4 TC Drift Detection

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. If, during the monitoring period, one TC in a capsule indicates significantly higher or lower temperatures relative to another TC in that capsule, then one of the TCs may be drifting. The calculated temperatures at TC locations from the thermal analysis are included here.

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.

The following control chart results give drift assessment for the capsule TC pairs that are comparable (meet the above assumptions) and still have surviving TC pairs. As AGR-2 irradiation progresses, there are fewer operational TCs left in the experiment, which make this TC drift detection method less and less effective. After the end of Cycle 152B, Capsule 6 has only one operational TC (i.e., TC3) and the other U.S capsules have no operational TCs left. Therefore, this technique cannot be used after Cycle 152B. Capsule 2 has only one operational TC for the entire irradiation; therefore, control charting is not possible for this capsule. All of these plots for valid TC temperature data are available on the NDMAS web portal (http://ndmas.inl.gov) under "AGR-2/Analysis/Temperatures."

3.2.4.1 Control Chart Results—TC1 and TC2 in Capsule 6 are Stable. Figure 22 shows the control chart results for TC1 and TC2 in Capsule 6. The TC differences (TC1 – TC2) are found on both sides of the average line, indicating TC1 and TC2 are stable relative to each other during all seven ATR cycles before TC1 failed at the end of ATR Cycle 151A.

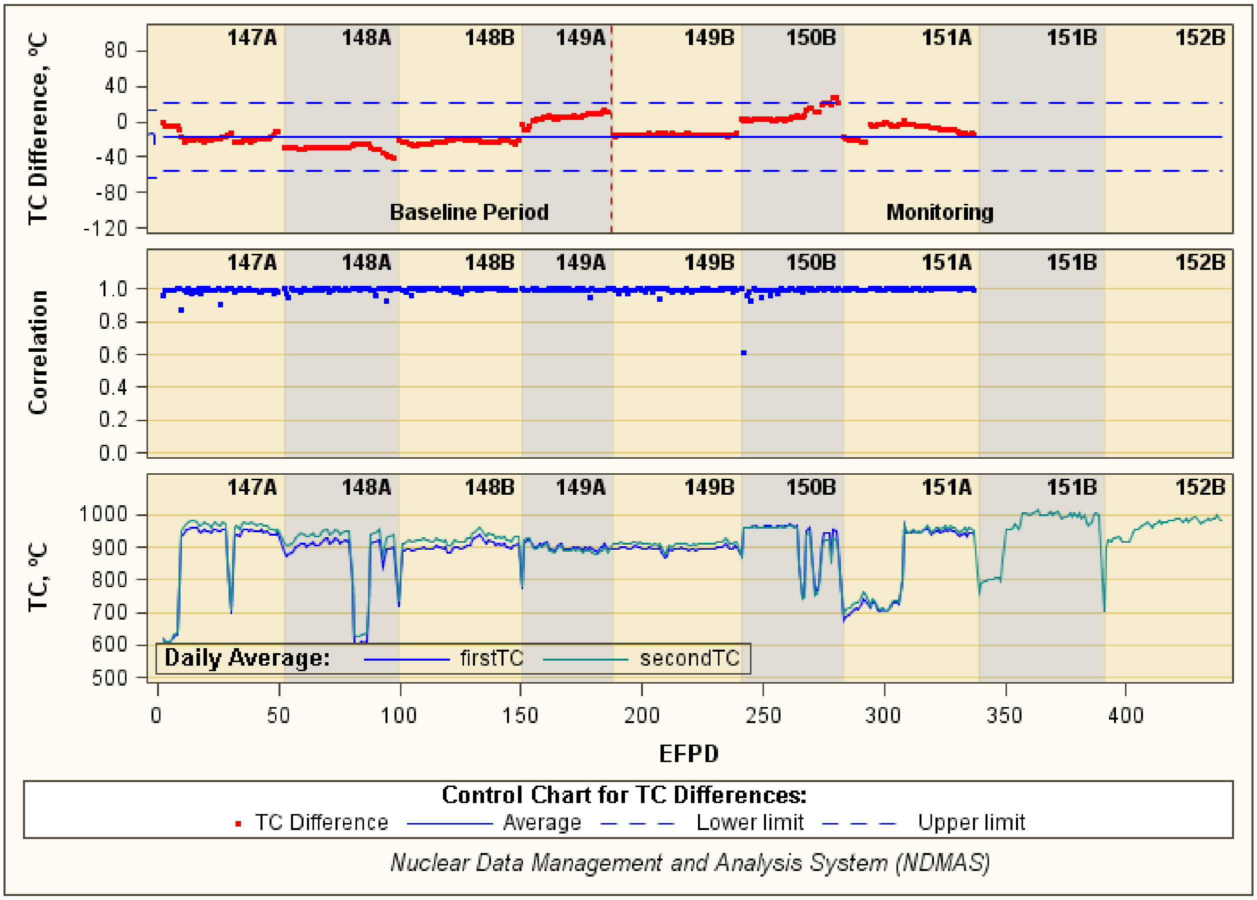

Figure 22. Control chart for the TC1/2 pair in Capsule 6.

3.2.4.2 Control Chart Results—TC1 and TC5 in Capsule 6 are Stable. Figure 23 shows the control chart results for TC1 and TC5 in Capsule 6. The TC differences (TC1 – TC5) being around the average line indicate TC1 and TC5 were stable relative to each other during two ATR cycles before TC5 failed at the end of ATR Cycle 148A.

3.2.4.3 Control Chart Results—TC3 in Capsule 6 is Slightly Drifting Upward Starting from ATR Cycle 149B Relative to TC2. Figure 24 shows the control chart results for the only surviving TC pair in Capsule 6 (i.e., TC2/3) before the end of Cycle 152B. The TC differences (TC2 – TC3) dropped lower than the lower limit of the control charts in the first panel, suggesting that there is a possible downward drift of TC2 or upward drift of TC3 during Cycle 152B. The control chart for TC1 and TC2 presented in Section 3.2.4.1 shows that both TC1 and TC2 are stable; therefore, it is more likely that TC3 might be gradually drifting upward from ATR Cycle 149B to 152B by about 80°C.

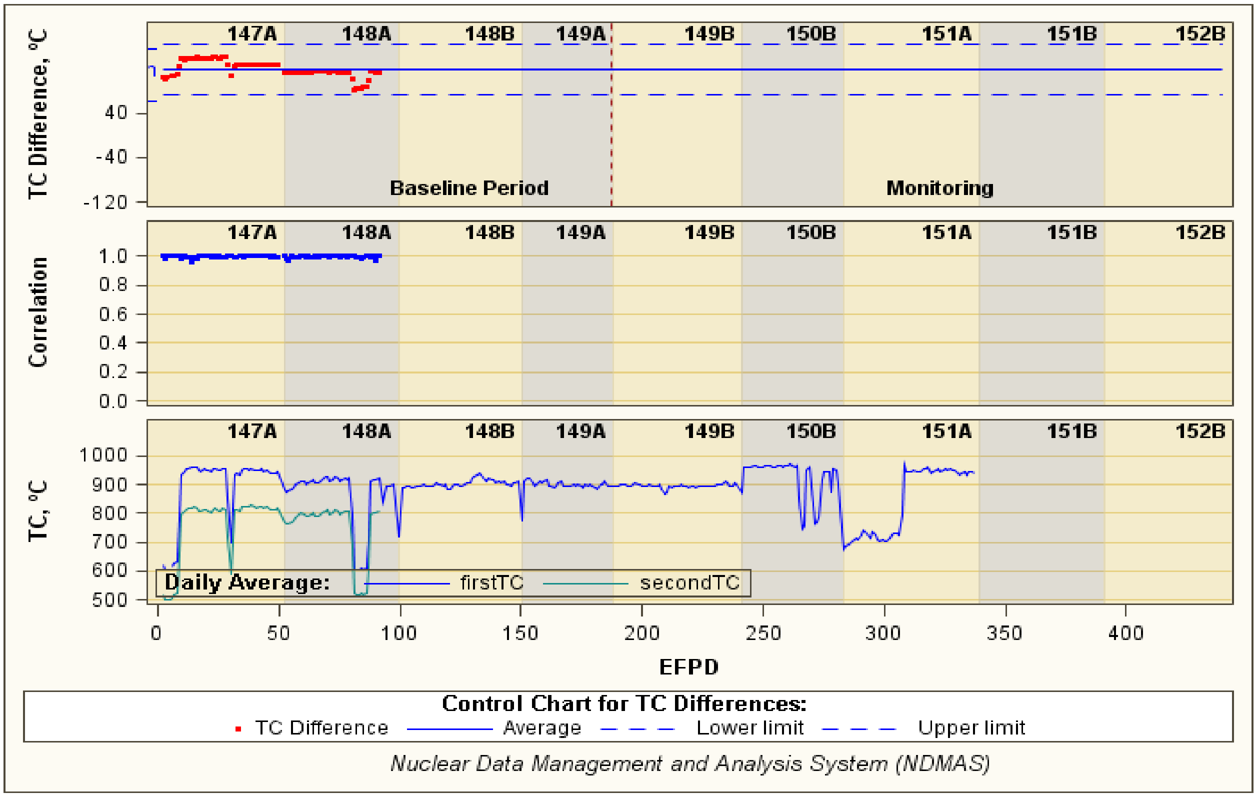

Figure 23. Control chart for the TC1/5 pair in Capsule 6.

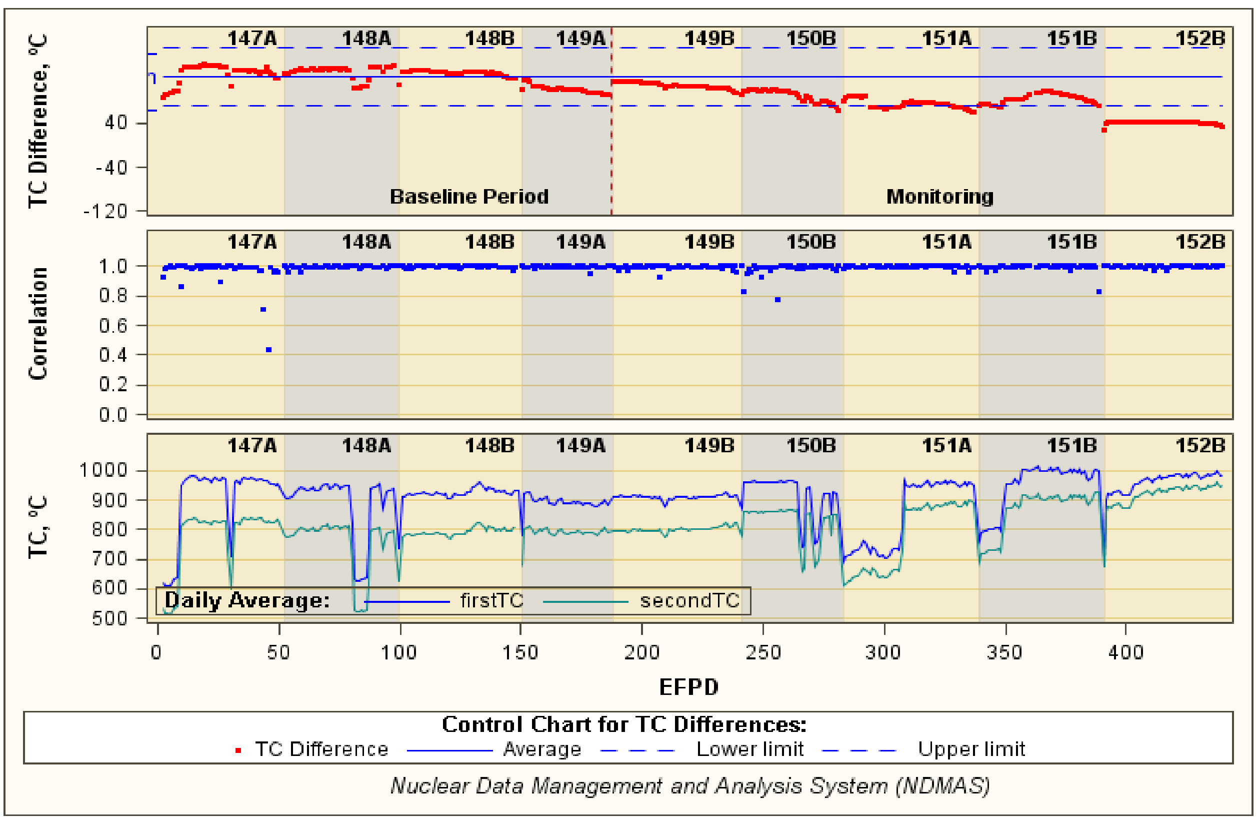

Figure 24. Control chart for the TC2/3 pair in Capsule 6.

3.2.4.4 Control Chart Results— TC4 in Capsule 6 is Drifting Upward Relative to TC2 from Start of Irradiation. Figure 25 shows the control chart results for TC2 and TC4 in Capsule 6. The TC differences (TC2 – TC4) are gradually decreasing and dropped lower than the lower limit of the control charts during ATR Cycles 150B and 151A (Panel 1). This indicates either possible downward drift of TC2 or upward drift of TC4. The control chart for TC1 and TC2 presented in Section 3.2.4.1 shows that both TC1 and TC2 are stable; therefore, it is more likely that TC4 might be drifting upward as apparent in Panel 3. However, the correlations between TC2 and TC4 readings are not deteriorating; therefore, TC4 upward drift might be caused by the changes in capsule thermal condition (e.g., neutron-induced change in conductivity of the graphite holder).

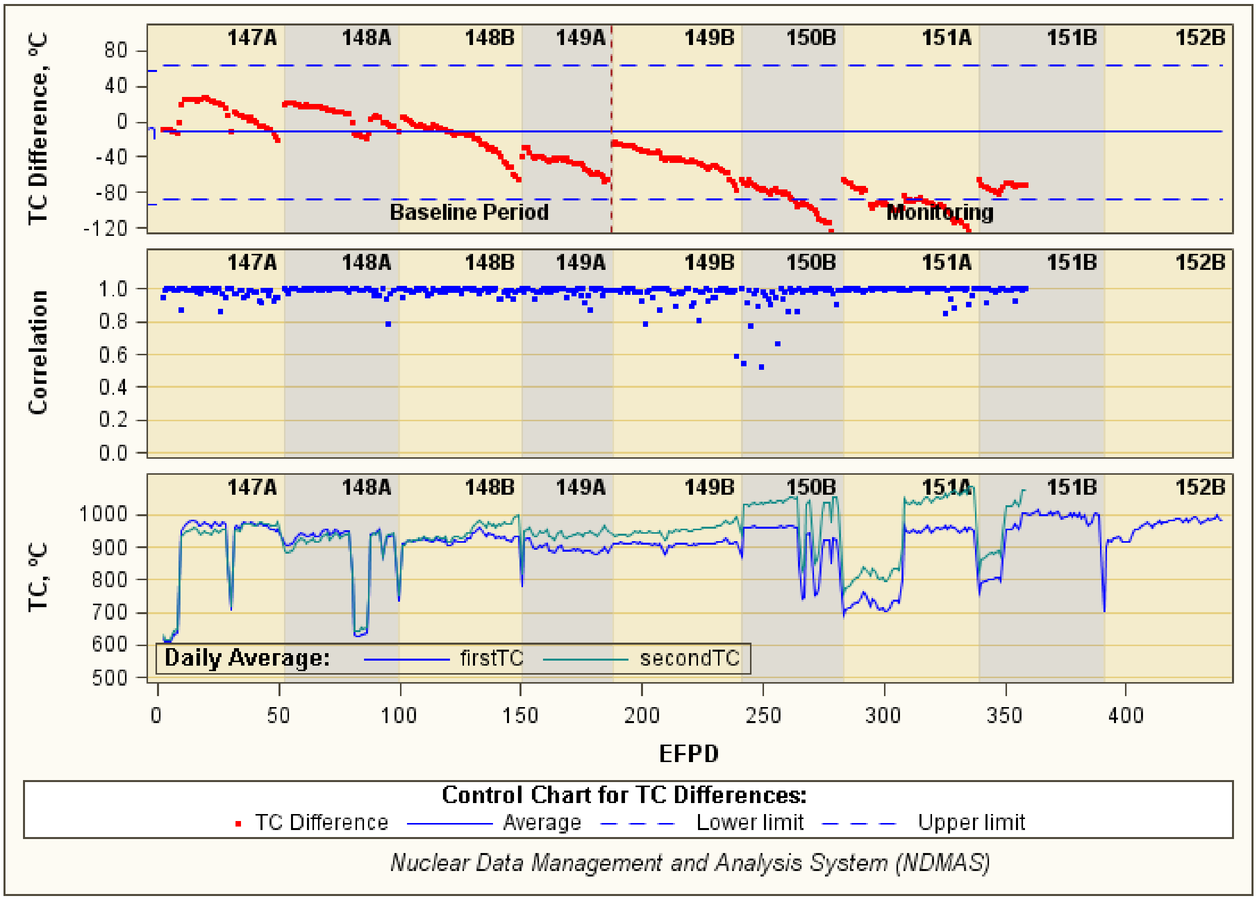

Figure 25. Control chart for the TC2/4 pair in Capsule 6.

3.2.4.5 Control Chart Results—TCs in Capsule 5 are Stable. Control charts of temperature differences between TC1 and TC2 in Capsule 5 in Figure 26 show that the TC differences are slightly and gradually increasing during the first four cycles (Panel 1) before they both failed by the end of Cycle 149A. However, their reading correlations are consistently close to 1 (Panel 2). Therefore, these two TCs in Capsule 5 were likely stable (not drifting).

3.2.4.6 Control Chart Results—TCs in Capsule 3 are Stable. Control charts of temperature differences between TC1 and TC2 in Capsule 3 in Figure 27 indicate that these two TCs were very stable relative to each other before they both failed by the end of Cycle 152B, as shown in Figure 13.

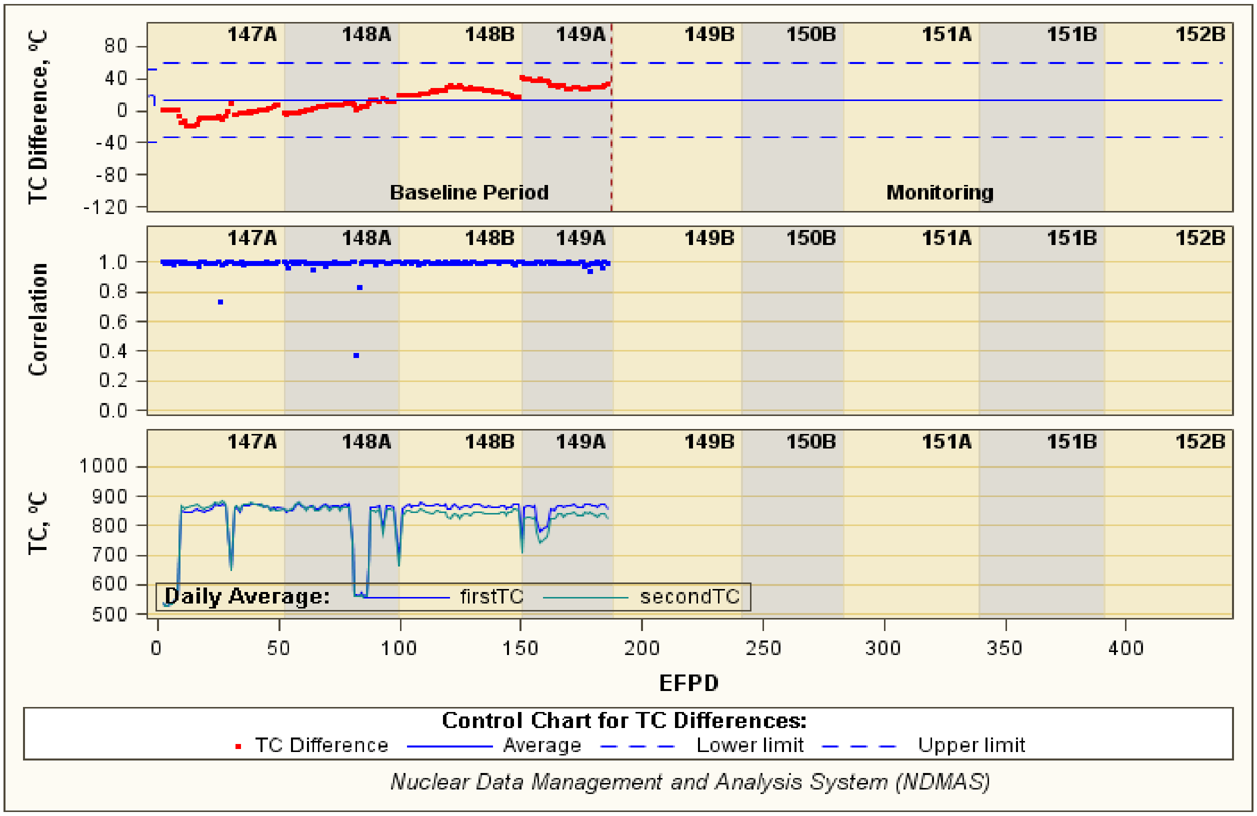

Figure 26. Control chart for the TC1/2 pair in Capsule 5.

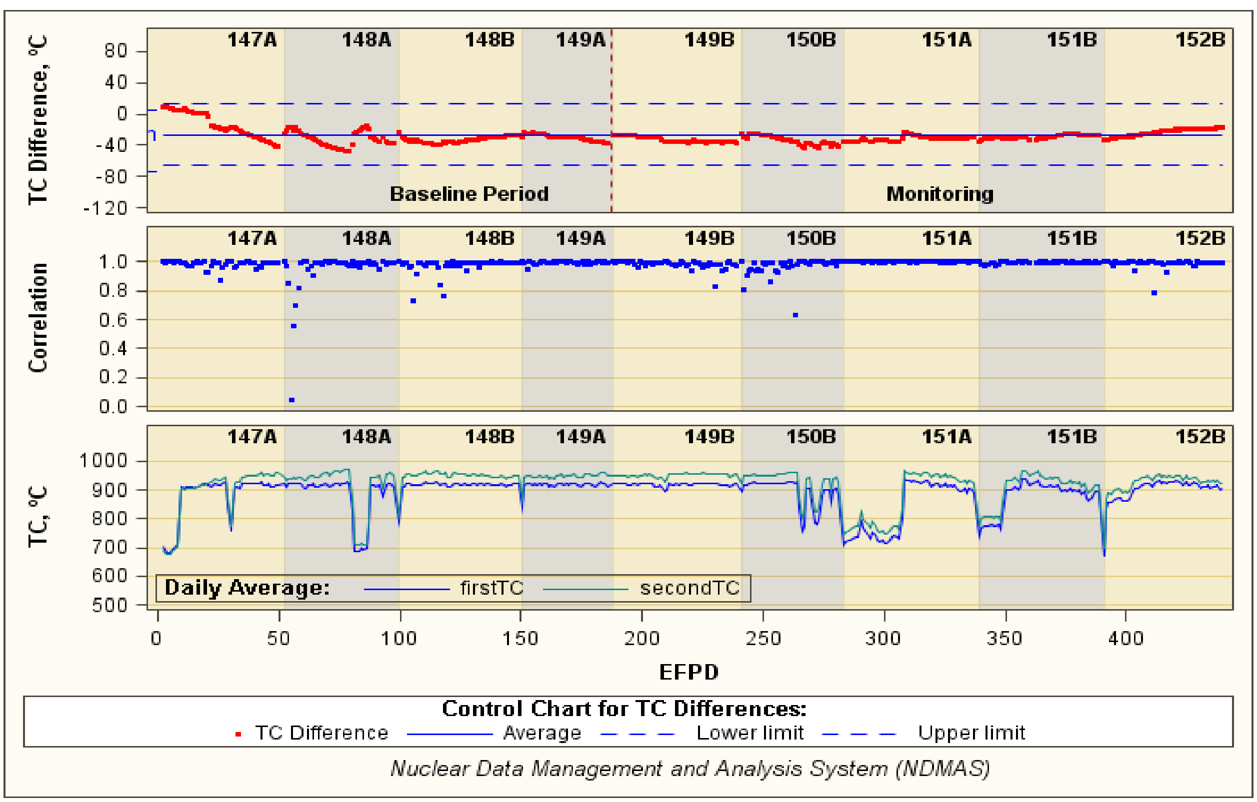

Figure 27. Control chart for the TC1/2 pair in Capsule 3.

3.2.5 TC Virtual Junction Detection

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 28 shows an example of the correlation coefficients for the TCs in Capsule 6. This plot shows that, for the majority of the time, all of these TCs are most highly correlated with some other TC in Capsule 6, indicating no virtual junctions. After January 18, 2013, (end of Cycle 152B) Capsule 6 had only one operational TC3 left; therefore, it is most highly correlated with two surviving TCs in Capsule 4. There is no virtual junction failure detected for TCs in all capsules.

Because there are only two operational TCs left in AGR-2 after PALM Cycle 153B (i.e., TC3 in Capsule 6 and TC2 in Capsule 4), this statistical analysis method is not useful for TC virtual junction detection after Cycle 153B.

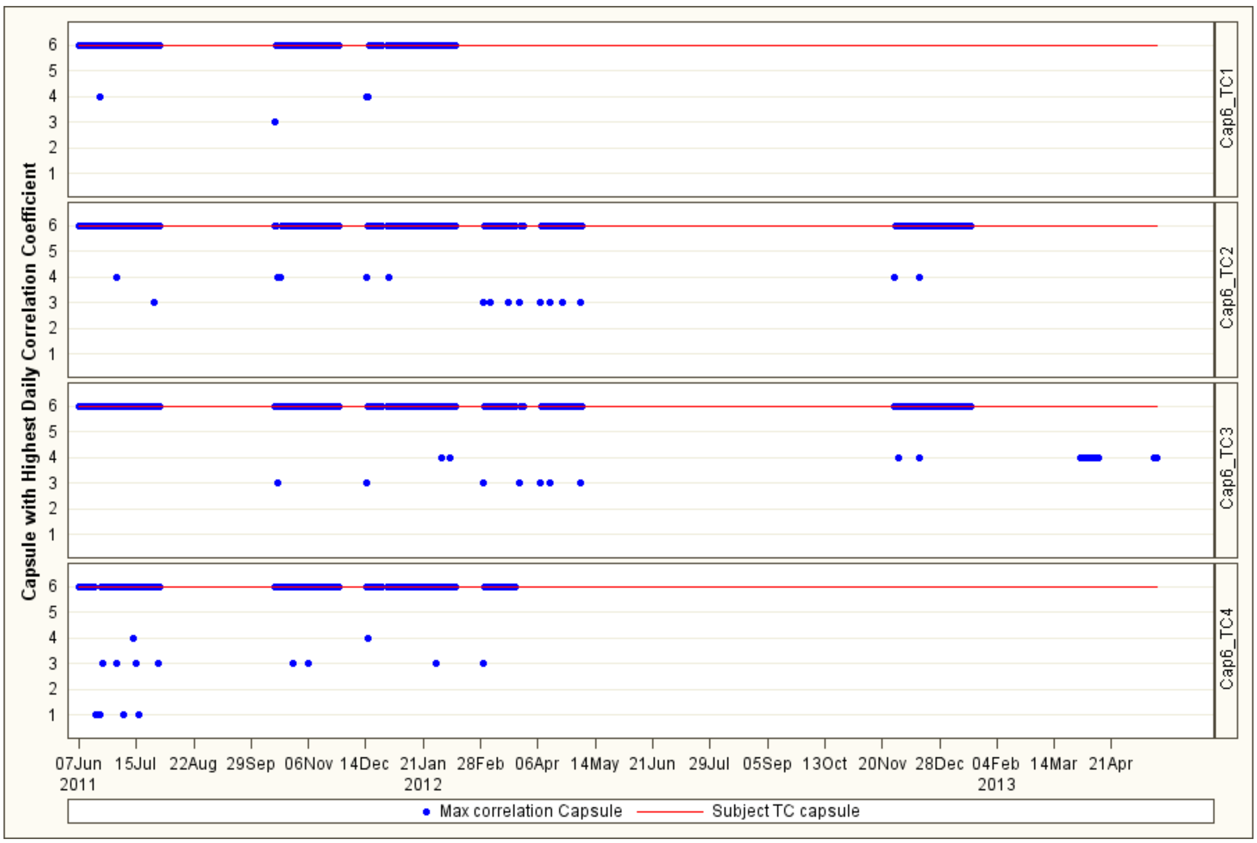

Figure 28. Example of correlation plot for the TCs (1 through 4) installed in Capsule 6. Except for some random scatter, each TC is most highly correlated with another TC in the same capsule, indicating no virtual junction.

3.3 Testing Results for Gas Flow Rates

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. The five failure modes of gas flow rate measurements are: (1) missing, (2) out-of-range, (3) stuck, (4) invalid values due to maintenance activities of the gas flow system, and (5) failure to maintain the same neon fraction in all six capsules and leadout. Modes (1) and (2) are identified by range testing within the NDMAS data capture process. Modes (3), (4), and (5) are identified by data analysis within the data qualification process. Details of the data failures are presented in the following subsections.

As the result of the AGR-2 gas flow data testing and analysis, there are many gas flow rate records classified as "*Failed"* due to missing, negative, and stuck values. The majority of these failures occurred during the ATR outage periods, when the impact of bad flow data is not critical to the test objectives. However, some of those "*Failed"* flow records occurred when the ATR was at full power, preventing exact determination of the neon fractions for the capsules. The neon fractions are crucial inputs to the capsule thermal models used for fuel temperature calculation. Therefore, an effort was made to repair the *Failed* flow data, especially during ATR full power periods as described in the following section. This data repair helps reduce the number of "*Failed"* gas flow rate records.

3.3.1 Repair AGR-2 Gas Flow Data in the NDMAS Database

All of the "Capture Failed" gas flow rate records, which were outside the specified limits for flow rates (0 to 102 sccm as listed in Table 3), including missing values, were closely inspected. The results show that all of the negative flow rates are only slightly less than 0 sccm when flow rates are near zero, thus, they are considered to be valid because they are still within the measurement uncertainty of the flow meter.

The results also show that some of these failed records were caused by the flaws in the data output script instead of the flow meter failures, thus, they can be repaired. The automated data output script reads irradiation data from the CDCS historian and transfers output data files automatically to the NDMAS server every 2 hours. This data output script occasionally generates stuck or missing gas flow rates when flow rates are near zero. In order to correct those erroneous data, the additional AGR irradiation data from the CDCS historian, which collects and stores the capsule irradiation data, were received. These data files are used as reference for the repair of stuck and missing data on top of the data inconsistency revealed by data analysis. Three files stored in NDMAS folder "\\isasapp\NGNP_Data\ATR_Incoming\CDCS_Fillin_by_Cycle" are: (1) "AGR1_OPC_Data_Outputs - 2012Nov27 0000 to 2012Dec10 2100 @1 Min.csv" for ATR Cycle 152B, (2) "AGR1_OPC_Data_Outputs - 2013Apr16 1000 to 2013May24 0700 @1 Min.csv" for ATR Cycle 154A, and (3) "AGR1_OPC_Data_Outputs - 2013Jul22 0800 to 2013Aug20 0000 @1 Min.csv" for ATR Cycle 154B.

3.3.1.1 Replace Stuck Neon Flow Rates. Figure 29 shows neon flow rates in Capsules 1, 2, 3, 5, and 6 during ATR Cycles 154A and 154B. Notably, the neon flow rates in all capsules except Capsule 1 are following each other perfectly. This is by design because the gas mixture is maintained at the same level for all capsules due to cross-talk between their gas lines. Several occasions were identified when neon flow rates in Capsules 2, 3, 5, and 6 are at zero level, but the neon flow rates in Capsule 1 (bottom panel of Figure 29) are stuck at higher values (more than 10 sccm). These periods are highlighted with the dark blue rectangles. Neon flow rates in Capsule 1 would have been approximately the same as all the other capsules during these periods. Therefore, periods of elevated neon gas flow rate in Capsule 1, identified by the blue rectangles, were estimated using the neon gas flow rates of Capsule 2, which were near zero (as they should be). The specific time intervals are (1) April 16, 2013, 08:44:00 to May 20, 2013, 11:17:01 (ATR Cycle 154A), (2) May 21, 2013, 04:18:01 to May 25 (ATR Cycle 154A), 2013, 06:08:01, and (3) July 22, 2013, 08:47:39 to August 18, 2013, 00:00:00 (ATR Cycle 154B).

These neon flow rate corrections in Capsule 1 were supported by the additional data in the following files: (1) "AGR1_OPC_Data_Outputs - 2013Apr16 1000 to 2013May24 0700 @1 Min.csv" for ATR Cycle 154A and (2) "AGR1_OPC_Data_Outputs - 2013Jul22 0800 to 2013Aug20 0000 @1 Min.csv" for ATR Cycle 154B.

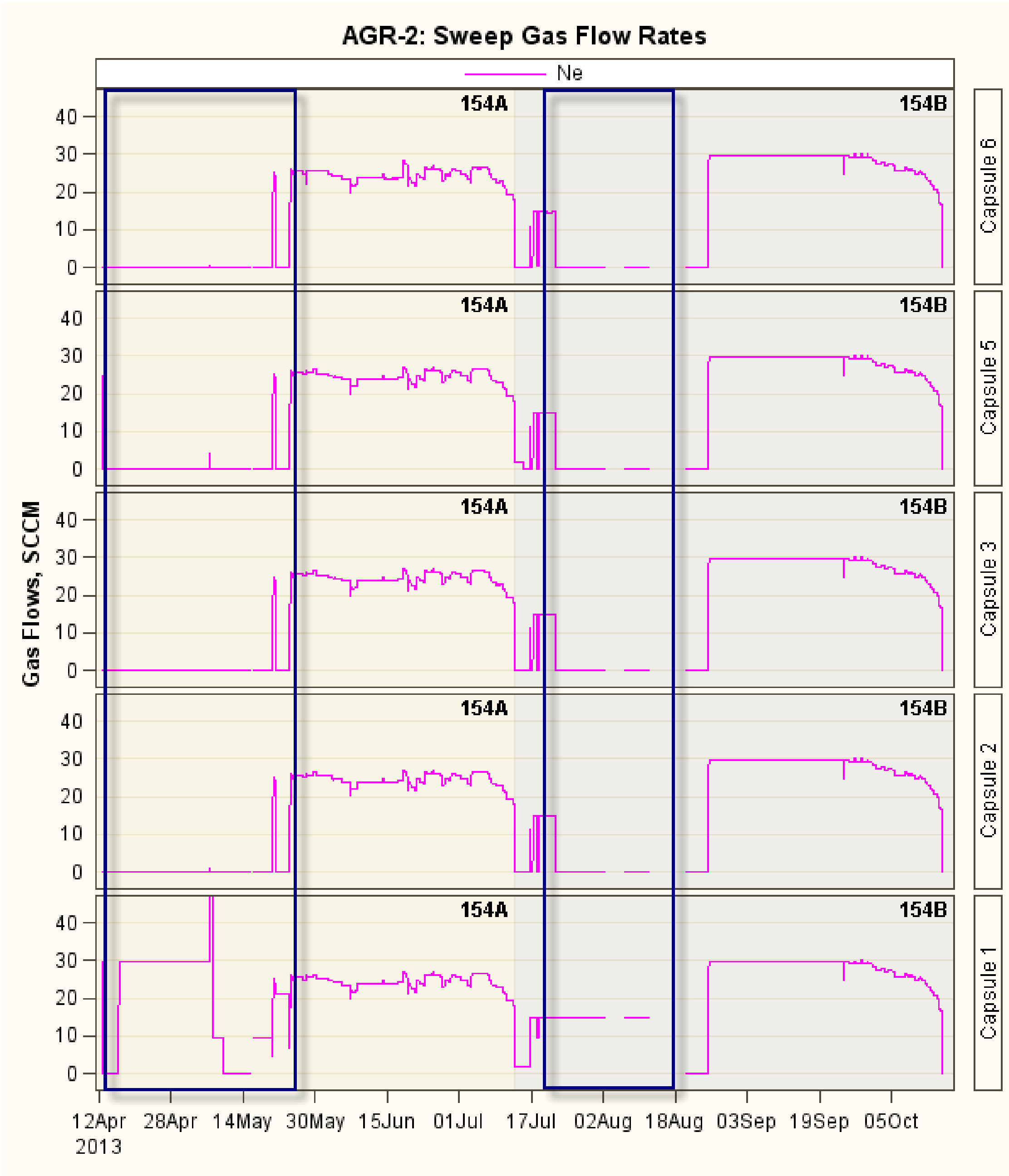

Figure 29. Capsule neon flow rates for ATR Cycles 154A and 154B, showing the periods (within rectangles) when neon flow to Capsule 1 was reported erroneously due to a programming error in the automated data output script.

3.3.1.2 Replace Negative Gas Flow Rates with zero. During the AGR-2 experiment, there were 7,846 records where gas flow was between -0.1 and 0.0 sccm. These very small negative values are all within the uncertainty of the flow meter and reflect no gas flow through the meter. The 7,846 negative gas flows were replaced with 0 sccm to avoid the use of negative gas flow values in calculations of other experimental parameters, such as fission product R/B ratios.

3.3.1.3 Fill-in Missing Neon Flow Rates. A number of neon gas flow values are missing during ATR Cycle 152B. Missing neon gas flow periods are shown in Figure 30, identified with rectangles for

Capsule 1 prior to power-up for Cycle 152B and for leadout in the early days of ATR Cycle 152B. All capsules were being fed the same gas mixtures because of capsule cross-talk issues; therefore, the missing neon gas flow data for Capsule 1 can be estimated using the gas flow from the adjacent Capsule 2. Missing neon gas flow rates to Capsule 1 for the periods Nov 27, 2013, 12:00 to November 29, 2013, 22:35 were replaced with near-zero neon gas flow rates from Capsule 2. The missing leadout data cannot be estimated from the other capsules, because no neon was being fed through the leadout early in ATR Cycle 152B. Therefore, the missing leadout neon values were estimated to be 0 sccm during the period from November 30, 2012, 00:45 to December 10, 2012, 17:17:02. These fill-in neon flow rates were confirmed by additional data in the file "AGR1_OPC_Data_Outputs - 2012Nov27 0000 to 2012Dec10 2100 @1 Min.csv" for ATR Cycle 152B.

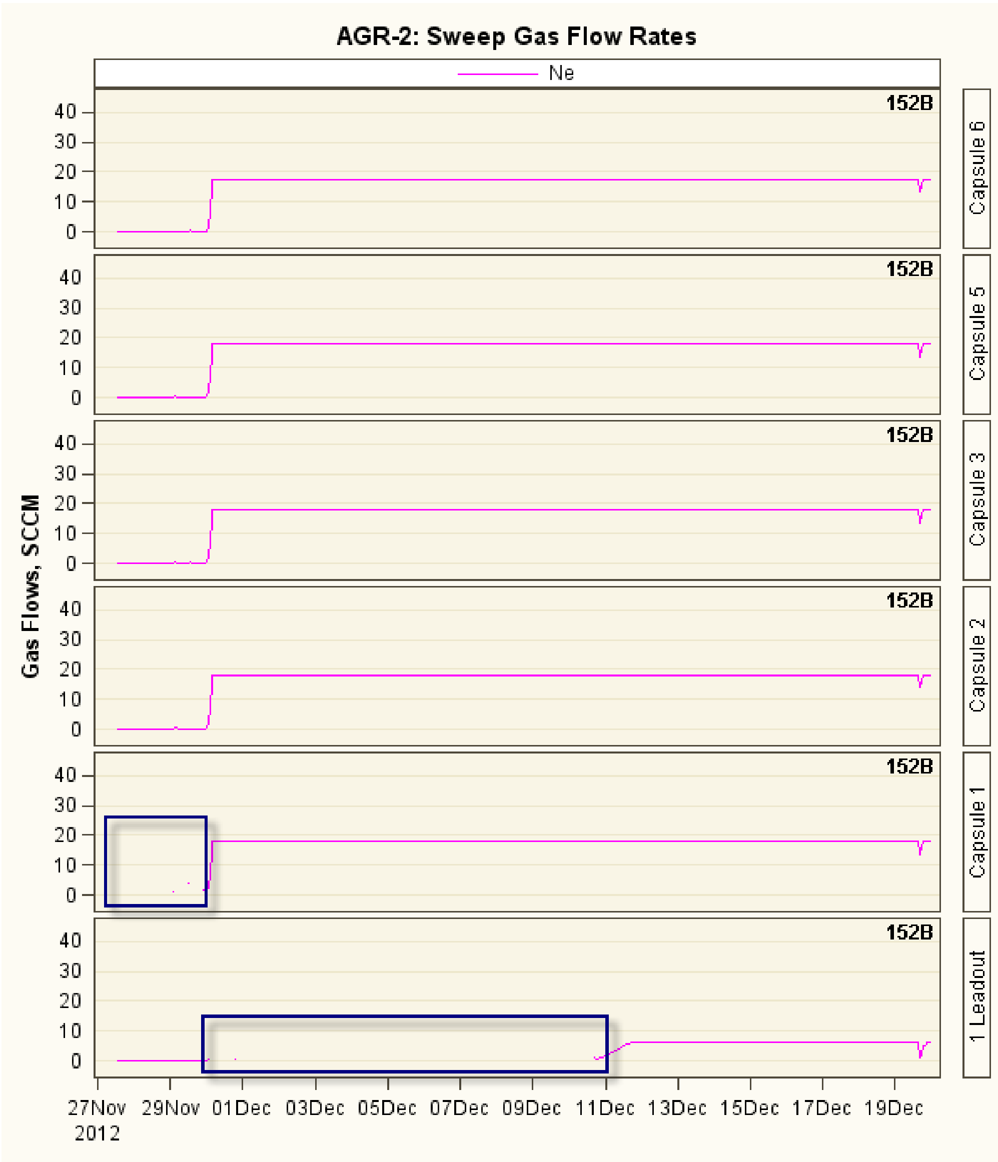

Figure 30. Neon gas flow rates in AGR-2 after power-up for ATR Cycle 152B. Periods of missing gas flow data for Capsule 1 and leadout are identified with rectangles.

3.3.2 Capsule Gas Flow Rates

This section discusses data failures for neon and helium inlet and outlet flow data of four U.S. capsules and leadout after the data repair described in Section 3.3.1. The failures of the FPM flow data are discussed separately in Section 3.3.3. The summary of capsule gas flow rate data is presented in Table 8. A total of 8,727,950 flow rate records were captured in the NDMAS database and, of these data, 223,333 records (2.6% of the total) were *Failed* due to missing values, too high values, and invalid values during periods of maintenance of the gas flow system.

Table 8. Number of neon, helium, and outlet gas flow records failed from database testing.

ATR Cycle	Total No. of Records	Min. Value	Max. Value	No. of Missing	No. of Too High	No. of Failed	Qualified (Percent)	Failed (Percent)
147A	113,246	0	64.8	144	0	144	99.9	0.1
148A	141,120	0	59.8	1,283	0	1,283	99.1	0.9
148B	155,316	0	104.8	72	26	98	99.9	0.1
149A	165,438	0	104.9	111	26	137	99.9	0.1
149B	226,100	0	102.6	0	9	9	100.0	0.0
150A	8,876	0	18.9	0	0	0	100.0	0.0
150B	173,922	0	73.3	0	0	0	100.0	0.0
151A	254,156	0	59.2	1	0	1	100.0	0.0
151B	329,434	0	102.7	4	1	5	100.0	0.0
152A	1,304,310	0	105.5	36,639	63	36,702	97.2	2.8
152B	1,072,652	0	35.1	129	0	129	100.0	0.0
153A	521,486	0	39.6	28,631	0	28,631	94.5	5.5
153B	648,312	0	103.3	0	1,963	27,430 a	95.8	4.2
154A	1,814,344	0	100.0	90	0	128,764 b	92.9	7.1
154B	1,799,238	0	34.5	0	0	0	100.0	0.0
Total	**8,727,950**	**—**	**—**	**67,104**	**2,088**	**223,333**	**97.4**	**2.6**

a. Failed records during ATR Cycle 153B include 25,467 records during the "securing gas flow" period from March 12 at 05:26 to March 13 at 14:00 in 2013 (outage phase of ATR Cycle 153B).

b. Failed records during ATR Cycle 154A include 128,674 records during the "lock-out tag-out" period from 04:15 April 30, 2013 until 15:44 May 6, 2013 (outage phase of ATR Cycle 154A).

3.3.2.1 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 67,104 missing flow rates out of a total of 8,727,950 flow data records (or 0.77%), representing 30% of all gas flow failed data. Table 8 breaks down the number of missing data into cycles, showing that most of the missing data are during the "Low power" Cycle 152A, followed by the "Outage" Cycle 153A. For these cycles, the AGR-2 test ran on pure helium; therefore, the missing values are not hard to fill in, if needed. Additionally, it was decided that there will be no need to perform physics and thermal simulations for these cycles; therefore, the need for gas flow data is limited. All missing records during ATR full power were filled in as necessary (Section 3.3.1.3).

<u>DRC recommendation</u>: Fail all missing flow rate records.

3.3.2.2 Out-of-Range Data. Because the gas flow rates range from 0 to 102 sccm, the negative flow rates and "too high" flow rates (greater than 102 sccm) are assigned *"Failed"* data status as a result of the NDMAS capture range testing. However, all slightly negative flow rates recorded for AGR-2 were replaced with 0 sccm (as described in Section 3.3.1.2). There are only 2,088 too-high flow rates out of a total of 8,727,950 neon, helium, and outlet flow data records (or 0.02% of total records), representing about 1% of all the capsule gas flow failed data.

Too high gas flow rates: The PALM cycle, Cycle 153B, has the most number of "too-high" flow rates with 1,963 records, as shown in Table 8. The 1,963 "too-high" records are helium flow rates in Capsule 6 recorded from March 12 to13, 2013, during the outage of Cycle 153B. They are all equal to 103.2705 sccm, suggesting stuck values.

DRC recommendation: Fail all too-high flow rate records.

3.3.2.3 Maintenance Activities of Gas Flow System. There are two known maintenance activities of the gas flow system, which lead to invalid flow rate data for the AGR-2 experiment during these time periods. The first period is between March 12, 2013, at 05:26 and March 13, 2013, at 14:00. According to the experimental log book (based on the phone message to Dawn Scates from the ATR operator), ATR personnel were performing secured gas flow (meaning stopped gas flow) for AGR-2 during the outage phase of ATR Cycle 153B. Figure 31 shows neon, helium, and outlet flow rates from March 11 to 16, 2013, for Capsules 2, 3, 5, and 6. During the "secured gas flow" period, the helium inlet flow rates in Capsules 2, 5, and 6 are unusually high (the green lines are near 100 sccm), when the neon inlet (pink lines) and outlet flow rates (blue lines) are at 0 sccm as expected (see Figure 31). Therefore, all of these abnormal gas flow rates should be *"Failed"*.

The second period is between April 30, 2013, at 04:15 and May 6, 2013, at 15:44 (outage phase of ATR Cycle 154A). This is a "lock-out/tag-out" period when the ATR personnel were performing maintenance of the gas flow system after the AGR-2 experiment moved back to the B-12 location from the temporary I-24 location. Figure 32 shows neon, helium, and outlet flow rates from April 28 to May 7, 2013, for Capsules 2, 3, 5, and 6. During the "lock-out/tag-out" period, the helium inlet flow rates in Capsules 2, 5, and 6 are still at 15 sccm (the green lines), when the neon inlet (pink lines) and outlet flow rates (blue lines) are at 0 sccm as expected (see Figure 32). Therefore, all of these abnormal gas flow rates should be *"Failed"*.

DRC recommendation:

1. Fail all flow rate records during the "secured gas flow" period between March 12, 2013, at 05:26 to March 13, 2013, at 14:00 in 2013 (outage phase of ATR Cycle 153B).
2. Fail all flow rate records during the "lock-out tag-out" period between April 30, 2013, at 04:15 and May 6, 2013, at 15:44 (outage phase of ATR Cycle 154A).

3.3.3 Downstream (FPM) Gas Flow Rates

The outlet lines transport mixed gas together with any fission products released from the capsules to the FPMS, which is capable of measuring fission product release activities and detecting individual fuel particle failures. A relief valve was installed before each detector to maintain required gas pressure in each capsule. If this valve lifts, then the mixed gas will leak out before reaching the detector, preventing it from correctly counting the isotope activities of fission products released from the capsule. To detect and prevent valve lifting, seven additional gas flow meters were installed at the outlets of the seven FPMS detectors to measure downstream gas flow rates from these detectors during the outage cycle (i.e., ATR Cycle 153A). FPMS gas flow meter number 7 is for the spare detector, which is used as a replacement for any failed detector. The first record of FPM flow data received by NDMAS was on February 26, 2013, at 10:40. Ideally, the downstream gas flow rates (labelled "FPM") should be equal to the outlet flow rates measured at the capsule outlets when the relief valves are closed, allowing all mixed gas from the capsules to flow to their corresponding FPMS detectors. This feature will be used to assess the quality of the downstream data. Figure 33 shows hourly averaged flow rates of downstream (purple line) and outlet (blue line) flows for AGR-2 U.S. capsules from the time when the downstream data were first captured in the NDMAS database.

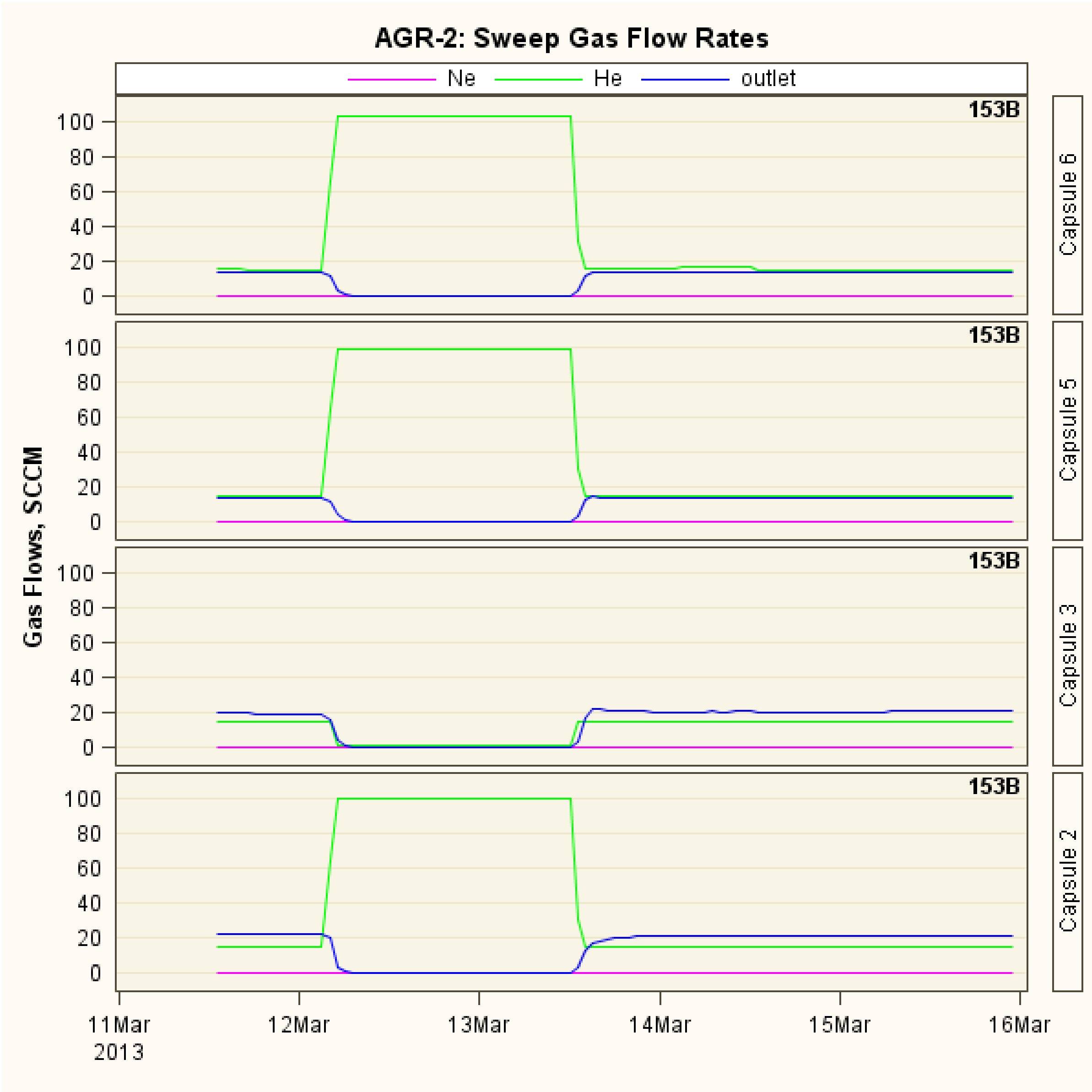

Figure 31. Neon, helium, and outlet flow rates during the "secured gas flow" period between March 12, 2013, at 05:26 to March 13, 2013, at 14:00 (outage phase of ATR Cycle 153B).

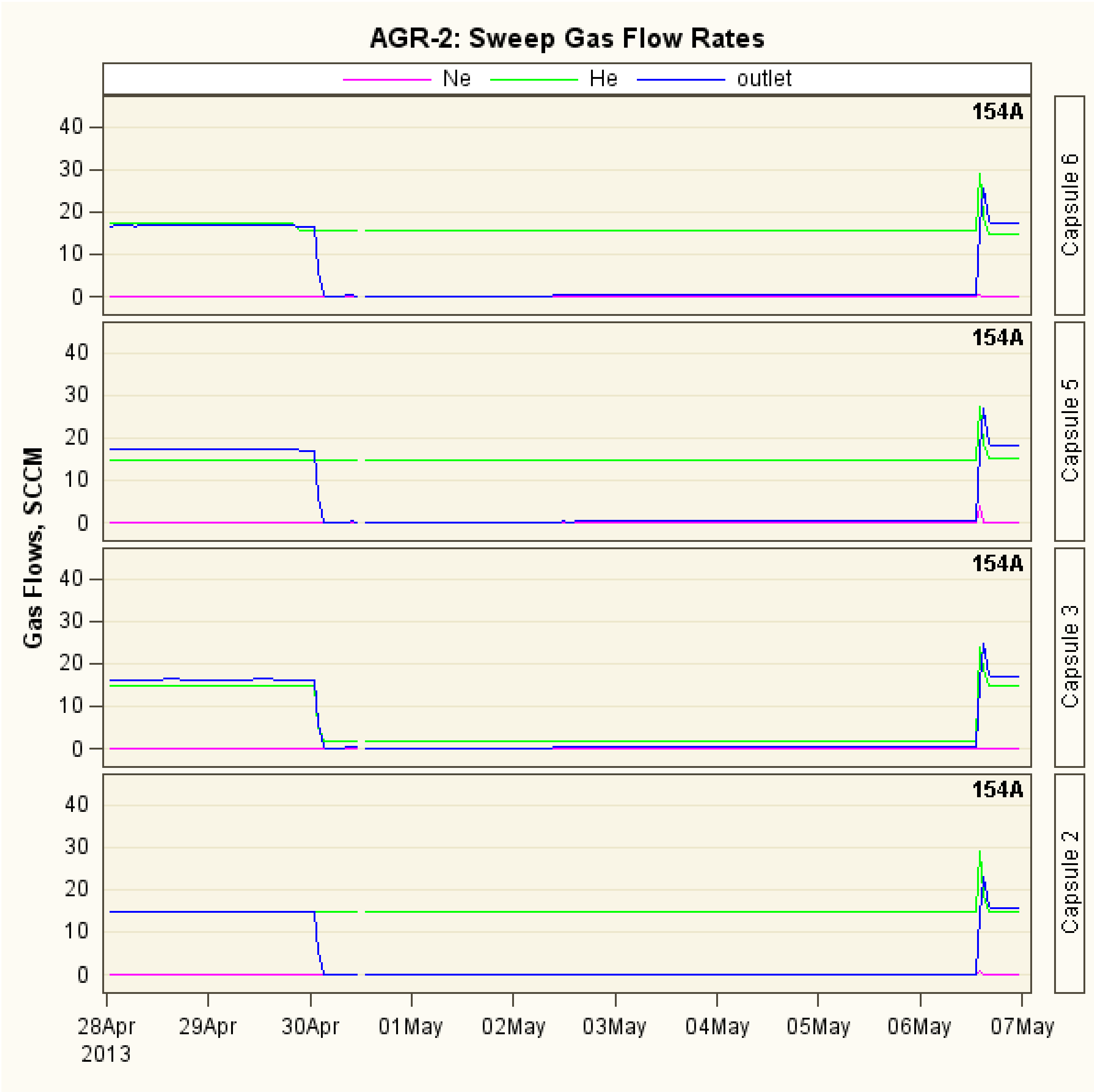

Figure 32. Neon, helium, and outlet flow rates during the “lock-out tag-out” period between April 30, 2013, at 04:15 and May 6, 2013, at 15:44 (outage phase of ATR Cycle 154A).

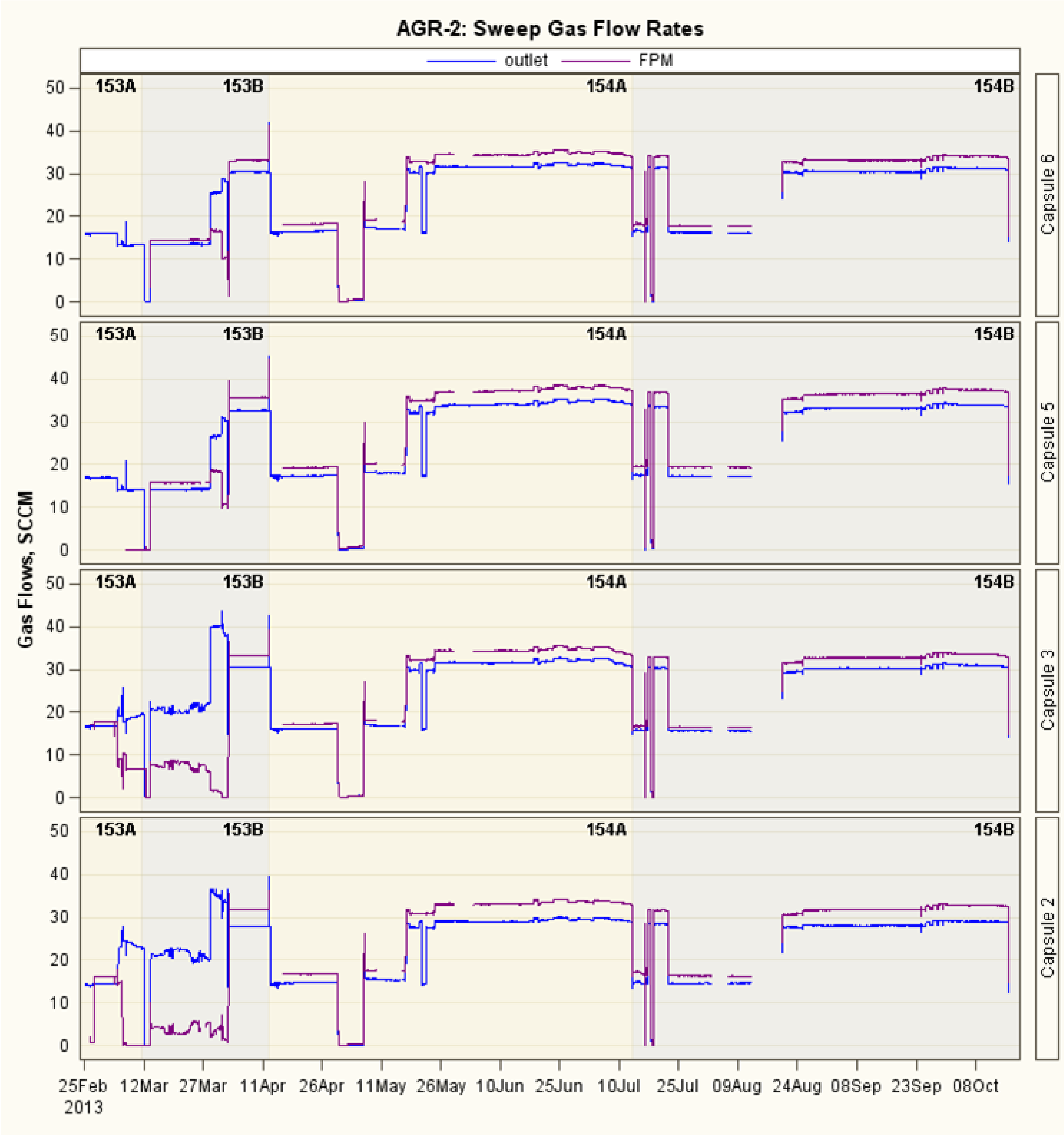

Figure 33. Downstream and outlet gas flow rates for AGR-2 U.S. capsules.

The following data issues of downstream gas flow rates are observed from these plots:

1. Missing values: The downstream flow rates are considered missing only when data existed for outlet flow rates. Most of the missing downstream flow data are during ATR outage periods indicated by lower outlet flow rates (less than 20 sccm). Because release data are not important to the program objectives during these time periods, these missing data do not need to be refilled. During ATR full power, the downstream data were missing from May 29, 2013, at 08:00 to June 3, 2013, at 08:00.

2. Too low values: The downstream flow rates are considered to be too low when they are significantly lower than outlet flow rates. Too low downstream flow rates could indicate two scenarios: (1) flow data are failed due to flow meter failure if the relief valve is confirmed to be working correctly; and (2) flow data are valid if the relief valve is confirmed lifted. At the startup of Cycle 153B, the downstream flow rates were lower than the outlet flow rates in all capsules, prompting the checking of all relief valves. It was confirmed that those valves did indeed lift.
3. Stuck values: The downstream flow rates did not follow the dip in outlet flow rates near May 21, 2013, indicating a possible problem with the downstream flow data. The plots in Figure 34 showing data “zoom-in” around that time reveal that the downstream flow rate measurements were stuck at the same number from May 18, 2013, at 23:10 to May 22, 2013, at 08:30 (as shown in Table 9). They remained at those levels even when the outlet flow rates were reduced to about 15 sccm around May 21, 2013.
4. Consistent bias (too high) values: After fixing the relief valves on April 3, 2013, the downstream flow rates were consistently higher than the outlet flow by up to 4 sccm in all capsules. However, because the plots of downstream and outlet flow rates were fairly parallel to each other over time, the high values were probably caused by instrument bias.

Table 9. Stuck downstream flow rates for AGR-2 U.S. capsules.

Downstream Flow Rate (sccm)			
Capsule 6	Capsule 5	Capsule 3	Capsule 2
32.78854	35.00435	32.28494	30.96644

<u>DRC recommendation</u>:

1. Flag all FPM flow rate data prior to Cycle 154A from February 26, 2013, at 10:40 as *“Failed”* due to downstream flow meter adjustments and relief valves issues.
2. Flag all FPM flow rates during Cycles 154A and 154B as *“Trend”* data due to measurement bias.

3.3.4 Gas Line Crosstalk and Capsule Neon Fractions

Significant capsule gas line crosstalk and leadout leakage problems that started to occur early in Cycle 150B after the AGR-2 test was reinserted in the reactor following the PALM Cycle 150A. The crosstalk issue was discussed in detail in TEV-2004 (Pham 2014). These cross-talk and leakage problems made it impossible to control the temperature in each capsule by independent gas mixtures as designed. Therefore, AGR operational staff continued a procedure to set all capsules to the same helium/neon gas mixture ratio (neon fraction) for overall experiment temperature control from the middle of ATR Cycle 151A as shown in Figure 35. The neon fraction estimation process for AGR-2 capsules during ATR Cycle 150B and the first half of ATR Cycle 151A, based on a regression relationship between the neon fraction and relevant parameters (such as TC readings, fuel heat rate, and fast fluence), is also presented in TEV-2004 (Pham 2014).

However, there is a concern that the helium/neon gas flows recorded during subsequent cycles may not adequately represent the gas flow mixture through their associated capsule because of gas line crosstalk and capsule leakage (the data are correct but do not support application to their defined intended use) when the inlet neon fractions are not the same for all capsules and the leadout.

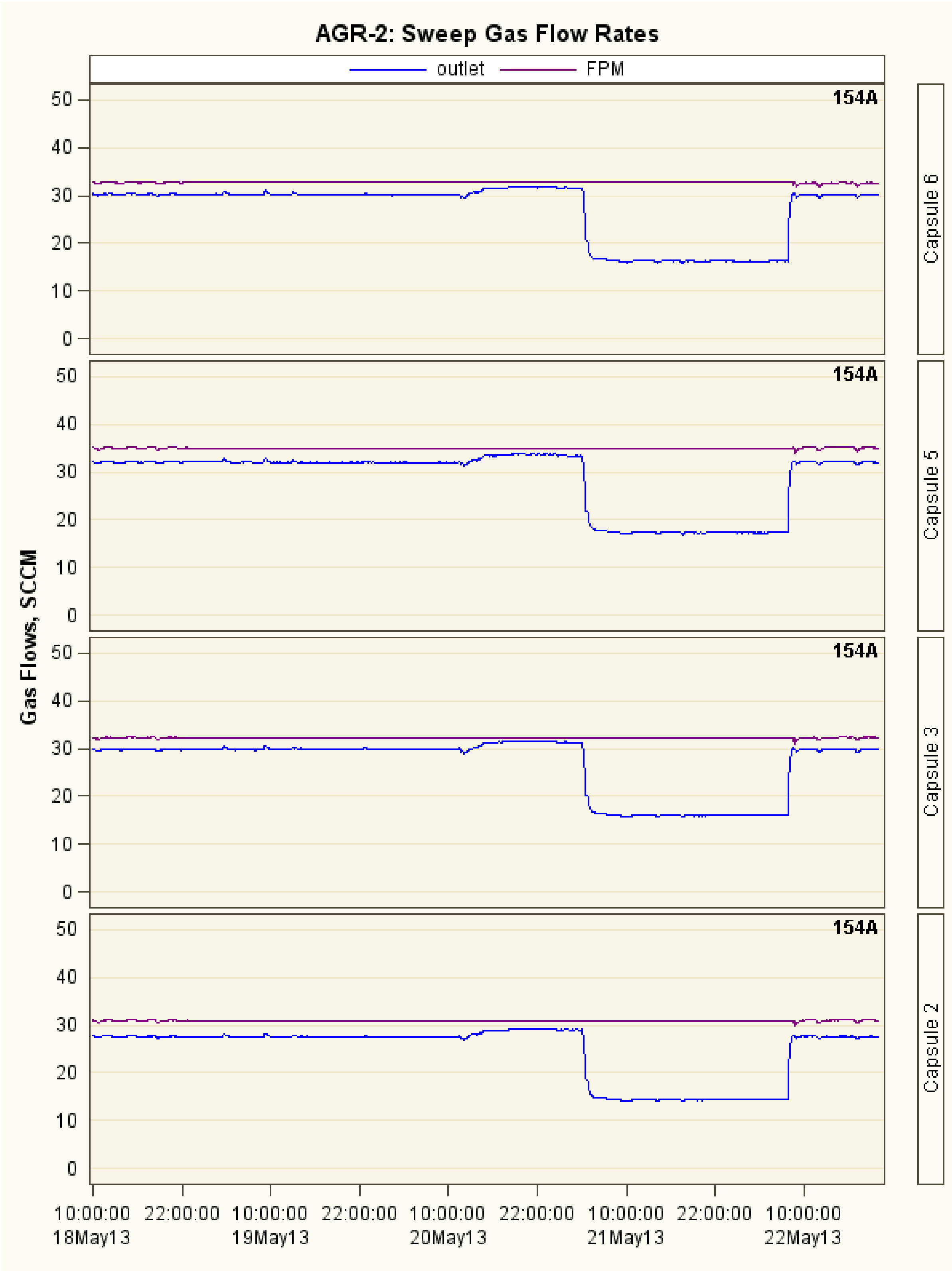

Figure 34. Downstream and outlet gas flow rates when the downstream flow rate measurements seem stuck (or unresponsive).

To identify unreliable helium/neon inlet gas flow records (those that do not represent true individual capsule gas flow mixtures), the following procedure was used:

1. Capsule gas mixture data (e.g., neon fraction) after the PALM Cycle 150A are assumed to be valid only when the gas flow mixture ratio (e.g., neon fraction) was approximately the same between all capsules (and the leadout). This operating procedure was fully implemented on January 17, 2012, in the middle of Cycle 151A.
2. When the neon fraction for a given capsule was not approximately the same as all other capsules, the helium/neon inlet records for all capsules for that time step were considered to be unreliable. These unreliable records were identified by: (1) calculating the mean neon fraction of all capsules for each time step (5-minute data records); and (2) identifying those records where the ratio of the maximum capsule neon fraction to mean neon fraction for a given time step was greater than 0.08.

The DRC approved the above procedure during qualification of data from the previous cycles. The neon fractions in Capsule 6 were lower than the neon fraction in the other five capsules by as much as 0.16 (0.715 neon fraction in Capsule 6 versus 0.875 in the other five capsules) from June 17, 2013 to July 13, 2013 (end of Cycle 154A), as shown in Figure 35. Additionally, there was only one surviving TC in the AGR-2 test train during that time, which makes it impossible to accurately estimate neon fraction in each capsule as had been done for earlier cycles subsequent to Cycle 150A. Therefore, these lower neon fractions in Capsule 6 will increase the uncertainties of neon fractions in all six capsules due to their cross-talk. However, there is no indication of flow meter failure during this time; therefore, the inlet neon and helium flow rates are *"Qualified",* with the caution that the neon fractions calculated as a fraction of inlet neon/helium flow rates for all capsules might not be the actual neon fractions. The impact of high uncertainty of capsule neon fraction on uncertainty of the AGR-2 thermal model temperature prediction should be quantified accordingly.

The DRC also decided that all capsule outlet flow (Q_Mix_Out) data received after Cycle 150A may have capsule cross-talk; therefore, they are not reliable for their intended use in determining FPMS release rates and R/Bs. However, all of the capsule outlet gas flow rates records for these cycles are still *"Qualified"* to be used for other purposes because there is no indication of flow meter failure.

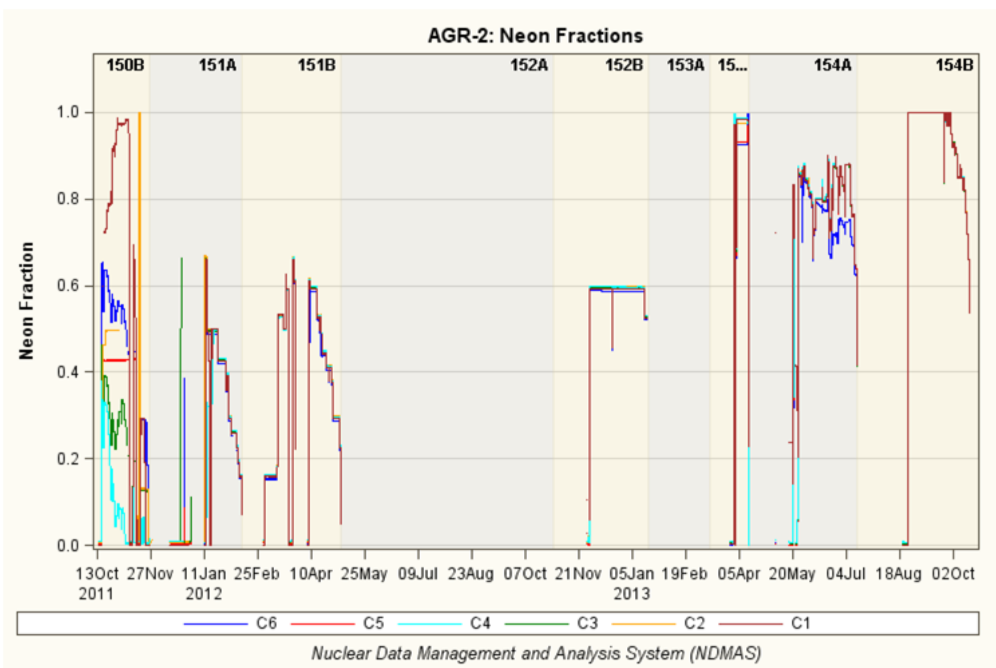

Figure 35. Capsule neon fractions after ATR PALM Cycle 150A.

4. DATA RECORD QUALIFICATION SUMMARY

This section summarizes the data qualification decisions made by the DRC for the data packages received by NDMAS from June 19, 2010, (three days before startup of Cycle 147A) through October 23, 2013, (seven days after Cycle 154B shutdown). 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

4.1.1 Testing Result Summary

AGR irradiation monitoring data captured in the NDMAS database from ATR Cycles 147A through 151B are of 10-minute or 5-minute averaged data and from ATR Cycle 152A are 1-minute instantaneous measurements. From the beginning of Cycle 152A, the new automatic data transfer from the CDCS provides NDMAS with 1-minute instantaneous irradiation monitoring data every 2 hours. The increased amount of irradiation data and increased delivery frequency prompted NDMAS to implement a more flexible database structure and online testing. 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 gas flow measurements.

4.1.1.1 TC Readings. The decisions made in several DRC meetings convened throughout AGR-2 irradiation confirmed all TC failures as presented in Section 3.2.2. They also disqualified all missing and negative TC reading values. Table 10 provides the summary of data qualification status of all TC records for four AGR-2 U.S. capsules for each of the fifteen cycles. This table also contains the cycle maximum and minimum temperature values for reference. A total of 6,857,675 TC temperature records were captured in the NDMAS database and of these data, 5,288,249 records (77.1% of the total) were *"Failed"* and 418,569 records (6.1% of the total) were *"Trend"* due to large differences between readings of TC3 in Capsule 6 and calculated values. By the end of ATR Cycle 154A, all TCs in the AGR-2 test train failed. However, the overall percentage of failed TC records is high, partially because of the fact that TCs failed toward the end of irradiation when the recording frequency was higher from ATR Cycle 152A (every minute instead of 5 or 10 minutes).

The majority of *Failed* TC records were due to instrument failures as described in Section 3.2.2. Besides those, there are only 3,321 missing records from operational TCs, which are counted as *"Failed missing"* records and only 6 negative TC readings as seen by the cycle minimum values presented in Column 3 of Table 10. There are no TC readings exceeding the upper limit of 1400°C during the entire AGR-2 irradiation as shown by the cycle maximum values in Column 4 of Table 10.

Among qualified TC temperature records, there are no virtual junction failures detected using the analysis of correlation of all TC pairs. Also, there are no drift failures detected for TCs in Capsule 3 and Capsule 5. Capsule 2 has only one operational TC, and TC labels in Capsule 6 are in question as described in Appendix B; therefore, the drift detection method cannot provide conclusive evidence about TC drift failure.

Table 10. Summary of the qualification status of the TC temperatures.

ATR Cycle	Total No. of Records	Min. Value (°C)	Max. Value (°C)	No. of Missing	No. <0°C	No. of Trend[a]	No. of Failed	Qualified (Percent)	Trend[a] (Percent)	Failed (Percent)
147A	88,979	-321431	1069	535	2	8,089	8,625	81.2	9.1	9.7
148A	110,880	18	1064	1,289	0	9,845	12,803	79.6	8.9	11.5
148B	122,034	-168169	1062	738	1	10,796	28,876	67.5	8.8	23.7
149A	129,987	-399966	972	141	1	11,746	35,697	63.5	9.0	27.5
149B	177,650	22	1010	0	0	16,150	80,750	45.5	9.1	45.5
150A	6,974	22	63	0	0	634	3,170	45.5	9.1	45.5

ATR Cycle	Total No. of Records	Min. Value (°C)	Max. Value (°C)	No. of Missing	No. <0°C	No. of Trend[a]	No. of Failed	Qualified (Percent)	Trend[a] (Percent)	Failed (Percent)
150B	136,653	20	1074	0	0	12,423	62,115	45.5	9.1	45.5
151A	199,694	20	1104	0	0	18,154	90,770	45.5	9.1	45.5
151B	258,841	18	1083	0	0	23,531	155,983	30.6	9.1	60.3
152A	1,024,815	0	550	44	1	93,161	652,171	27.3	9.1	63.6
152B	842,798	21	1006	144	0	76,616	536,343	27.3	9.1	63.6
153A	409,739	7	693	0	0	37,249	372,490	0.0	9.1	90.9
153B	509,388	19	622	0	0	46,308	463,080	0.0	9.1	90.9
154A	1,425,556	-45	911	430	1	53,867	1,371,689	0.0	3.8	96.2
154B	1,413,687	19	39	0	0	0	1,413,687	0.0	0.0	100.0
Total	**6,857,675**			**3,321**	**6**	**418,569**	**5,288,249**	16.8	6.1	77.1

a. Trend records are readings of TC3 in Capsule 6 before failure time on May 21, 2013 at 04:45 (ATR Cycle 154A).

4.1.1.2 Sweep Gas Flow Rates. Table 11 provides the summary of the data qualification status of gas flow rates recorded for four AGR-2 U.S. capsules (i.e., 2, 3, 5, and 6) during the entire irradiation. A total of 10,144,020 flow rate records were captured in the NDMAS database and of these data, 503,803 records (5.0% of the total) were *"Failed"* and 1,135,600 records (11.2% of the total) were *"Trend"*. The results of the DRC decisions are as follows:

1. For the first nine cycles (i.e., ATR Cycle 147A through 151B), the flow rates are 5-minute or 10-minute averaged values. The DRC failed all missing values and too high values (greater than 102 sccm) resulting in failure rates that are less than 1% for all cycles.
2. For the next five cycles (i.e., ATR Cycle 152A through 154A), the flow rates were 1-minute instantaneous values. The decisions of the DRC are as follows:
   a. *Failed* neon, helium, and outlet flow rates for all capsules and the leadout during two periods: (1) from 05:26 March 12, 2013, to 14:00 March 13, 2013, (due to secured gas flow in Cycle 153B outage) and (2) from 04:15 April 30, 2013, to 15:44 May 6, 2013, (due to ATR system "lock-out/tag-out" event in Cycle 154A outage)
   b. *Failed* all missing values and too high values (greater than 102 sccm)
   c. *Failed* FPM flow rates for all capsules during Cycles 153A and 153B
   d. 757,960 FPM flow rates during Cycle 154A flagged as *"Trend"*.
3. The *Failed* gas flow records in the low power Cycle 152A are due mostly to missing neon flow rates. The gas flow failures in ATR Cycle 153A also include 74,400 *"Failed"* FPM flow rates. The gas flow failures during ATR Cycle 153B include 206,070 failed FPM flow records and 25,467 records during "secured gas flow" period. For ATR Cycle 154A, *"Failed"* flow records are due mostly to 128,674 records during the ATR system "lock-out/tag-out" event.
4. For the last cycle, ATR Cycle 154B, all capsule flow records (neon/helium inlet for capsules and leadout and capsule outlet) are *"Qualified"* and all FPM flow records are *"Trend"*.

Table 11. Summary of the qualification status of the neon, helium, outlet, and FPM gas flow rates.

ATR Cycle	Total No. Records	Min. Value	Max. Value	No. of Missing	No. of >102 sccm	No. of Trend[a]	No. of Failed	Qualified (Percent)	Trend[a] (Percent)	Failed (Percent)
147A	113,246	0	64.8	144	0	0	144	99.9	0.0	0.1
148A	141,120	0	59.8	1,283	0	0	1,283	99.1	0.0	0.9
148B	155,316	0	104.8	72	26	0	98	99.9	0.0	0.1
149A	165,438	0	104.9	111	26	0	137	99.9	0.0	0.1
149B	226,100	0	102.6	0	9	0	9	100.0	0.0	0.0
150A	8,876	0	18.9	0	0	0	0	100.0	0.0	0.0
150B	173,922	0	73.3	0	0	0	0	100.0	0.0	0.0
151A	254,156	0	59.2	1	0	0	1	100.0	0.0	0.0
151B	329,434	0	102.7	4	1	0	5	100.0	0.0	0.0
152A	1,304,310	0	105.5	36,639	63	0	36,702	97.2	0.0	2.8
152B	1,072,652	0	35.1	129	0	0	129	100.0	0.0	0.0
153A	595,886	0	39.6	28,631	0	0	103,031[b]	82.7	0.0	17.3
153B	854,382	0	103.3	0	1,963	0	233,500[b]	72.7	0.0	27.3
154A	2,437,874	0	100.0	90	0	623,530	128,764[c]	69.1	25.6	5.3
154B	2,311,308	0	34.5	0	0	512,070	0	77.8	22.2	0.0
Total	**10,144,020**			**67,104**	**2,088**	**1,135,600**	**503,803**	**83.8**	**11.2**	**5.0**

a. Trend records are the FPM flow rates during ATR Cycles 154A and 154B.

b. Failed records during ATR Cycles 153A and 153B include 280,470 failed FPM flow rates.

c. Failed records during ATR Cycle 154A include data during "lock-out tag-out" period from 04:15 April 30, 2013 until 15:44 May 6, 2013 (outage phase of ATR Cycle 154A).

4.1.2 Data Qualification Summary

NDMAS received a total of 17,001,695 irradiation monitoring data records for four U.S. Capsules (i.e., 2, 3, 5, and 6) during the fifteen reactor cycles evaluated in this report (Table 12). Of these data, 9,655,474 records (56.8% of the total) met the requirements for *"Qualified* "data, 5,792,052 records (34.1% of the total) were *"Failed"* data, and 1,554,169 records (9.1% of the total) were *"Trend"* data. The trend data are downstream FPM flow rates during ATR Cycles 154A and 154B and readings of TC3 in Capsule 6 before failure on May 21, 2013, at 4:45. For TC temperature data, there were 5,288,249 TC records (77.1% of the total TC data) that were *"Failed"* because of TC instrument failures (see Section 3.2.1 for details). For gas flow rate data, there were 503,803 records (5.0% of the total flow data) that were *"Failed"*, which include 280,470 *"Failed"* FPM flow records during ATR Cycles 153A and 153B. Also, there are 1,135,600 *"Trend"* records (11.2% of the total flow data), which are FPM flow rates during ATR Cycles 154A and 154B. All of the pressure and moisture (humidity) sweep gas data were classified as *"Qualified"* by the DRC.

Table 12. Summary of the qualification status of the irradiation monitoring data (TC temperature and gas flow rate) received by NDMAS during AGR-2 irradiation.

ATR Cycle	Total No. of Records	No. of Trend (Gas Flow Rates)	No. of Failed (Gas Flow Rates)	No. of Trend (TC)	No. of Failed (TC)	Total No. Trend	Total No. Failed	Qualified (percent)	Trend (percent)	Failed (percent)
147A	202,225	0	144	8,089	8,625	8,089	8,769	91.7	4.0	4.3
148A	252,000	0	1,283	9,845	12,803	9,845	14,086	90.5	3.9	5.6
148B	277,350	0	98	10,796	28,876	10,796	28,974	85.7	3.9	10.4
149A	295,425	0	137	11,746	35,697	11,746	35,834	83.9	4.0	12.1
149B	403,750	0	9	16,150	80,750	16,150	80,759	76.0	4.0	20.0
150A	15,850	0	0	634	3,170	634	3,170	76.0	4.0	20.0

ATR Cycle	Total No. of Records	No. of Trend (Gas Flow Rates)	No. of Failed	No. of Trend (TC)	No. of Failed	Total No. Trend	Total No. Failed	Qualified	Trend (percent)	Failed
150B	31,0575	0	0	12,423	62,115	12,423	62,115	76.0	4.0	20.0
151A	453,850	0	1	18,154	90,770	18,154	90,771	76.0	4.0	20.0
151B	588,275	0	5	23,531	155,983	23,531	155,988	69.5	4.0	26.5
152A	2,329,125	0	36,702	93,161	652,171	93,161	688,873	66.4	4.0	29.6
152B	1,915,450	0	129	76,616	536,343	76,616	536,472	68.0	4.0	28.0
153A	1,005,625	0	103,031	37,249	372,490	37,249	475,521	49.0	3.7	47.3
153B	1,363,770	0	233,500	46,308	463,080	46,308	696,580	45.5	3.4	51.1
154A	3,863,430	623,530	128,764	53,867	1,371,689	677,397	1,500,453	43.6	17.5	38.8
154B	3,724,995	512,070	0	0	1,413,687	512,070	1,413,687	48.3	13.7	38.0
Total	**17,001,695**	**1,135,600**	**503,803**	**418,569**	**5,288,249**	**1,554,169**	**5,792,052**	**56.8**	**9.1**	**34.1**

4.2 FPMS Data

As of this report publication, NDMAS has received and processed into its database release rate and R/B data for all AGR-2 reactor cycles (i.e., ATR Cycle 147A through 154B), as shown in Figure 11 and Figure 12. The latest version of R/B data contains R/Bs calculated using the daily birthrates as described in ECAR-2420 (Scates 2014). This consists of 190,416 (mostly nominal 8-hour) release rate records and 190,416 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). Each release rate, as well as each R/B, has its estimated uncertainty, which can be used to filter meaningful data for analysis. According to FPMS staff, the release rate and R/B with uncertainty greater than 50% are not reliable data; therefore, they should be removed from fission product analysis. All of these data have been capture passed, stored in the NDMAS database, and made available on the NDMAS web portal (see Figure 11 and Figure 12).

Because of relief valve failures during ATR Cycles 149A and 149B and capsule flow cross-talk issues that began during Cycle 150B, the subsequent FPMS data will not be qualified. However, the data still provide useful information for identifying particle failures and performing additional analyses and will be flagged as *"Trend"*. As a result, the qualification status of these data has been set to *"Qualified"* for the first three cycles (i.e., 147A, 148A, and 148B) and set to *"Trend"* for the remaining cycles (i.e., ATR Cycles 149A through 154B).

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 Program participants as shown in Figure 36. The website is organized by experiment (e.g., AGR-2) and data stream (e.g., IRR for irradiation data). These web pages (blue bar on left in Figure 36) 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.

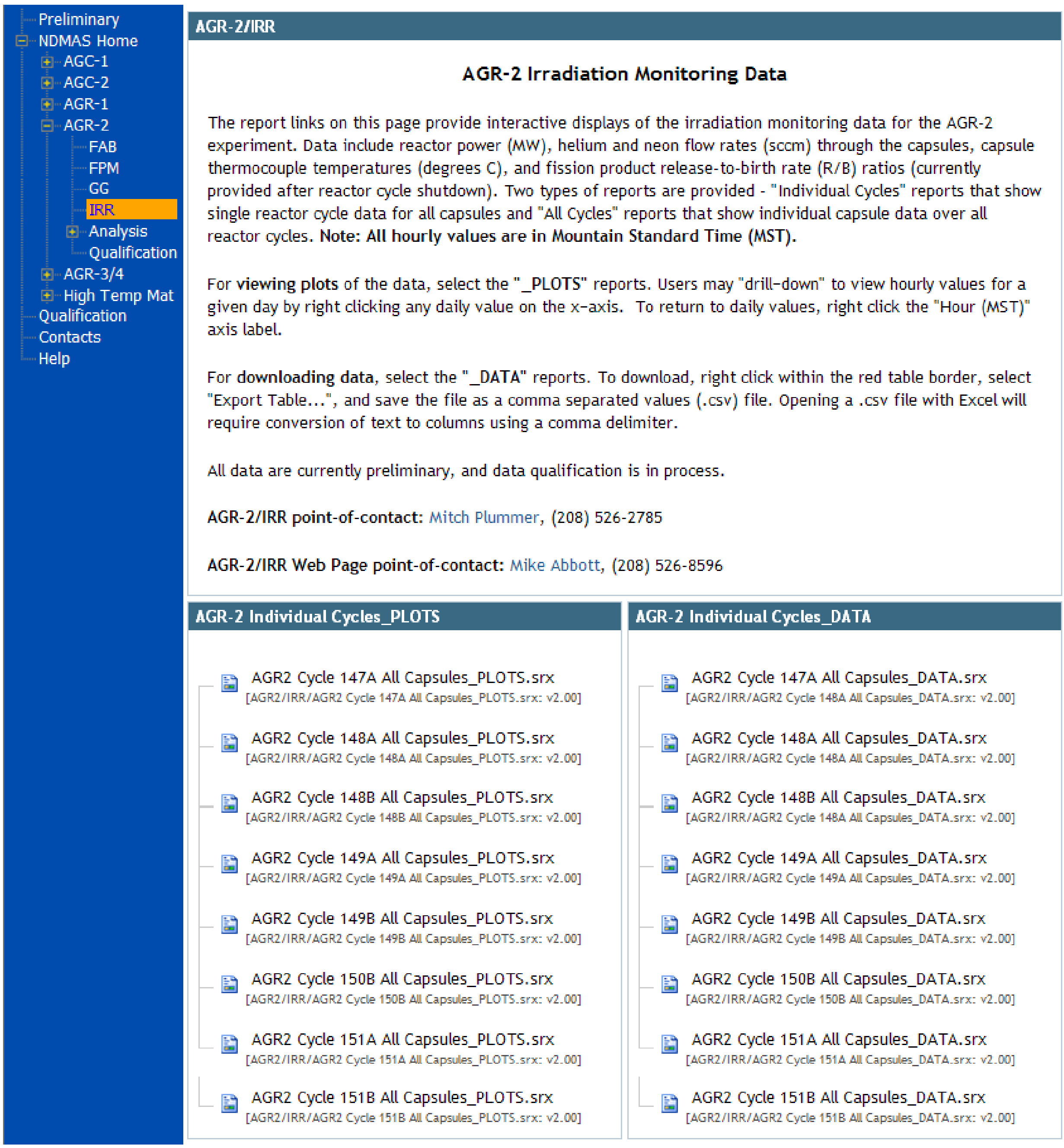

Figure 36. The AGR-2 web page (in blue bar on left) on the NDMAS web portal provides access to numerous types of data reports, graphs, and images.

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Appendix A

Credentials of the Technical Reviewer

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Credentials of the 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-2 experiment, of which he wrote the Irradiation Experiment Test Plan.

Appendix B

Inconsistencies between Capsule 6 TC Readings and Thermal Model Predictions

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Inconsistencies between Capsule 6 TC Readings and Thermal Model Predictions

Figure 3 shows TC radial locations and insertion depths in AGR-2 capsules with the ATR core to the right. Capsule 6, located at the top of the test train, has 5 TCs and Capsules 1 to 5 each have 2 TCs inserted at the colder peripheral locations away from the ATR core. Figure 37 shows the calculated temperature contour plot of the cutaway view of the graphite holder, where TCs are terminated. According to the thermal simulation results for Capsule 6 TC locations (second panel in Figure 38), the hottest temperature is at the TC3 center location followed by temperatures at TC1 and TC4 that terminate deeper near the capsule middle and the lowest temperatures are at TC2 and TC5 peripheral locations away from the ATR core (Figure 37). However, the actual TC readings in Capsule 6 plotted on the first panel in Figure 38 are clearly not consistent with the calculated temperature profile: readings at the hottest TC3 location (green line) are lower than the highest TC readings by almost 200ºC, and conversely, readings at one of the coolest locations, TC2 (blue line), are among the highest TC readings. Additionally, large TC residuals shown in the third panel in Figure 38 for TC2 (blue dots) and especially TC3 (green dots) also indicate inconsistency between TC measurement and calculation. This discrepancy between measured and calculated temperatures at TC locations in Capsule 6 suggests that TC mislabeling may have occurred during assembly.

In order to correctly interpret temperatures in Capsule 6 and to be able to use TC readings for thermal model calibration, TC labels should be corrected as much as the physics allow. The small differences between calculated temperatures at some TCs such as between TC1/4 and TC2/5 pairs makes it very difficult and unreliable to correct the TC labels based solely on the calculated temperature profile. Therefore the TC labels should be corrected only when credible evidence can be established as follows:

<u>Data labeled as TC4 relabeled as TC3</u>: TC3 is located in the center of the capsule at a depth of 1.905cm and according to the thermal calculation this TC is exposed to the highest temperature among the five TC locations in Capsule 6. Additionally, the neutron fluence increase over irradiation time causes a decrease in both graphite and fuel compact conductivities. This, in turn, will lead to an increase of the temperature difference between the center TC3 readings and the other peripheral TC readings. In order to control temperature in the AGR-2 capsules, the readings of a control TC at a peripheral location, e.g., TC1, are maintained at a predefined set point. Therefore, only readings of the central TC3 will increase over time relative to the control TC readings while readings from other peripheral TCs would stay level with the control TC readings. As shown in Figure 38, the readings of TC4 (cyan line on Panel 1) are consistent with the expected readings of the TC3 (green line on Panel 2) because they are increasing over time relative to the other four TC readings.

<u>Data labeled as TC3 relabeled as TC2</u>: TC2 is a peripheral location and away from the ATR core, so its readings should be among the lower temperatures, similar to TC5 temperatures, and lower than TC1 and TC4 by about 100ºC. This is more consistent with readings of TC3 (green line on Panel 1) or TC5 (pink line on Panel 1). Because differences between calculated TC2 and TC5 are small, it is impossible to differentiate these two locations based on their readings. To minimize TC relabeling, TC5 would stay the same and measured TC3 is relabeled as TC2.

<u>Data labeled as TC2 relabeled as TC4</u>: There are two TCs left, TC1 and TC2, to match with TC1 and TC4 locations. According to the thermal calculations TC1 and TC4 readings should be at a similar level (see red and cyan lines on Panel 2), so to minimize relabeling TC1 would stay the same and TC2 will be relabeled as TC4 location.

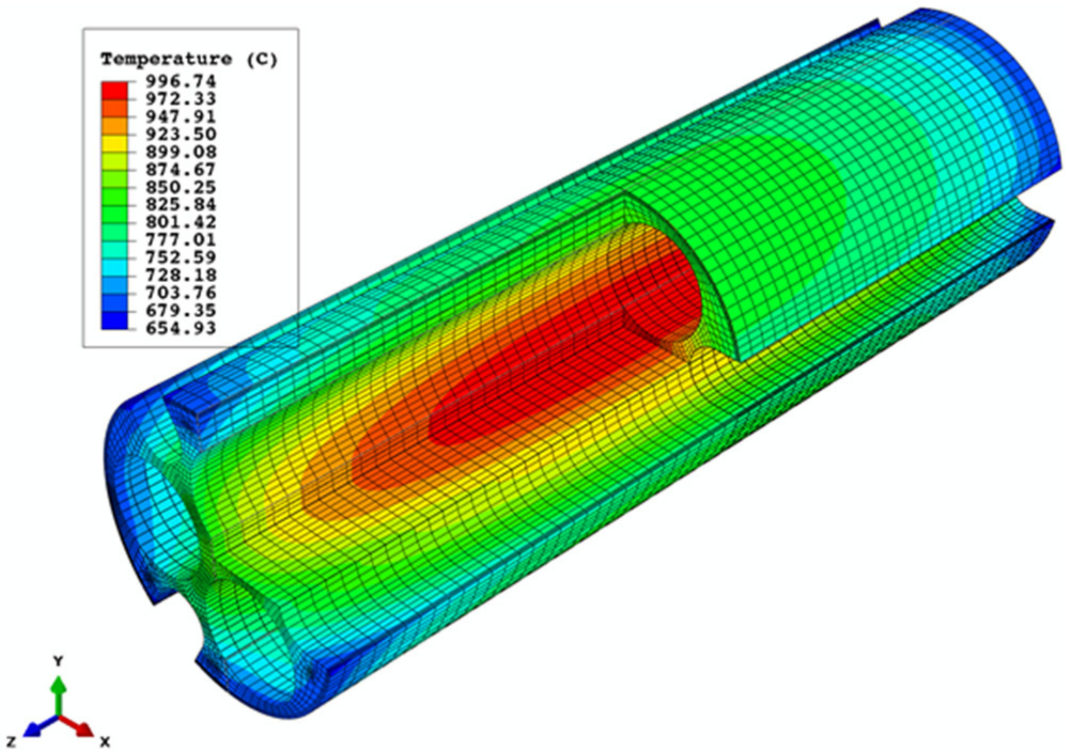

Figure 37. Temperature (°C) contour plot of the cutaway view of the graphite holder.

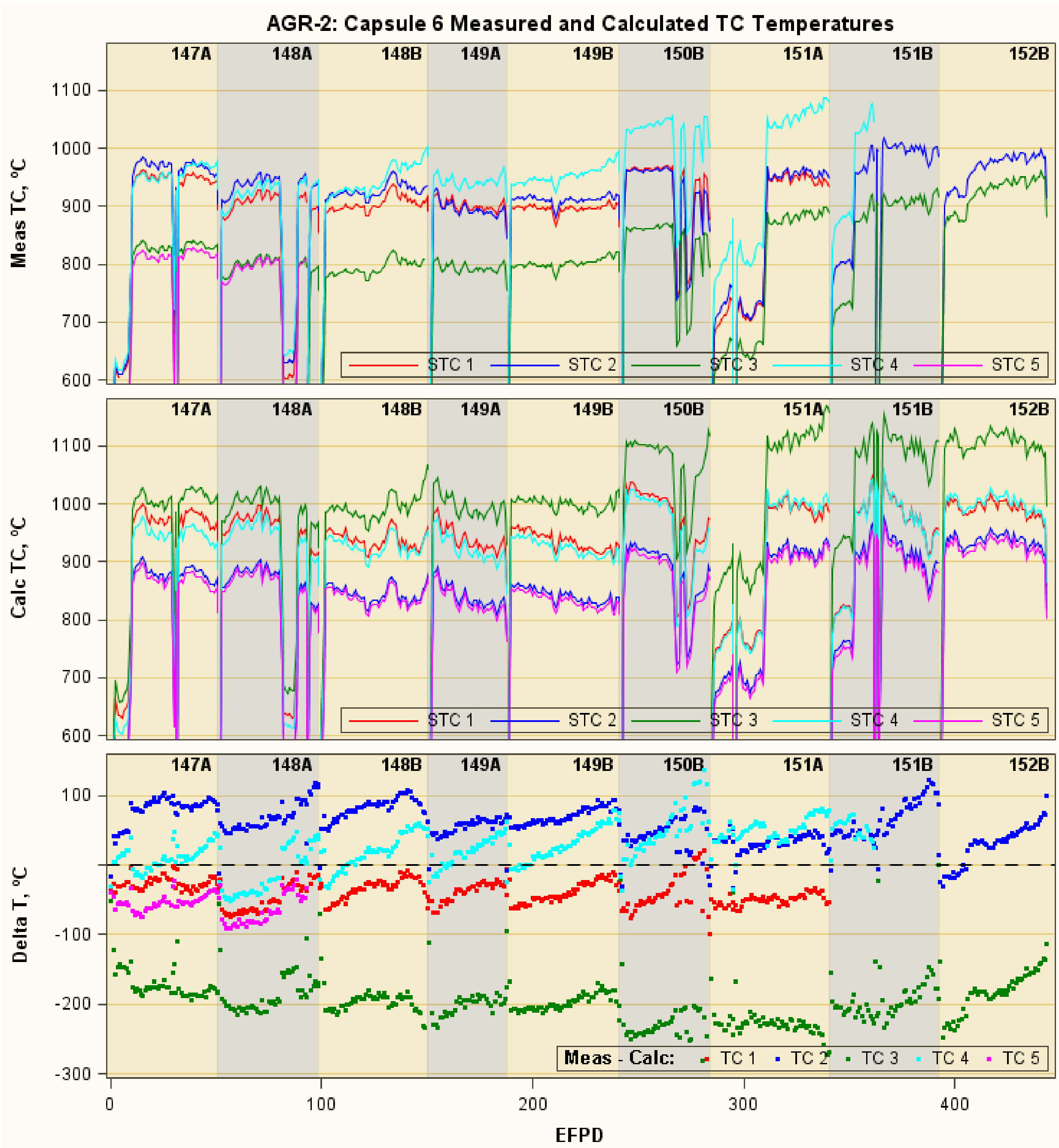

Figure 38. Capsule 6 measured and calculated TC temperatures.