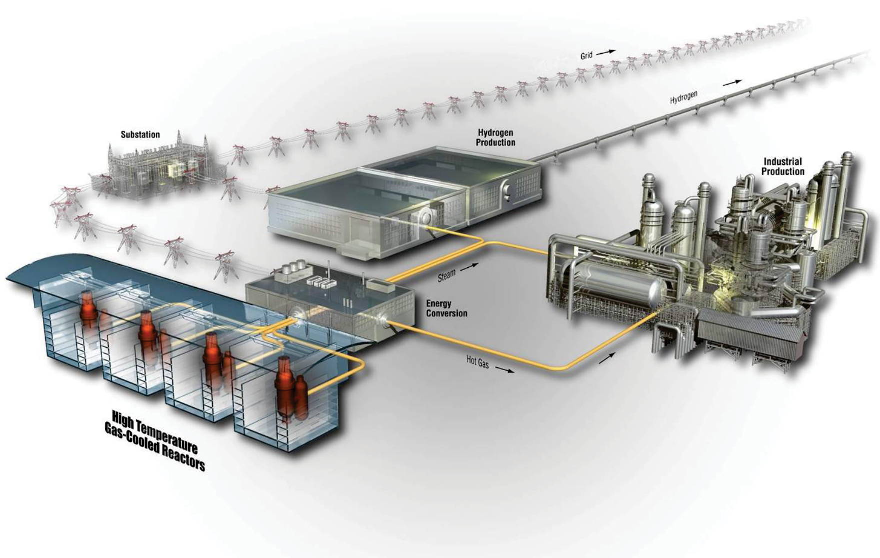
INL/EXT-13-29701

# AGR-2 Data Qualification Report for ATR Cycles 151B-2, 152A, 152B, 153A, 153B and 154A

Binh T. Pham
Jeffrey J. Einerson

September 2013

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# AGR-2 Data Qualification Report for ATR Cycles 151B-2, 152A, 152B, 153A, 153B and 154A

Binh T. Pham
Jeffrey J. Einerson

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Idaho National Laboratory
Very High Temperature Reactor Technology Development Office
Idaho Falls, Idaho 83415

http://www.inl.gov

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Very High Temperature Reactor Technology Development Office

# AGR-2 Data Qualification Report for ATR Cycles 151B-2, 152A, 152B, 153A, 153B and 154A

**INL/EXT-13-29701**

**September 2013**

Approved by:

| | |
|---|---|
| Binh T. Pham<br>Author | 09/09/2013<br>Date |
| Jeffrey J. Einerson<br>Author and NDMAS Data Review Committee | 9-9-2013<br>Date |
| Blaise Collin<br>Independent Technical Reviewer | 09/09/2013<br>Date |
| Kirk W. Bailey<br>VHTR Quality Assurance | 9.9.2013<br>Date |
| Diane V. Croson<br>VHTR TDO Deputy Director | 09/09/2013<br>Date |

# SUMMARY

This report provides the data qualification status of AGR-2 fuel irradiation experimental data from Advanced Test Reactor (ATR) Cycles 151B-2, 152A, 152B, 153A, 153B, and 154A, as recorded in the Nuclear Data Management and Analysis System (NDMAS). Cycle 151B-2 qualification was documented in INL/EXT-11-26184, *AGR-2 Data Qualification Report for ATR Cycles 149B, 150A, 150B, 151A, and 151B* as part of Cycle 151B. An unplanned outage from March 27, 2012 to April 7, 2012 resulted in an operating cycle change since there was a change in the core configuration. As a consequence, Cycle 151B-2 was created. Because Cycle 151B-2 was covered in the previous AGR-2 data qualification report, it will not be repeated here. Two cycles, 152A and 153A, occurred when the ATR core was briefly at low power, so AGR-2 irradiation data are not used for physics and thermal calculation. During the Power Axial Locator Mechanism (PALM) cycle (Cycle 153B), the experiment was temporarily moved from the B-12 location to the I-24 location to avoid being overheated. During the "Outage" cycle, 153A, seven flow meters were installed downstream from seven Fission Product Monitoring System (FPMS) monitors to measure flows from the monitors and this data was 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 FPM downstream flows, pressure, and moisture content), and FPMS data (release rates and release-to-birth rate ratios [R/Bs]) for each of the six capsules in the AGR-2 experiment. 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 (VHTR) Program Quality Assurance (QA), and NDMAS analysts. The Data Review Committee, which convened on August 21, 2013, 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 this report.

A total of 14,520,022 instantaneous (every minute) TC temperature and sweep gas data records were received and processed by NDMAS for this period. Of these records, 5,050,861 (34.9% of the total) were determined to be *Failed*. For temperature data records, there were 4,265,567 records (74.3% of the total TC data) that were *Failed* due to TC instrument failures. By the end of Cycle 154A there is only one operational TC in the entire AGR-2 test train, TC2 in Capsule 4. The TC failures include nine TCs that failed during the first eight cycles (TC1/2 in Capsule 1, TC1/2 in Capsule 2, TC1/2 in Capsule 5, and TC1/4/5 in Capsule 6) in addition to five new TC failures during this period (TC1/2 in Capsule 3, TC1 in Capsule 4 and TC2/3 in Capsule 6).

For sweep gas data, there were 9,143,560 gas flow records and of these data only 795,294 gas flow records (~ 9.1% of the gas flow data) were *Capture Failed* mostly due to missing or negative values when the flow rates are near zero. Because of capsule gas cross-talk and leakage problems that occurred after Cycle 150A [Abbott 2012] a procedure was implemented by AGR2 operations staff on January 17, 2012 (Cycle 151A) to use uniform neon fraction of gas mixtures in all six capsules and the leadout so the capsule's actual gas mixture can be accurately defined. Use of the capsule outlet gas flow data after Cycle 150A in

calculating FPMS release rate and R/B data should take into account 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 preliminary release and R/B data for three “full power” reactor cycles (Cycles 152B, 153B, and 154A). This data consists of 28,896 release rate records and 28,896 R/B records for the 12 radionuclides reported. Due to the 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.*

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 VHTR Program participants.

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# ACRONYMS

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

# AGR-2 Data Qualification Report for ATR Cycles 151B-2, 152A, 152B, 153A, 153B and 154A

# 1. INTRODUCTION

This report presents the data qualification status of fuel irradiation monitoring data from the ongoing Advanced Gas Reactor (AGR-2) experiment being conducted in the Advanced Test Reactor (ATR) at Idaho National Laboratory . 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 the performance of TRISO fuel particles containing UCO (uranium oxycarbide) and $UO_2$ (uranium dioxide) fuel produced in a large (6-inch) coater.

AGR-2 irradiation was first at full power on June 23, 2010 and was planned to continue for 600 effective full power days (approximately 3.5 calendar years; PLN-3798). Qualification of data from the first nine AGR-2 cycles (ATR Cycles 147A, 148A, 148B, 149A, 149B, 150A, 150B, 151A, and 151B) was documented in Abbott and Pham (2011 and 2012). An unplanned outage from March 27, 2012 to April 7, 2012 resulted in an operating cycle change since there was a change in the core configuration. As a consequence, Cycle 151B-2 was created. The qualification of data from this cycle was included as part of Cycle 151B in Abbott and Pham (2012) and will not be repeated here. This current report continues the qualification process for data from the subsequent five AGR-2 cycles, which corresponds to ATR Cycles 152A, 152B, 153A, 153B and 154A. Among them there are one "Low power" cycle, 152A, and one "Outage" cycle, 153A, when the ATR power was slightly up () for a few short periods of time resulting in the averaged effective power of 0.209 MW for 89.6 hours for Cycle 152A and 1.082 MW for 0.25 hours for Cycle 153A. From a physics point of view, these cycles can be considered as extended power outages for the test fuel depletion calculation. During this time, the experiment was run on pure helium for both capsule and leadout gas flows. During the ATR Powered Axial Locator Mechanism (PALM) cycle, 153B, the experiment was moved from the large B-12 location to the more peripheral I-24 location (next to the northwest [NW] lobe) to prevent over-heating of fuel compacts due to high ATR lobe power. The data examined in this report covers the period from May 5, 2012, through July 13, 2013.

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 (SQL) Server database, performs testing on and analysis of the data for anomalies identification, presents the data via an access-controlled Web portal, and documents the qualification status of the data.

## 1.1 Purpose and Scope

The AGR-2 fuel irradiation monitoring data streams examined in this report include capsule thermocouple (TC) temperatures, sweep gas measurements (gas flows, pressure, and moisture), and fission product monitoring data. The evidence of questionable data revealed by NDMAS data analysts were presented to the Data Review Committee (DRC). The DRC is comprised of project technical leads, Quality Assurance (QA), NDMAS analysts, and an independent technical reviewer (Appendix A). Final data qualification status for these data streams is determined by the DRC. The DRC considers: (1) whether the data meet the requirements for data collection as specified in Test Plans, Test Specifications, Technical and Functional Requirements (TFR), and QA plans; (2) the results of data testing and statistical analyses as performed by the NDMAS; (3) other QA-approved data reports submitted by data generators such as Engineering Calculations and Analysis Reports (ECARs); and (4) whether the data support applications to the defined intended use (MCP-2691). 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 (EDMS).

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

Fuel irradiation monitoring data reported herein include the following for each of six 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 (helium, neon, outlet, downstream) measurements (mass flow rates, pressure, and moisture content)
- Krypton and xenon radionuclide (12 isotopes) release rates measured by the fission product monitoring system (FPMS) and subsequently calculated krypton and xenon radionuclide release-to-birth rate ratios (R/Bs).

Previously, the basis for the qualification status of FPMS data is QA-approved ECARs submitted by the FPMS technical staff. These ECARs provide independent verification that the FPMS data submitted to NDMAS meet data collection requirements and conform to NQA-1 (ASME NQA-1-2008 with 1a 2009 addenda) requirements. However, the FPMS data during this reporting period are flagged as *Trend* due to the fission product cross talk between capsules and there might not be ECARs issued for these cycles. No similar ECARs exist for the TC and sweep gas data, so the basis for their data qualification is the DRC review of the data, data testing and analysis results, and data collection documentation as presented in this report.

This document does not address the qualification status of three additional AGR-2 data streams stored in the NDMAS database: fuel fabrication data, thermal/neutronics simulation data, and post-irradiation examination (PIE) data. All 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 up to the end of Cycle 152B and their data state is in-process, thus can be used for analysis only as preliminary data until the ECAR is issued by the modeler. AGR-2 PIE has not yet begun.

ATR operating conditions data, including lobe powers, outer shim control cylinder positions, neck shim positions, and control rod positions, are stored in the NDMAS database and presented with AGR irradiation data on the NDMAS Web portal to help experimental interpretation and to provide input for physics calculations. Because ATR data are generated outside of the VHTR 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 calculation.

## 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:

- 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 quality assurance program plan (PLN-2690), and the records management plan (PLN-3319), and testing the data to ensure accuracy. NDMAS is currently using SAS® Enterprise Guide and a secure Microsoft SQL server (the "Vault") for these purposes.
- Analyzing irradiation monitoring data to identify possible data anomalies and trends using various SAS® statistical tools such as range testing, control charts, correlation analyses, and regression analyses. These results are included in data qualification reports (such as this one) that are considered by the DRC in their determination of final data *Qualification State*.
- Documenting the receipt of QA-approved data reports (e.g., ECARs) for FPMS and fuel fabrication data, which provide the basis for their data qualification status.
- Providing secure and appropriate Web access to the data (http://ndmas.inl.gov), information on the data qualification status, and requested data analyses to end users, including external research partners. In this instance with AGR-2, this includes secure limited data access to external research partners in France and South Africa.

All the AGR-2 data currently being collected at INL are considered to be *Type A*—data obtained within an NQA-1 QA program that must meet specific requirements for data collection with independent verification that those requirements were met (MCP-2691). The final results of this process are one of three data *Qualification States* applied to each data record:

- *Qualified*. Independent verification documenting that the data meet the requirements for a specific end use as defined in a data collection plan and were collected within an NQA-1 or equivalent QA program. Any nonconformances are concluded to not affect the usability of the data.
- *Trend*. Independent verification identifying minor flaws or gaps in meeting requirements for data use. Even so, the data still provide information that can be used by the program. Data were collected within an NQA-1 or equivalent QA program. This qualification state has not been applied to any AGR-2 (or AGR-1) data to date.
- *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 is being processed by NDMAS and prior to the data receiving a final Qualification State, NDMAS sets the data Qualification State to *In Process*. Time-critical data, such as the fuel irradiation data, are made available on the NDMAS Web portal while *In Process* to facilitate near real-time monitoring of experimental results by project staff to improve control of the test condition predefined in the test specification plan (SPC-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 in the large B-12 location of the ATR core as shown in Figure 1 in June 2010. AGR-2 is comprised of six individual capsules, approximately 1-3/8 in. in diameter and 6 in. 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 capsule has independently controlled helium and neon gas flows, which have different thermal conductivities to control capsule fuel temperatures. The mixed gas outlet lines transport any fission products released from the capsules to the FPMS, which is capable of detecting individual fuel particle failures. Figure 2 shows the simplified flow path for AGR-2 sweep gas. During the "Outage" cycle, 153A, seven additional gas flow meters were installed at the outlets of seven FPMS detectors to measure downstream gas flow rates from these detectors. Normally, gas mixture from capsules 1-6 flow to corresponding detectors 1-6 and 7 is a spare detector for replacement of a potentially failed detector. The downstream gas 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.

There are five TCs located in Capsule 6 and two TCs in the remaining capsules, as shown in Figure 3. During the first nine AGR-2 cycles, nine of the 15 installed TCs in the AGR-2 experiment failed: TC1/TC2 in Capsule 1, TC1/TC2 in Capsule 2, TC1/TC2 in Capsule 5, and TC1/TC4/TC5 in Capsule 6 (INL/EXT-11-22798 and INL/EXT-12-26184). Additional TC failures occurred for the subsequent five reactor cycles addressed in this report, and these are described in detail in subsequent sections.

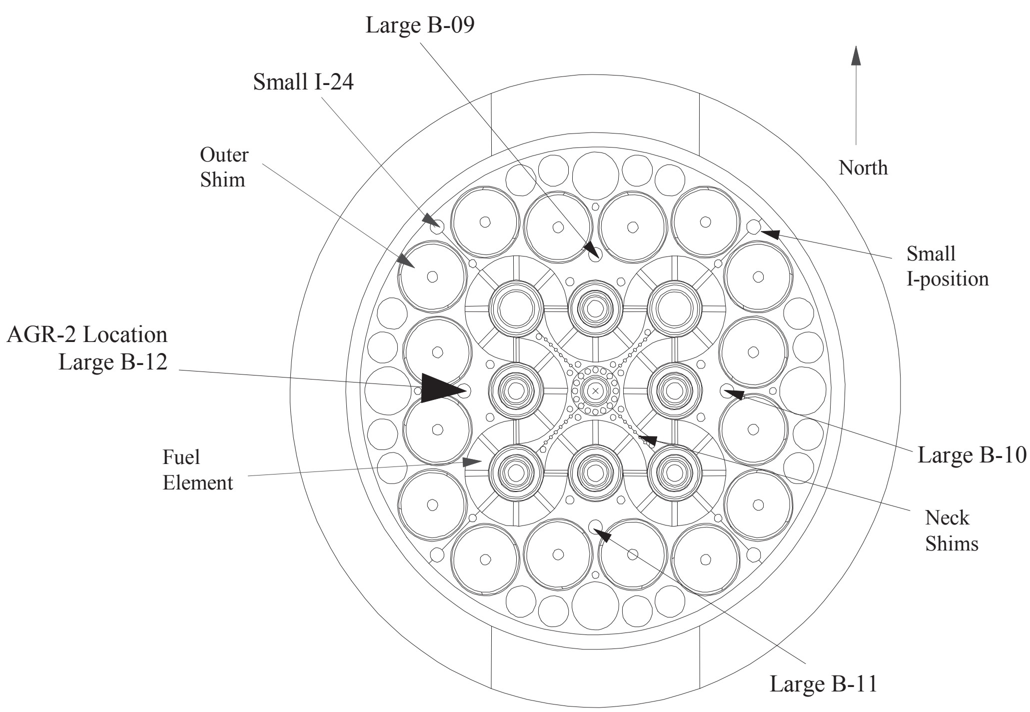


Figure 1. AGR-2 location in ATR core cross section.

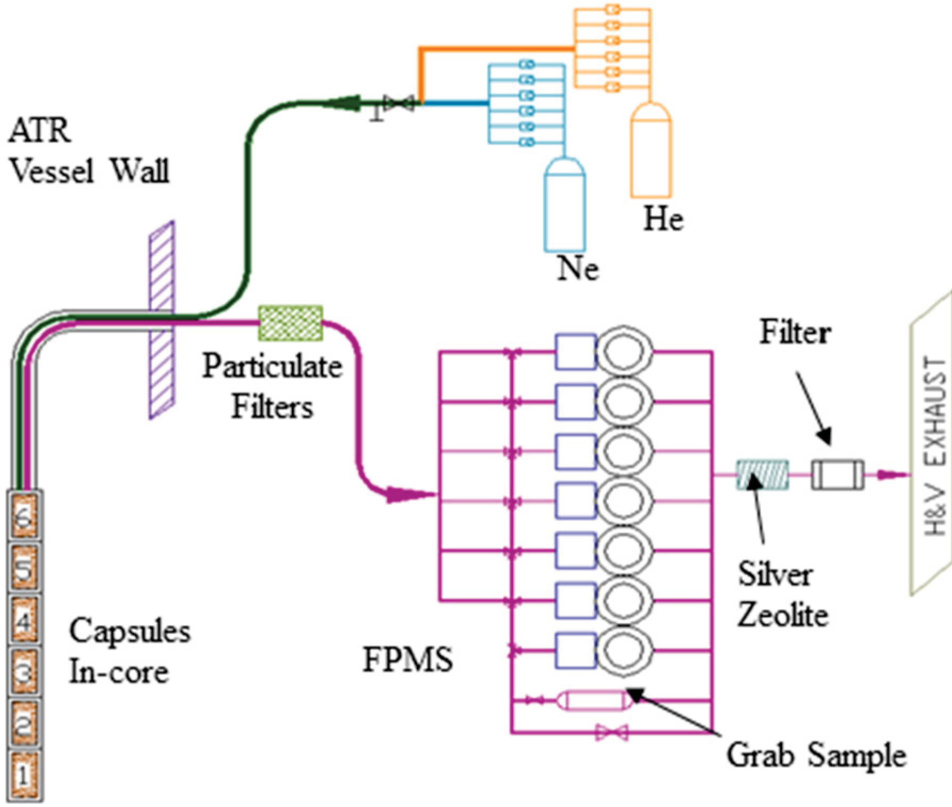


Figure 2. Simplified flow path for AGR-2 sweep gas.

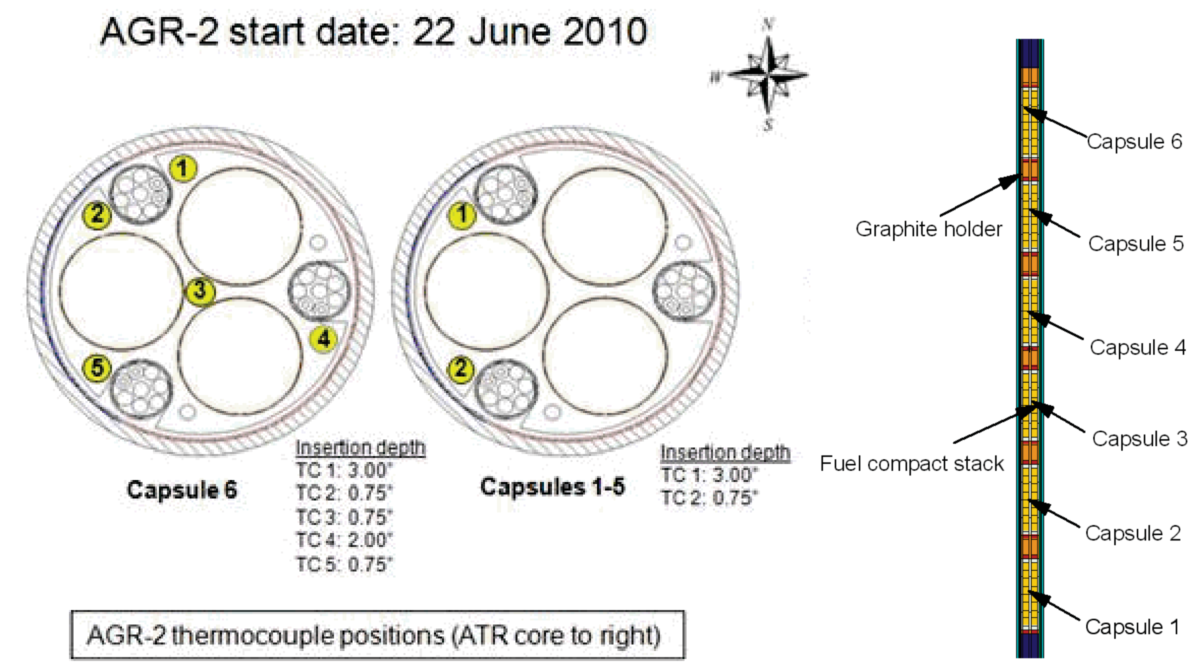


Figure 3. Radial (left) and axial (right) views of the AGR-2 capsules with TC locations (yellow circles).

Each AGR-2 capsule contains only one fuel type. U.S. UCO fuel is in Capsules 2, 5, and 6; U.S. $UO_2$ fuel is in Capsule 3; French $UO_2$ fuel is in Capsule 1; and South African $UO_2$ fuel is 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.

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 $UO_2$ |

## 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 AGC and AGR experiments) every two 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 (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 PIE 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 one 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 (helium, neon, 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, 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, "Requirements for the Design of the Advanced Gas Reactor Experiment AGR-2 for Irradiation in the ATR," 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 failures, and able to identify in which capsule each failure had occurred (operation requirement in SPC-1064).
- Transit time of sweep gas <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, "AGR-2 Irradiation Test Specification").
- 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 (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 practiced database technology. This structure allows storing a large amount of data and all aspects of associated information

(Meta data) for reduced storage space. The systematic table structure in this relational database also speeds up the retrieval of a large amount of data via the predefined views 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 in (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 particular work flow pathway along with related data flow into NDMAS. A *Data package* is a batch of data provided to NDMAS from the data generator. The number of data packages ranges from one to dozens, depending on the data stream. *A data value* is a single variable value recorded that provides information about the system or object being measured. Data values include response elements, usually numeric values that describe the response of the object or system (e.g., pressure or temperature) and attribute elements that generally describe the object or system being measured, or provide categorical or spatial information about the object such as thermocouple composition, graphite grade, or capsule position. When applicable (e.g., NQA-1 requirements for AGR experiments data) each data value also includes data state and qualification state representing data quality.

AGR-2 experiment has two time series data streams, which are irradiation monitoring and FPMS. Figure 4 shows general data schema for time series data adopted for the NDMAS database design. The use of common “key” tables sharing between multiple data streams increases the flexibility for storing various types of data associated information and reduces storage space by using unique numeric identification (ID) instead of descriptive text data. The data retrieval from the NDMAS Vault is achieved by the use of views associating data with metadata and context information such as location, instrument, measurement units, and data stream information.

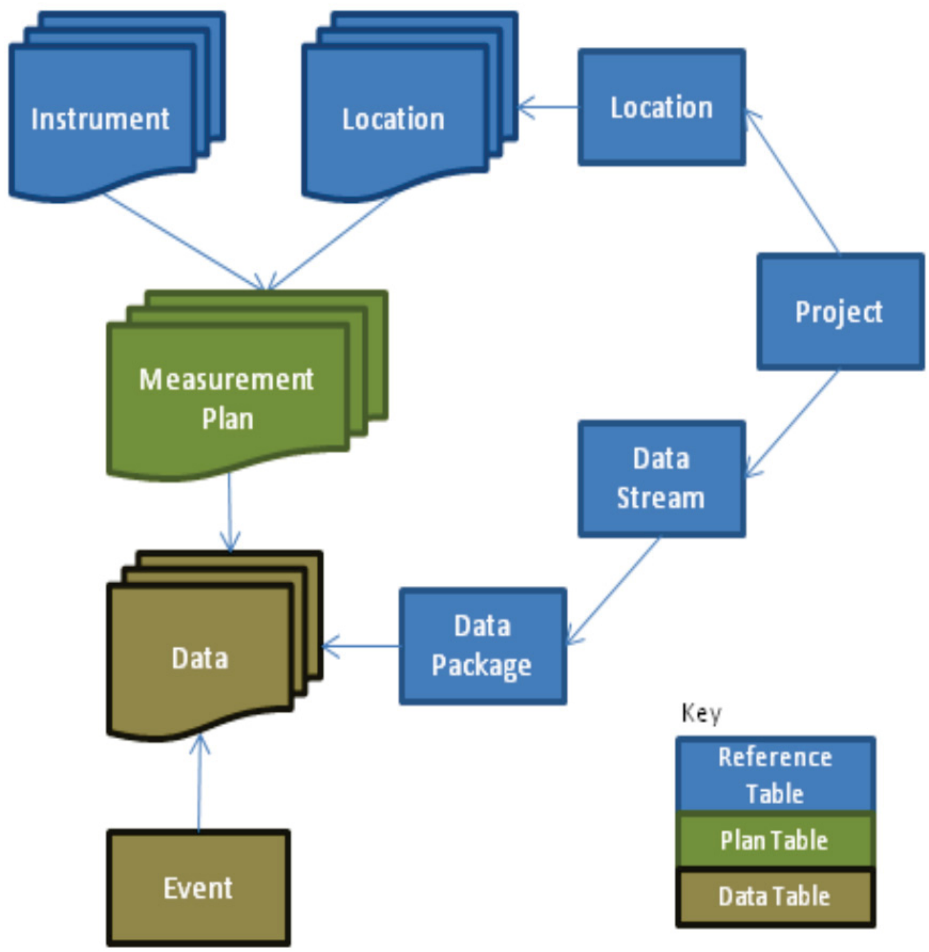


Figure 4. Data schema for time series data (Hull, 2012)

### 2.3.2 Data Values for AGR Experiments

The *data values* in the new design of NDMAS database include response elements and attribute elements as described in Section 2.3.1. Figure 5 shows the diagram for TC temperature values and Figure 6 shows the diagram for gas flow values for AGR experiments. The reference tables contain unique hardware IDs associated with actual domain hardware components such as measurement instruments (e.g., rThermocouple on top left of Figure 5 and Figure 6) or test train components (e.g., rAGR_Capsule on bottom left) used in the experiments. The plan tables (e.g., bAGR_Temperature_Plan in the middle) contain plan ID associated with the detailed description about the measured parameter to be stored in the database and hardware domain IDs to serve as a link between actual data records and experimental hardware. The data tables (e.g., dAGR_Temperature in top right), the largest tables in the database, contain data values (or records) and multiple associated integer IDs. These ID numbers correspond to unique attributes and descriptions in the reference tables and plan tables to link the data records with their metadata information. Since 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.

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 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 SQL query used to store data IDs to link a data value with all associated attributes from all supporting tables. For example, each temperature response in the database will be connected with its metadata such as TC description and capsule location as well as data state and qualification state. This data structure allows pulling the data state and qualification state individually for each measured temperature value as required (Hull, 2012).

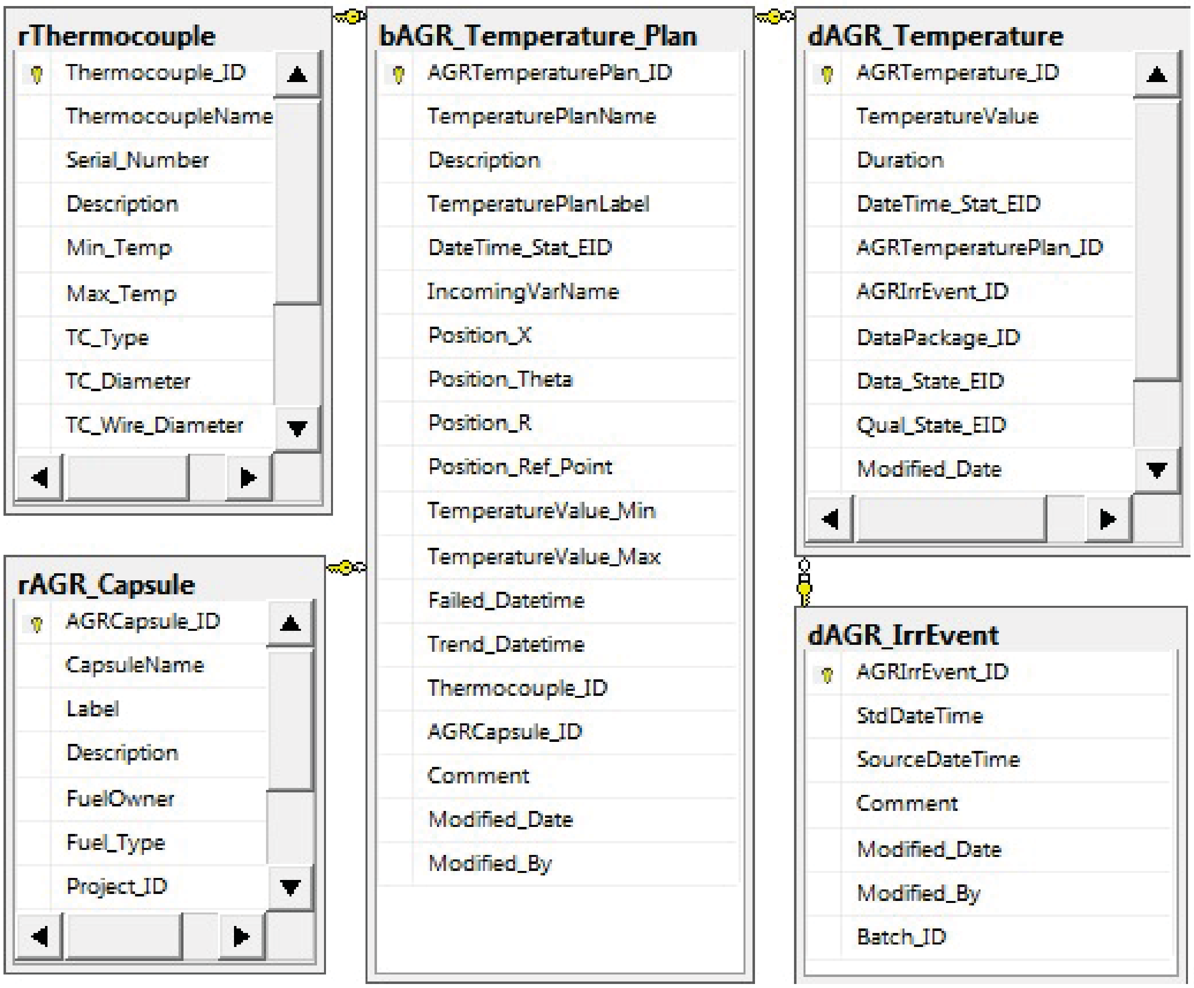


Figure 5. TC temperature value diagram of AGR experiment

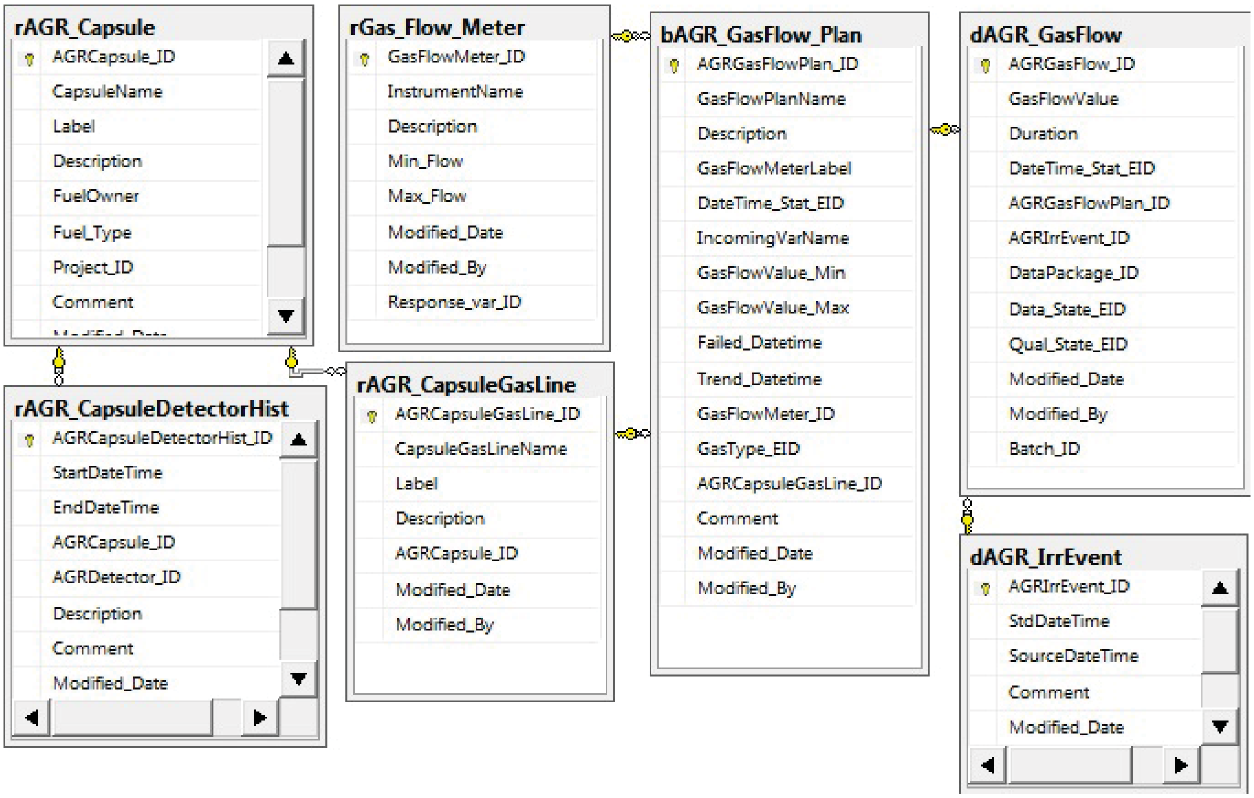


Figure 6. Gas flow value diagram of AGR experiment

Table 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) |
| 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 1–6 and leadout gas flow (ppmv) [xx=01-06, LO] |
| Cxx_in_PI | AGR2_C[01–06, LO] | Pressure in Capsules 1–6 and leadout gas flow (psia) |
| Cxx_in_Q_He | AGR2_C[01–06, LO] | Helium flow to Capsules 1–6 and leadout (sccm) |
| Cxx_in_Q_Ne | AGR2_C[01–06, LO] | Neon gas flow to Capsules 1–6 and leadout (sccm) |
| Cxx_out_Q_Total | AGR2_C[01–06] | Gas outflow from Capsules 1–6 (sccm) [xx=01-06] |
| GSpecxx_QTotal_out | AGR2_G[01–07*] | Gas outflow from Detectors 1–6 (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

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 two 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 AGC current experiments. The automatic data transfer includes instantaneous values at one 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 rate 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 (sample name containing the detector number, date/time, and instrument reset index), date, and time. Columns 4 and 5 contain parameters used by the FPMS technical staff to calculate radionuclide concentrations. The remaining 24 columns contain the release rates (or R/B values) and percent error for the 12 gaseous fission products.

### 2.3.4 Irradiation Monitoring Data Capture and Testing

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

(1) Extract data according to the tags described in the TFR-747

(2) Assign appropriate descriptive IDs for each response value and unique event ID for associated time stamp

(3) Assign data state flag either to "Capture Passed" or "Accuracy Failed" as resulting from the initial range test and instrument failure time tests to identify any clear anomalies

(4) Assign the data qualification flag to "In-process" until qualification flags are updated according to the qualification decisions from the DRC after its meeting

(5) Push response value and associated integer IDs into appropriate data tables (e.g., dAGR_Temperature for TC readings) and push time stamp with unique ID into event table (e.g., dAGR_IrrEvent) into the NDMAS production database

(6) Copy raw data files to NDMAS archive folder.

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

#### *2.3.4.1 Range Test*

Range tests evaluate whether instrument readings fall within an expected range of values, given what is known about experimental operating conditions or instrument range specifications. Range tests are used as a simple screening tool to identify data records that could potentially be bad, or they can be used to identify and reexamine extreme, but valid, data. For example, all of the TCs terminated in the graphite holders will read the graphite temperatures which are less than the fuel compact temperature. Therefore the time average peak fuel temperature specifications given in Section 2.1.1 can be used as a "coarse" upper test limit for a TC temperature range test. Range tests are currently only applied to the TC and sweep gas (flow rates, pressure, and moisture) data that NDMAS receives. The range test limits selected for these response variables are listed in Table 3.

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 1–6. 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 1–6 and leadout. Nominal flow rates are 0-30 sccm, but short-term peaks in helium flow up to and exceeding 100 sccm are assumed to be valid (TFR-259). |
| Capsule gas mixture outlet flow | 0 to 102 sccm | Capsules 1–6 (TFR-559). |
| Downstream gas mixture flow | 0 to 102 sccm | Flow from 7 FPM detectors: 1-6 corresponding to 6 capsule 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 1–6 and leadout. Pressure relief valve setting (TFR-559). |
| Moisture—capsule outlet | 0 to 5 ppm | Capsules 1–6 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.

#### *2.3.4.2 Prior Instrument Failure Time*

As the AGR-2 experiment progressed through the first nine cycles, nine of the 15 installed TCs in the AGR-2 experiment failed: TC1/TC2 in Capsule 1, TC1/TC2 in Capsule 2, TC1/TC2 in Capsule 5, and TC1/TC4/TC5 in Capsule 6 (INL/EXT-11-22798 and INL/EXT-12-26184). Failure times for the confirmed failed TCs are presented in Table 4 for the US capsules. Readings from these TCs after the failure times can be assigned to "Accuracy Failed" data state.

Table 4. TC Failure times for AGR-2 US capsules by the end of 151B

| Capsule # | TC # | Failure Time |
|---|---|---|
| 2 | 1 | 2010-11-27 16:11:00 |
| 2 | 2 | At fabrication |
| 5 | 1 | 2011-05-21 06:00:00 |
| 5 | 2 | 2011-05-21 06:00:00 |
| 6 | 1 | 2012-02-29 11:25:00 |
| 6 | 4 | 2012-03-22 15:35:00 |
| 6 | 5 | 2010-10-12 20:00:00 |

### 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 NDMAS database as follow: (1) date and time data inserted into "dAGR_FPMEvent" table; (2) R/B data inserted into "dAGR_FPMRatio" table; (3) release data inserted into "dAGR_FPMRelease" table; and (4) flow data inserted into "dAGR_FPMFlow" table.

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

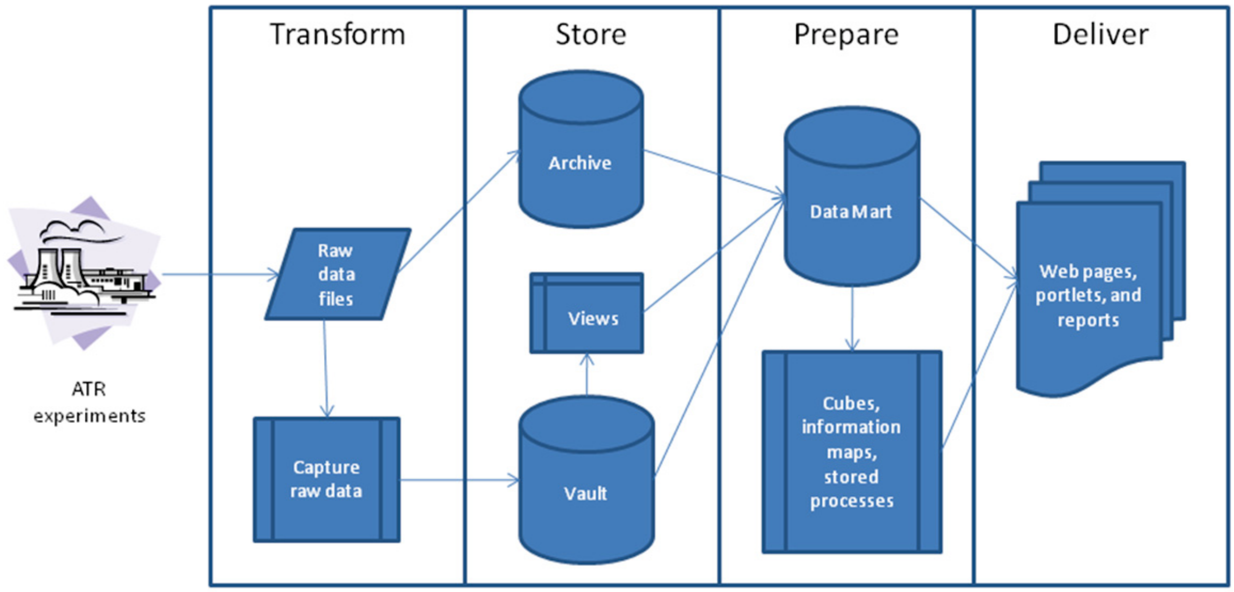


Figure 7. Stages of data processing in NDMAS.

## 3.1 Data Overview

This section provides overview plots of the data captured and processed by NDMAS for the five ATR cycles evaluated in this report (152A through 154A, including the "Low power" cycle, 152A, and "Outage" cycle, 153A). The qualification status of these data is presented in Section 4 of this report.

### 3.1.1 Reporting Cycles

This report provides the qualification status of AGR-2 fuel irradiation experimental data during five ATR fuel cycles, 152A, 152B, 153A, 153B, and 154A, as recorded in the NDMAS. (Cycle 151B-2 is covered in Abbott and Pham (2012)). Among them there are three untypical cycles: Cycle 152A is a "*Low power*" cycle; Cycle 153A is an unplanned "*Outage*" cycle; and Cycle 153B is an ATR PALM cycle. Table 5 provides a summary of all cycles of the data qualification report covering the period from May 5, 2012, through July 13, 2013.

During Cycles 152A and 153A the ATR core was raised to 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 Cycle 153A and 1.082 MW for 0.25 hours for Cycle 153A. 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 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 as shown in Table 5. Also, during the "*Outage*" cycle, 153A, seven flow meters were installed downstream from seven FPMS monitors to measure flows from them and their data was included in the NDMAS database. During the ATR PALM cycle, 153B, the experiment was moved from the large B-12 location to the more peripheral I-24 location (next to the NW lobe) to prevent over-heating of fuel compacts due to high ATR lobe powers.

Table 5. Overview of cycles for this reporting period

| ATR Cycle | Record Start | Power Up | Record End | No. of EFPDs | Total # Records | Cycle Comment |
|---|---|---|---|---|---|---|
| 152A | 05MAY12:15:00 | n/a | 30OCT12:00:00 | 0 | 3,258,675 | Low power |
| 152B | 30OCT12:00:30 | 27NOV12:21:00 | 18JAN13:10:10 | 51.0 | 2,681,630 | Normal |
| 153A | 18JAN13:10:10 | n/a | 11MAR13:13:07 | 0 | 1,433,775 | Unplanned outage |
| 153B | 11MAR13:13:07 | 29MAR13:04:17 | 10APR13:01:00 | 13.5 | 1,965,810 | PALM |
| 154A | 10APR13:01:00 | 18MAY13:23:35 | 13JUL13:09:05 | 52.3 | 5,546,750 | Normal |
| | | | *Total* = | 116.8 | 14,886,640 | |

### 3.1.2 Temperature Data

Excluding data from TCs that were failed during the first nine cycles of AGR-2 (TC1/2 in Capsule 2, TC1/2 in Capsule 5, and TC1/4/5 in Capsule 6) (Abbott and Pham 2011, 2012), there are two US capsules with operational TCs during this reporting time. The hourly TC temperature data averaged from instantaneous measurements are shown in Figure 8 for Capsules 3 and 6. Capsules 2 and 5 do not have any operational TCs and 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. A discussion on TC temperature anomalies as they relate to data qualification is presented in Section 3.2.

As discussed in previous subsections there were 3 cycles, 152B, 153B, and 154A, when ATR was up to full power. During the PALM cycle, 153B, the ATR power level could increase by as much as 50% above that during normal cycle, so 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 Figure 8) instead of ~950 ºC during the previous cycle, 152B. Soon after the ATR power was up during Cycle 154A, the last TC in US capsules, TC3 in Capsule 6, failed as its readings dropped to ~30 ºC for the rest of the power-up period. Details on TC failure evidence during this period are presented in Section 3.2.1

Cycle 152A is a "*Low power*" cycle, so TC readings were largely low ranging from ~30 to 50 °C except for one hour and 15 minutes on October 4, 2012 from 19:15 to 20:30 hours when TC1 and 2 in Capsule 3 raised to 431 °C and 432 °C in Capsule 3 and TC2 and 3 in Capsule 6 raised to 461 °C and 463°C. Cycle 153A was an unplanned "*Outage*" cycle due to technical issues at the ATR facility, therefore TC readings are also low in the ~20 to ~40 °C range.

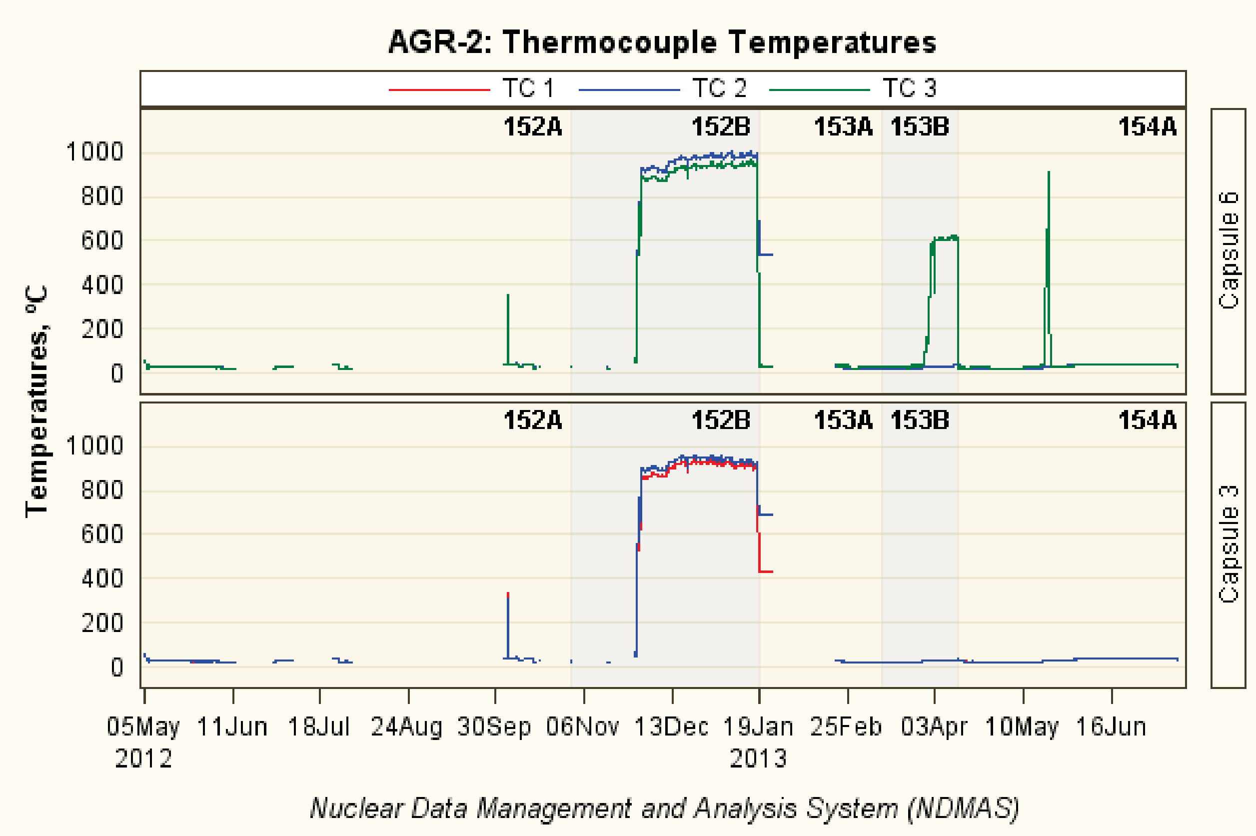


Figure 8. Capsules 3 and 6 TC temperature data for Cycles 152A–154A.

### 3.1.3 Sweep Gas Data

Figure 9 shows the hourly sweep gas flow rates averaged from instantaneous measurements for each capsule including helium inlet, neon inlet, total outlet, and newly added downstream meters at FPMS detector outlets (labeled "FPM"). Leadout gas flow (both helium and neon) are shown at the bottom panel of Figure 9 (same for all capsules). As in the above TC plots, gaps in gas flow plots represent periods with missing irradiation data during cycle outages. Fortunately, during that time AGR-2 usually runs on the same level of pure helium in all six capsules and  the leadout except for a few short flow meter testing periods when gas flow rate can be abnormally high (see vertical lines out of normal boundary in Figure 9). 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.

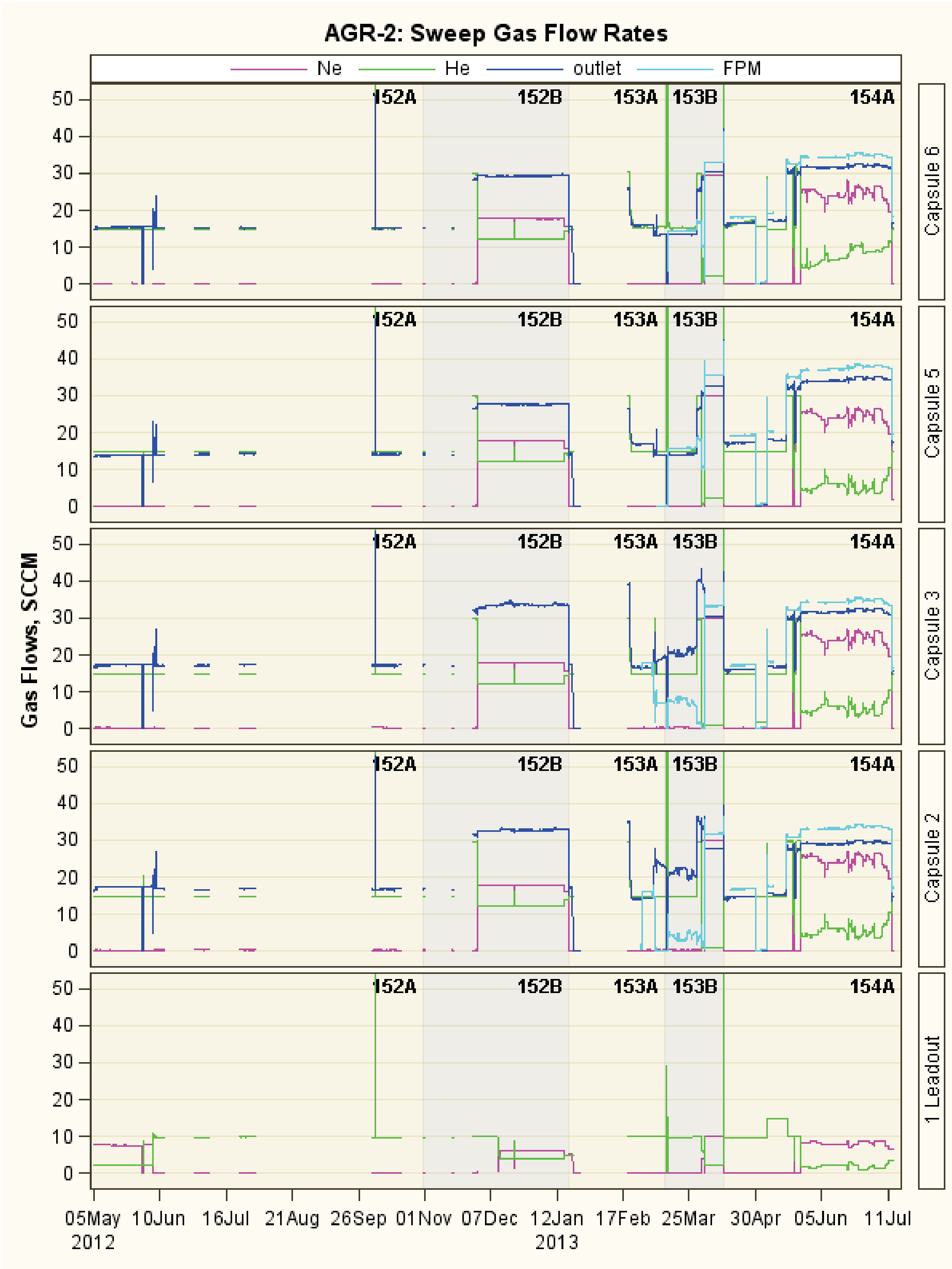


Figure 9. Capsule and leadout sweep gas flow rates (sccm).

### 3.1.4 FPMS Data

Figure 10 and Figure 11 plot fission product release rate and R/B data (nominal 8-hour count times) for the reactor cycles that have been submitted to NDMAS to date (152B, 153B, and 154A). Detailed documentation of the FPMS measurement and processing methods is contained in cycle-specific ECARs written by FPMS staff. These ECARs also provide the basis for FPMS data qualification. However, because of 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, so 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.*

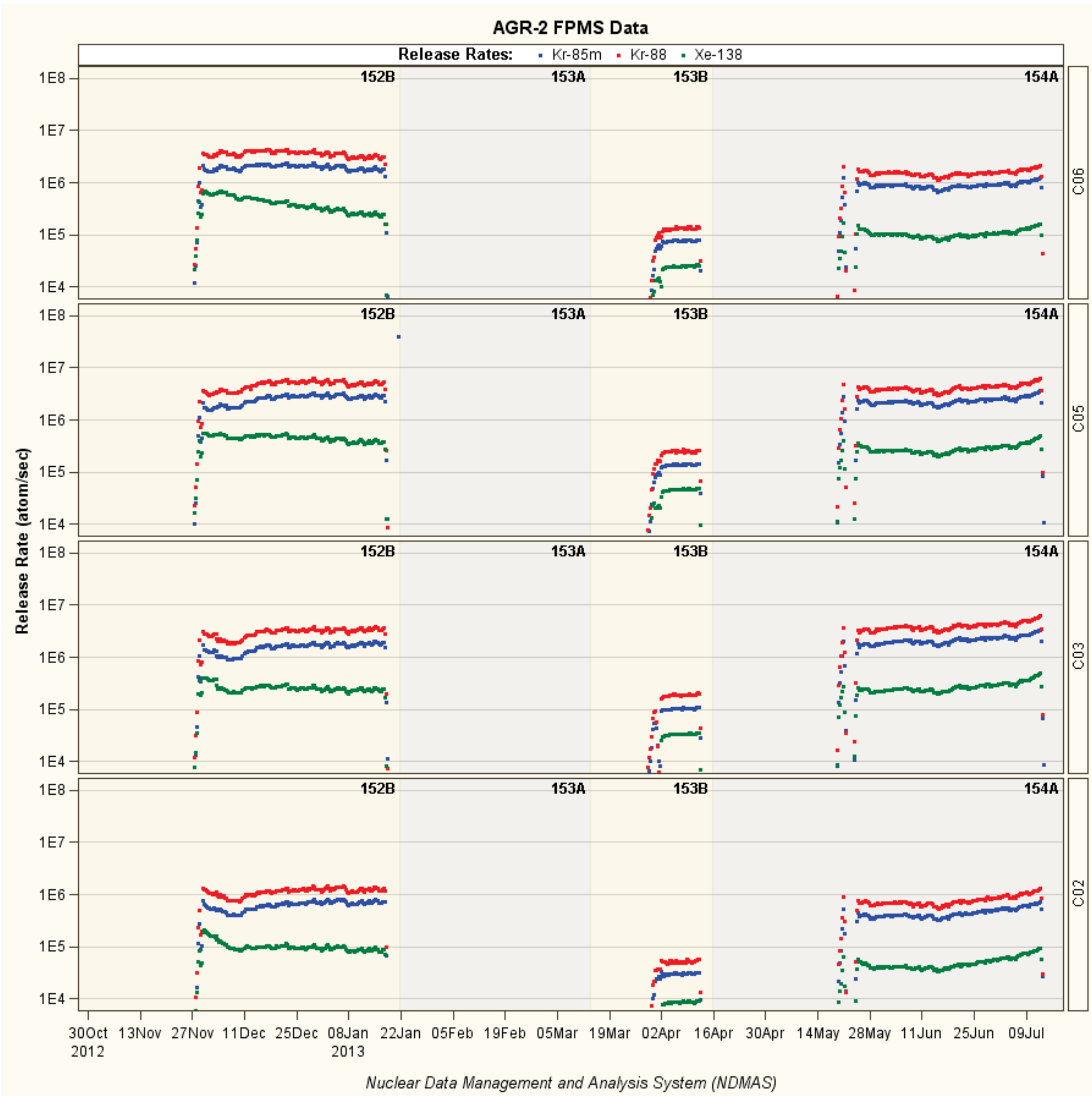


Figure 10. AGR-2 fission product release rates for Kr-85m, Kr-88, and Xe-138 for ATR Cycles 152B, 153A, 153B, 154A.

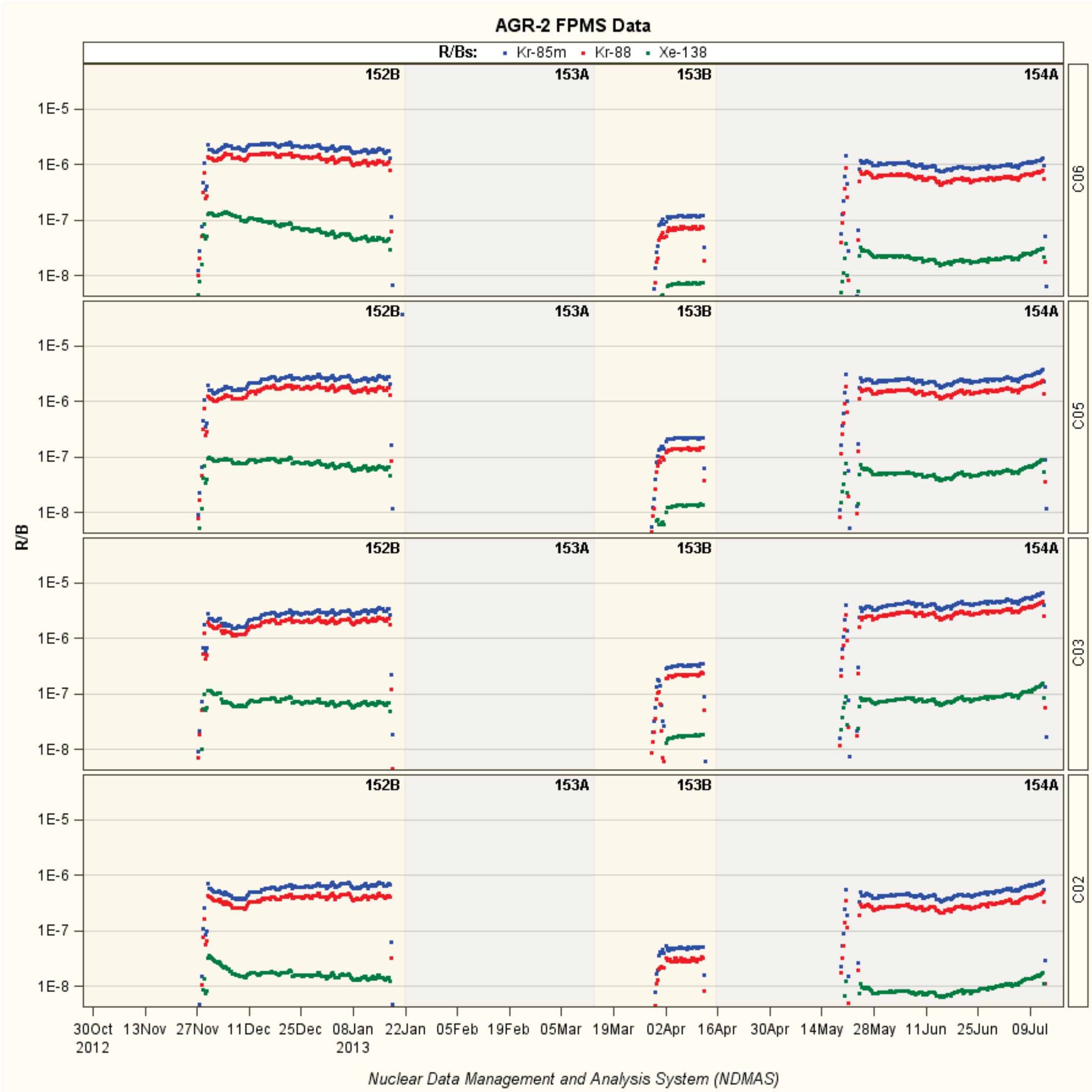


Figure 11. AGR-2 fission product R/B ratios for Kr-85m, Kr-88, and Xe-138 ATR Cycles 152B, 153A, 153B, 154A.

## 3.2 Testing for Data Anomalies of TC Temperatures

NDMAS runs a number of tests for TC temperature data to identify potential anomalies (Table 6). 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.

Table 6. NDMAS tests performed for AGR-2 irradiation monitoring data.

| Test Type | Test Name | Test Description |
|---|---|---|
| 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 Instrument Failure Testing

AGR TCs deteriorate and sometimes fail because of the high irradiation and temperature conditions that occur during test reactor cycles. Failures are likely caused by deterioration or damage to the TC sheath and/or dielectric insulating material that separates the TC thermal elements. This produces an electrical path ("virtual junction") at some location along the TC wire other than at the terminal tip. Failure is exhibited when the temperature reading drops to or near zero during full power conditions, does not respond during reactor power-up, or responds in a way that is inconsistent with reactor power conditions, gas mixture inlet flows, or other TC responses. During the first nine AGR-2 cycles, nine of the 15 installed TCs in the AGR-2 experiment failed: TC1/TC2 in Capsule 1, TC1/TC2 in Capsule 2, TC1/TC2 in Capsule 5, and TC1/TC4/TC5 in Capsule 6 (INL/EXT-11-22798 and INL/EXT-12-26184). These failures were visually identified by both VHTR program leads and NDMAS analysts over the course of the experiment, and the date/time of the failures were confirmed by the DRC during the data qualification process. After DRC verification, the Data State and Qualification State flags are set to "Failed" in the NDMAS database for all temperature records from the failed TC after the failure date. These failure flags ensure the data is managed and used appropriately (e.g., is not used in any plots or downloads and is identified as failed in data tables).

The DRC will review the data on the following new TC failure dates (Table 7) using plots and discussions in the following subsections (Capsule 4 discussions are CRADA-restricted and excluded in the final version of this report). The decisions of the DRC will be reported in the final version after the meeting.

Table 7. TC failure times for AGR-2 US capsules during this reporting time

| Capsule # | TC # | Failure Time | ATR Cycle |
|---|---|---|---|
| 6 | 2 | 2013-01-18 10:05:00 | End of 152B |
| 6 | 3 | 2013-05-21 04:45:00 | Start of 154A |
| 3 | 1 | 2013-01-18 10:05:00 | End of 152B |
| 3 | 2 | 2013-01-18 10:05:00 | End of 152B |

#### *3.2.1.1 TC2 in Capsule 6*

DRC Recommendation: Failure on 18 January 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 ~ 40°C as expected when ATR core powered down to zero at the end of Cycle 152B (Figure 12). TC2 then did not respond to the power-up phase during the next cycle, 153B (Panel 1 in Figure 8). Based on this response, TC2 is assumed to have failed on January 18, 2013 at 10:05 hours, and all data from this TC are failed after this date/time.

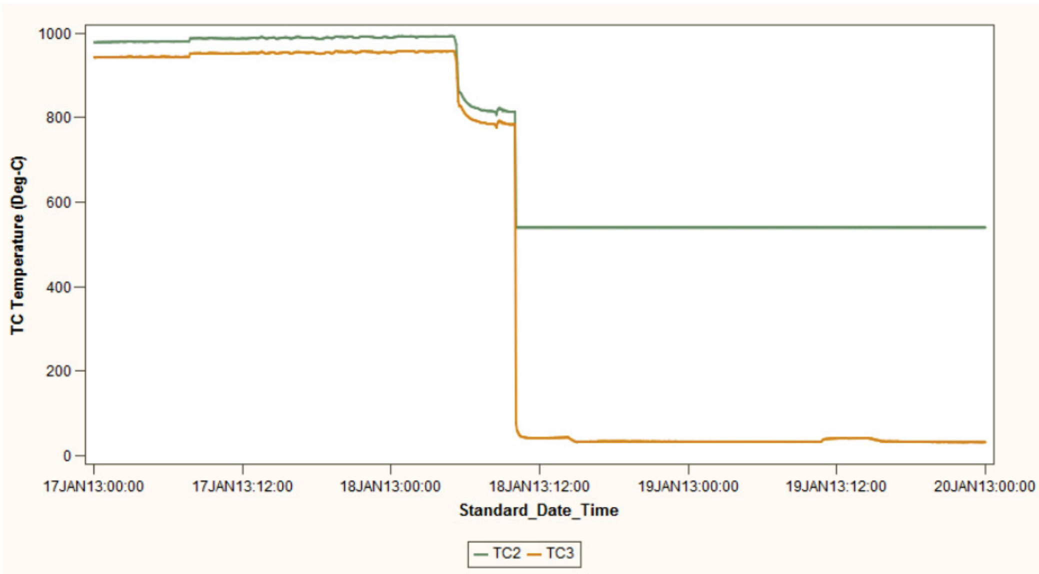


Figure 12. TC2 in Capsule 6 failed on 18 January 2013 at 10:05 (based on actual data).

#### *3.2.1.2 TC3 in Capsule 6*

DRC Recommendation: Failure on 21 May 2013 at 04:45 am (middle of Cycle 154A)

TC3 in Capsule 6 first dropped to 48.7 °C and stuck at that same level for an extended period (Figure 13). TC3 readings did not increase when ATR powered up during the same cycle, 154A (Panel 1 in Figure 8). Based on this response, TC2 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.

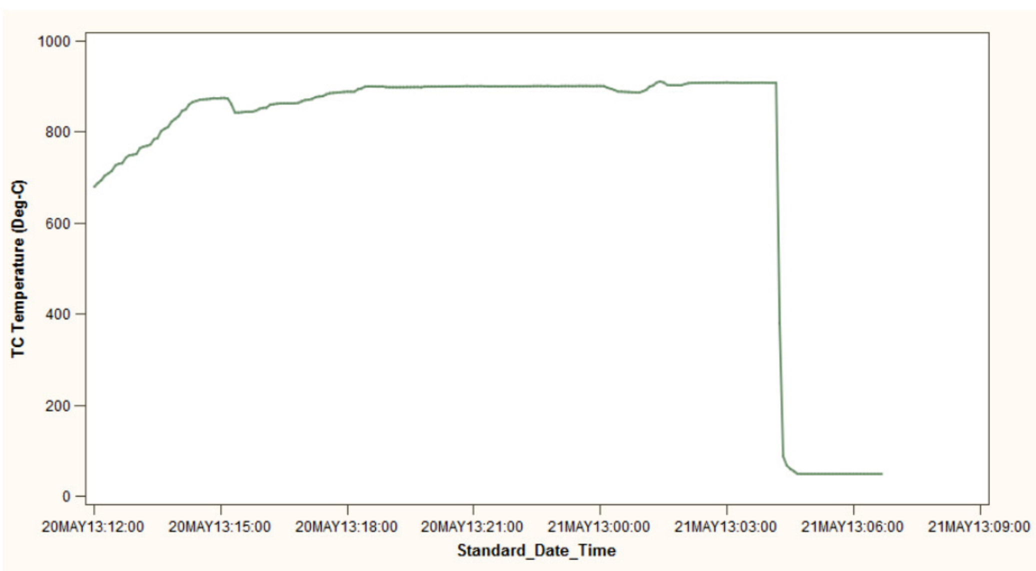


Figure 13. TC3 in Capsule 6 failed on 21 May 2013 at 04:45 (based on actual data).

#### *3.2.1.3 TC1 and TC2 in Capsule 3*

DRC Recommendation: Failure on 18 January 2013 at 10:05 (end of Cycle 152B)

Both TC1 and TC2 in Capsule 3 failed similarly to TC2 in Capsule 6 and at exactly the same time. TC1 dropped to 430°C and TC2 dropped to 693 °C on January 18, 2013 at 10:05 instead of decreasing to ~ 40°C as expected when ATR powered down to zero at the end of 152B (Figure 14). Then they did not respond to the power-up phase during the next cycle, 153B (Panel 2 in Figure 8). Based on this response, TC1 and TC2 are assumed to have failed on January 18, 2013 at 10:05 hours, and all data from these TCs are failed after this date/time.

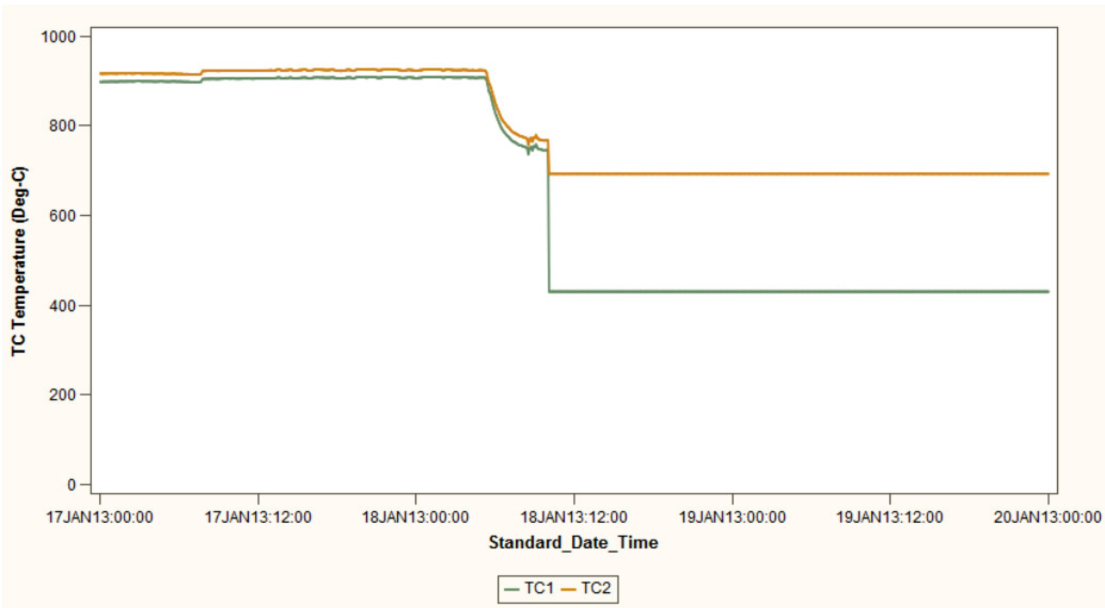


Figure 14. TC1 and TC2 in Capsule 3 failed 18 January 2013 at 10:05 (based on actual data).

### 3.2.2 TC Drift

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.

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 TC3 and by the end of 153B Capsule 4 has only TC2. Therefore, this technique cannot be used after Cycle 152B. 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.

#### *3.2.2.1 Control Chart Results—TC2/3 in Capsule 6*

Figure 16 shows the control chart results for the only surviving TC pair in Capsule 6, 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 relative to TC3 during Cycle 152B. In fact, TC2 in Capsule 6 failed by the end of this cycle as shown in Figure 12.

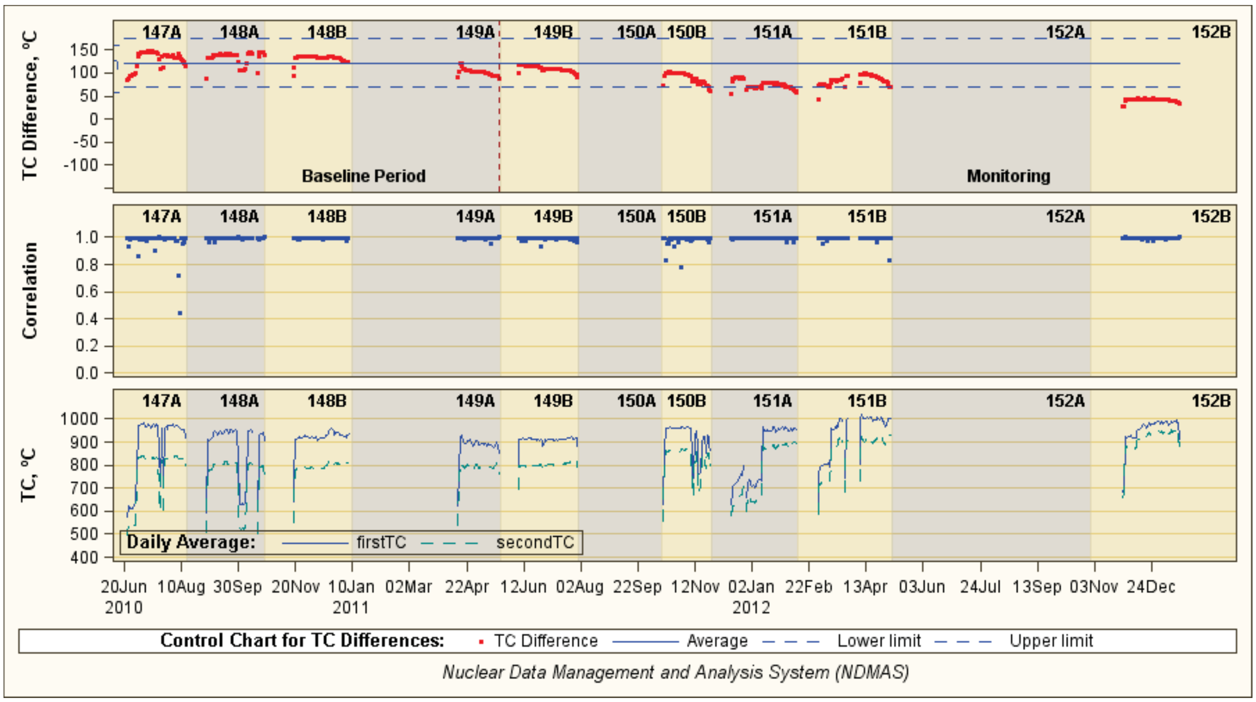


Figure 15. Control chart for the TC2/3 pair in Capsule 6.

#### *3.2.2.2 Control Chart Results—TCs in Capsule 3*

Control charts of temperature differences between TC1 and TC2 in Capsule 3 in Figure 16 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 14.

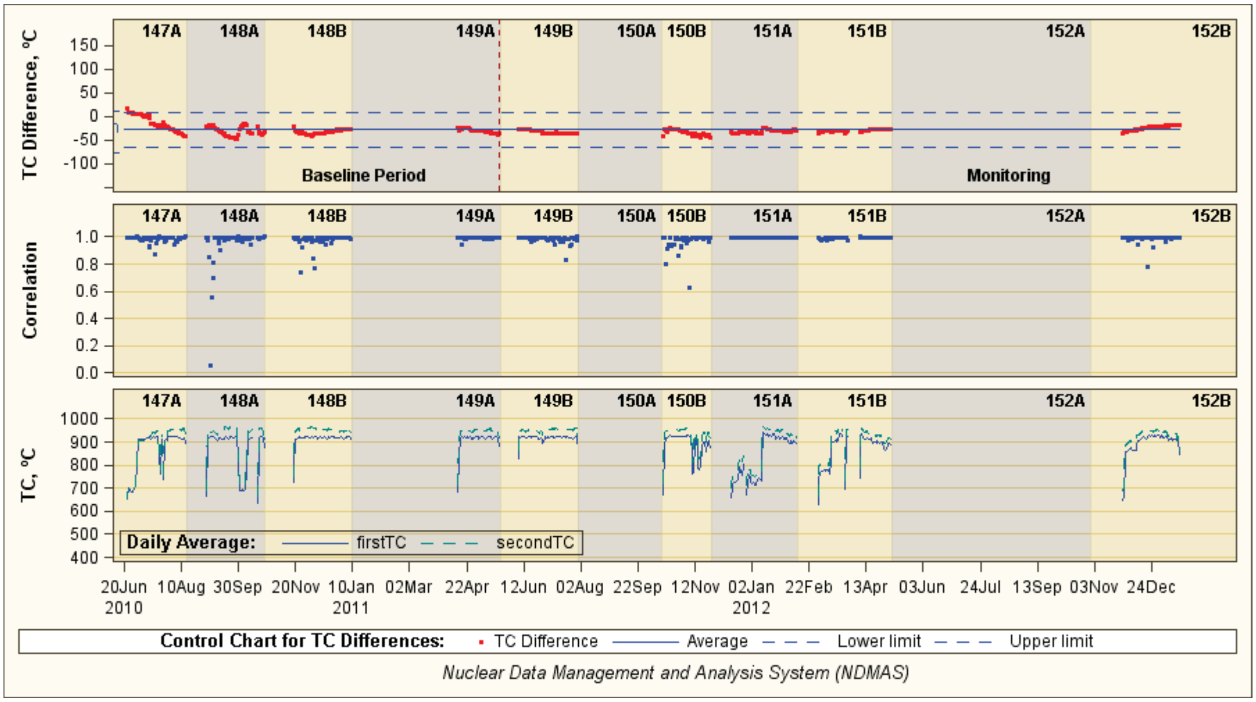


Figure 16. Drift monitoring for TC1 and TC2 in Capsule 3.

### 3.2.3 TC Virtual Junctions

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

When functioning properly, TC readings for a given capsule should be most highly correlated with other TCs in the same capsule. If a virtual junction occurs, the highest correlation will switch to a TC reading in a different capsule (where the junction occurs). To do this test for a given capsule, there needs to be at least two functioning TCs located in that capsule, and comparisons can only be made with other capsules that have functioning TCs. Figure 17 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.

Since there are only two operational TCs left in AGR-2 after PALM Cycle 153B, TC3 in Capsule 6 and TC2 in Capsule 4, this statistical analysis method is no longer useful for TC virtual junction detection.

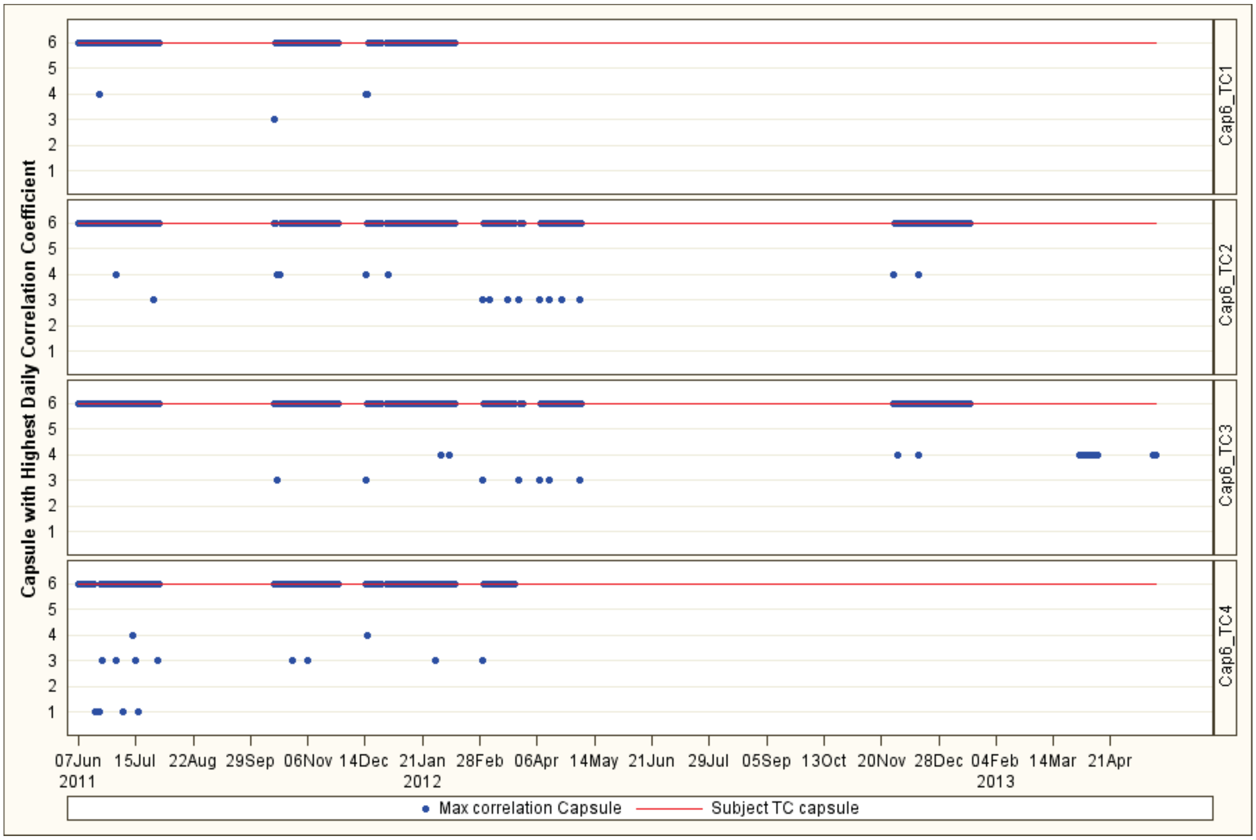


**Figure 17. Example correlation plot for the TCs (1-4) installed in Capsule 6. Except for some random scatter, each TC is most highly correlated with another TC in the same capsule, indicating no virtual junction.**

## 3.3 Testing for Data Anomalies of Gas Flow Rate Data

This section discusses data anomalies of gas flow rates resulting from data testing and DRC data qualification decisions along with their impacts to program objectives. The four failure modes of gas flow rate measurements are: (1) missing, (2) out-of-range, (3) failure to maintain the same neon fraction in all six capsules and leadout, and (4) stuck. Modes (1) and (2) are identified by range testing within the NDMAS data capture process. Modes (3) and (4) are identified by data analysis within data qualification process. Details of the data failures are presented in the following subsections.

### 3.3.1 NDMAS Capture Range Testing

In this section only neon, helium and outlet flow data testing results are discussed. The failures of the FPM flow data are discussed separately in Section 3.3.3.

#### *3.3.1.1 Missing Data*

Data is 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 214,277 missing flow rates out of a total of 7,657,440 flow data records (or 2.8%) representing 96.2% of all the 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, so the missing values are not hard to fill 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. Two out of three cycles with ATR at full power have missing gas flow measurements, 21,413 missing records during Cycle 152B and 135 missing records during Cycle 154A. These require further analysis of their impact on the determination of capsule gas mixture compositions.

Table 8. Missing gas flow data by cycle

| ATR Cycle | 152A | 152B | 153A | 153B | 154A |
|---|---|---|---|---|---|
| # of Missing | 131,303 | 21,413 | 61,561 | 0 | 135 |

For Cycle 152B, Table 9 shows that except for one missing helium flow rate and five missing outlet flow rates, all remaining missing gas flow measurements are neon inlet flow rates. Among them are 18,786 missing neon inlet flow rates that occurred during full power periods with the distribution by capsule and leadout presented in
Table 10. The table shows that only Capsule 1 and the leadout have significant numbers of missing neon flow rates. For Capsule 1, the missing neon flow rates occurred during the first three days immediately following the ATR power-up (November 27 to 29, 2012) and during a five hour period on the last day (January 18, 2013) as shown in

Table 11. Fortunately, during that time AGR-2 uniformly ran on pure helium in all six capsules and leadout, so all missing neon flow rates in Capsule 1 can be confidently filled-in with zero flow rates. One missing neon flow rate out of 1,440 records on December 20, 2012 can be ignored. For leadout, since the total of leadout flow rates (neon plus helium) is always equal to 10 sccm and helium flow rates are not missing, then the missing neon flow rate can be computed by subtracting the helium flow rate from the total leadout flow rate.

For Cycle 154A, an insignificant number of missing records exists for both neon and helium flow rates for Capsules 1, 5, and 6. However, these missing data occurred only for 44 minutes on May 29, 2013 from 7:43 to 8:27 am, so their impact on daily averaging is negligible and they can be estimated based on neighboring data when needed.

Table 9. Number of missing gas flow data for Cycles 152B and 154A

| 152B | | | 154A | | |
|---|---|---|---|---|---|
| Neon Inlet | Helium Inlet | Outlet | Neon Inlet | Helium Inlet | Outlet |
| 21,407 | 1 | 5 | 90 | 45 | 0 |

Table 10. Number of missing neon gas flow rates in Cycle 152B by capsules and leadout

| Capsule 6 | Capsule 5 | Capsule 4 | Capsule 3 | Capsule 2 | Capsule 1 | Leadout |
|---|---|---|---|---|---|---|
| 26 | 26 | 21 | 23 | 0 | 3,247 | 15,427 |

Table 11. Neon flow rates in other capsules and leadout when missing data in Capsule 1

| Date | # of Missing Neon Flow Rates in Capsule 1 | Capsule Daily Average Neon Flow Rate (sccm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 6 | 5 | 4 | 3 | 2 | Leadout |
| 27-Nov-12 | 180 | 0.10 | 0.09 | 0.27 | 0.22 | 0.23 | 0.11 |
| 28-Nov-12 | 1440 | 0.10 | 0.08 | 0.26 | 0.21 | 0.24 | 0.11 |
| 29-Nov-12 | 1320 | 0.07 | 0.05 | 0.23 | 0.18 | 0.25 | 0.10 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20-Dec-12 | 1 | 17.64 | 17.84 | 17.91 | 17.82 | 17.95 | 6.01 |
| 18-Jan-13 | 306 | 0.25 | 0.19 | 0.37 | 0.27 | 0.16 | 5.12 |

DRC recommendation: The analysis results support the conclusion that missing gas flow rate measurements during Cycles 152A to 154A do not affect determination of the capsule gas composition (e.g., neon fraction) needed in the thermal calculations for AGR-2 capsules.

#### *3.3.1.2 Out-of-Range Data*

Since the gas flow rates range from 0 to 102 sccm, the negative flow rates and "too high" flow rates (> 102 sccm) are assigned "failed" data status as a result of the NDMAS capture range testing. There are only 6,339 negative flow rates and 2,026 too high flow rates out of a total of 7,657,440 neon, helium, and outlet flow data records (or 0.11% of total records) representing 3.8% of all the gas flow failed data.

Table 12. Number of out-of-range gas flow data by cycle

| ATR Cycle | 152A | 152B | 153A | 153B | 154A |
|---|---|---|---|---|---|
| # of Too High | 63 | 0 | 0 | 1,963 | 0 |
| # of Negative | 79 | 0 | 158 | 4,424 | 1,678 |

*Too high gas flow rates*: There are 63 records during "Low power" Cycle 152A and 1,963 records during the PALM cycle (Cycle 153B) as shown in Table 12. All of them are helium flow rates in Capsule 6 and all of the 1,963 "too high" records were recorded on March 12 to13, 2013 during the outage of 153B. They are all equal to 103.2705 sccm suggesting stuck values. Figure 18 shows neon, helium, and outlet flow rates from March 11 to 16, 2013 for Capsules 2, 3, 5, and 6. During that time not only were helium flow rates in Capsule 6 were high, but helium flow rates in Capsules 2 and 3 were also unusually high (near 100 sccm). According to the experimental log book (based on the phone message to Dawn Scates from ATR operator), from 05:26 on March 12, 2013 the ATR personnel were performing secured gas flow (meaning stopped gas flow) for AGR-2 resulting in unusually high helium flow rates while neon flow rates and outlet flow rates were near zero (see Figure 18). Therefore all flow data from March 12, 2013 at 05:26 to March 13. 2013 at 14:00 should be failed.

DRC recommendation: Fail all flow data from March 12 at 05:26 to March 13 at 14:00 in 2013 which includes too high helium flow rates in Capsule 6 and all out-of-range data during 152A.

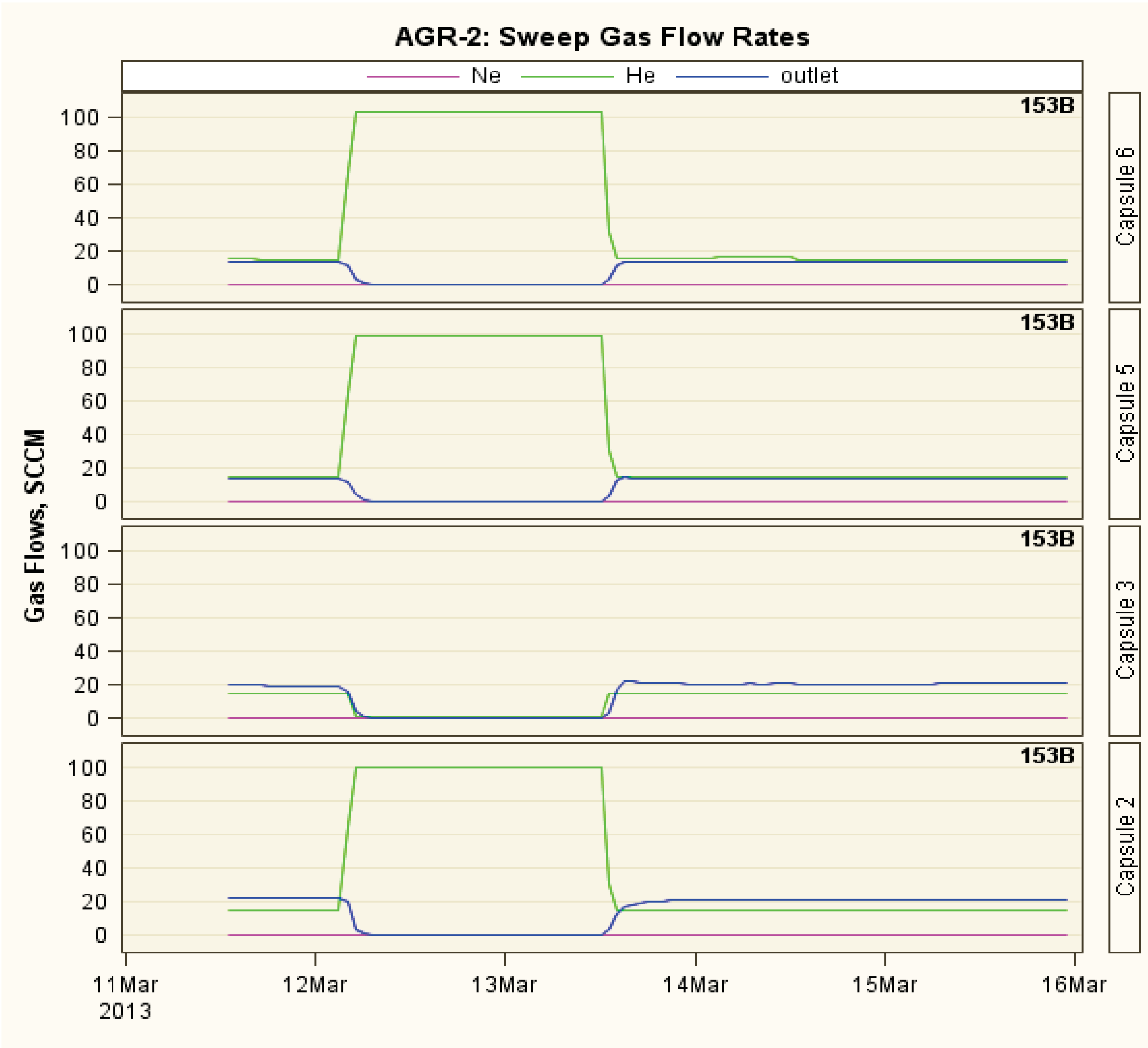


Figure 18. Neon, helium, and outlet flow rates during too-high helium flow rates in 153B

*Negative Gas Flow Rates*: Most negative flow rates occurred during the PALM cycle (153B) and Cycle 154A as shown in the bottom row of Table 12. All negative gas flow records during cycles 153B and 154A are outlet flow rates in Capsules 1, 3, 4, and 6, which are slightly less than zero ranging between -0.00289 sccm and -0.0206 sccm. Table 13 shows daily averages of negative outlet flow rates together with Ne and He flow rates during the same time for Cycles 153B and 154A to determine if the negative rates were still valid because they reflect the measurement noise when the flow rates are actually at zero.

For 153B: On March 12-13, 2013 the AGR-2 test was supposed to run on pure helium during the ATR outage. According to the experimental log book (based on the phone message to Dawn Scates from ATR operator), from 05:26 on March 12, 2013 the ATR personal were performing secured gas flow for AGR-2 resulting in unusually high helium flow rates while neon flow rates and outlet flow rates were near zero (see Figure 18), therefore all flow data from March 12, 2013 at 05:26 to March 13. 2013 at 14:00 should be *failed* including these negative outlet flow rates.

On April 2, 2013 (red color in Table 13), the ATR was at full power and there are only seven negative outlet flow rates in Capsule 6 while Ne and He flow rates were near zero indicating zero flow rate in

Capsule 6. Therefore these seven negative outlet flow rates are still *valid* representing normal measurement noise of flow meter.

For 154A: The negative outlet flow rates from April 30 to May 6, 2013 were associated with averaged helium inlet flow rates of about 15 sccm in all capsules but Capsule 3 (Figure 19), so they are not representing actual outlet flow rates. Additionally, according to the experimental log book (also based on the phone message to Dawn Scates from ATR operator), there was a "lock-out tag-out" period from 04:15 April 30, 2013 until 15:44 May 6, 2013 when the gas flow was established to go to 15 sccm helium and 0 sccm neon flow. Therefore all sweep gas flow data from 04:15 April 30, 2013 to 15:44 May 6, 2013 (period of zero outlet flow rates in Figure 19) should be *Failed*, which were included in the DRC recommendation for "too high gas flow rates".

DRC recommendation: Fail all sweep gas flow data from 04:15 April 30, 2013 to 15:44 May 6, 2013 that includes negative gas flow rate data.

Table 13. Daily averaged outlet, neon, and helium flow rates when outlet flow data are negative

| Date | Cycle | Capsule | N# records | Outlet | Ne | He |
|---|---|---|---|---|---|---|
| 12-Mar-13 | 153B | C01 | 989 | -0.003 | 0.100 | 1.421 |
| 12-Mar-13 | 153B | C03 | 150 | -0.010 | 0.213 | 1.245 |
| 12-Mar-13 | 153B | C04 | 779 | -0.004 | 0.279 | 66.457 |
| 12-Mar-13 | 153B | C06 | 278 | -0.004 | 0.017 | 103.271 |
| 13-Mar-13 | 153B | C01 | 789 | -0.003 | 0.100 | 1.421 |
| 13-Mar-13 | 153B | C03 | 268 | -0.009 | 0.222 | 1.245 |
| 13-Mar-13 | 153B | C04 | 788 | -0.005 | 0.293 | 66.457 |
| 13-Mar-13 | 153B | C06 | 376 | -0.004 | 0.023 | 103.271 |
| 2-Apr-13* | 153B | C06 | 7 | -0.004 | 0.007 | 0.396 |
| 30-Apr-13 | 154A | C03 | 366 | -0.008 | 0.178 | 1.919 |
| 30-Apr-13 | 154A | C06 | 47 | -0.002 | 0.007 | 15.455 |
| 1-May-13 | 154A | C03 | 972 | -0.008 | 0.195 | 1.919 |
| 1-May-13 | 154A | C06 | 3 | -0.002 | 0.007 | 15.455 |
| 2-May-13 | 154A | C03 | 269 | -0.008 | 0.206 | 1.919 |
| 2-May-13 | 154A | C06 | 21 | -0.002 | 0.007 | 15.455 |
| * During ATR full power period | | | | | | |

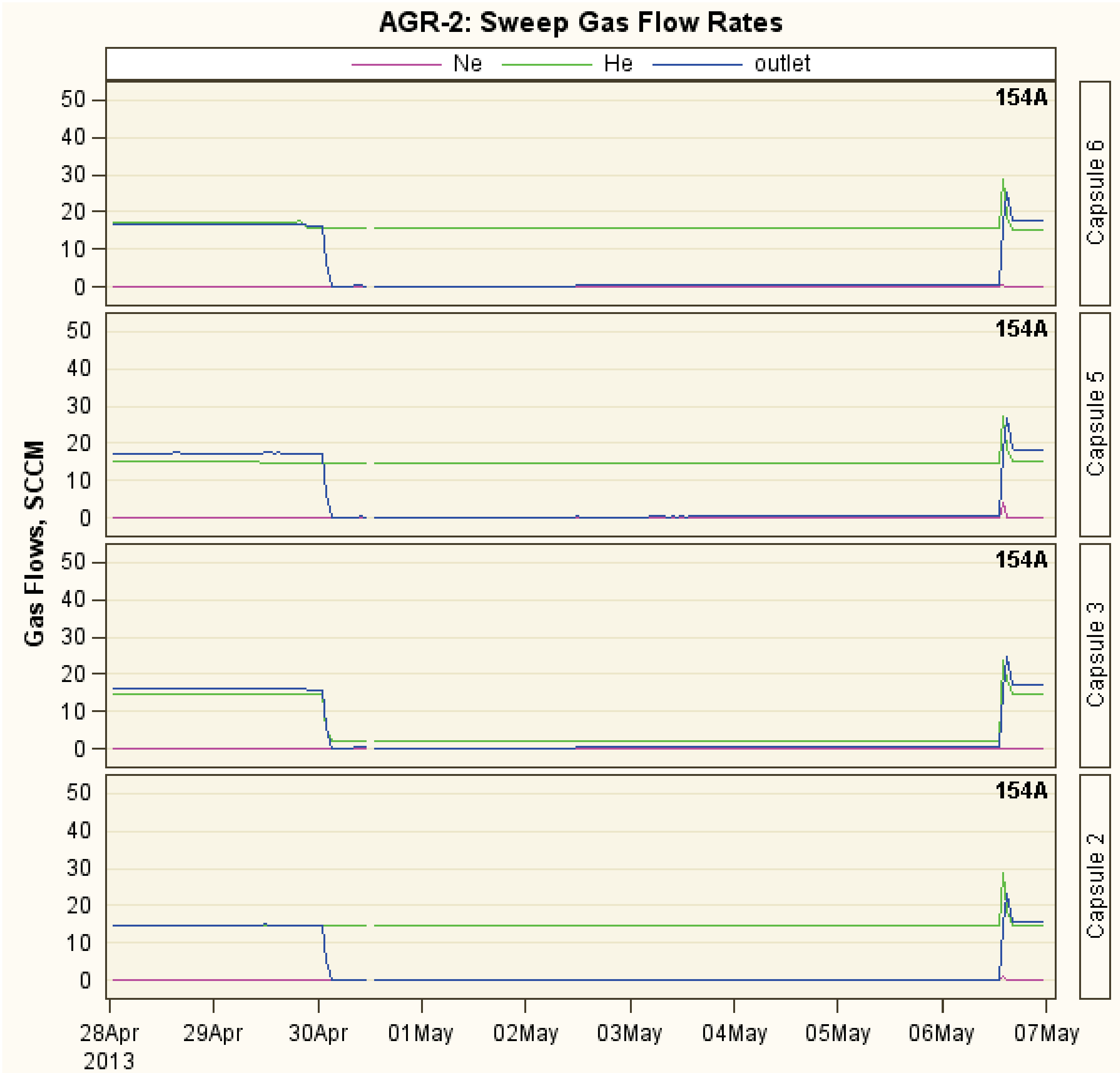


Figure 19. Neon, helium, and outlet flow rates during negative outlet flow rates in Cycle 154A

### 3.3.2 Testing for Failure to Maintain the Same Neon Fractions in Six Capsules and Leadout

Significant capsule gas line crosstalk and leadout leakage problems that started to occur early in Cycle 150B after the AGR-2 test was reinstalled back into the reactor following the 150A PALM cycle are still present during the five cycles in this report. These cross-talk and leakage problems made it impossible to control the temperature in each capsule by independent gas mixtures as designed. So 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.

However, there is a concern that the helium/neon gas flows recorded during these times 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).

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 after the 150A PALM cycle 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 mid-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-min 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 to July 13, 2013 (End of 154A) as shown in Figure 20. 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 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, so the inlet neon and helium flow rates are *qualified* with the caution that the neon fractions calculated as 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 and are therefore 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 (152A, 152B, 153A, 153B, and 154A) are still *qualified* to be used for other purposes because there is no indication of flow meter failure.

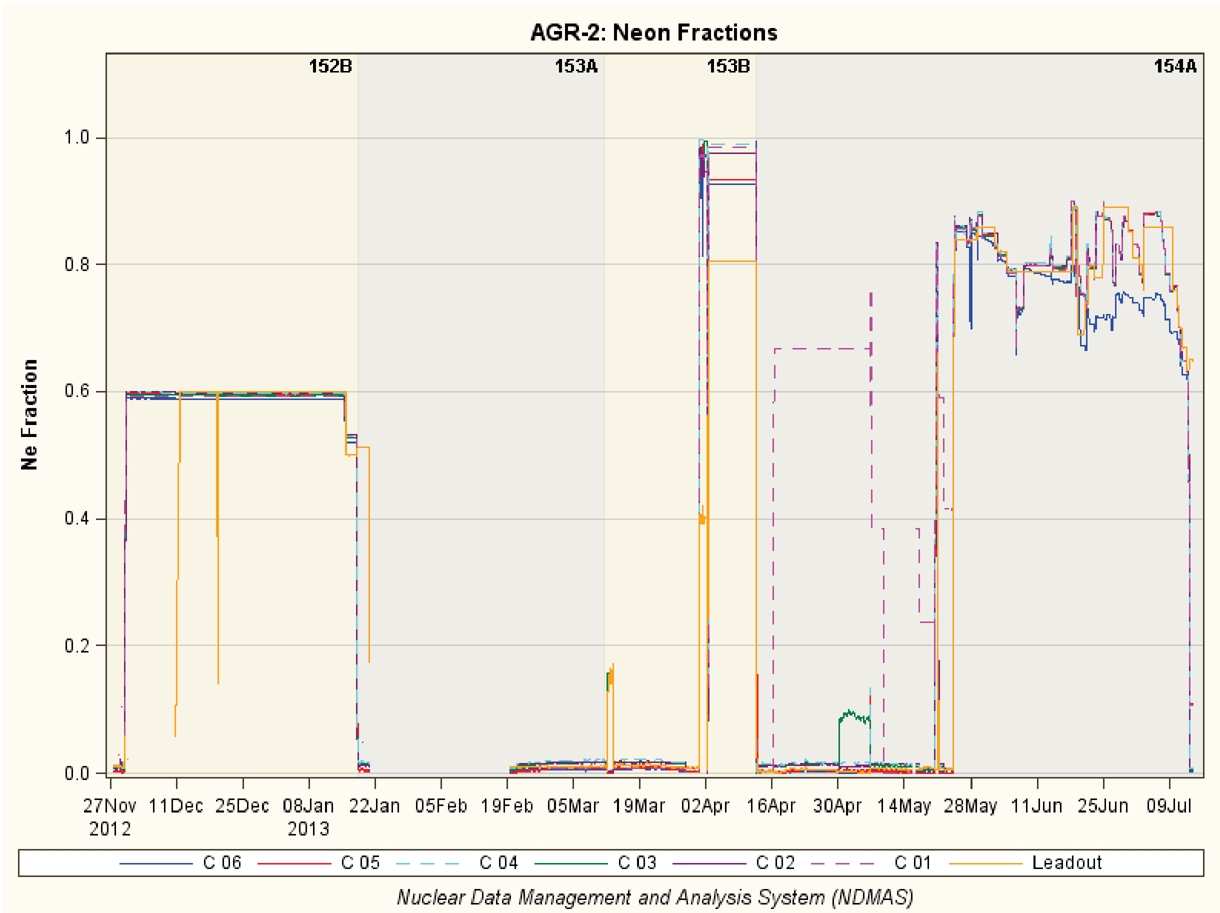


Figure 20. Capsule neon fractions for Cycles 152B, 153A, 153B, and 154A.

### 3.3.3 Downstream Gas Flow Data Failures

Section 3.3.1 addresses easy-to-spot gas flow rate failures by simple range testing. This section reveals possible failures of seemingly valid flow data (or "capture passed" after the range test) based on results of additional analysis such as flow rate comparison across capsules and/or between gas flows (e.g., outlet, neon, helium, and downstream) using their inherent relationships.

The outlet lines transport mixed gas together with any fission products released from the capsules to the FPMS, which is capable of 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 thus preventing it from correctly counting the release rate from the capsule. To detect and prevent valve lifting during Cycle 153A, seven additional gas flow meters were installed at the outlets of the seven FPMS detectors to measure downstream gas flow rates from these detectors. 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. The downstream gas flow rates should be similar to the outlet flow rates measured at the capsule outlets when the relief valves are tight allowing all mixed gas from the capsules to flow to their corresponding FPMS detectors. This feature will be used to assess quality of the downstream data.

Figure 21 shows hourly averaged flow rates of downstream (purple line) and outlet (blue line) flows for AGR-2 US capsules from the time when the downstream data were first captured in the NDMAS database. 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 (< 20 sccm). Since 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 start-up 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. Too high values: After fixing relief valves on April 3, 2013, the downstream flow rates are consistently higher than the outlet flow by up to 4 sccm in all capsules. However, since the plots of downstream and outlet flow rates are fairly parallel to each other over time, then the high values are probably caused by instrument biases.
4. 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 22 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 14. They remain at those levels even when the outlet flow rates were reduced to ~15 sccm around May 21, 2013.

Table 14. Stuck downstream flow rates for AGR-2 US capsules

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

DRC recommendation: (1) flag all FPM flow rate data prior to Cycle 154A from February 26, 2013 at 10:40 due to downstream flow meter adjustments and relief valves issues as *fail*ed, and (2) flag all FPM flow rates during Cycle 154A as *trend* data due to measurement biases.

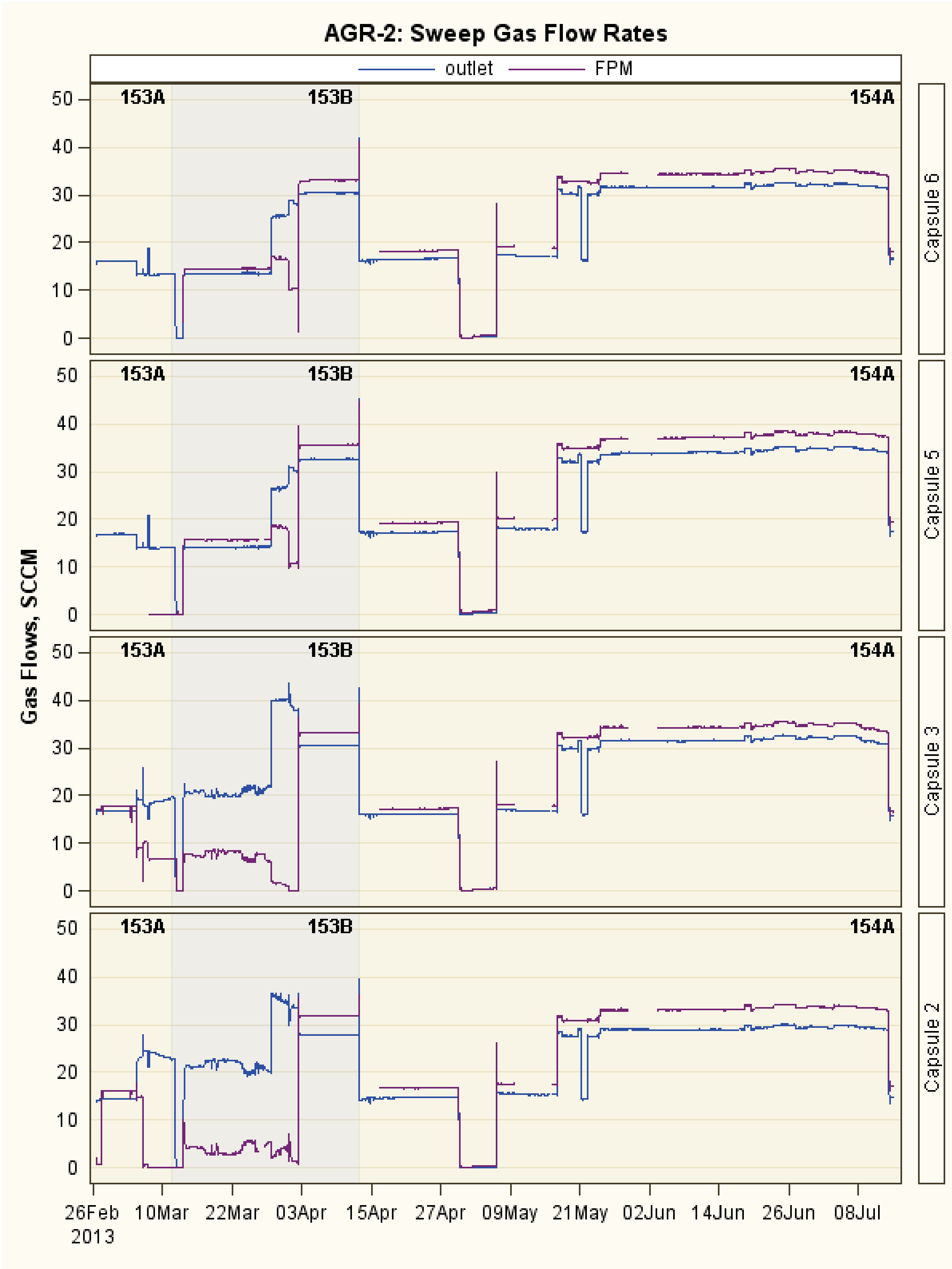


Figure 21. Downstream and outlet gas flow rates for AGR-2 US capsules

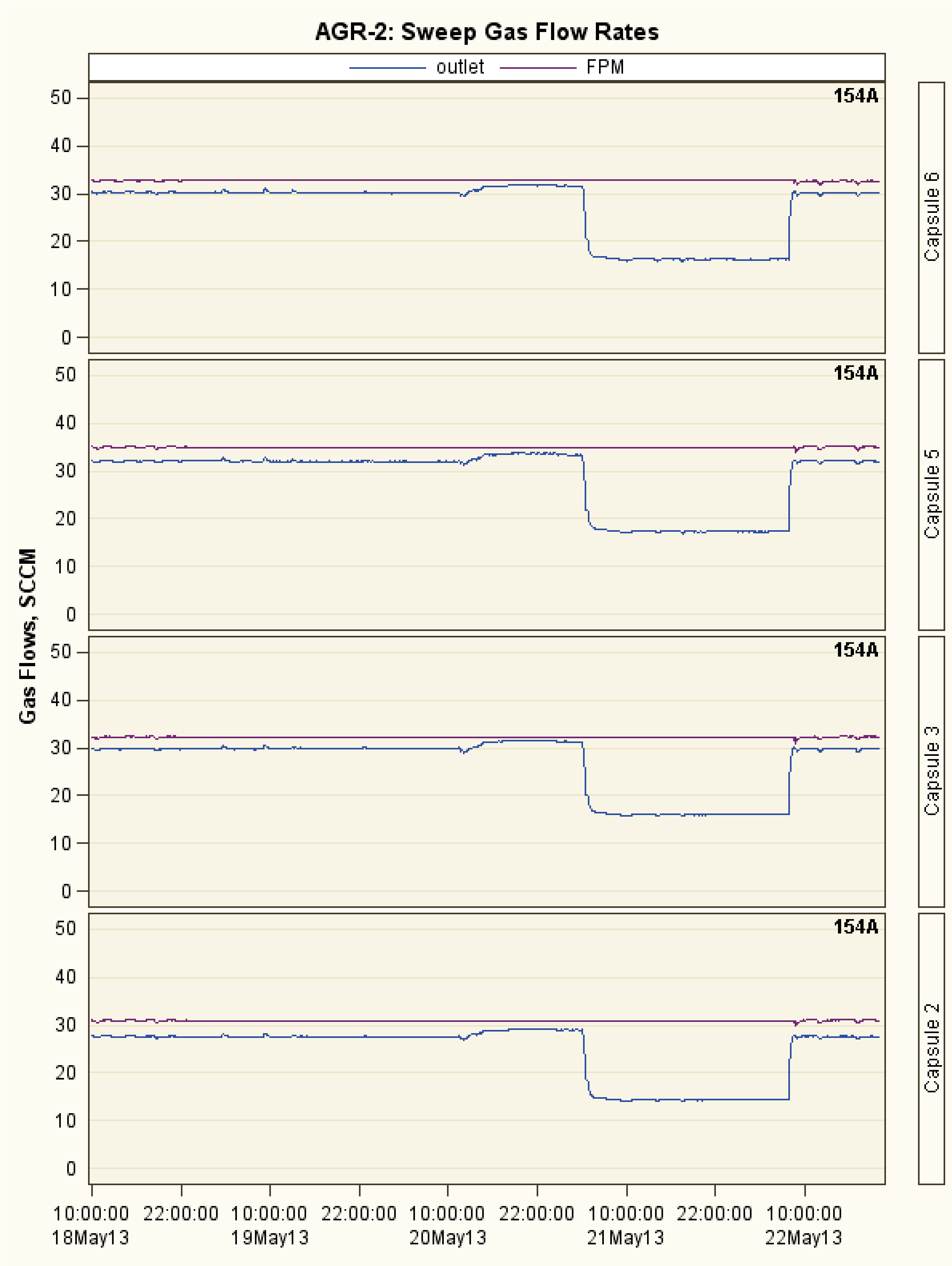


Figure 22. Downstream and outlet gas flow rates when the downstream flow rate measurements seem stuck (or unresponsive).

# 4. DATA RECORD QUALIFICATION SUMMARY

This section summarizes the data qualification decisions made by the DRC for the data packages received by NDMAS from May 5, 2012 (start of Cycle 152A) through July 7, 2013 (two days after the Cycle 154A 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

AGR irradiation monitoring data captured in the NDMAS database are now 1-minute instantaneous measurements instead of 10-minute or 5-minute averaged data as was the case during earlier cycles. The new data delivery method provides NDMAS with significantly more irradiation data and therefore requires implementation of a more flexible data structure and online database testing.

### 4.1.1 Database Testing Results

From the beginning of Cycle 152A, the new automatic data transfer from the CDCS provides NDMAS with 1-minute instantaneous irradiation monitoring data every two hours instead of the weekly 10-minute or 5-minute averaged data provided during earlier cycles. 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*

Table 15 lists the number of TC records failed from the database testing as described in Section 2.3.4. Missing records from operational TCs are counted as *failed missing* records. The majority of failed TC records were due to instrument failures. There are only three *negative* TC readings and no TC reading exceeded the upper limit of 1400 °C during the five cycles.

Table 15. Number of TC records failed from database testing

| | | | | No. of Failed Records | | | | |
|---|---|---|---|---|---|---|---|---|
| ATR Cycle | Record Start | Record End | Total # Records | Negative | Missing | N# Failed | % Failed | Notes |
| 152A | 05MAY12:15:00 | 30OCT12:00:00 | 1,396,575 | 1 | 60 | 837,429 | 60.0% | a |
| 152B | 30OCT12:00:30 | 18JAN13:10:10 | 1,149,270 | 0 | 214 | 689,564 | 60.0% | a |
| 153A | 18JAN13:10:10 | 11MAR13:13:07 | 558,675 | 0 | 0 | 446,940 | 80.0% | a,b |
| 153B | 11MAR13:13:07 | 10APR13:01:00 | 694,620 | 0 | 0 | 555,696 | 80.0% | a,b |
| 154A | 10APR13:01:00 | 13JUL13:09:05 | 1,943,940 | 2 | 559 | 1,735,938 | 89.3 | a,b,c |
| | | ***Total =*** | **5,743,080** | **3** | **833** | **4,265,567** | **74.3%** | |

a. Cycles 1 through 9 TC failures: C1_TC1/2, C2_TC1/2, C5_TC1/2, C6_TC1/4/5.

b. New failures (starting 18Jan13:10:00): C3_TC1/2, C6_TC2.

c. New failures: C4_TC1 starting on 2 May 2013 at 10:00 and C6_TC3 starting on 21 May 2013 at 04:45 am

#### *4.1.1.2 Sweep Gas Data*

Table 16 lists the number of gas flow records failed from the database testing as described in Section 2.3.4 for neon helium, and outlet flow rates. The percentage of *Failed* gas flow records is unexpectedly high for the "*low power*" cycle (152A) and "*outage*" cycle (153A). During these two cycles, AGR-2 was run on pure helium, therefore the neon flow responses should be zero or close to zero. However, there are a significant number of *Failed* neon flow records due to negative values or missing values.

Table 16. Number of neon, helium, and outlet gas flow records failed from database testing

| ATR Cycle | Total # Records | No. of Failed Records | | | | % Failed |
|---|---|---|---|---|---|---|
| | | No. of Missing | No. of out-of-range | | N # Failed | |
| | | | Negative | Too high | | |
| 152A | 1,863,300 | 131,423 | 79 | 63 | 131,565 | 7.06% |
| 152B | 1,532,360 | 21,413 | 0 | 0 | 21,413 | 1.40% |
| 153A | 744,900 | 61,561 | 158 | 0 | 61,719 | 8.29% |
| 153B | 926160 | 0 | 4,424 | 1,963 | 6,387 | 0.69% |
| 154A | 2,591,920 | 135 | 1,678 | 0 | 1,813 | 0.07% |
| ***Total =*** | **7,658,640** | **214,532** | **6,339** | **2,026** | **222,897** | **2.91%** |

a. all 1,963 "too high" gas flow rates are He flow rates on March 12-13,2013 (outage 153B) and equal 103.2705 sccm.

### 4.1.2 Analytical Testing Results

The analytical testing results do not change the qualification status of TC readings during this period as reported in Table 15. However, the decisions of the DRC meeting on August 21, 2013 will change the qualification status of some gas flow records as reported in Table 16. These changes include: (a) *Failed* neon, helium, and outlet flow rates for all capsules and 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 154A outage); (b) *Failed* FPM flow rates for all capsules during cycles 153A and 153B; and (c) 757,960 FPM flow rates during Cycle 154A flagged as *Trend*. Table 17 summarizes gas flow data failures during this reporting period.

Table 17. Number of final gas flow records failed resulted from the DRC decisions

| ATR Cycle | Total # Records | No. of Failed Records | | | | % Failed |
|---|---|---|---|---|---|---|
| | | Inlet Ne/He | Outlet flow | FPM Flow | Total # | |
| 152A | 1,863,300 | 131,417 | 148 | n/a | 131,565 | 7.06% |
| 152B | 1,532,360 | 21,408 | 5 | n/a | 21,413 | 1.40% |
| 153A | 818,046 | 61,361 | 358 | 73,146 | 134,865 | 16.47% |
| 153B | 1,213,356 | 27,370 | 11,730 | 287,196 | 326,296 | 26.89% |
| 154A | 3,349,880 | 128,949 | 52,206 | 0* | 181,155 | 5.41% |
| ***Total =*** | **8,776,942** | **370,505** | **64,447** | **360,342** | **795,294** | **9.06%** |

* 757,960 FPM flow rates during Cycle 154A flagged as *Trend.*

### 4.1.3 Data Qualification Summary

NDMAS received a total of 14,520,022 1-minute irradiation monitoring data records for the five reactor cycles evaluated in this report (Table 18). Of these data, 59.9% met the requirements for *Qualified* data, 34.9% were *Failed* data*,* and 5.2% were *Trend* data (FPM flow data during Cycle 154A). There were 4,265,567 TC records (74.3% of the total) that were *Failed* because of TC instrument failures (see Section 3.2.1 for details). There were 370,505 helium/neon inlet gas flow records and 64,447 outlet gas flow records that were *Failed* because of the gas flow maintenance activities such as securing gas flow and of the missing values. For FPM flow rates, there are 757,960 *Trend* records during Cycle 154A and 360,342 *Failed* records during Cycles 153A and 153A. All of the pressure and moisture (humidity) sweep gas data were classified as *Qualified* by the DRC.

Table 18. Summary of the qualification status of the irradiation monitoring data (TC temperature and sweep gas) received by NDMAS during Cycles 152A, 152B, 153A, 153B, and 154A.

| ATR Cycle | Record Start | Record End | Total # Records | No. of Failed Records: TC | No. of Failed Records: Gas Flow | % Qualified | Notes |
|---|---|---|---|---|---|---|---|
| 152A | 05MAY12:15:00 | 30OCT12:00:00 | 3,259,875 | 837,429 | 131,565 | 70.3% | a |
| 152B | 30OCT12:00:30 | 18JAN13:10:10 | 2,681,630 | 689,564 | 21,413 | 73.5% | a |
| 153A | 18JAN13:10:10 | 11MAR13:13:07 | 1,376,721 | 446,940 | 134,865 | 57.7% | a,b,c,e |
| 153B | 11MAR13:13:07 | 10APR13:01:00 | 1,907,976 | 555,696 | 326,296 | 53.8% | a,b,c,d,e,f |
| 154A | 10APR13:01:00 | 13JUL13:01:00 | 5,293,820 | 1,735,938 | 181,155 | 63.8% | a,b,c,d,f |
| | | ***Total =*** | **14,520,022** | **4,265,567** | **795,294** | **59.9%** | |

a. Cycles 147A through 151B TC failures: C1_TC1/2, C2_TC1/2, C5_TC1/2, C6_TC1/4/5.

b. New C6_TC2 failures (starting 18JAN2013 10:05:00).

c. New C3_TC1/2 failures (starting 18JAN2013 10:05:00).

d. New C4_TC1 starting on 2 May 2013 at 10:00 and C6_TC3 failures (starting 21MAY2013 04:45:00).

e. FPM flow rate failures during 153A and 153B.

f. Sweep gas flow rate failures during March 12 – 13 and April 30 – May 6, 2013.

(*) Qualified percentage does not count 757,960 trend FPM flow records during 154A.

## 4.2 FPMS Data

As of this report publication, NDMAS has received and processed into its database preliminary release rate and R/B data for reactor Cycles 152B, 153B, and 154A (see Figure 10 and Figure 11). This consists of 28,896 (nominal 8-hour) release rate records and 28,896 R/B records for 12 reported radionuclides (Kr-85m, Kr-87, Kr-88, Kr-89, Kr-90, Xe-131m, Xe-133, Xe-135, Xe-135m, Xe-137, Xe-138, and Xe-139). All of these data have been capture passed, stored in the NDMAS database, and made available on the NDMAS Web portal (see Figure 10 and Figure 11). Due to the 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.* The qualification status of these data has been set to *In Process* until appropriate documentation is received from the data generator.

# 5. DATA ACCESS

The irradiation monitoring data and data qualification status are available on the NDMAS Web portal (http://ndmas.inl.gov) for secure access by VHTR Program participants as shown in Figure 23. 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 23) 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.

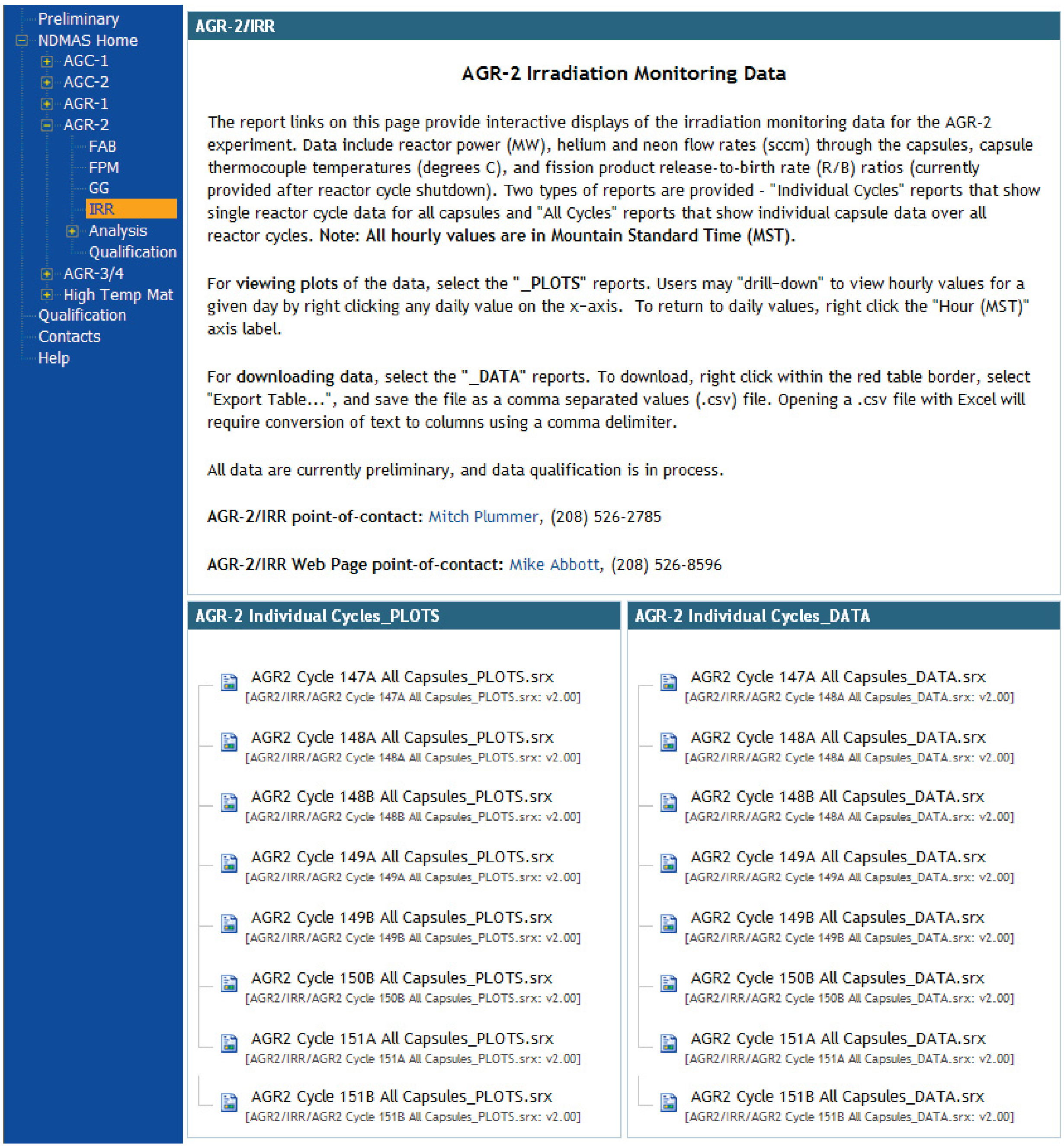


Figure 23. The AGR-2 Web page (in blue bar on left) on the NDMAS Web portal provides access to numerous types of data reports, graphs, and images.

# 6. REFERENCES


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# Appendix A

# Credentials of Technical Reviewer

### Credentials for Blaise Collin

Blaise Collin is a senior nuclear physicist and engineer with more than ten 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.