INL/EXT-09-16460

AGR-1 Data Qualification Interim Report

Michael L. Abbott
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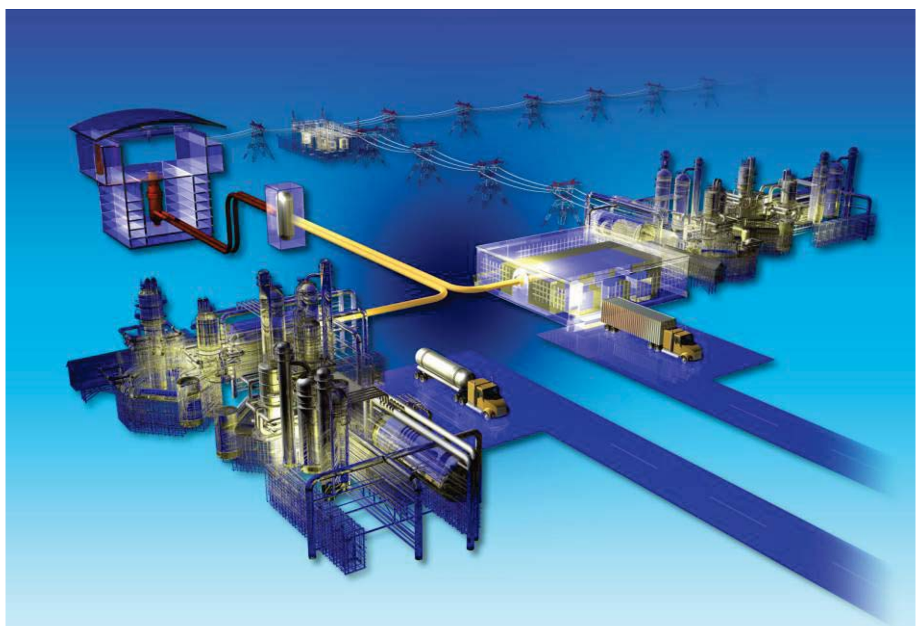
August 2009



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

Next Generation Nuclear Plant

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August 2009

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ABSTRACT

Projects for the very high temperature reactor (VHTR) Technology Development Office (TDO) 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 has established the NGNP Data Management and Analysis System (NDMAS) to ensure that VHTR data are (1) qualified for use, (2) stored in a readily accessible electronic form, and (3) analyzed to extract useful results.

This document focuses on the first NDMAS objective. It describes the data streams associated with the first Advanced Gas Reactor experiment (AGR-1), the processing of these data within NDMAS, and reports the interim FY 2009 qualification status of the AGR-1 data to date. Data qualification activities within NDMAS for specific types of data are determined by the data qualification category assigned by the data generator. They include: (1) capture testing, to confirm that the data stored within NDMAS are identical to the raw data supplied, (2) accuracy testing, to confirm that the data are an accurate representation of the system or object being measured, and (3) documentation that the data were collected under an NQA-1 or equivalent quality assurance program. The interim qualification status of the following four data streams is reported in this document: fuel fabrication data, fuel irradiation data, fission product monitoring system data, and Advanced Test Reactor operating conditions data. Data stream problems from both data stream generation and NDMAS processing are reported, along with current and proposed problem resolutions. A final report giving the NDMAS qualification status of all AGR-1 data (including cycle 145A), except post-irradiation examination data, is planned for February 2010.

A summary of the interim NDMAS data processing and qualification status for the four data streams reported herein is as follows:

1. Fuel fabrication data. One kernel data package and four particle (one baseline, three variant) data packages have been received. NDMAS database processing and capture testing is currently in progress.

2. Fuel irradiation data. Fifteen data packages covering measurements from ATR cycles 138B through 144B (through July 5, 2009) have been stored and tested. Of these, 86% have been qualified and 14% have failed NDMAS accuracy testing.

3. FPMS data. Eleven end-of-cycle data packages (138B through 144A) have been stored and capture tested. One data package has been qualified (ATR cycle 143A).

4. ATR Operating Conditions Data. Data for all AGR-1 cycles through June 29, 2009 (144B) have been stored and capture tested. These data, which come from outside the VHTR program, are assumed to be qualified by ATR quality control procedures. NDMAS expects to obtain qualification documentation for these data at the conclusion of the AGR-1 experiment.

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ACRONYMS

AGR	Advanced Gas Reactor
ASME	American Society of Mechanical Engineers
ATR	Advanced Test Reactor
DST	daylight-savings time
ECAR	Engineering Calculations and Analysis Report
FPMS	Fission Product Monitoring System
HPGe	High Purity Germanium (detector)
INL	Idaho National Laboratory
IPyC	inner pyrolytic carbon layer (fuel kernel coating layer)
MDT	Mountain Daylight Time
MST	Mountain Standard Time
NDMAS	NGNP Data Management and Analysis System
NGNP	Next Generation Nuclear Plant
NQA	Nuclear Quality Assurance
PDF	Portable Document Format
OPyC	Outer pyrocarbon (fuel kernel coating layer)
QA	Quality Assurance
QAPP	Quality Assurance Program Plan
R/B	release-to-birthrate [ratio]
SiC	Silicon carbide (fuel kernel coating layer)
SQL	Structured Query Language
TDO	Technology Development Office
VHTR	Very High Temperature Reactor (program) and very high temperature gas-cooled reactor

AGR-1 Interim Data Qualification Report

1. INTRODUCTION

This report provides the interim FY 2009 status of Advanced Gas Reactor (AGR) AGR-1 irradiation experiment data qualification as performed by the NGNP Data Management and Analysis System (NDMAS). AGR-1 is the first 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-1 test train is being conducted over 13 Advanced Test Reactor (ATR) cycles beginning with Cycle 138B on December 23, 2006, and ending with Cycle 145A, which has a planned outage on October 23, 2009.

This report gives the interim data qualification status of three data streams, or general types of data, currently being collected and processed by NDMAS from the AGR Fuel Development and Qualification Project: Fuel Fabrication, Fuel Irradiation, and Fission Product Monitoring System (FPMS) data. A fourth data stream, ATR operating conditions data, is also addressed, which supports evaluation of Fuel Irradiation data. Data qualification of graphite characterization data collected under the Graphite Technology Development Project is reported in a separate interim status report (Hull 2009).

A final report giving the NDMAS qualification status of all AGR-1 data (including Cycle 145A), except post-irradiation examination (PIE) data, is planned for February 2010. This report will address the final status of the above data streams in addition to reporting on the Neutronics and Thermal Analysis Data stream, which is planned for incorporation into NDMAS. The neutronics analyses produce estimates of neutron flux and the energy released by fission which are then used for model predictions of temperatures in the fuel and associated structural materials. PIE of AGR-1 fuel will commence in FY2010 and continue for several months. Qualification of PIE data will begin as soon as data become available.

2. OVERVIEW OF NDMAS DATA QUALIFICATION

NDMAS was developed to provide a single controlled repository for all AGR data, data qualification, advanced data analysis, and Web access of the data. A detailed discussion of the NDMAS structure and the data qualification requirements performed within NDMAS is given in the Very High Temperature Reactor Program Data Management and Analysis Plan (INL 2009a).

Data qualification is the act of reviewing, inspecting, testing, checking, or otherwise determining and documenting whether data conform to specified requirements. Data processed by NDMAS are classified into four categories to determine the level of data qualification and whether the data were collected within a Nuclear Quality Assurance (NQA) NQA-1 (ASME 2000) or equivalent approved quality assurance (QA) program. The category is assigned by the data generator based on the needs of the project and the intended use of the data. The data categories are defined as:

1. *Archive.* Information that serves as backup or support for data analysis and interpretation activities. Files are copied and stored in native format. Archive data may or may not have been collected within an NQA-1 or equivalent approved QA program.
2. *Trend.* Data collected within an NQA-1 or equivalent approved QA program that provide an indication of tendency, but not necessarily absolute values. Trend data captured into NDMAS are tested to verify capture, and may be subjected to some accuracy testing.
3. *Existing.* Data collected outside an NQA-1 or equivalent approved QA program that are loaded into NDMAS for programmatic use. Data are tested to verify capture, and may be tested to verify accuracy based on the needs of the program.

4. *Qualified.* Data that have passed NDMAS capture and accuracy testing, received formal certification review, as appropriate, and been collected within an NQA-1 or equivalent approved QA program.

NQA-1 requirements for data collected within the VHTR program are implemented through the *Very-High-Temperature Gas-Cooled Reactor Technology Development Office Quality Assurance Program Plan* (VHTR TDO QAPP) (INL 2009b). The documents that verify these QA requirements for each data stream are given in the data stream sections of this report.

Capture testing is performed for all *Trend*, *Existing*, and *Qualified* data uploaded into the NDMAS database. Capture testing includes automated checks to verify there are no obvious data processing errors in the source files (e.g., date/time chronology checks) and that the data stored within NDMAS are identical to the source data provided to NDMAS.

Accuracy testing evaluates whether the data are an accurate representation of the system or object being measured or modeled. Accuracy testing is required for data in the *Qualified* data category, and may be performed for data in other categories depending on the needs of the program. For AGR-1, NDMAS accuracy testing includes visual examination of the data, range tests (e.g., thermocouple temperature range of 0 to 1,300°C), and documentation of program-specific data approval certifications (e.g., approved Engineering Calculations and Analysis Report for FPMS data). More rigorous accuracy testing for thermocouple failure is currently under development (see Section 4, "Fuel Irradiation Data").

3. FUEL FABRICATION DATA

AGR-1 fuel is fabricated from low-enriched uranium oxycarbide kernels that are coated with multiple layers to form particles. The first coating is a low-density carbon layer (buffer layer), followed by a high-density inner pyrolytic carbon (IPyC) layer, a silicon carbide (SiC) layer, and finally, a high-density outer pyrocarbon (OPyC) layer. For AGR-1 fuel, coating conditions were varied during particle fabrication to create a baseline and three variant particle composites. Process conditions for the baseline and three variants are described in Barnes (2006). Once the coatings are applied, thousands of particles are formed into cylindrical compacts using a graphite-resin matrix. For this data stream, design specifications were established, and the delivered hard copy data packages are the quality record that the design specifications were met or have been accepted as is.

3.1 Description of the Data Stream

The AGR-1 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 (Einerson 2006). 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 Kernel Data

A kernel composite consists of multiple kernel batches combined and mixed to ensure uniformity prior to sampling for acceptance. The composite lot of kernels (G73D-20-69302) used to make AGR-1 baseline and variant particles was fabricated by BWX Technologies (BWXT), now called Babcock and Wilcox (B&W) under a quality program that conformed to the requirements of NQA-1 1997 (ASME 1997), as per the requirements in effect at the time of kernel fabrication. Complete characterization data for this kernel lot are compiled in Data Certification Package, BWXT (2005). Kernel composite properties included in NDMAS and corresponding specifications are listed in Table 3-1. Some kernel properties were also measured by ORNL prior to fabricating particles and compacts, but only the BWXT data were used for fuel certification. However, the ORNL kernel data were included in NDMAS for comparison purposes.

Table 3-1. Properties and specifications for AGR-1 fuel kernels (Lot G73D-20-69302).

Kernel Property	Specified Range for Mean Value
U-235 enrichment (wt%)	19.80 ± 0.10
Total Uranium (wt%)	≥ 87.0
Oxygen/Uranium (atomic ratio)	1.50 ± 0.20
Carbon/Uranium (atomic ratio)	0.50 ± 0.20
[Carbon+Oxygen]/Uranium (atomic ratio)	≤ 2.0
Sulfur impurity (ppm – wt)	≤ 1500
All other impurities[(a)]	Various
Density (g/cm^3)	≥ 10.4
Diameter (μm)	350 ± 10
Aspect ratio (sphericity or ellipticity)	Not specified

a. Not included in NDMAS because all impurities were below detection limits and within specifications

3.1.2 Particle Data

AGR-1 fuel kernels were shipped to Oak Ridge National Laboratory (ORNL) where the coatings were added and the compacts fabricated under a quality program that conformed to the requirements of NQA-1 2000 (ASME 2000). Particles were coated in batches and particle composites were made from three or four coated batches. There are four particle composites for AGR-1 fuel—one for the baseline and each of the three variants. Complete characterization data for the four particles composites are compiled in data packages Hunn and Lowden (2009, 2006a, 2006b, 2006c). Particle properties included in NDMAS and corresponding specifications are listed in Table 3-2.

Table 3-2. Properties and specifications for AGR-1 coated particle composites.

Property	Specified Range for Mean Value
Buffer density (g/cm^3)	0.95 ± 0.15
Buffer thickness (μm)	100 ± 15
IPyC density (g/cm^3)	1.90 ± 0.05
IPyC thickness (μm)	40 ± 4
IPyC anisotropy (BAFo)	≤ 1.035
SiC density (g/cm^3)	≥ 3.19
SiC thickness (μm)	35 ± 3
OPyC density (g/cm^3)	1.90 ± 0.05
OPyC thickness (μm)	40 ± 4
OPyC anisotropy (BAFo)	≤ 1.035
Gold spot defect fraction	$\leq 2.0 \times 10^{-4}$
Defective SiC coating fraction	$\leq 2.0 \times 10^{-4}$

Defective OPyC coating fraction	≤ 1.0 x 10^{-2}
IPyC anisotropy post compact deconsolidation (BAFo)	Not specified
OPyC anisotropy post compact deconsolidation (BAFo)	Not specified
Aspect ratio (sphericity)	Mean not specified[(a)]

a. Critical region is specified such that ≤ 1 % of the particles shall have an aspect ratio ≥ 1.14.

3.1.3 Compact Data

AGR-1 fuel compacts were fabricated by ORNL under a quality program that conformed to the requirements of NQA-1 2000 (ASME 2000). The same compacting process was used for the baseline fuel and all three variants, however the molding pressure did vary by compact. Complete characterization data for the four compact lots are compiled in data packages Hunn and Lowden (2009, 2006a, 2006b, 2006c). Compact properties included in NDMAS and corresponding specifications are listed in Table 3-3.

Seventy-nine compacts each were fabricated from Baseline, Variant 1, and Variant 3 particles, while 67 compacts were fabricated from Variant 2 particles. Compact mass, diameter, and length for each compact of each variant were included in NDMAS, even for compacts that didn't meet length specifications. In general, approximately one-third of the compacts from each lot were sacrificed for characterization. The remaining compacts were made available for irradiation testing.

Table 3-3. Selected properties for AGR-1 compacts.

Property	Specified Range for Mean Value
Mean uranium loading (g U/compact)	0.905 ± 0.04
U contamination fraction[(a)] (g $U_{exposed}$ /g U)	≤ 1.0 x 10^{-4}
Iron content (μg Fe outside SiC/compact)	≤ 25
Chromium content (μg Cr outside of SiC/compact)	≤ 75
Manganese content (μg Mn outside of SiC/compact)	≤ 75
Cobalt content (μg Co outside of SiC/compact)	≤ 75
Nickel content (μg Ni outside of SiC/compact)	≤ 75
Calcium content (μg Ca outside of SiC/compact)	≤ 90
Aluminum content (μg Al outside of SiC/compact)	≤ 45
Titanium content (μg Ti outside of SiC/compact)	Note[(b)]
Vanadium content (μg V outside of SiC/compact)	Note[(b)]
Diameter[(c)] (mm)	12.22 – 12.46
Length[(c)] (mm)	25.02 – 25.40
Compact mass (g)	Not specified
Molding pressure (MPa)	Not specified[(d)]

a. Value is an estimate of an attribute property, not the mean of a variable property.
b. Mean value specification of ≤ 400 μg Ti plus V outside of SiC/compact.
c. Allowable range corresponding to upper and lower critical limits specified with no compacts exceeding the limits which requires 100 % inspection of all compacts.
d. Not a variable, but a process condition that varied by compact.

3.1.4 Data Structure

Prior to capturing the data in NDMAS, a hierarchal data structure based on components was created to make the data easier to process and analyze. A component is the generic name for the object or system being measured. In NDMAS, the fuel properties shown in Tables 3-1, 3-2, and 3-3 are known as response variables, and each response variable is a measurement or property associated with a component. For AGR-1 fuel, the component types are kernels, particles, particle layers, and compacts. Table 3-4 shows the component naming structure for each of the component types. There are 336 unique components for all four variants.

Table 3-4. Component types and names for AGR-1 fuel data.

Component_type	Component_name
Kernel Batch	LEU01
Buffer Layer[a]	LEU01-XXB
IPyC Layer[a]	LEU01-XXI, and LEU01-XXT-ZI[b]
SiC Layer[a]	LEU01-XXS, and LEU01-XXT-ZO[b]
OPyC Layer[a]	LEU01-XXO
Particle Composite	LEU01-XXT
Compacts	LEU01-XXT-ZYY
Compact Lot	LEU01-XXT-Z

a. Layers added to the kernels to make particles.

b. Some layer properties were measured on particles from deconsolidated compacts.

XX = number associated with variant (46=Baseline, 47=Variant 1, 48=Variant 2, 49=Variant 3).

YY = compact number (79 each for Baseline, V1 and V3 variants, 67 for V2).

In NDMAS, components are related to each other by an assembly tree. The component assembly tree for AGR-1 fuel data is shown in Figure 3-1. At the base of the tree is the compact lot. The compact lot is composed of particles from the particle composite, which is composed of kernels from the kernel batch. Individual compacts are associated with (a branch of) the compact lot, and particle layers are associated with the particle composite. All the chemical properties in Table 3-3 are representative of the compact lot. The physical properties (diameter, length, and mass) are measured on individual compacts.

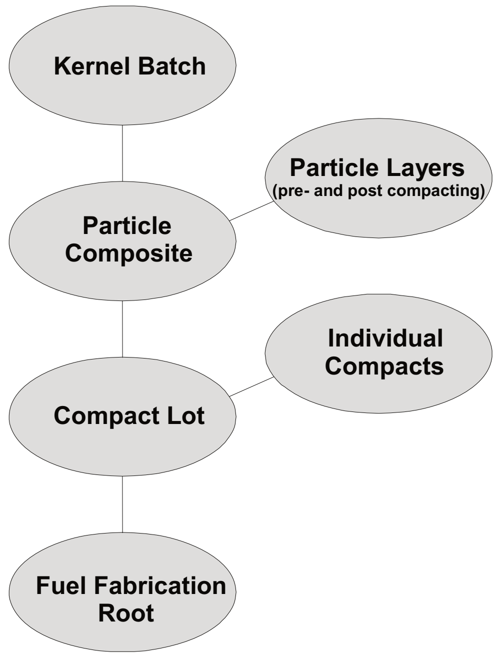

Figure 3-1. Fuel fabrication data component assembly tree structure.

A careful review of the data packages identified the 33 unique response variables listed in Table 3-5. Where a mean value is indicated, there is also a response variable for the standard deviation and the number of samples in the population. For defect fractions, there is no standard deviation because these are attribute properties (defective or not defective).

Table 3-5. Response variables for AGR-1 fuel data.

Response_var_name	Response_var_description	Units
u235_enrich_mean	Mean weight percent of U-235 enrichment in kernel composite	wt%
u_wt_percent_mean	Mean total weight percent Uranium in kernel composite	wt%
o_to_u_ratio_mean	Atomic ratio of Oxygen to Uranium in kernel composite	ratio
c_to_u_ratio_mean	Atomic ratio of Carbon to Uranium in kernel composite	ratio
c_plus_o_to_u_ratio_mean	Atomic ratio of Carbon plus Oxygen to Uranium in kernel composite	ratio
sulfur_content_mean	Mean Sulfur content of kernel composite	ppm-wt
env_dens_mean	Mean envelope density measured by mercury porosimetry	g/cm^3
diameter_kernel_mean	Mean kernel diameter	µm
aspect_ratio_mean[a]	Ratio of maximum to minimum diameter (a.k.a. sphericity)	D_{max}/D_{min}
aspect_ratio_defect_frac	Fraction of samples that exceed aspect ratio specification	fraction
thickness_mean	Mean thickness of TRISO composite layer	µm
sink_float_dens_mean	Mean density measured using density-gradient column	g/cm^3
anisotropy_mean	Mean anisotropy of layer (BAFo equivalent)	BAFo
defective_SiC_frac	Fraction of particles with defective SiC layer	fraction
gold_spot_defects_frac	Fraction of particles with soot inclusion (gold spot) in SiC layer	fraction
diameter_compact	Diameter of compact (mean of 6 measurements 2-top, 2-mid, 2-bot)	mm
length_compact	Length of the compact	mm
mass_compact	Mass of the compact	g

molding_pressure	Molding pressure used to create the compact	MPa
u_loading_mean	Mean Uranium loading per compact	g/compact
u_contamination_frac	Fraction of Uranium in compact not encapsulated by retentive layer	g $U_{exposed}$/g U
defective_IPyC_frac	Fraction of particles with defective IPyC layer	fraction
defective_OPyC_frac	Fraction of particles with defective OPyC layer	fraction
fe_content_mean	Mean Iron content per compact (outside SiC layer)	μg/compact
cr_content_mean	Mean Chromium content per compact (outside SiC layer)	μg/compact
mn_content_mean	Mean Manganese content per compact (outside SiC layer)	μg/compact
co_content_mean	Mean Cobalt content per compact (outside SiC layer)	μg/compact
ni_content_mean	Mean Nickel content per compact (outside SiC layer)	μg/compact
ca_content_mean	Mean Calcium content per compact (outside SiC layer)	μg/compact
al_content_mean	Mean Aluminum content per compact (outside SiC layer)	μg/compact
ti_content_mean	Mean Titanium content per compact (outside SiC layer)	μg/compact
v_content_mean	Mean Vanadium content per compact (outside SiC layer)	μg/compact
sink_float_dens_SiC_mean[b]	Mean SiC density measured using density-gradient column	g/cm^3

a. Although a mean value for aspect ratio is included, there is not an accompanying standard deviation because it is an attribute property.

b. A separate response variable was used for the sink-float density of the SiC layer because it was measured using a different method than the other layers.

3.2 Fuel Fabrication Data Processing within NDMAS

The complete kernel data package (BWXT 2005) was transmitted to Idaho National Laboratory (INL) in hardcopy format. A summary of the kernel data package was transmitted in electronic PDF (Portable Document Format). The baseline and variant data packages for the particles and compacts (Hunn and Lowden 2009, 2006a, 2006b, 2006c) were transmitted in electronic PDF file format. None of the data in the data packages were in machine readable format. Before they could be captured into NDMAS, the data were entered into an Excel spreadsheet file named agr1_fuel_fab_data.xls.

The agr1_fuel_fab_data.xls spreadsheet file contains a separate worksheet for components, response variables, response variable values, and methods. Most of the response variable values were entered directly from the data packages into the worksheet. However, the mean and standard deviation density values for the buffer layers, IPyC layers and OPyC layers were not available for the entire population used to make the composite particles. Recall the composite particles were made from three or four coated batches. Means and standard deviation values for individual batches were reported in the data packages, but not for the entire population. In these cases, the batch mean and standard deviation values were used to calculate an overall mean and standard deviation (IPyC layers), or the density values of all samples in all the batches were used to calculate the mean and standard deviations for the entire population (OPyc layers). This was done in a separate Excel spreadsheet file called agr1_fuel_fab_density_calculations.xls. The calculated density values were then entered into the agr1_fuel_fab_data.xls file. Both Excel files are stored on the NGNP SAS Server in the directory \\Sasngnp\ngnp\NGNP_Data\Fuel_Fab\AGR1\. All density calculations will be documented in a separate report.

Each worksheet of agr1_fuel_fab_data.xls was captured as a SAS dataset using the program \\Sasngnp\ ngnp\ NDMAS Version 1.1\Fuel_Fab\ Capture_native_fuel_fab_data.egp. The four new SAS datasets (COMPONENTS, VARS, VALUES and METHODS) are stored in the SAS Library FUEL_FAB on the SAS Server. A different program, Capture_native_fuel_fab_data.egp, reads these SAS datasets and through a series of joins, filters, queries, and transposes, creates three additional datasets (EXP_COMP_for_upload, EXP_COMP_ATTRIB_for upload, EXP_ASSY_TREE_for_upload) to be appended to the appropriate files in the NDMAS Structured Query Language (SQL) database ("vault").

3.3 Description of Fuel Fabrication Data Qualification

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

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

3.3.1 Capture Tests

The transmitted data are manually entered into the Excel spreadsheet file agr1_fuel_fab_data.xls. 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're identical. An independent person performs the comparison and the review is documented. For the calculated density values (see Section 3.2), the values used in the calculations are checked against the data in the data packages.

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 (see Section 3.1.4)

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 a 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 person checks response variable values in the database against the data in the data packages and documents the results. Values determined from calculations (see Section 3.2) are compared against the Excel spreadsheet agr1_fuel_fab_density_calculations.xls.

3.3.2 Accuracy Tests

The scope of accuracy testing is limited to the certification that AGR-1 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 (BWXT 2005, Hunn and Lowden 2009, 2006a, 2006b, 2006c). 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.

3.4 Verify Fuel Fabrication Data QA Documentation

Kernels for AGR-1 fuel were produced under a quality program that conformed to the requirements of the 1997 version of NQA-1, which was in effect at the time of kernel fabrication. Coated particles and compacts were produced under a quality program that conformed to the requirements of the NQA-1 2000 as implemented and documented by the fuel fabricator’s quality assurance program plan (ORNL, 2006).

3.5 Fuel Fabrication Data Qualification Status

A preliminary manual inspection was performed on a portion of the data in the Excel spreadsheet file agr1_fuel_fab_data.xls. The check found one error out of 230 values checked. The printed file was signed by the independent reviewer and placed in the project file. The official manual inspection will be performed on all 1,500+ data values. Some referential integrity tests are being developed but are not finalized. The other capture tests have not been performed because the data has not yet been loaded into the SQL database.

As stated previously, no additional accuracy testing beyond what was done for data certification will be performed. Nevertheless, all data in the data packages met specifications with three exceptions. The first nonconformance is the 95% Lower Confidence Limit for kernel uranium enrichment was 19.6962 wt%, slightly less than the specification of 19.7%. The nonconformance report (included in the data package) shows the kernels were submitted for customer disposition and approved as is. The second nonconformance was also related to the kernels in that the Carbon/Uranium (C/U) dispersion did not meet the specification as documented in Ebner (2005). Barnes (2005) provided the basis for the kernels to be used as is, and INL issued a Procurement Change Notice to BWXT releasing them from meeting the specification. The third nonconformance was the length of some of the Baseline and Variant 2 compacts were slightly less than the specified minimum length. The nonconformance reports (provided as part of the data packages) documents the recommendation and acceptance that the specimens be used as is for both irradiation and destructive characterization.

3.6 Fuel Fabrication Data Problems and Resolution

A problem with the AGR-1 fuel fabrication data is that it was not supplied in machine readable format. Some tables of data in the data packages appear to be scans of Excel spreadsheet files, but the Excel files were not readily available. The Excel files were scanned to preserve the signatures of operators, reviewers, and supervisors. These scanned images were high-quality reproductions and there were no problems discerning the data/numbers from the PDF files. Nevertheless, not having machine readable data requires each value to be entered by hand into a spreadsheet and checked manually. It is recommended that future fuel fabrication data packages be transmitted in machine readable format. Efforts should also be made where possible to standardize the formatting, especially for similar data types, with the goal of reducing any preprocessing required to handle distinct and unique files or tables. Having the data in standardized machine readable format may be more of a convenience issue than a problem, but it will be more efficient to process the data and reduce the possibility for errors.

No other problems were identified at this time, but after all the data have been successfully loaded into the SQL database and all capture tests performed, any problems that emerge will be included in the final AGR-1 qualification status report.

4. FUEL IRRADIATION DATA

4.1 Description of the Data Stream

The fuel irradiation experiment includes monitoring of the controlled gas flows to the capsule train that provide some temperature control and that collect emissions from the six fuel capsules and route them to the fission product monitoring system. Ten variables are measured, and these data are subsequently processed and stored in NDMAS (Table 4-1). 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 temperatures at several locations within each capsule. 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 generally collected at 5-minute intervals, except where data management issues during the first two reactor cycles (138B, 139A) provided only 2-hour interval data (INL ICARE NCR 42791, 2008).

Table 4-1. Measurement variables in the Fuel Irradiation data stream.

Measurement Variable	Description	Units
Moisture Content	Moisture content in gas flow line	Parts per million volume (ppmv)
Pressure	Pressure in gas flow line	Pounds per square inch atmosphere (psia)
Q_He	Helium flowrate	Standard cubic centimeters per min (sccm)
Q_Ne	Neon flowrate	Standard cubic centimeters per min (sccm)
Q_Total	Total outlet line gas flowrate	Standard cubic centimeters per min (sccm)
TC_1	Thermocouple No. 1 temperature	ºC
TC_2	Thermocouple No. 2 temperature	ºC
TC_3	Thermocouple No. 3 temperature	ºC
TC_4	Thermocouple No. 4 temperature	ºC
TC_5	Thermocouple No. 5 temperature	ºC

The capsule thermocouples are of two different types and two different diameters, and thermocouple identification numbers may be associated with different positions and insertions depths in different capsules. A summary diagram of the thermocouples positions in the capsules is shown in Figure 4-1.

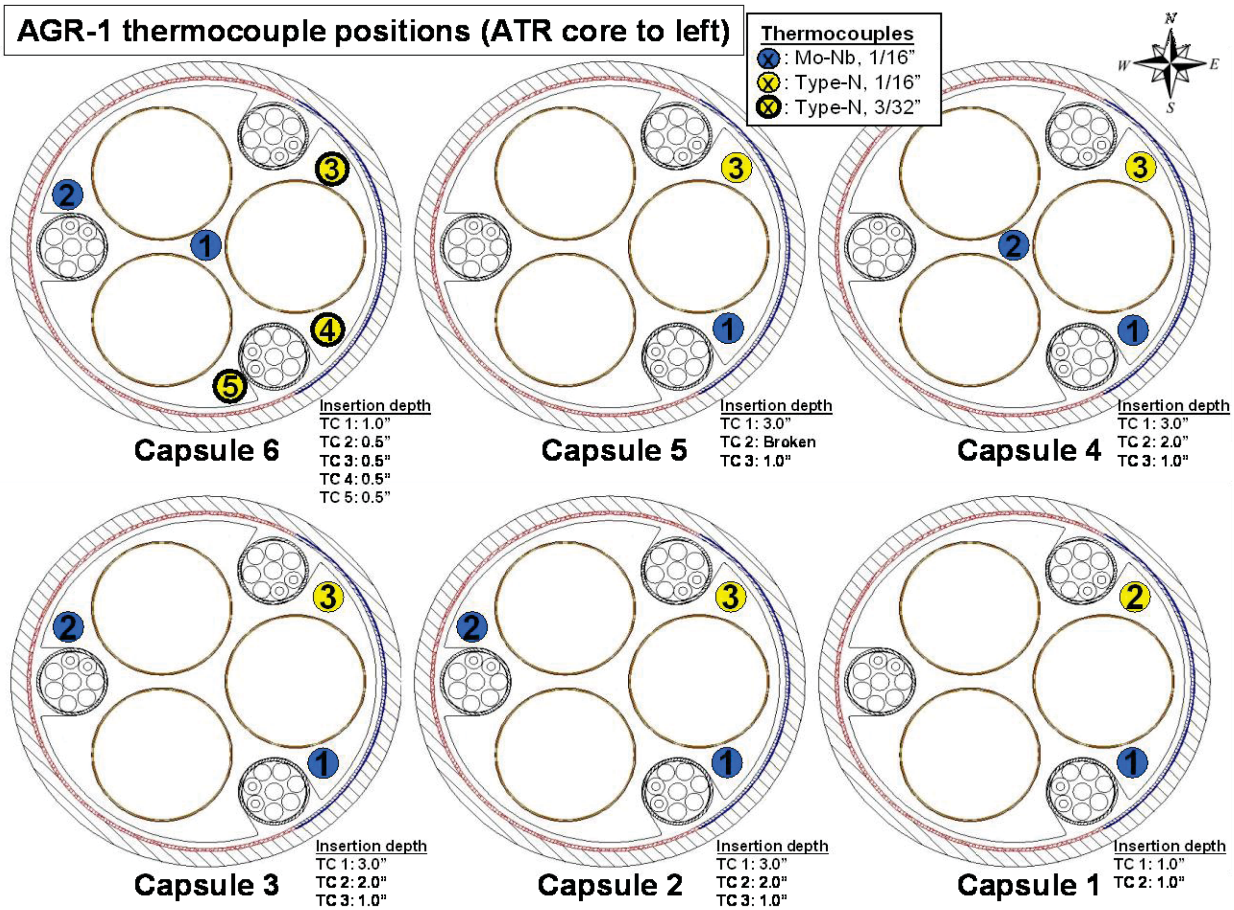

Figure 4-1. AGR-1 thermocouple descriptions and location information.

4.2 Fuel Irradiation 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 folders on the FSISC1 server as shown in Figure 4-2. Each folder contains one data file for each capsule with leadout system data included in the file for Capsule 1. 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-savings 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.

Raw AGR-1 Irradiation data:

FSISC server location:

- *\\FSISC1\Projects\AGRData*

Folder names:

- '2400' followed by ending date of dataset in 'mm-dd-yy' format)

File names:

- *'AGR1x.RPT'* (6 files per cycle, x = capsule 1-6)
- *'HE_FLOW.RPT'* (Gas flow data for FPMS)

AGR-1 Irradiation data processing steps:

- Copy new file folders from FSISC1 to *\\Sasngnp\NGNP\NGNP_Data\AGR-1*
- FROM NDMAS directory, '*Vault_PushPull*'
    1) Run batch file 'update.bat' that creates/updates the list of relevant folder names to be processed
    2) Run Enterprise Guide Project file 'Update or build Irrad dataset.egp' *to construct SAS dataset for new data*
        - *Builds/appends all new data as SAS dataset*
        - *Pushes new data to SQL_NDMAS (NDMAS vault)*
        - *Checks that vault data is correctly entered*
    3) Update log file *'Irradiation capture-push instructions and log.doc'*
    4) Run Enterprise Guide Project file *'Vault tests.egp' and examine* any failed data
    5) Resolve failed data as necessary
    6) *Run* Enterprise Guide Project file 'Combine_Irrad_ATR_FPMS.egp' to populate N_MART directory with new SAS data sets and cubes containing updated irradiation data

Figure 4-2. Raw AGR-1 irradiation data and data processing steps.

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, each data package is then compared to the SAS dataset from which it was built to ensure that the data were correctly stored. Results are stored in the electronic log, Irradiation capture-push instructions and log.doc.

4.3 Description of Fuel Irradiation Data Qualification Tests

Several tests, or analyses, are performed to attempt to identify data anomalies that may represent instrument drift or failure. Some of these methods are simple tests that, for example, check that the data are in a value range appropriate to the measurement. Others are more detailed analyses that rely on statistical analysis of past behavior 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. Anomalies identified by these tests are then examined with input from the technical leads and resolved to determine whether the anomalies represent (1) instrument failures or other errors that disqualify the data from use for their intended purpose, (2) values that are unusual but accurate, and therefore *qualified data*, or (3) instrument data that is reasonably precise, for use as *trend data*, but insufficiently accurate to be considered *qualified data*.

Range tests, which detect data values outside expected ranges of measurement, include the parameters and values listed in Table 4-2.

Table 4-2. Range test values.

Parameter	Requirement
Temperature	0ºC < X < 1300ºC
Gas pressure	10 psia < X < 20 psia
Gas moisture content	0 ppm < X < 5 ppm
Gas flow	-2 SCCM < X < 52 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:

- Requirements for gas moisture content are specified in TFR-248 (West et al. 2005), Section 3.1.2.4: "Moisture content of the inlet sweep gas shall be measured on the inlet side of the capsule at least once after each gas cylinder change and shall be < 5 parts-per-million (ppm) H_2O."
- Based on the desired volume-averaged temperatures for the fuel in the experiment, the AGR-1 test train design requires temperature measurements in the 970–1,290°C range (Palmer 2006). As initial data from the experiment suggested that operating temperatures did not generally approach the higher end of that range, 1,300°C 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 52ºC and, at full power, exits the vessel at a temperature of 71ºC (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 0ºC.
- The range test for gas flow rates to the capsules is based on the nominal flow rates specified in TFR-248 (West et al. 2005), Section 3.1.2.2: "The tubing, valves, and MFCs 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."
- Expert judgment. Monitoring data may be qualified according to physical principles or other information not revealed by statistical analyses. Temperature measurements, for example, are periodically compared to numerical simulations of heat flow that calculate temperatures at the thermocouple locations. Where the temperatures differ by greater than ~50ºC, the thermocouples may be judged to have failed, sometimes by formation of a new junction. Such judgments, as recorded in controlled documents, are used to qualify the data where appropriate. For the AGR-1 experiment, examples include notes like the following from Maki (2007b):

  > These "TCs have provided measurements in excess of 200°C difference from calculated values (Ambrosek 2007). Such large differences indicate either the thermocouples have formed virtual junctions outside of the intended capsule or have developed another form of malfunction."

4.4 Verify Fuel Irradiation Data QA Documentation

The NGNP data collection process includes plans describing how data will be collected and the QA activities associated with those data. Review of those plans assures that the work will generate data of appropriate quality for use in the NQA-1 program. Metadata generated by the initial documentation, audits, and acceptance inspection provide the evidence that data meet the requirements of an NQA-1 data collection program. This is documented at the data stream level for fuel irradiation data. Documentation of the QA Program in NDMAS is primarily accomplished by references to documents. These include plans, audit reports, nonconformance reports, Engineering Design Files (EDFs), and Engineering Calculations and Analysis Reports (ECARs) which are approved by the VHTR-TDO QA Lead.

The following documents provide evidence that the data for the fuel irradiation data stream meet the requirements of NQA-1 Part 1:

1. R. G. Ambrosek, "AGR-1 As-Run Thermal Evaluations – Cycle 138B, 139A and B," ECAR-102, Draft, December 4, 2007.
2. J. T. Maki, "AGR-1 Irradiation Test Specification," EDF 4731, Rev. 1, July 2004.
3. J. T. Maki, *AGR-1 Irradiation Experiment Test Plan*, INL/EXT-05-00593, Rev. 2, March 2007.
4. J. T. Maki, 2007b, *AGR-1 As-Run Analysis Status For FY-07*, INL/EXT-07-13630, Rev 0, December 2007.
5. A. J. Palmer, "Thermocouple recommendations for the AGR-1 test," EDF-6809, Rev. 0, May 2006.
6. P. B. West, G. A. Marts, E. W. Killian, J. K. Hartwell, and S. B. Grover, "Temperature Control and Off Gas Monitoring Systems for Advanced Gas Reactor Experiment AGR-1," TFR-248, Rev. 1, March 2005.
7. P. B. West, G. A. Marts, E. W. Killian, J. K. Hartwell, and S. B. Grover, "Requirements for Design of the Advanced Gas Reactor Experiment AGR-1 for Irradiation in the Advanced Test Reactor," TFR-249, Rev. 1, December 2004.
8. INL ICARE NCR-42791, 2008, "ATR Experiment Data Collection System and Resulting Data," May 28, 2008.

4.5 Fuel Irradiation Data Analysis and Accuracy Testing

In addition to the basic qualification tests described in Section 4.3, data from AGR-1 are being used to develop additional accuracy testing methods for the fuel irradiation data that can be used in AGR-2 and subsequent irradiation experiments. Focusing on detecting thermocouple failure, NDMAS has explored several different methods that can predict thermocouple temperatures from ATR/AGR operating parameters and thus provide an independent measure of thermocouple deviation from expected values. NDMAS is also examining data from thermocouples that were judged to have failed during AGR-1 but still appeared to provide realistic temperatures. Using those examples of failures, and the data used to differentiate failed data, NDMAS anticipates that additional failure detection methods may be developed.

Examples of tests being developed using analyses of AGR-1 data include:

- Independent temperature estimation based on historical temperatures and observed relationships between temperature and ATR operating conditions. For sufficiently short time periods, fission power heating should be well correlated with ATR configuration. Thermocouple temperatures should thus be well predicted from ATR configuration and the thermal conductivity of the gas flow mixture delivered to each capsule. Preliminary regression modeling demonstrates, for example, that temperatures in Capsule 6 are well predicted by a first-degree polynomial expression involving only the angle of control cylinder S1D2 and the neon fraction of gas flow to the capsule. Subsequent analysis will examine how the uncertainty of the predicted temperature varies with ATR configuration and length of time.
- Gas flow tests were used to identify several thermocouple failures in the first three AGR-1 cycles. NDMAS posits that periodic, automatic, preprogrammed gas-flow tests that sequentially alter gas flow mixtures in the capsules and automatically analyze temperature response to those changes should offer a robust means of identifying thermocouple deviations.
- While temperatures between capsules are well correlated, increased correlation between thermocouples in different capsules may reflect formation of a new junction in the thermocouple

leads from the distal capsule. NDMAS is currently examining failed data from cases where this is believed to have occurred in order to develop tests that can identify those and other failures.

4.6 Fuel Irradiation Data Qualification Status

The overall qualification status for the separate AGR-1 fuel irradiation data packages is provided on the 'Qualification' page, INL NDMAS Web portal (https://sasweb.inl.gov). As of August 1, 2009, approximately 11 million irradiation data records have been stored in NDMAS, entered, and tested as 15 separate packages. The qualification status for these packages is summarized in Table 4-2.

Table 4-2. Qualification status of fuel irradiation monitoring data received as of August 1, 2009.

	Accuracy Failed	Qualified	Total
Data Package	Records	Records	Records
Irradiation data ending 20070703	113,439	546,478	**659,917**
Irradiation data ending 20090216	1,136,008	6,742,058	**7,878,066**
Irradiation data ending 20090222	18,144	98,784	**116,928**
Irradiation data ending 20090301	18,144	98,784	**116,928**
Irradiation data ending 20090308	18,144	98,784	**116,928**
Irradiation data ending 20090315	18,144	98,784	**116,928**
Irradiation data ending 20090323	18,144	122,976	**141,120**
Irradiation data ending 20090412	54,324	368,196	**422,520**
Irradiation data ending 20090419	18,144	122,976	**141,120**
Irradiation data ending 20090621	39,332	242,908	**282,240**
Irradiation data from Folder 2400 04-26-09	18,144	122,976	**141,120**
Irradiation data from Folder 2400 05-24-09	18,144	122,976	**141,120**
Irradiation data from Folders 2400 05-09-09 and 2400 05-17-09	35,883	243,207	**279,090**
Irradiation data from Folders 2400 05-31-09 and 2400 06-07-09	36,288	245,952	**282,240**
Irradiation data from Folders 2400 06-14-09 and 2400 06-21-09	16,128	266,112	**282,240**
Totals	**1,576,554**	**9,541,951**	**11,118,505**

4.7 Fuel Irradiation Data Problems and Resolution

4.7.1 Data Collection Issues

During the AGR-1 experiment, data from the capsule gas flow and temperature monitoring system were collected on one computer system and then transferred via floppy disk to another computer connected to the INL intranet. This system significantly limited NDMAS access to the data and thereby the frequency at which updates to NDMAS displays could be affected. During AGR-2 and subsequent experiments, it is expected that NDMAS will have a direct connection to an automated data collection system for the capsule gas flow and temperature monitoring data.

AGR-1 data have been collected with a local date/time stamp that periodically shifts to mountain daylight time (MDT) at times not always consistent with official times for those changes. To provide a consistent time and record for all data sets, it is recommended that subsequent AGR experiments also maintain a Mountain Standard Time (MST), or other standard time, date/time stamp for all records.

4.7.2 Failed Irradiation Data

Data problems with the irradiation experiment include failures in the data collection system and failures in accuracy. The former failure occurred during all of the first AGR-1 cycle (ATR Cycle 138B) and the first week of the second AGR-1 cycle (ATR Cycle 139A), when all of the electronic data files were irretrievably lost. Available data from that period are therefore restricted to that contained in hardcopy logs sheets which contain control thermocouple data and sweep gas data recorded at 2-hour intervals. Because data collection for that period did not conform to TFR-248 (West et al. 2005) requirements for the experiment, INL ICARE NCR 42791 (2008) was issued to address the issues associated with that data loss and ensure that future data management would be in compliance with TFR-248 (West et al. 2005).

Data from the fuel irradiation data monitoring stream that have failed accuracy tests are plotted in Figures 4-3, 4-4, and 4-5. The failed data generally reflect shakedown issues that occurred during the first three cycles, including:

- "repair of minor gas leaks, repair of faulty gas line valves; the need to position moisture monitors in regions of low radiation fields for proper functioning; the enforcement of proper on-line data and the need to monitor thermocouple performance." (Maki 2007b).
- By the end of the third cycle, it was concluded that the moisture monitors had degraded and then failed due to radiation damage to the sensor electronics. This implied that all moisture readings through the first three cycles were erroneous. During the reactor outage between the third and fourth cycles, the moisture monitors were replaced with new sensors and relocated to an area with significantly reduced radiation fields.
- During the first three cycles of irradiation, at least six of the AGR-1 thermocouples were determined to have failed (Maki 2007b), including:
  - TC-2 in Capsule 5 was damaged during fabrication of the test train and never was operational
  - As a result of the neon injection tests, it was concluded that TC-1 in Capsule 1 had formed a virtual junction near the location of Capsule 6, and was thus considered failed
  - Near the end of the third cycle, TC-2 in Capsule 1 had failed
  - TC-3 in capsule 2 failed after the end of the 3rd cycle, Sept. 30, 2007
  - The following thermocouples have provided measurements in excess of 200°C difference from calculated values (Ambrosek 2007), indicating that the thermocouples have either formed virtual junctions outside of the intended capsule or developed another form of malfunction:
    - Capsule 3 TC-2
    - Capsule 2 TC-1
    - Capsule 2 TC-2.

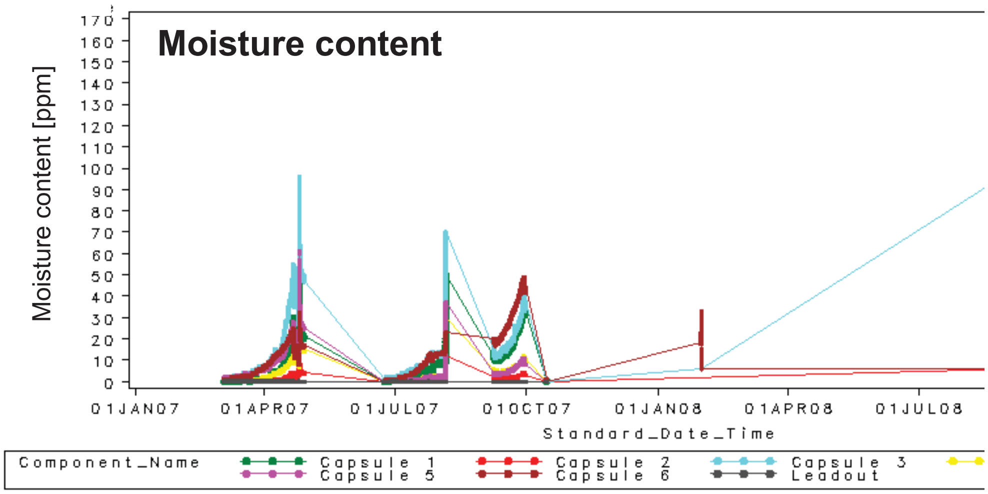

Figure 4-3. Gas moisture content data from AGR-1 that failed accuracy tests implemented by NDMAS.

Figure 4-4. Gas pressure data from AGR-1 that failed accuracy tests implemented by NDMAS.

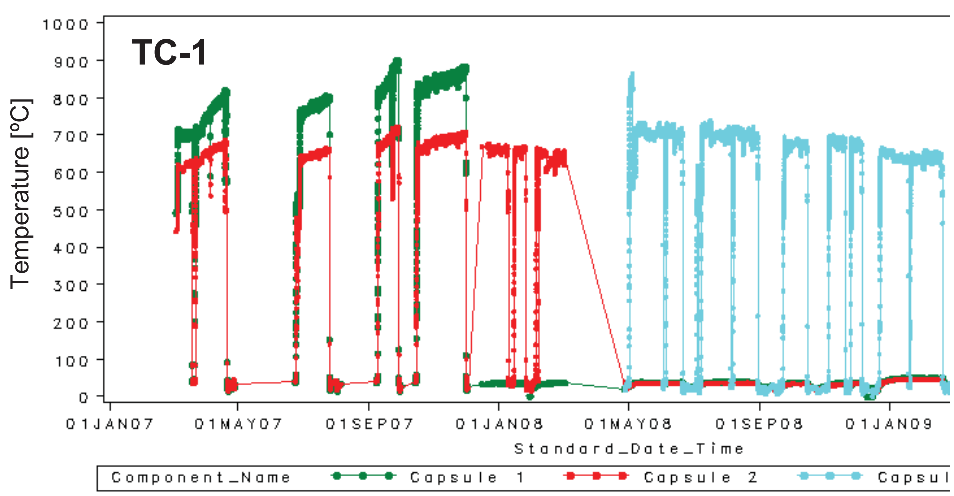

Figure 4-5. Thermocouple temperature data from AGR-1 that failed accuracy tests implemented by NDMAS.

5. FPMS DATA

5.1 Description of the Data Stream

The gas effluent in each of the six capsules of the AGR-1 experiment is monitored by a radiation detector system consisting of a gross radiation sodium iodide detector and a gamma-ray high purity germanium spectrometer. The collection of radiation measurement systems is known as the AGR-1 FPMS. The two types of FPMS data provided to NDMAS by the FPMS technical staff and their data qualification categories are:

1. Gross gamma data consisting of sequential 8-hour binary files of 3.5-sec gross gamma counts. These data are classified as *Archive* data.
2. Processed (by FPMS technical staff) spectral files consisting of radionuclide release rates (in atoms/sec) and release-to-birthrate (R/B) ratios for 12 noble gas fission product gases (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). These data are classified as *Qualified* data.

The gross gamma count data are processed by NDMAS to provide graphical displays on the INL NDMAS Web portal (https://sasweb.inl.gov). These data are used to provide an early indicator of potential fuel particle failures and are classified in the *Archive* data category. As such, they do not undergo any capture or accuracy testing within NDMAS and are not stored in the NDMAS SQL database.

Separate spectral release rate and R/B ASCII text files for each capsule are supplied to NDMAS at the end of each reactor cycle (six release files and six R/B files). Each data record in these files consists of processed fission product release rates (in atoms/sec) or R/B data (unitless), each with its associated uncertainty (%) over nominal 8-hour counting intervals (Table 5-1). A detailed description of the FPMS data processing done by the FPMS technical staff can be found in the User's Guide for the Fission Product Monitoring System (Drigert, Scates, and Walter 2009). Qualification of the data in these files is performed outside of NDMAS by the FPMS technical staff and documented in an ECAR (Scates 2009) for each data cycle. These ECARs are approved by the VHTR-TDO QA Lead and the VHTR-TDO Irradiations Technical Lead. Additional data capture testing is performed within NDMAS to ensure the stored data are identical to the original data (see next section). In addition, NDMAS performs data analysis (e.g., statistical distributions, correlations with thermocouple temperatures) and displays the results on the Web portal to assist researchers in data interpretation.

Table 5-1. FPMS release and R/B data provided to NDMAS.

Variable Name	Description
SpecID	Sample record name in the form GxYmmddhhzz, where Gx = detector number (G1 – G7), Y = last digit of year, mm = month (01 – 12), dd = day of month (01 – 31), hh = hour of day (00 – 23), zz = index number for detector restart
Date/Time	Local (Mountain Standard Time [MST] or Mountain Daylight Time [MDT]) start time of sample
<flow>	Detector gas flow rate in standard cm^3 per second
n	Number of gas flow readings used in the FPMS post-processing
Kr_85M_Rel/_Err	Release rate (atoms/s) and associated error (%) for Kr-85m (2 variables)
Kr_87_Rel/_Err	Release rate (atoms/s) and associated error (%) for Kr-87 (2 variables)
Kr_88_Rel/_Err	Release rate (atoms/s) and associated error (%) for Kr-88 (2 variables)
Kr_89_Rel/_Err	Release rate (atoms/s) and associated error (%) for Kr-89 (2 variables)
Kr_90_Rel/_Err	Release rate (atoms/s) and associated error (%) for Kr-90 (2 variables)

Table 5-1. (continued).

Variable Name	Description
Xe_131M_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-131m (2 variables)
Xe_133_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-133 (2 variables)
Xe_135_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-135 (2 variables)
Xe_135M_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-135m (2 variables)
Xe_137_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-137 (2 variables)
Xe_138_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-138 (2 variables)
Xe_139_Rel/_Err	Release rate (atoms/s) and associated error (%) for Xe-139 (2 variables)
Kr_85M_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Kr-85m
Kr_87_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Kr-87)
Kr_88_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Kr-88
Kr_89_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Kr-89
Kr_90_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Kr-90
Xe_131M_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-131m
Xe_133_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-133
Xe_135_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-135
Xe_135M_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-135m
Xe_137_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-137
Xe_138_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-138
Xe_139_Rat/_REr	Release-to-birthrate (R/B) ratio and associated error (%) for Xe-139

5.2 FPMS Data Processing within NDMAS

5.2.1 Gross Gamma Counts

The gross gamma count data are captured in their original binary file format, converted to text data, processed within SAS, and displayed as graphs on the "FPMS Gross Gamma Data" page of the NDMAS Web Portal (https://sasweb.inl.gov). The raw binary (.dgt) files are automatically transferred on a daily basis by FPMS staff to \\FSISC1\Projects\SASDATA\SAS Projects\NGNP\NGNP_Data\spectra\[ATR cycle#] where they are archived and accessed for SAS plotting. Specific data processing steps for the SAS plotting of the gross gamma data are:

1. Daily run of 'Read_Binary_GrossGamma.bat,' located on \\Sasngnp\NGNP\NDMAS Version 1.1\FPMS\GrossGamma\Capture.

2. The above batch file runs the SAS 9.1 code, 'Read_Binary_GrossGamma.sas.' This code searches the above source (.dgt) file folder any new files that have not been captured since the previous search, invokes a Fortran executable code to convert these binary files to text, and appends the count data into 7 detector SAS data sets located on \\sasngnp\Ngnp\Data\FPMS (e.g., dtr1_grgamma.sas7bdat). The SAS metadata library for these files is FPMS.

3. Plots of the data are developed in the SAS E-Guide file, 'GrossGammaPlots.egp,' located on \\Sasngnp\NGNP\NDMAS Version 1.1\FPMS\GrossGamma\Graphics. This file contains three stored processes, which control processing of the following: (1) "Plot Recent Gross Gamma Counts" – a 7-

day plot of the most recent processed data, (2) "Plot Short Term Gross Gamma Counts" – a plot of the data for any user-selected time period less than 24 hours, and (3) "Plot Long Term Gross Gamma Counts" – a plot of the data for any user-selected time period greater than or equal to 24 hours.

5.2.2 Release and R/B Data

At the end of each reactor cycle, the FPMS technical staff provides six capsule-specific release rate and R/B data files on FSISC1 server location \\FSISC1\Projects\AGRData\BirthRates. These 12 cycle-specific files comprise an FPMS data package within NDMAS. The files are captured and processed within NDMAS using steps shown in Figure 5-1.

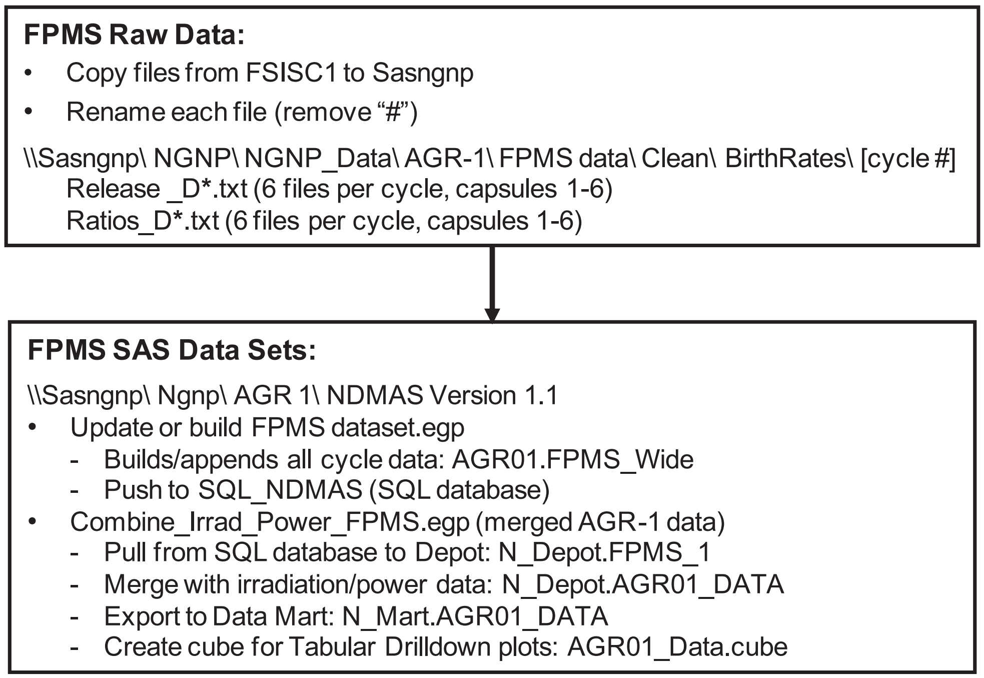

Figure 5-1. SAS processing of FPMS data (radionuclide release rates and R/B ratios).

5.3 Description of FPMS Data Qualification Tests

The FPMS release and R/B data are in the *Qualified* data category. Two general types of qualification tests are performed on these data in NDMAS:

- Capture tests verify that there are no simple raw data processing errors in the source files and that the data captured and stored within NDMAS are identical to the source data provided to NDMAS.
- Accuracy tests verify that the data are an accurate representation of the system parameters they are intended to measure.

The qualification tests for the FPMS release and R/B data are listed in the 'NDMAS Test Library.srx'on 'Qualification' page of the NDMAS Web portal (https://sasweb.inl.gov). Two time-related capture tests are currently performed on these data using the SAS E-Guide file, '\\SASNGNP\NGNP\NDMAS Version 1.1\Vault_PushPull\Update or build FPMS dataset.egp' to check that there are no obvious data processing errors in the source files:

- Test to ensure data records are in chronological order; if a data record is not in chronological order, an error is recorded for that record in the SAS dataset.

- Test to ensure the date/time entries for each data record are consistent with those in the SpecID variable in the data file (sample record ID). SpecID is in the form “GxYmmddhhzz,” where Gx = detector number (G1–G7), y= last digit of year (e.g., 9 for 2009), mm= month (00–12), dd = day of month (01–31), hh=hour of day (00–23), zz = index number for detector restart (e.g., 00 = initial start). If the SpecID does not match the sample date/time, an error is recorded for that record in the SAS dataset.

A final capture test is performed in the same SAS E-Guide file to verify that the data captured and stored within the NDMAS SQL database are identical to the source data provided to NDMAS. This test uses a SAS procedure (PROC-COMPARE) to compare the SAS dataset used as input to the SQL database with the SQL database output. Records of these test results are maintained for each FPMS reactor cycle data package processed within NDMAS.

Currently, the accuracy of the release and R/B data files for each reactor cycle is verified by the FPMS technical staff using an ECAR. After an ECAR is approved, the NDMAS staff is notified, and an ECAR accuracy test is logged as complete in the SQL database. Documentation of the ECAR approval for a cycle of FPMS data is recorded on the NDMAS Web portal (https://sasweb.inl.gov, “FPMS Release and R/B Data” page). FPMS release and R/B data for a given reactor cycle are considered *Qualified* after successful completion of both the NDMAS capture tests and the ECAR accuracy test.

5.4 Verify FPMS Data QA Documentation

The data collection process includes writing a plan describing how data will be collected and the QA activities associated with that data. Review of the plan assures that the planned work will generate data of appropriate quality for use in the NQA-1 program. Metadata generated by the initial documentation, audits, and acceptance inspection provide the evidence that data meet the requirements of an NQA-1 data collection program. This is documented at the data stream level and, for FPMS data, at the data package level (for each end-of-cycle file package). Documentation of the QA Program in NDMAS is primarily accomplished by reference to documents. These include plans, audit reports, nonconformance reports, and ECARs, which are approved by the VHTR-TDO QA Lead.

The following documents provide evidence that the data for the FPMS data stream meet the requirements of NQA-1 Part 1.

1. J. T. Maki, *AGR-1 Irradiation Experiment Test Plan*, INL/EXT-05-00593, Rev 2, March 2007.
2. D. M. Scates, J.K. Hartwell, *Fission Product Monitoring System Operability Test Plan for the AGR-1 Experiment: Phase II*, PLN-2350, December 2006.
3. M. W. Drigert, D. M. Scates, J. B. Walter, Users’ Guide for the Fission Product Monitoring System, GDE-503, Rev 0, 04/16/09.
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5. Approved ECARs (e.g., ECAR-525, Rev. 1, 07/20/2009 for ATR Cycle 143A FPMS data package).

5.5 FPMS Data Analysis

Data analyses beyond the data qualification requirements are performed on the FPMS release and R/B data stored in the NDMAS SQL database to assist in data interpretation by researchers. The results of these analyses are displayed on the NDMAS Web portal (https://sasweb.inl.gov, ‘FPMS Release and R/B Data’ page). Some examples of these analyses are: (1) plots of all cycle (AGR-1) R/Bs, releases, and calculated birthrates (Figure 5-2), (3) statistical characterization analyses (Figure 5-3), (4) R/B statistical summary plots (Figure 5-4), and R/B correlation analyses (Figure 5-5).

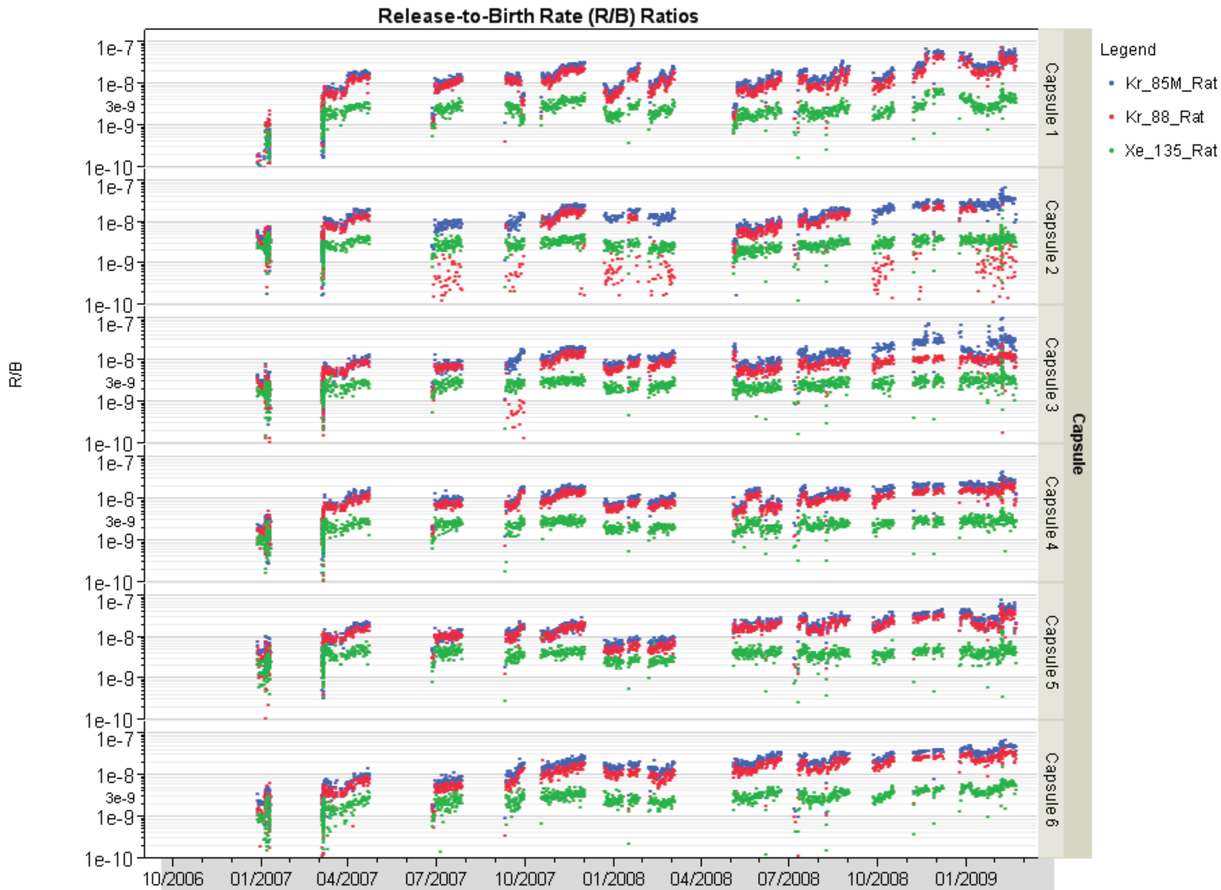
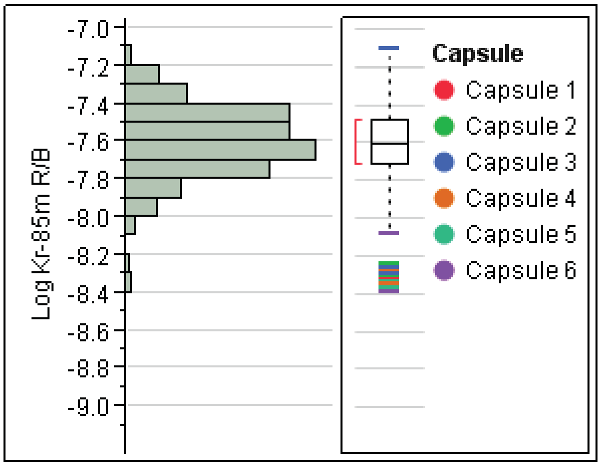


Figure 5-2. Example of R/B plots available on the NDMAS Web portal.



100.0%	maximum	-7.110
99.5%		-7.198
97.5%		-7.224
90.0%		-7.393
75.0%	quartile	-7.474
50.0%	median	-7.606
25.0%	quartile	-7.713
10.0%		-7.837
2.5%		-7.993
0.5%		-8.323
0.0%	minimum	-8.394

Figure 5-3. Example of an R/B statistical distribution analysis (for Cycle 142B) available on the NDMAS Web portal.

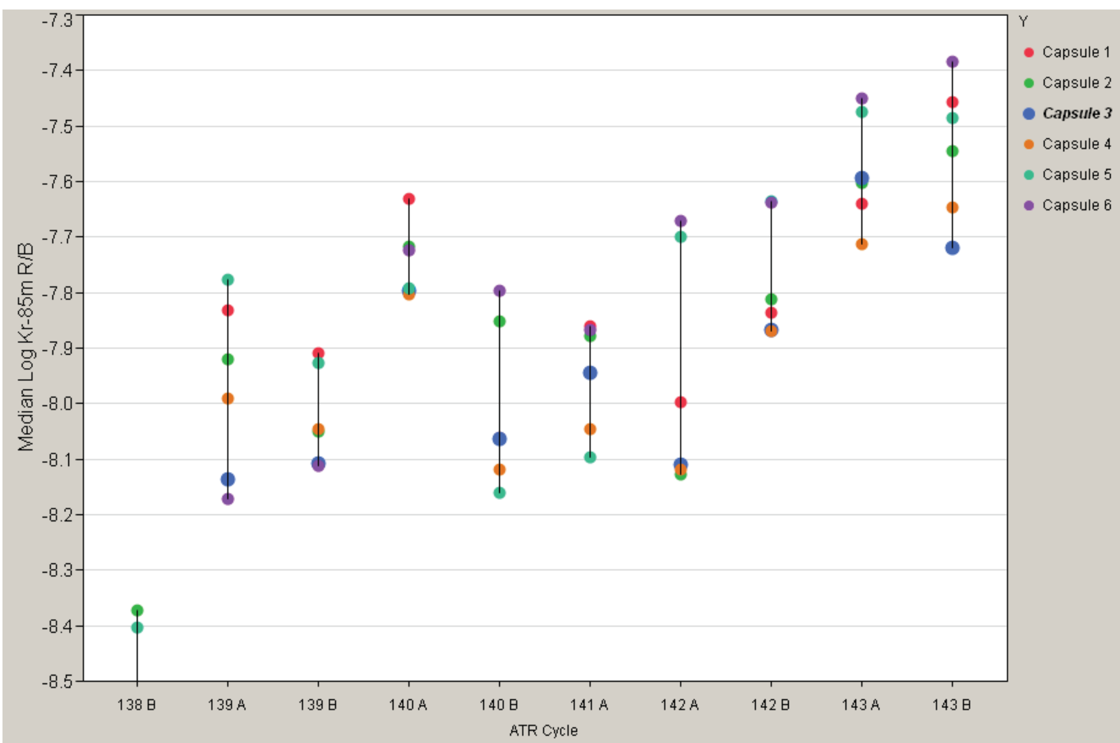
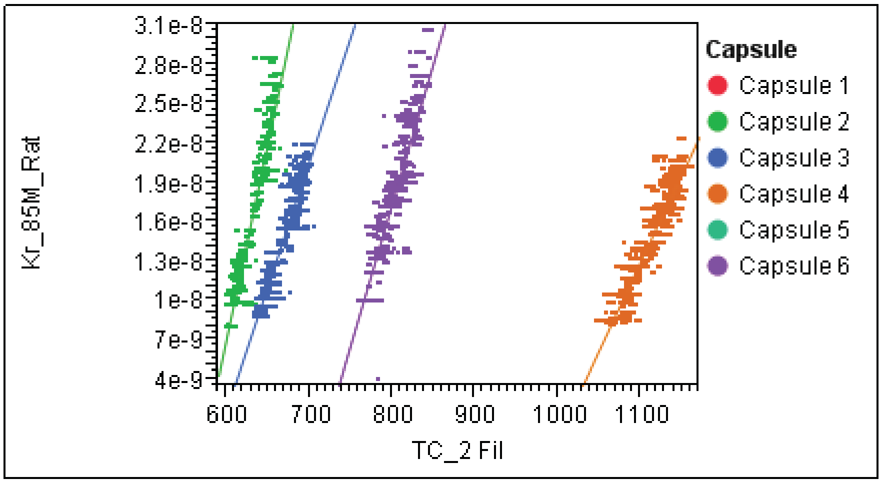


Figure 5-4. R/B statistical summary plot for all cycles and all capsules available on NDMAS Web portal.



Linear Fit Capsule=="Capsule 2"

Kr_85M_Rat = -1.738e-7 + 3.019e-10*TC_2 Fil

Summary of Fit

RSquare	0.913326
RSquare Adj	0.913319
Root Mean Square Error	1.607e-9
Mean of Response	1.807e-8
Observations (or Sum Wgts)	12411

Figure 5-5. Example of R/B correlation analysis (with thermocouple 2 temperatures, ATR Cycle 140A) available on the NDMAS Web portal.

5.6 FPMS Data Qualification Status

The overall qualification status for the individual cycle FPMS data packages is provided on the 'Qualification' page of the NDMAS Web portal (https://sasweb.inl.gov). As of August 1, 2009, the first 11 AGR-1 reactor cycle data packages have been received with the qualification results listed in Table 5-2.

All of the data packages received have passed NDMAS capture testing with no identified errors. Currently, one of the data packages—Cycle 143A—has received an approved ECAR and is therefore classified as *Qualified*. Data packages for the last two AGR-1 cycles (ATR reactor Cycles 144B and 145A) have not yet been received.

Table 5-2. Qualification status of AGR-1 FPMS release and R/B data received as of August 1, 2009.

ATR Cycle Data Package	Start Date	End Date	Number of Records[a]	Summary Qualification Status[b]
138B	26DEC2006:08:14	08JAN2007:23:40	5,26/25,248	*Capture Passed*
139A	04MAR2007:02:45	23APR2007:07:40	1,207/57,936	*Capture Passed*
139B	24JUN2007:03:33	30SEP2007:04:50	1,185/56,880	*Capture Passed*
140A	15OCT2007:02:48	02DEC2007:19:00	912/43,776	*Capture Passed*
140B	21DEC2007:07:52	28JAN2008:23:56	713/34,224	*Capture Passed*
141A	29JAN2008:07:56	02MAR2008:23:55	602/28,896	*Capture Passed*
142A	28APR2008:05:45	23JUN2008:07:19	1,033/49,584	*Capture Passed*
142B	26JUN2008:22:37	01SEP2008:03:00	1,248/59,904	*Capture Passed*
143A	19SEP2008:00:16	10DEC2008:07:39	1,322/63,456	*Qualified*[c]
143B	21DEC2008:22:36	25FEB2009:15:09	1,323/63,504	*Capture Passed*
144A	02MAR2009:07:34	26APR2009:19:34	1,010/48,480	*Capture Passed*
Total number of records =			11,081/531,888	

a. First value is number of sample records (with numerous variables) in the raw data files; second value is the number of single variable records in the NDMAS database.

b. *Capture Passed* data packages will become *Qualified* once an approved ECAR is received.

c. ECAR-525, Rev 1, 07/20/09.

5.7 FPMS Data Problems and Resolution

There is a delay of 1 to 2 months between shutdown of a reactor cycle and submittal of the preliminary FPMS data packages to NDMAS by the FPMS technical staff. This delay is primarily due to the time needed by the FPMS technical staff for data processing after reactor shutdown and the dependence of that processing on modeled birthrate data, which may not be available until some time after reactor shutdown. NDMAS processing usually requires about 1 - 2 days to get the data loaded into the SQL database and displayed on the NDMAS Web portal.

Several revisions to the processed FPMS data have been generated by the FPMS technical staff after the initially-supplied data files were loaded into NDMAS, requiring that the NDMAS data be deleted, reloaded, and retested. These revisions were due to a number of technical issues discovered after the initial data package submittal, including: a discrepancy between the FPMS time scale (calendar days) and that used for modeled birthrates (effective power days), an error in the assumed reactor startup time for ATR Cycle 143A, and, most recently, a problem on the spectral analysis of Kr-88. Identification of measurement anomalies like the latter are easily identified using available NDMAS data analysis tools (Figure 5-6). The primary NDMAS issue with revisions to the FPMS data packages is how to best track and report these revisions within the NDMAS SQL database and on the Web portal, where the data can be downloaded by external researchers. Currently, old (incorrect) versions of FPMS data files are not maintained in the NDMAS SQL database, although they are currently maintained by the FPMS technical staff on the FSISC1 server. Data files available on the NDMAS Web portal ('FPMS Release and R/B Data' page) have the most recent source file date in the file name (e.g., Release_143A_05282009) and a text warning that all data files available for downloading are subject to revisions. To date, all of the data packages received have passed NDMAS capture testing with no identified errors. Currently, one of the data packages—Cycle 143A—has received an approved ECAR and is therefore classified as *Qualified* within NDMAS. However, even these data packages are subject to future revisions since the data are still classified as "preliminary" by the FPMS technical staff.

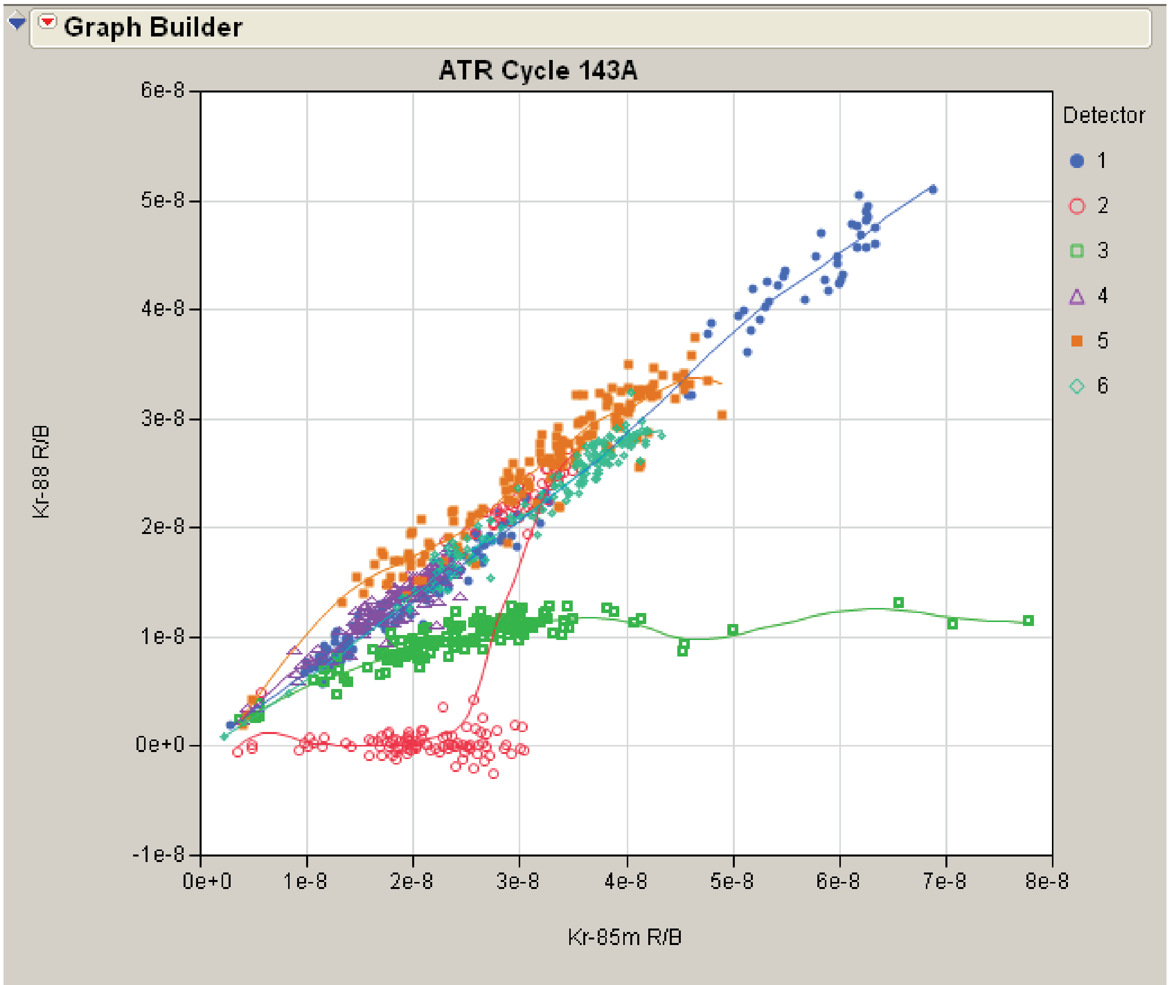


Figure 5-6. Anomalous behavior in the measurement of Kr-88 for some detectors is clearly shown using NDMAS data analysis tools (JMP software).

6. ATR OPERATING CONDITIONS DATA

6.1 Description of the Data Stream

ATR operators collect data describing the configuration and state of the reactor at high frequency (sub-minute intervals), and some of those parameters are collected and stored in the NDMAS to facilitate various analyses of the AGR experimental data (e.g., thermocouple temperatures). During the AGR-1 experiment, ATR operating conditions data were provided in miscellaneous files that contained data recorded at 1-hour intervals. Since April 25, 2008, ATR data have been provided to NDMAS in daily files with measurements at 1-minute intervals. The data provided and stored in NDMAS include the parameters summarized in Table 6-1.

Table 6-1. ATR operating conditions variables stored in NDMAS.

Variable	Description	Example of Raw Data from 6-18-08:00:00:28	Units
TNRD	Number of readings total	1.00	[-]
FPRD	Number of readings at full power	1.00	[-]
FPTM	Time at full power	1.00	[-]
LCNW	Current power for NW lobe	22.94	MW
LCNE	Current power for NE lobe	18.05	MW
LC_C	Current power for C lobe	25.20	MW
LCSW	Current power for SW lobe	24.70	MW
LCSE	Current power for SE lobe	23.11	MW
LINW	Integrated power for NW lobe	1024.75	MW
LINE	Integrated power for NE lobe	801.69	MW
LI_C	Integrated power for _C lobe	1097.50	MW
LISW	Integrated power for SW lobe	1105.75	MW
LISE	Integrated power for SE lobe	1023.88	MW
N16R		0.70	
TPQ1	Thermal power for quadrant 1	22.50	MW
TPQ2	Thermal power for quadrant 2	29.52	MW
TPQ3	Thermal power for quadrant 3	32.54	MW
TPQ4	Thermal power for quadrant 4	29.21	MW
TPSM	Thermal power - sum	113.77	MW
TPTO	Thermal power - total	112.88	MW
REG1	Position of regulating rod 1	28.65	[in]
REG2	Position of regulating rod 2	47.73	[in]
N3D4	Position of shim cylinders	88.50	[degrees]
E1D2	Position of shim cylinders	88.50	[degrees]
E3D4	Position of shim cylinders	92.98	[degrees]
S1D2	Position of shim cylinders	92.98	[degrees]
S3D4	Position of shim cylinders	115.48	[degrees]
W1D2	Position of shim cylinders	115.48	[degrees]
W3D4	Position of shim cylinders	93.52	[degrees]
N1D2	Position of shim cylinders	93.52	[degrees]
PCIT	Reactor process water inlet temperature	113.16	[ºC]
PCOT	Reactor process water outlet temperature	130.56	[ºC]

Table 6-1. (continued).

Variable	Description	Example of Raw Data from 6-18-08:00:00:28	Units
RPWF	Reactor process water flow	43.70	
NERL	Position of NE neck shims (note 1)	0.00	[-]
SERL	Position of SE neck shims (note 1)	100300.00	[-]
SWRL	Position of SW neck shims (note 1)	200.00	[-]
NWRL	Position of NW neck shims (note 1)	1000000.00	[-]
SROD	Safety rod limit switch status (note 2)	0.00	[-]
RDAS	Bit pattern sent by RDAS	5.00	[-]
CSUM	Checksum sent by RDAS	13048.00	[-]
RDCD	RDAS normal or abnormal (note 3)	0.00	[-]
RDTD	RDAS (DAC or DAN) transmitting data (note 4)	1.00	[-]
N16D	N16 system - normal or calibrate (note 5)	0.00	[-]
OSCD	OSC indication - normal or error (bad drums are indicated as zero) (note 6)	0.00	[-]
WPMD	Water power calculator in use -- system 1 or 2 (note 7)	0.00	[-]
SPRD	System power constraint	0.00	

1. Neck shim rod limit status:
   Rods 1 to 6 are presented by 6 characters left to right. Leading zeros are omitted.
   1 = Inserted 0 = Withdrawn
   3 = Reg Rod#1 (SE) 2 = Reg Rod#2 (SW)
2. Safety rod limit status:
   Rods N-E-SE-S-SW-W are presented by 6 characters left to right. Leading zeros are omitted.
   1 = Inserted 0 = Withdrawn
   9 = Both or neither limit switch
3. RDCD - RDAS status (0 = Normal, 1 = Abnormal)
4. RDTD - RDAS system transmitting data (0 = DAC, 1 = DAN)
5. N16D - N16 system status (0 = Normal, 1 = Calibrate)
6. OSCD - Outer shim cylinders (0 = Normal, 1 = Error)
7. WPMD - Water power calculator (0 = System one, 1 = System two)
8. SPRD - System power constraint (0 = Constrained, 1 = Unconstrained)

6.2 ATR Data Processing within NDMAS

Data processing and storage within NDMAS occurs via the following process (Figure 6-1). After raw ATR data files each covering one day of measurements are placed in folders on the FSISC1 server (AGRData folder), those files are copied to a NDMAS server location devoted to raw data storage. A batch file is then run to update the NDMAS-maintained list of relevant file names in that directory, from which new file names will be processed. A SAS Enterprise Guide project entitled ‘Update or build ATR dataset.egp’ subsequently reads the new data files and assembles the data into a single SAS dataset, which represents the primary source for ATR data within NDMAS. Those data are then averaged to 5-minute intervals to match the interval used for the fuel irradiation monitoring and then stored in the NDMAS SQL database. Processing and storage in NDMAS occurs approximately once per week, so that numerous data files are generally processed and entered as a single package. Data processing includes numerous 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

Raw ATR operating conditions data:
FSISC server location*:*
- *\\FSISC1\Projects\AGRData\reactor data\RP daily*

Daily file names
- *'d'* followed by date *in 'yyyy-mm-dd'* format

ATR operating conditions processing steps:
1) Copy new file folders from FSISC1 server to:
   - *\\Sasngnp\NGNP\NGNP_Data\AGR-1\reactor data\RP daily*
2) FROM NDMAS directory, '*Vault_PushPull*'
   1) Run batch file '*update.bat*'
      - Creates/updates the list of relevant file names to be processed
   2) Run Enterprise Guide Project file 'Update or build ATR dataset.egp' to construct SAS dataset for new data
      - Builds/appends all new data as SAS dataset
      - Pushes new data to SQL_NDMAS (NDMAS vault)
      - Checks that vault data is correctly entered
   3) Update log file *'Irradiation capture-push instructions and log.doc'*
   4) Run Enterprise Guide Project file *'Vault tests.egp'* and examine any failed data
   5) Resolve failed data as necessary
   6) Run Enterprise Guide Project file '*Combine_Irrad_ATR_FPMS.egp*' to populate N_MART directory with new SAS data sets and cubes containing updated irradiation data

Figure 6-1. Raw ATR operating conditions data and processing steps.

- Completed SAS datasets are visually inspected and compared against the raw data files.
- A Mountain Standard Time (MST) is assigned to each measurement that corrects for the switching between MST and MDT that occurs in the raw data. The switch to MDT 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 detecting the MDT shifts is not fully automated, because the changes are not always made at the correct date and time. The data is manually checked to find MDT shifts on dates/times that do not correspond with national shift time.
- 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, each data package is then compared to the SAS dataset from which it was built to ensure that the data were correctly stored. Results are stored in the electronic log "ATR capture-push instructions and log.doc."
- ATR parameters that reflect internal testing of the ATR system are used to identify data potential problems with data from instruments or systems being tested. Lobe powers, for example, can fluctuate during calibration of the N16 system. The calibration system status indicators can thus be used to eliminate those data from datasets used for neutronics or other analyses.

6.3 ATR Data Qualification

NDMAS conducts routine testing on collected ATR data, but ATR operating conditions data are qualified by the quality control procedures of the ATR, not by the VHTR program or NDMAS. INL's QA requirements and procedures govern work at the ATR, and NDMAS expects to obtain qualification documentation for the ATR operating conditions at the conclusion of the AGR-1 experiment.

6.4 ATR Data Problems and Resolution

During the early cycles of the AGR-1 experiment, NDMAS obtained ATR data from informal records of NGNP technical personnel, rather than directly from the ATR data recording system, and in several different file formats and with different parameter lists. To provide the highest-integrity record of ATR data, and to use, rather than reproduce, time-averaging and other data integration features of the ATR data collection system, it is recommended that NDMAS have a direct link to archived data of the ATR system and its qualification status records.

As with AGR-1 fuel irradiation monitoring data, ATR data are collected with a local date/time stamp that periodically shifts to MDT at times not always consistent with official times for those changes. To provide a consistent time/record for all data sets, it is recommended that the ATR also maintain a MST or other standard-time date/time stamp for all records.

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