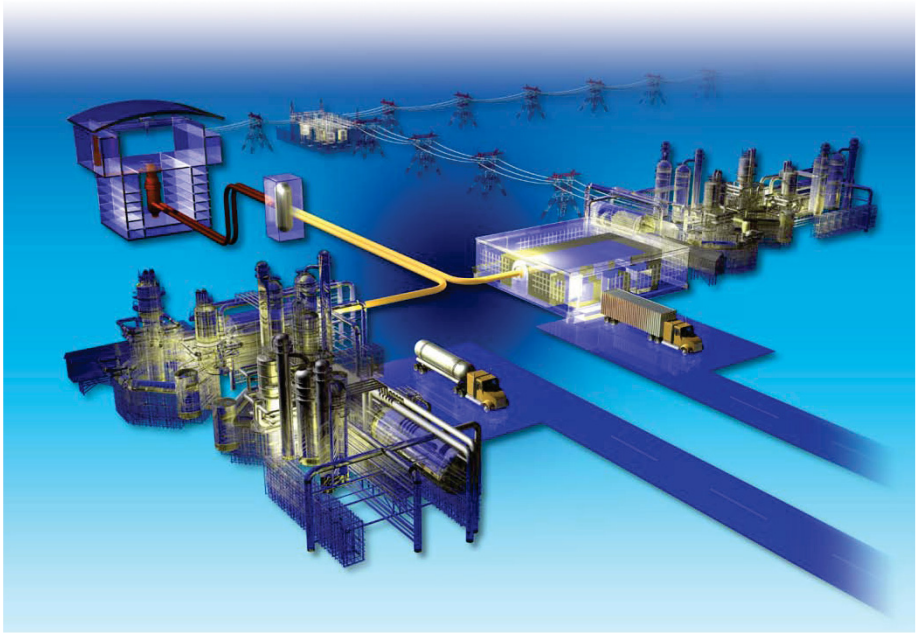
INL/EXT-10-19676

AGR-2 Data Qualification Interim Report

September 2010



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AGR-2 Data Qualification Interim Report

September 2010

Idaho National Laboratory
Next Generation Nuclear Plant Project
Idaho Falls, Idaho 83415

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Next Generation Nuclear Plant Project

AGR-2 Data Qualification Interim Report

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ABSTRACT

Projects for the very high temperature reactor (VHTR) Technology Development Office program provide data in support of Nuclear Regulatory Commission licensing of the VHTR. Fuel and materials to be used in the reactor are tested and characterized to quantify performance in high temperature and high fluence environments. The VHTR program established the NGNP Data Management and Analysis System (NDMAS) to store all NGNP data in secure electronic form, perform analysis of the data, provide electronic Web-based data delivery, and manage and document VHTR data qualification.

This document gives the status of NDMAS processing and qualification of data associated with the initial reactor cycle (147A) of the second Advanced Gas Reactor (AGR-2) experiment which began on June 21, 2010. Because it is early in the AGR-2 experiment, data from only two AGR-2 data streams are reported on: Fuel Fabrication; and Fuel Irradiation data. As of August 9, 2010, approximately 361,000 irradiation data records have been stored in NDMAS, and qualification tests are in progress. The initial data indicate that TC 2 in Capsule 2 failed prior to start of the experiment, and NDMAS range testing has thus far identified six anomalous data entries (two TC readings and four gas flow readings).

Data from the Fission Product Monitoring System (FPMS) are not currently processed until after reactor cycle shutdown and have not yet been received. A description of the ATR operating conditions data associated with the AGR-2 experiment (e.g., power levels) are summarized in the AGR-1 data qualification report (INL/EXT-09-16460). Since ATR data are collected under ATR program data quality requirements (i.e., outside the VHTR program), the NGNP program and NDMAS do not take additional actions to qualify these data other than NDMAS capture testing. Data qualification of graphite characterization data collected under the Graphite Technology Development Project is reported in a separate status report (Hull 2010).

CONTENTS

FIGURES

TABLES

ACRONYMS

AGR	Advanced Gas Reactor
ASME	American Society of Mechanical Engineers
ATR	Advanced Test Reactor
B&W	Babcock and Wilcox
CEA	Atomic Energy Commission (France; Commissariat à l'Energie Atomique)
CRADA	Cooperative Research and Development Agreement
DRC	data review committee
DST	Daylight Saving Time
ECAR	Engineering Calculations and Analysis Report
EDMS	Electronic Document Management System
FPMS	fission product monitoring system
GDMS	glow discharge mass spectrometry
INL	Idaho National Laboratory
LEUCO	low enrichment uranium oxide/uranium carbide kernals
MDT	Mountain Daylight Time
MST	Mountain Standard Time
NDMAS	NGNP Data Management and Analysis System
NGNP	Next Generation Nuclear Plant
NQA	Nuclear Quality Assurance
ORNL	Oak Ridge National Laboratory
PDF	Portable Document Format
PMBR	pebble bed modular reactor
QA	Quality Assurance
QAPP	Quality Assurance Program Plan
SiC	silicon carbide (fuel kernel coating layer)
SQL	Structured Query Language
TDO	Technology Development Office
TEV	Technical Evaluation
TFR	Technical and Functional Requirements
TRISO	tri-structural-isotropic
VHTR	Very High Temperature Reactor (program) and very high temperature gas-cooled reactor

AGR-2 Data Qualification Interim Report

1. INTRODUCTION

This report provides the interim data qualification status of Advanced Gas Reactor (AGR)-2 irradiation experiment data as performed by the NGNP Data Management and Analysis System (NDMAS). AGR-2 is the second in a series of eight planned irradiation experiments for the AGR Fuel Development and Qualification Program, which supports development of the very high temperature gas-cooled reactor (VHTR) under the Next Generation Nuclear Plant (NGNP) Project. Irradiation of the AGR-2 test train began at the Advanced Test Reactor (ATR) with Cycle 147A on June 21, 2010. Data qualification status of the first AGR-1 experiment was reported in INL/EXT-10-17943 (Abbott et al. 2010).

Because it is early in the AGR-2 experiment, preliminary data from only two AGR-2 data streams are reported on: Fuel Fabrication and Fuel Irradiation. Data from the fission product monitoring system (FPMS) are not currently available until after reactor cycle shutdown. Data qualification of graphite characterization data collected under the Graphite Technology Development Project is reported in a separate status report (Hull 2010).

2. OVERVIEW OF NDMAS DATA QUALIFICATION

Currently, all the AGR-2 data being collected at Idaho National Laboratory (INL) are considered to be *Type A*—data obtained within a Nuclear Quality Assurance (NQA)-1 (ASME 2000) QA program that must meet specific requirements for data collection with independent verification that those requirements were met (INL 2010). The final results of the independent verification are one of three data *Qualification State* flags applied to each data record:

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

NDMAS roles and responsibilities regarding data qualification are provided in the "Very High Temperature Reactor Program Data Management and Analysis Plan" (INL 2010a), and include the following:

- Develop and maintain a controlled and secure electronic data storage environment compliant with the VHTR Technology Development Office (TDO) Quality Assurance Program Plan (QAPP) (INL 2010b) and NGNP Records Management Plan (INL 2010c). Provide backup, security, and control of data and procedures to capture and maintain the data and the system. NDMAS does this by storing the processed data on a secure Microsoft SQL server (a database known as the "Vault").
- Archive (native format of a data set) all data that are actively being used as backup support for data analysis and interpretation activities. This is done by storage of the data generator's raw data files in a secure location on an SAS server (currently ISASAPP) under version control (using the Subversion client Tortoise SVN).
- Verify that the data captured within the NDMAS database are equivalent to the native data files. This is done by running an automated SAS comparison procedure on all data processed into the Vault and periodic manual comparisons of the data.
- For the fuel irradiation data stream, examine the incoming data for possible anomalies and problems that suggest the data are not an accurate representation of the system or object being measured. This is being done using various SAS statistical tools such as range testing, control charts, correlation analyses, and regression analyses. Once enough data has been obtained to draw valid conclusions, NDMAS will submit the results of these analyses to a Data Review Committee (DRC) comprised of project technical leads, Quality Assurance, and NDMAS analysts to determine the final data *Qualification State*.
- For the qualification of other data streams (e.g., fuel fabrication, FPMS), the final data *Qualification State* is determined when NDMAS receives a QA-approved data report from the data generator. A data report can take the form of formal report, Engineering Calculation and Analysis Report (ECAR), Technical Evaluation (TEV), or other document. The final approved data report is stored in the INL Electronic Document Management System (EDMS) for future access. These reports provide the independent verification that the data meet the requirements for their intended use and that the data collection activities and processing were done in conformance with NQA-1 requirements.
- Provide secure Web access to the data, the data *Qualification State*, and requested data analyses to end users, including external research partners. Web pages are currently being developed on a new

Web portal (http://ndmas.inl.gov) with only the AGR-2 fuel irradiation data and ATR operating conditions currently available. Web pages for the other data streams will be developed as the new data are received. Starting with AGR-2, this includes secure limited data access to external research partners in France and South Africa.

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, may be made available on the NDMAS Web portal while *In Process* (prior to final qualification) to facilitate near real-time monitoring of experimental results by project staff. When this occurs, the Web page and/or data field links will clearly indicate that the data *Qualification State* is *In Process*, indicating that the data are of unknown quality.

3. FUEL FABRICATION DATA

There are four separate fuels being evaluated in AGR-2: LEU-05 (Atomic Energy Commission [France; Commissariat à l'Energie Atomique (CEA)]), LEU-08 (pebble bed modular reactor [PBMR]), LEU-09, and LEU-11. This report will cover only LEU-09 and LEU-11.

AGR-2 is designed to use compacts made from tristructural-isotropic (TRISO)-coated particles manufactured in a large coater to demonstrate fuel performance, and obtain data that will help relate fuel performance to coating process parameters. AGR-2 experiment includes variant fuels, which are fuels containing particles produced at different specified coating conditions. The LEU-09 fuel is based on UCO while the LEU-11 fuel is based on UO_2. These are included in separate capsules of the AGR-2 experiment. Table 1 shows summary information for the two LEUs.

Table 1. LEU summary information.

Parameter	LEU-09	LEU-11
Fuel Base	UCO	UO_2
Coated Particle Diameter (um)	425	500
%LEU	14.0	9.6
Buffer Layer Thickness (um)	100	100
IPyC Thickness (um)	40	40
SiC Thickness (um)	35	35
OPyC Thickness (um)	40	40
U Load (g/compact)	1.251	0.993
Compact Diamter (mm)	12.29	12.27
Compact Length (mm)	25.14	25.13
Compact Mass (g)	6.295	6.100
Compact Matrix Density (g/cc)	1.59	1.68

3.1 LEU-09

The AGR-2 fuel fabrication data stream consists of properties obtained from measurements made on representative samples of fuel kernels, coated fuel particles, and fuel compacts. These properties are listed in the following sections along with specified acceptance criteria (INL PLN-2691) (Einerson 2009). The appropriate acceptance criterion depends on whether the property is a variable property or an attribute property. Variable properties are defined by a continuous distribution while attribute properties are discrete properties in the sense that the particle is either defective or not, in terms of that property. For variable properties, the criteria are stated in terms of a population mean and/or population dispersion with the mean having to lie within a specified interval. The acceptance criterion for attribute properties is stated in terms of the allowable fraction of defective particles.

3.1.1 Description

LEU-09 is comprised of UCO variant fuel compacts fabricated from lot LEU09-OP2-Z. The compacts were produced by Oak Ridge National Laboratory (ORNL) for AGR-2 using Babcock and Wilcox (B&W) coated particle lot G73J-14-93073A, which was an upgraded batch of TRISO-coated 425 μm diameter, 14% low enrichment uranium oxide/uranium carbide kernels (LEUCO). These particles consist of a spherical kernel coated with a dense (~50%) carbon buffer layer (100 μm nominal thickness),

followed by a dense inner pyrocarbon (IPyC) layer (40 μm nominal thickness), followed by a silicon carbide (SiC) layer (35 μm nominal thickness), followed by another dense outer pyrocarbon (OPyC) layer (40 μm nominal thickness). The kernels of these particles were also manufactured by B&W and identified as kernel lot G73I-14-69307.

The AGR-2 Fuel Specification (INL SPC-923) (Barnes 2009) provides the requirements necessary for acceptance of the fuel manufactured for the AGR-2 irradiation test. Section 3.3 of SPC-923 provides the property requirements for the heat treated compacts. INL PLN-2691(Einerson 2009) provides additional guidance regarding statistical methods for product acceptance and recommended sample sizes.

3.1.2 Acceptance Testing

The compact lot, LEU09-OP2-Z, did not meet all the requirements of SPC-923. There was a nonconformance due to a higher than allowed fraction of exposed uranium. The nonconformance, however, was determined by the program to be acceptable for the AGR-2 irradiation test. The exposed uranium was due to cracked TRISO layers in the coated particle composite. These cracks are thought to have occurred at B&W when particles were removed from the coating furnace using a suction device. The final disposition of this compact lot was to "use as is" for the AGR-2 irradiation test and was documented in INL NCR-44791.

3.1.3 AGR-2 Process Conditions

The LEU09-OP2-Z (UCO Variant) compact lot was made in accordance with the AGR-2 Fuel Specification (SPC-923). The specified AGR-2 process limits are listed below.

- Molding Pressure: < 60 MPa
- Carbonization parameters: < 350ºC/hr in He atmosphere
  - Hold at 950 ± 50ºC for 1.0 ± 0.4 hr
  - Furnace cool
- Heat treatment parameters: ~20ºC/min in vacuum (<1.3 Pa)
  - Hold at 1650-1850ºC for 60 ± 10 min
  - Furnace cool at ~20ºC/min to below 700ºC.

3.2 LEU-11

3.2.1 Description

LEU-11 is comprised of UO_2 variant compacts fabricated from lot LEU11-OP2-Z. The compacts were produced by ORNL for AGR-2 using Babcock and Wilcox (B&W) coated particle lot G73H-10-93085B, which was an upgraded batch of TRISO-coated 500 μm nominal diameter, 9.6% low enrichment uranium oxide (LEUCO) kernels. These particles consist of a spherical kernel coated with an ~50% dense carbon buffer layer (100 μm nominal thickness), followed by a dense inner pyrocarbon layer (40 μm nominal thickness), followed by a SiC layer (35 μm nominal thickness), followed by another dense outer pyrocarbon layer (40 μm nominal thickness). The kernels of these particles were also manufactured by B&W and identified as kernel lot G73AA-10-69308.

3.2.2 Acceptance Test Results for LEU11-OP2-Z

The compact lot, LEU11-OP2-Z, did not meet all the requirements in section 4.3 of SPC-923, Rev. 3. A nonconformance related to a higher than allowed fraction of exposed uranium was determined by the

program to be acceptable for the AGR-2 irradiation test. The final disposition of this compact lot was to "use as is" for the AGR-2 irradiation test and was documented in INL NCR-44791 (Barnes 2009).

3.2.3 AGR-2 Process Conditions

The LEU11-OP2-Z (AGR-2 B&W UO_2) compact lot was made in accordance with SPC-923. The specified AGR-2 process limits are listed below:

- Molding Pressure: < 60 MPa
- Carbonization parameters: < 350ºC/hr in He atmosphere
  - Hold at 950 ± 50ºC for 1.0 ± 0.4 hr
  - Furnace cool
- Heat treatment parameters: ~20ºC/min in vacuum (<1.3 Pa)
  - Hold at 1650-1850ºC for 60 ± 10 min
  - Furnace cool at ~20ºC/min to below 700ºC.

3.3 Impurity Analysis of Matrix, Resin, and Graphites

For both LEU-09 and LEU-11, the AGR-2 Fuel Specification (SPC-923) lists the maximum limits on the elemental impurities Al, Ca, Ti, V, Cr, Mn, Fe, Co, and Ni. A graphite or resin was considered "qualified" if it could produce a compact that was within specification on impurities. Data from AGR-2 compacts showed that compacts could be made from these matrix constituents and pass the impurity specification. The qualification process involved receiving natural graphite and synthetic graphite and testing them via glow discharge mass spectrometry (GDMS) in order to establish their initial impurity concentrations.

3.3.1 Nonconformance Reports

Both LEU-09 and LEU-11 had nonconformances related to a higher than allowed fraction of exposed uranium. In both cases these nonconformances were determined by the program to be acceptable for the AGR-2 irradiation test. In both cases, the exposed uranium was due to cracked TRISO layers in the coated particle composite and these cracks are thought to have occurred at B&W when particles were removed from the coating furnace using a suction device. The final disposition of both compact lots was to "use as is" for the AGR-2 irradiation test. The nonconformances were documented in INL NCR-44791.

3.4 Data Structure and Processing

Reports containing fuel fabrication data for AGR-2 have been received by NDMAS staff. All reports are in pdf format that can be transferred to data files. Data from these reports are in the process of being transferred to Excel files and then into the NDMAS system. Some of the data structure from AGR-1 is expected to be used and this is fully described in INL/EXT-09-17943 "AGR-1 Data Qualification Report" (Abbott et al. 2010). Generally, we expect to retain a component as the generic name for the object or system being measured and a response variable as the measurement or property associated with a component. One key difference is that there will be data from both the French (CEA LEU-05) and South African (PBMR LEU-08) fuels tested. These data will be protected as described in the Cooperative Research and Development Agreements (CRADA) established with each organization.

For AGR-1, components in NDMAS were related to each other by an assembly tree. The component assembly tree for AGR-1 fuel data is shown in Figure 1. It is expected that this same relation will be kept for AGR-2 data.

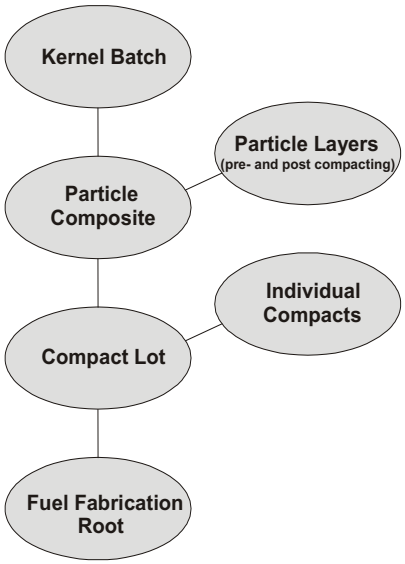

Figure 1. Fuel fabrication data component assembly tree structure.

3.5 Description of Fuel Fabrication Data Qualification

Two general types of qualification tests are performed on data loaded into NDMAS:

- Capture tests, which verify that data captured and stored within NDMAS are identical to the source data provided to NDMAS.
- Accuracy tests, which verify the data, are an accurate representation of the parameters they are intended to measure.

3.5.1 Capture Tests

The transmitted data are manually entered into an Excel spreadsheet file. Once the data are transferred, every response variable value in the spreadsheet is manually checked against the values in the data packages to make sure they are identical. An independent person performs the comparison and the review is documented.

The second capture test is a referential integrity test to make sure that all components, component attributes and response variables, and response variable values are properly linked.

The third capture test verifies that the data in the SQL database are the same as the data loaded (pushed) into the SQL database. This test uses an SAS procedure (PROC-COMPARE) to compare the SAS dataset pushed to the SQL database with the database output.

The final capture test is to compare the SQL database output with the original data in the data packages. This is another manual inspection similar to the first capture test. An independent entity checks response variable values in the database against the data in the data packages and documents the results.

3.5.2 Accuracy Tests

The scope of accuracy testing is limited to the certification that AGR-2 fuel data for kernels, particles (including layers), and compacts meet specifications as outlined in Einerson (2006). Certification is performed by the data generators and documented in the subcontract deliverable data packages. Nonconformance reports are included in the data packages for any data that does not meet specifications. Certified data are verified and accepted by the Contractor. Nonconformance data are reviewed and either rejected or accepted by the Contractor.

The process of verifying that all data in the data packages meet specifications is a thorough process with multiple checks to ensure data accuracy. Because this process is so rigorous, no additional accuracy tests are planned for the fuel fabrication data.

3.6 Verify Fuel Fabrication Data QA Documentation

Kernels, coated particles and compacts for AGR-2 were produced under a quality program that conformed to the requirements of NQA-1 2000 as implemented and documented by the fuel fabricator's QA Program Plan. Specifications for AGR-2 fuels are described in SPC-923. Einerson (2009) provides additional guidance regarding statistical methods for product acceptance and recommended sample sizes. Acceptance testing for each fuel is described in Sections 3.1.2 and 3.2.2 above.

3.7 Fuel Fabrication Data Qualification Status

Qualification of fuel fabrication data for the AGR-2 fuel compacts is in progress. Data compilation reports containing fuel fabrication data for AGR-2 have been received by NDMAS staff. All reports are in PDF format that are being transferred to Excel data files. Capture tests to determine if all data received are accurately transferred to Excel files for input into NDMAS are in progress. Certification reports are cited in each data compilation report and meet the NDMAS requirement for accuracy testing. This is described in Sections 3.1.2 and 3.2.2 of this report. It is expected that all of the fuel fabrication data will be flagged as qualified after NDMAS data processing, capture testing, and documentation of vendor acceptance/certification reports. This is anticipated to be completed by the end of FY 2010.

4. FUEL IRRADIATION DATA

4.1 Description of the Data Stream

The AGR-2 fuel irradiation experiment includes measurements of controlled gas flow rates, gas moisture content, thermocouple temperatures, and fission product releases from six stacked fuel capsules (each approximately 1-3/8 in. in diameter and 6 in. long) in the AGR-2 test train. Figure 2 shows the locations of the thermocouples in each of the capsules and the location of the test train in the ATR B-12 position.

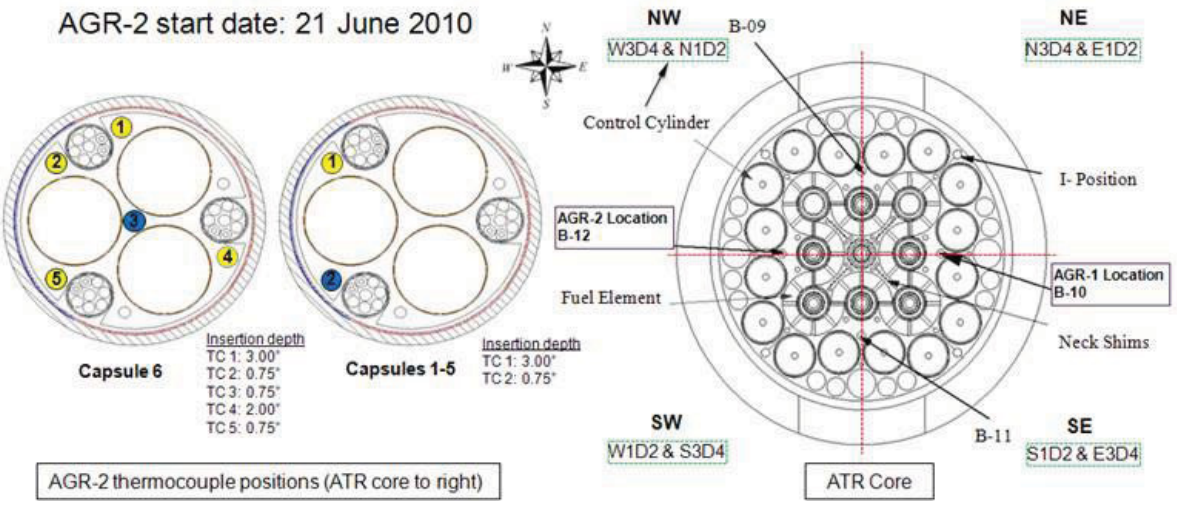

Figure 2. AGR-2 thermocouples (yellow circles) and control thermocouples (blue circles) in cross sectional view.

The ten variables measured and stored within NDMAS for the irradiation data stream are listed in Table 2. The data include flow rates of helium and neon gases to and from each capsule, gas pressure upstream of each capsule, moisture content of the gas flow mixture downstream of each capsule, and thermocouple temperatures at several locations within each capsule (Figure 2). Gas pressure, flow rates, and moisture content are also collected for the leadout system—the pressurized space around each capsule that prevents leakage of capsule gas flows into adjacent capsules. These data are currently collected at 10-minute intervals in the form of Excel spreadsheets.

Table 2. Measurement variables in the fuel irradiation data stream.

Measurement Variable	Description	Units
Pressure_In	Capsule inflow gas pressure	Pounds per square inch atmosphere (psia)
Q_He_In	Capsule inflow helium flow rate	Standard cubic centimeters per min (sccm)
Q_Ne_In	Capsule inflow neon flow rate	Standard cubic centimeters per min (sccm)
Q_Mix_Out	Capsule outflow total gas flow rate	Standard cubic centimeters per min (sccm)
Moisture_Out	Capsule inflow moisture content	Parts per million volume (ppmv)
TC1	Thermocouple No. 1 temperature	ºC
TC2	Thermocouple No. 2 temperature	ºC
TC3	Thermocouple No. 3 temperature	ºC
TC4	Thermocouple No. 4 temperature	ºC
TC5	Thermocouple No. 5 temperature	ºC

4.2 Preliminary Data through August 9, 2010

Preliminary irradiation data from the start of AGR-2 (June 21, 2010) through this interim reporting period (August 9, 2010) are available under AGR-2 on the NDMAS external Web portal at http://ndmas.inl.gov. Qualification for all of these data is *In Process*. Two types of data presentations are provided on the Web pages: (1) graphical summary plots on the 'AGR-2 Home' page; and (2) "drilldown" plots and downloadable data table reports on the 'AGR-2/IRR' page (Figure 3). A third page, 'AGR-2 Analysis,' containing statistical analysis of the irradiation data for DRC review, will be available shortly. The Graphical Summary plots (AGR-2 Home page) for Capsules 6, 5, 3, and 2 for irradiation data through August 9, 2010, are shown in Figures 4-7. Data for Capsules 4 and 1 are CRADA protected and are therefore not presented in this report.

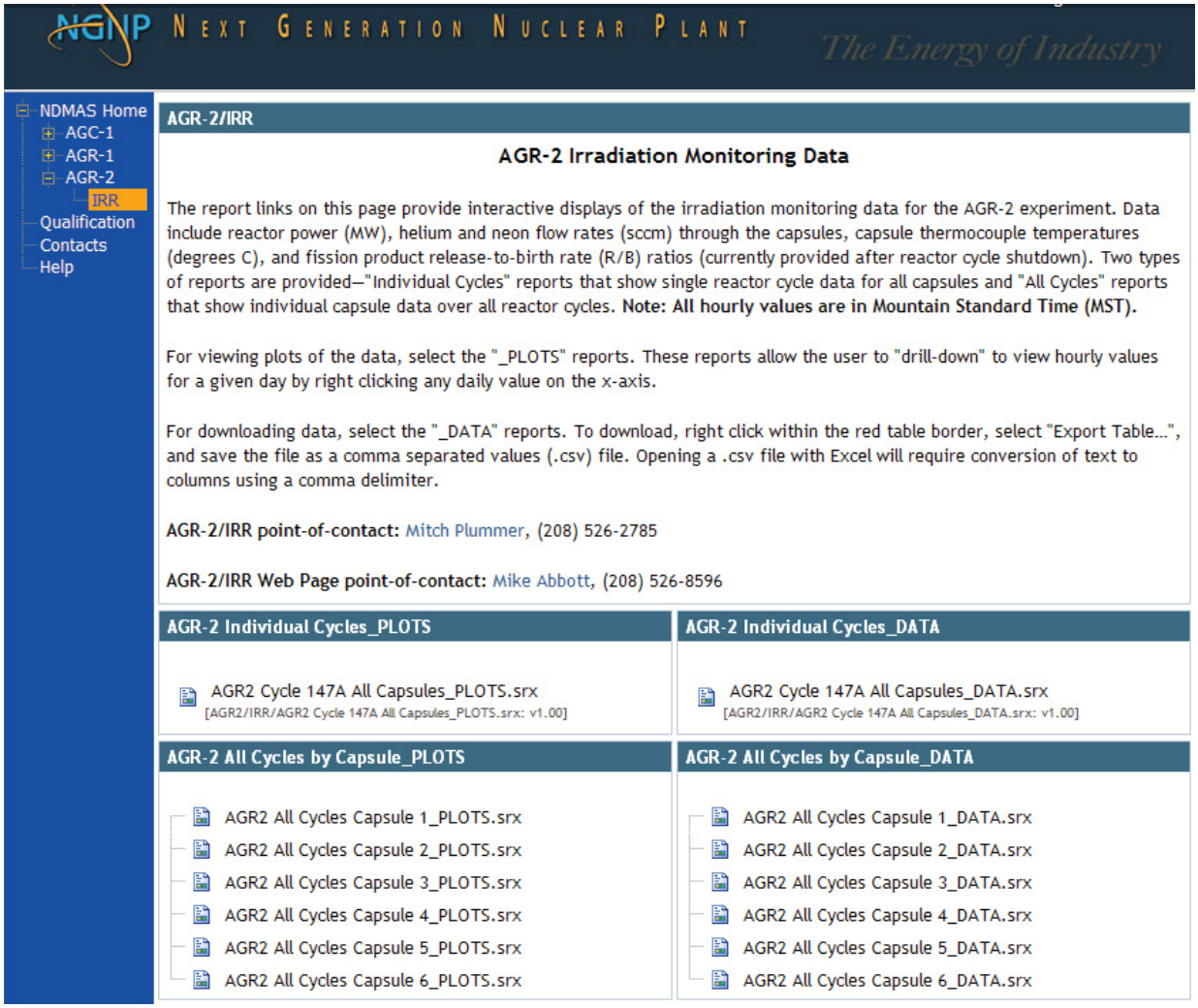

Figure 3. AGR-2/IRR Web page on the NDMAS Web portal (http://ndmas.inl.gov).

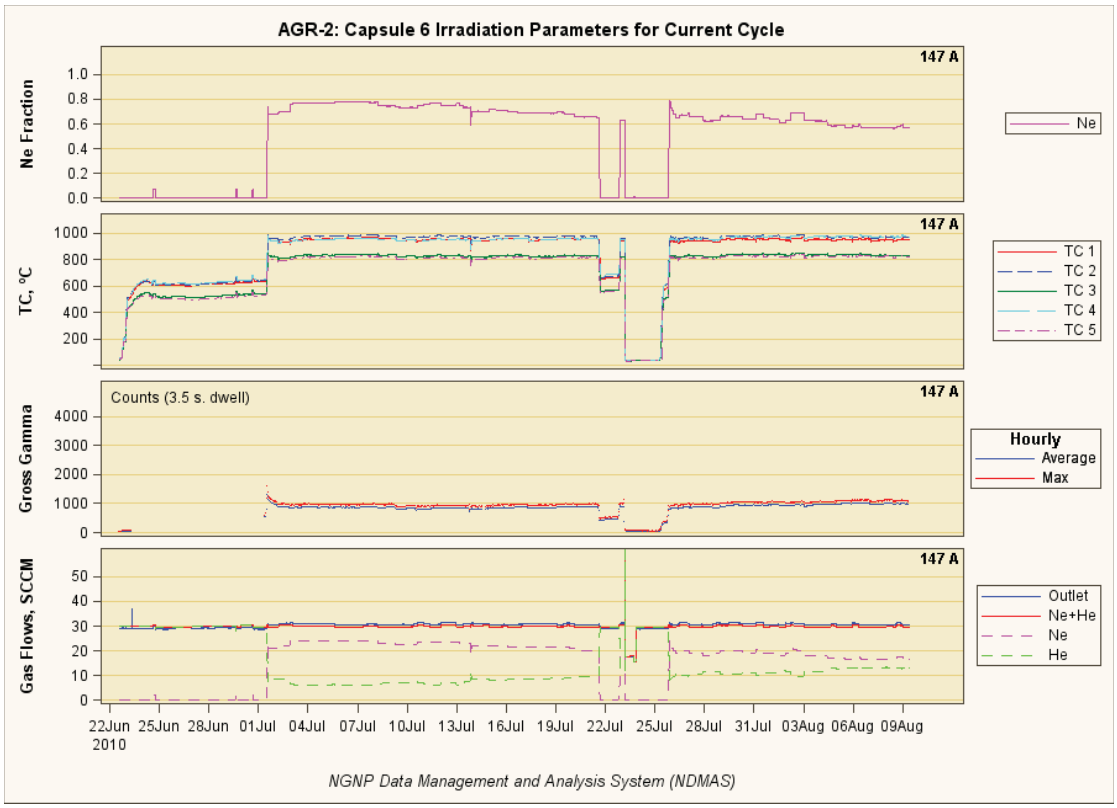

Figure 4. Capsule 6 irradiation data from ATR cycle 147A through August 9, 2010.

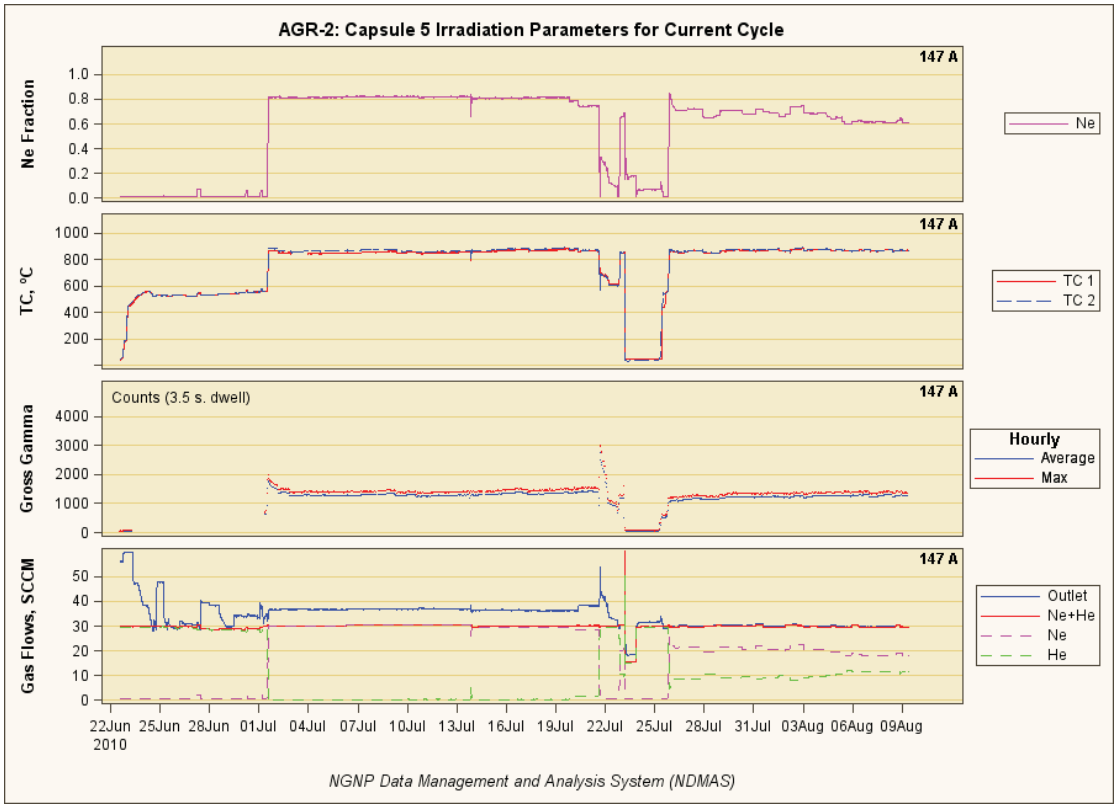

Figure 5. Capsule 5 irradiation data from ATR cycle 147A through August 9, 2010.

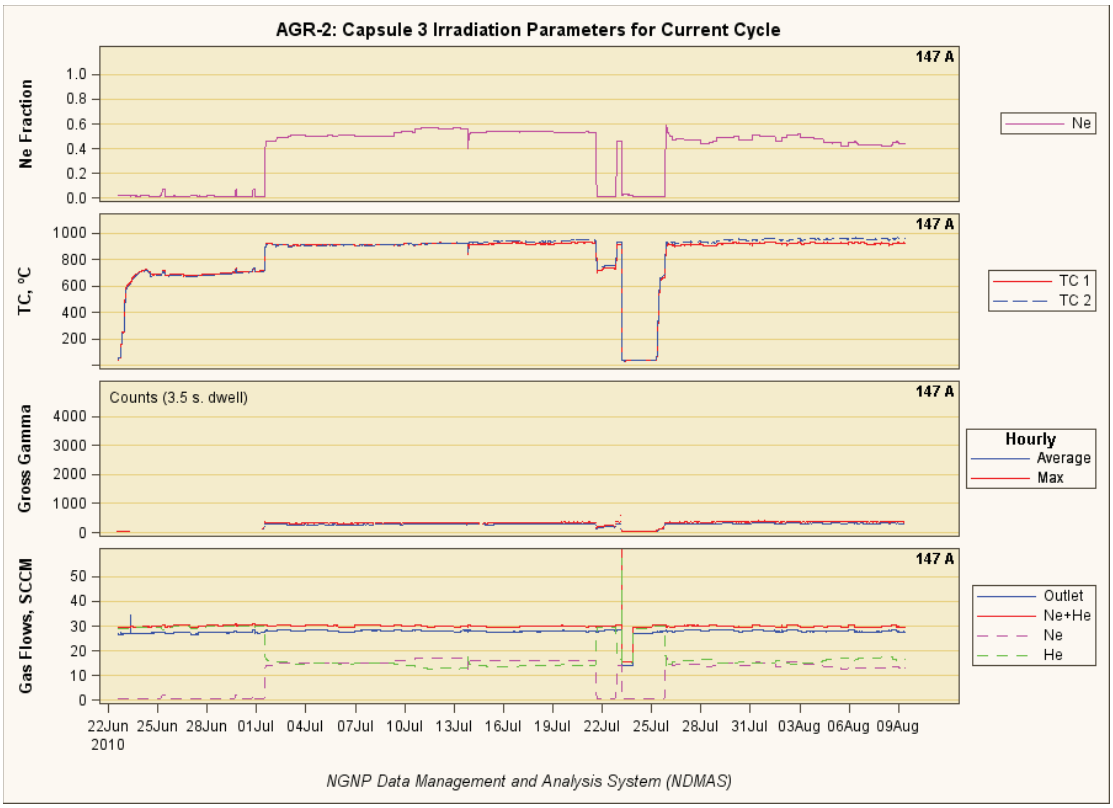

Figure 6. Capsule 3 irradiation data from ATR cycle 147A through August 9, 2010.

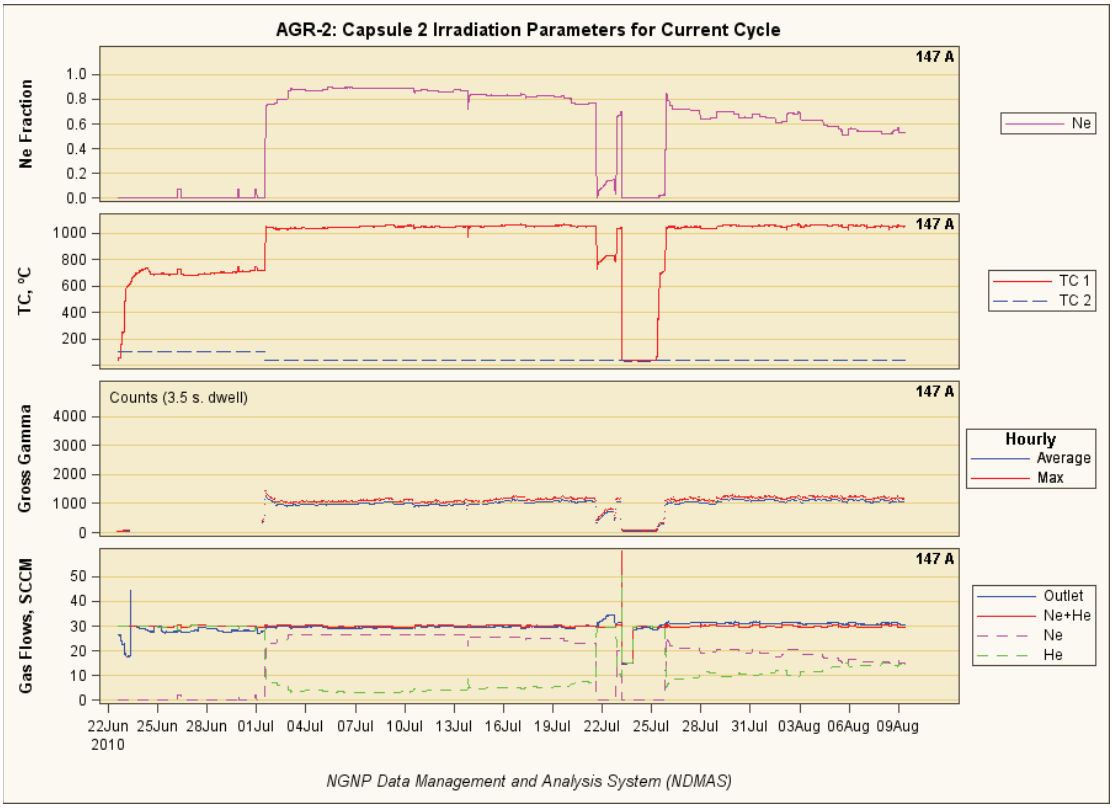

Figure 7. Capsule 2 irradiation data from ATR cycle 147A through August 9, 2010.

4.3 Data Processing within NDMAS

Data processing and storage within NDMAS occurs via the following process. Raw data files covering about one week of measurements are placed in a folder on the FSISC1 server. A SAS Enterprise Guide project titled, "Update or Build Irradiation dataset.egp," reads these data, assembles the data into a single SAS dataset, and stores the data in the NDMAS SQL database (Vault). Processing and storage in NDMAS occurs approximately once per week so that several folders of data may be processed and entered as a single package. Data processing includes the following error checks to ensure that the data are accurately captured:

- Dates are checked for proper syntax and chronology.
- Data are checked for duplicated measurement times with conflicting variable values.
- Completed SAS datasets are visually inspected and compared against the raw data files.
- A mountain standard date/time is assigned to each measurement that corrects for the switching between Daylight Saving Time (DST) and standard time that occurs in the raw data measurements. The switch to DST leads to repeated measurement times with different variable values, while the switch to standard time leads to a gap in measurement times.

The process of entering each data packages is recorded in an electronic log, with appropriate notes about any problems or corrections encountered. After being entered into the NDMAS SQL database, capture testing is performed for each data package to compare the database output with the SAS dataset from which it was built to ensure that the data were correctly stored.

4.4 Description of Fuel Irradiation Data Qualification Tests

Several tests, or analyses, are performed by NDMAS to identify data anomalies that may represent instrument measurement problems. These problems include thermocouple drift (e.g., from loss of calibration) and thermocouple virtual junction, caused by temperature-induced electrical shunting of the thermal elements somewhere along the midsection of the thermocouple. Two types of NDMAS tests are performed to identify potential measurement errors: (1) simple automated range testing to check that the data are in the range appropriate for the test conditions, and (2) more rigorous statistical analysis of past measurement data as a guide to the range expected for new data values. These checks are programmed as a series of tests applied to each data package entered in the NDMAS SQL database. The data *Qualification State* will remain *In Process* (Qual_State_ID = 4) while these tests are being conducted, although the data may be displayed on the NDMAS Web portal while in this status. At predetermined intervals in the experiment (e.g., every 4 cycles), the results of the tests will be submitted to a DRC comprised of project technical leads, quality assurance, and NDMAS analysts for determination of final data *Qualification State* (*Qualified, Trend, or Failed* – Section 2). After this is completed, the data qualification state will be updated both in the NDMAS database and on the Web portal pages.

4.4.1 Range Tests

The first types of accuracy tests applied to the irradiation data are range tests that detect data values outside expected ranges of measurement as shown in Table 3.

Table 3. Range test values.

Parameter	Requirement
Temperature	0ºC ≤ X ≤ 1,800ºC
Gas pressure	0 psia ≤ X ≤ 90 psia
Gas moisture content	0 ppm ≤ X ≤ 5 ppm
He/Ne gas flow rate	0 sccm ≤ X ≤ 50 sccm
Gas mixture flow rate	50 sccm ≤ X ≤ 100 sccm

These range tests are based on a combination of physical limitations and/or requirements described in Technical and Functional Requirements (TFR) documents and other AGR-1 reference documents as follows:

1. Gas moisture: Moisture content of the inlet sweep gas should be <5 parts-per-million (ppm) H_2O (TFR-248, Maki 2010).
2. Thermocouple (TC) temperatures: The AGR-2 test train design requires a capsule instantaneous peak temperature of ≤ 1800°C (Waite 2010), and that value was selected as an upper limit for the NDMAS range test. The lower limit for temperatures should be limited by that of the water surrounding the capsule train, which enters the reactor vessel at an average temperature of 52°C and, at full power, exits the vessel at a temperature of 71°C (INL 2008). However, because the thermocouples commonly read low in the low-temperature range, the prescribed lower limit for the range test is set at 0°C.
3. Gas Pressure: Range tests for capsule inlet pressure are based on TFR-559, which specifies that the pressure relief valves are set at 90 psig.
4. Gas flow rate: Range tests for gas flow rates to the capsules are based on the nominal flow rates specified in TFR-248, Section 3.1.2.2: "The tubing, valves, and MFCs [mass flow controllers] shall be sized for a flow rate in each system up to 100 standard cubic centimeters per minute (sccm) with a nominal flow rate of 50 sccm thru the FPMS."

4.4.2 Statistical Analyses

The second set of accuracy tests consists of a set of statistical analyses performed to identify possible data anomalies (e.g., TC drift). These analyses are presented on the AGR-2/Analysis page of the NDMAS external Web portal at http://ndmas.inl.gov:

1. TC drift detection using control charts for differences in same capsule TC readings (Figure 8, top panel). A TC in a hotter position in a capsule might be expected to consistently give a higher reading than another TC in the same capsule, but the *differences* in the two readings are expected to remain fairly constant because the relative heat transfer rate of the control gas is constant for both TCs. To develop the control chart, the average and standard deviation of the daily average differences are estimated. When there are few data points, a large variation is seen in the standard deviation estimates. This variation drops as more data are obtained. A "baseline period" is defined as the period of initial data collection to characterize how the daily average differences behave. When the estimates become stable, the average daily difference, the average plus three times the estimated standard deviation, and the average minus three times the estimated standard deviation are projected on a control chart. The average is a solid line, while the other two lines are dotted. The actual daily averages are plotted as an overlay on the control chart. Actual daily averages falling outside the band established by the chart are flagged as possible indicators of data quality problems. Note that over 99% of the data are expected to lie inside the band if the difference averages are normally distributed. An occasional outlier is expected but a sequence of two or three shows a change in the process or problems with the data.

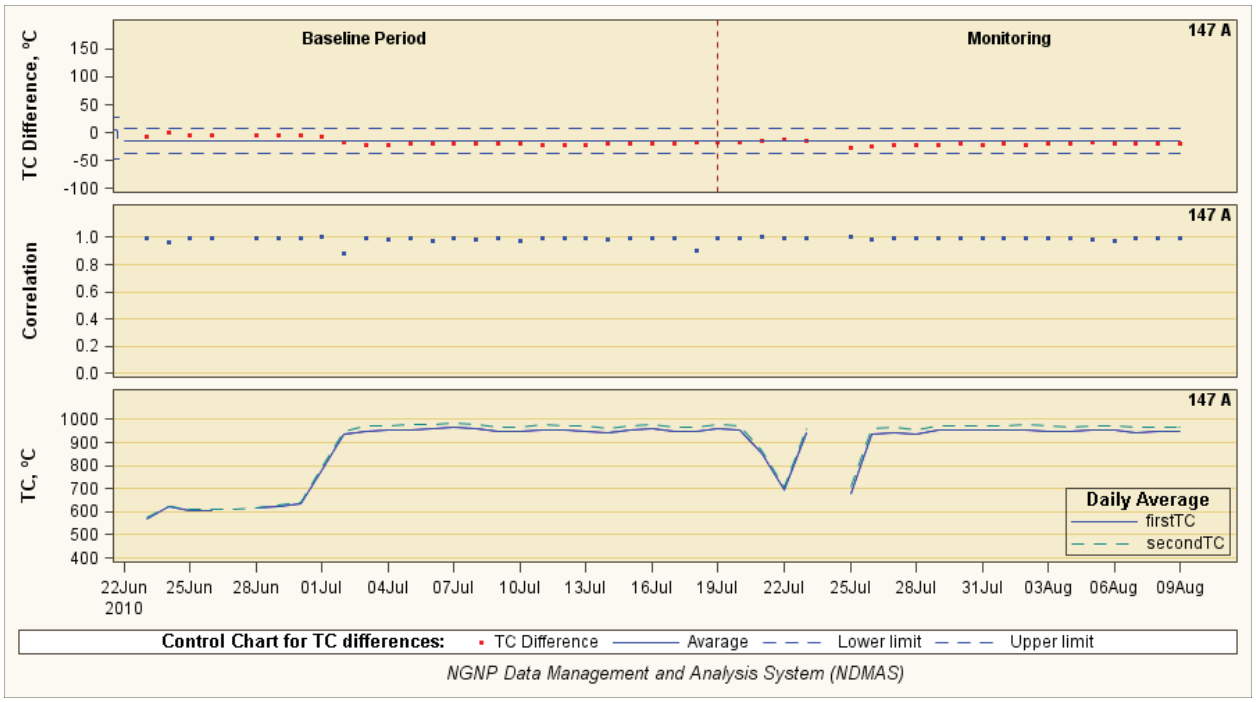

Figure 8. Statistical analyses performed on TC readings in the same capsule to detect potential drift (Capsule 3, TC1, and TC2 shown here). Top panel is a control chart; middle panel shows the daily correlation coefficients.

2. TC drift detection using daily correlations from TCs in the same capsule at the same time (Figure 8, middle panel). On a daily basis, the Pearson product-moment correlation coefficient estimates are computed and the resulting values are plotted in time. When a sequence of such values consistently trails away from 1.0, a potential problem exists with the data.

3. TC junction detection using daily correlations for all possible pairs of TCs in the experiment (Figure 9). Correlation coefficients for TCs in the same capsule are expected to be higher on average than correlations between TCs in different capsules where different control gas mixtures exist. For each day and each TC, the set of correlation coefficients with the other TCs is examined to identify the TC whose measurements are most closely correlated with the subject TC. The capsule containing this TC is expected to be the same capsule as the subject TC. A TC junction failure would be indicated by a maximum correlation estimate that is consistently (for several days) in a higher capsule (nearer the top of the test train) than the capsule of the subject TC.

When any of the three tests described above indicates a possible data anomaly, the evidence is prepared for presentation to the DRC. If the DRC determines that the data are not reliable, the data *Qualification State* will be set to failed, and the data will be removed from the NDMAS Web portal. If the data is judged to be reliable, the *Qualification State* will be set to *Qualified*, and the following changes will be made to the above accuracy tests:

- A new baseline period will be created for the control charts, characterizing the new performance of the data
- A note will be added to the correlation plots explaining the lower correlations
- A note will be added to the capsule number plots explaining the apparent discrepancies.

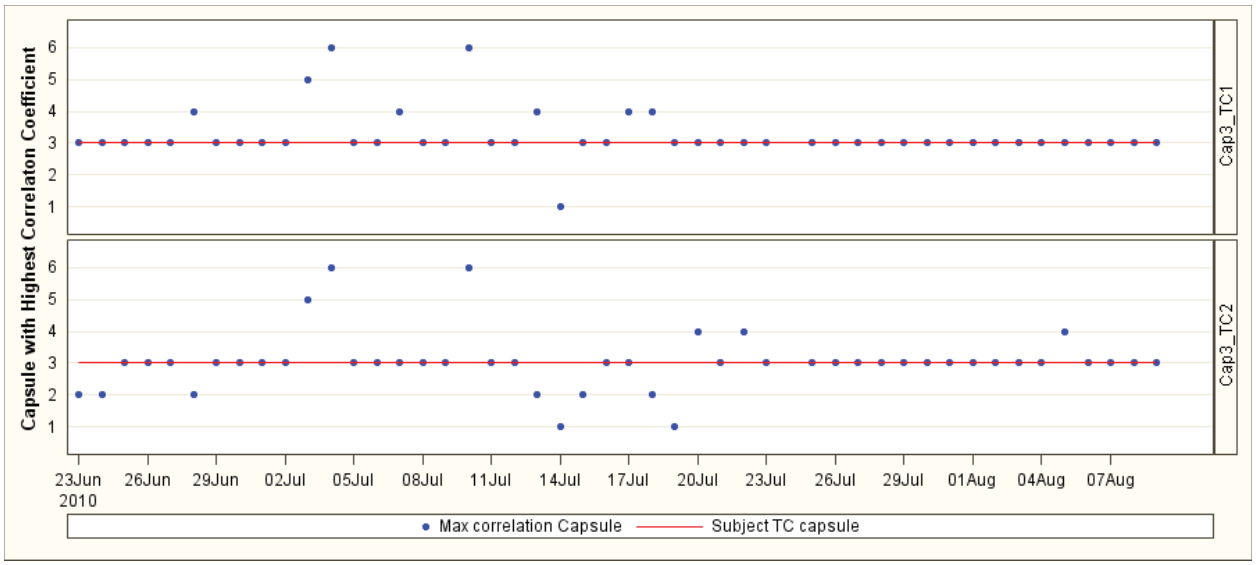

Figure 9. Evaluation of TC junction detection for capsule 3 using daily correlations for all possible pairs of TCs in all capsules.

All of the above plots are available on the NDMAS Web portal, 'AGR-2 Analysis' page.

4.5 Fuel Irradiation Data Qualification Status

The qualification status for the separate AGR-2 fuel irradiation data received to date is provided on the NDMAS Web portal 'Qualification' page (http://ndmas.inl.gov). As of August 9, 2010, 361,326 irradiation data records have been stored in NDMAS. Preliminary NDMAS range tests indicate that TC 2 in Capsule 2 failed prior to start of the experiment (Figure 10) and identified six additional anomalies from the METSO data collection system (Table 4). Thus, a total of 7,379 records are stored in the database as having failed NDMAS range tests but are still in the process of qualification. Their final *Qualification State* will be determined after review by the DRC.

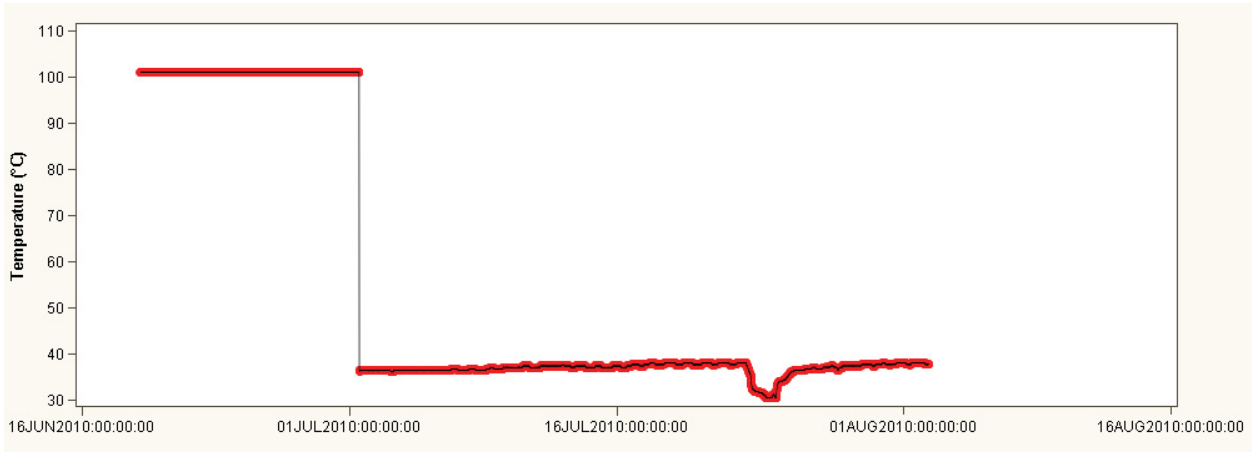

Figure 10. Thermocouple data from TC 2 in Capsule 2 from the start of AGR 2, preliminarily identified as failed during fabrication of the capsule train.

Table 4. AGR-2 data failing NDMAS accuracy tests.

Date and Time	Capsule	Measure	Test	Value	Number of Records	Data Package ID
ALL	2	TC 2	Expert judgment	~30 to 100°C	7,373	ALL
24 JUN 2010 13:00	2	TC 2	Out of range	-321431°C	1	126
24 JUN 2010 13:00	6	TC 1	Out of range	-161062°C	1	123
23 JUL 2010 04:20	4	Q_He_In	Out of range	61 sccm	1	138
23 JUL 2010 04:20	5	Q_He_In	Out of range	51 sccm	1	138
23 JUL 2010 04:20	6	Q_He_In	Out of range	65 sccm	1	138
23 JUL 2010 04:20	3	Q_He_In	Out of range	58 sccm	1	138

5. REFERENCES

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