ANL-ART-124

FIPD: EBR-II Fuels Irradiation & Physics Database

Nuclear Engineering Division

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FIPD: EBR-II Fuels Irradiation & Physics Database

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Summary

FIPD: EBR-II Fuels Irradiation & Physics Database

The DOE Advanced Reactor Technology program has supported efforts to recover and preserve metallic fuel data generated throughout the US sodium cooled fast reactor program (SFR). Those efforts have been focused on establishing databases of the experimental data that were mainly generated during the Integral Fast Reactor program including data generated at EBR-II, FFTF, and TREAT reactors, as well as out of pile data. The data is essential for future-licensing activities of metallic fuel based advanced fast reactors. This report describes the EBR-II Fuels Irradiation & Physics Database (FIPD). It covers the scientific knowledge available in the database, the logical storage of the data in the database, and the web interface used to access the data. The report also covers the QA plan (SQAPP) developed to cover all aspects of the FIPD system. Summaries of activities from previous years, the current fiscal year (FY17), and future plans are also provided.

Table of Contents

List of Figures

List of Tables

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FIPD: EBR-II FUELS IRRADIATION & PHYSICS DATABASE

1 INTRODUCTION

Sodium fast reactors (SFR) fuels knowledge in the US are related to data collected at EBR-II and FFTF reactors during their operations starting in the early 1960's for EBR-II and 1984 for FFTF until their shutdown. This experience generated data for both metallic and oxide fuels. In particular, U-Zr based metallic alloy fuel data were generated during the integral fast reactor (IFR) program as well as oxide fuel data generated at FFTF and during the Japanese oxide fuels program at EBR-II. This knowledge base includes general reactor information, ANL reports, IFR reports, run reports, memos, post irradiation examination (PIE) reports, drawings, experiments qualification reports, publications in journals and conferences, information regarding measured properties (e.g., IFR metallic fuels handbook), and documents of out of pile experiments. Also, measurement documents like micrographs, profilometry data, fission gas release data, and other data are available. At the time, there was development of a database (IMIS) that combined all of that information [1], however it not completed, as it stopped development at the end of the IFR program. In particular, detailed data associated with each fuel pin in those experiments (irradiation history) and its association with fabrication and PIE data was not archived. This detailed information is mostly based on a combination of physics and thermal hydraulic information that are generated using reactor run operations data and fuel fabrication information. Other information (e.g., general properties data in the IFR fuels handbook, code calculations, etc.) are not currently available in an accessible form that can facilitate its use by interested analysts.

1.1 Motivation

The above accumulated knowledge represents a large US investment in advanced nuclear power research and development, provides a wealth of information to different groups of interest, and needs to be well archived and maintained so it is easily accessed and utilized in the future. Preserving this detailed fuel and physics knowledge will enable support to reactor designers in their design and evaluation of advanced fast reactor concepts. It will also support reactor vendors and utilities in their effort to make a licensing case for using similar fuel in a fast reactor in the US or abroad. In addition, detailed database information on fuel performance in the reactor support fuel analysts in understand fuel behavior and supporting the development of advanced fuel performance codes for design and licensing purposes.

A fast reactors metallic fuels database that compiles fuel's accurate and detailed operating and performance parameters is important to industry and different institutions who have shown interest in developing metallic fuel based fast reactors (e.g., Terrapower, Toshiba, GE, Oklo, ARC, KAERI, ...). Those potential end-users have interests related to establishing a safety case for this type of fuel within a given operations envelope in a commercial reactor. The database can be used for demonstrating to the licensing authorities the availability of a well-established database that supports safe reactor operations. In addition, the industry and relevant institutions have interest in developing or using an existing fuel performance code that is well calibrated and validated with the most accurate sets of data to provide best estimate descriptions of fuel behavior in a reactor. Well validated code calculations can be used for the purposes of core design, safety analysis, reactor operations, and satisfying licensing requirements. In general, the database discussed in this report can provide accurate and detailed fuel irradiation and physics data needed for support of future design and licensing activities of metallic fuels based fast reactors. In addition to this main goal, the details and accuracy associated with the database will be useful to other DOE areas of interest related to fuel behavior model development and validation.

1.2 Background

Since its start, EBR-II hosted experiments in support of different US fast reactor programs to test the behavior and performance of different types of fuels including metallic, oxide, mixed oxide, and mixed carbide fuels. A wealth of information was generated from those experiments where most of the existing metallic fuels database is associated with the IFR program that ran from 1984 to 1994. The IFR metallic fuel experiments looked at one or more of the following;

- prototypic fuel behavior
- run beyond cladding breach behavior (RBCB)
- fuel swelling and restructuring
- lead IFR experiment
- fabrication parameters
- design parameters
- high temperature behavior
- large slug diameter
- blanket safety
- fuel qualification
- fuel impurities

PIE data from those experiments included fission gas release, fuel volumetric and fuel length change, cladding diametral change, and cladding wastage. Axial profiles are available for fuel radial growth at low burnup (prior to and including initial fuel-cladding contact) and for cladding radial growth for a wide range of burnups and fast fluences. Some data that are available on a more limited basis are radial and axial variations in U, Pu, Zr; fission gas porosity; axial variations in fraction of porosity filled (logged) with Na; as well as the depth of C-depleted and Ni-depleted zones in HT9 and D9 cladding materials, respectively. The intent of this database effort is to create a web-accessible relational database as an archive of information from EBR-II fuels irradiation experiments, combine it with other forms of information that are based on calculations, and make it available in a form that is appropriate for use by fuels and reactors analysts/modelers.

The database development is an ongoing effort over the past few years [[1]–[6]], and continues to the present (FY17). The database structure, interface, and current status are described in the subsequent sections.

2 DATABASE CONTENTS

The term "database" can have several meanings in the context of this work, including the high-level "collection of scientific content available", the experience-focused "web-based interface with which users interact", and the low-level "relational database which stores data". This section describes the high-level meaning, covering the scientific content available. The FIPD database consists of both assembly-level and pin-level information, shown schematically in Figure 1.

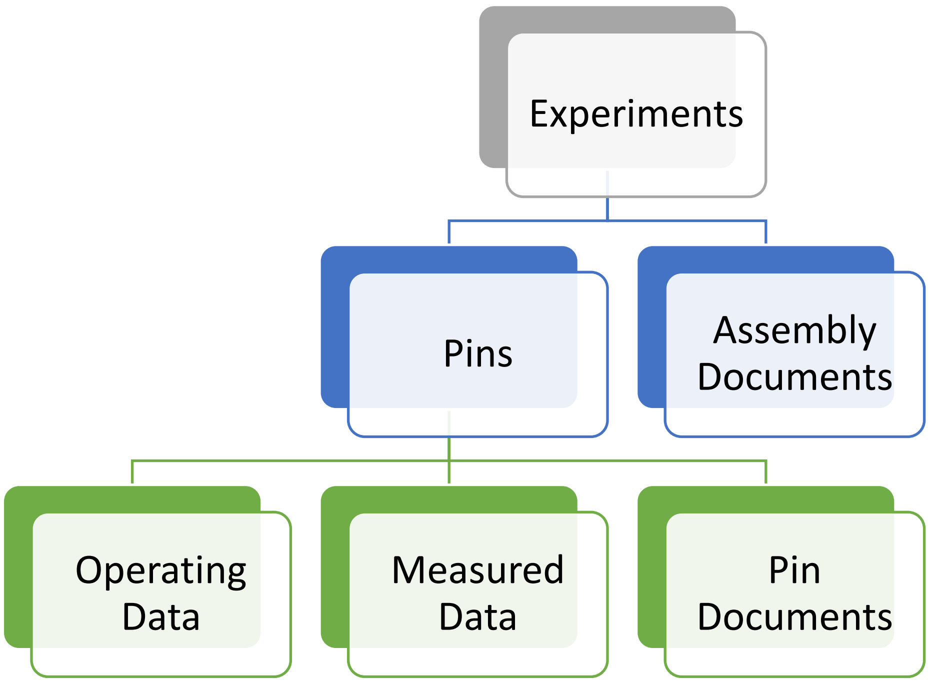


Figure 1: Overview of content available in FIPD.

2.1 Operating Parameters

ANL's physics, thermal hydraulics, and safety analysis codes which have been used in the past in relation to EBR-II simulation include REBUS, EBRFLOW, RCT, RCTP, and SUPERENERGY-II [7]. Although those tools existed during the IFR program, the safety and preparation packages for EBR-II experiments were developed using the older, legacy tools that have been used for many years at EBR-II. Those older tools produced adequate information for qualification and running of those experiments; however, the information was not adequately detailed for use by analysts and modelers studying PIE data. The newer IFR-era tools are being used to generate more useful data for the experiments, while the data for many of the experiments are based on the older set of tools. Thus, subassembly operating parameters, for all but the subset of updated experiments, depended on operating parameters that were generated with this older methodology and did not include pin-by-pin depletion calculations and other related details for calculating the temperatures within a subassembly and detailed pin temperatures. Further effort was needed to generate such detailed set of data for the remaining experiments and to make it available to current and future analysts interested in metallic fuels. In addition, effort was needed to relate those detailed data sets to the available documentation and PIE information in the advanced database both to facilitate access to the information and to connect the experimental data to the detailed calculation for those experiments.

Some of the data files used in generating the EBR-II Physics Analysis Database (PADB) [8] can be utilized in generating detailed EBR-II fuel pins database under consideration. A processor of these data files (SE2P [9]) that evaluates some of the irradiation parameters used in the analysis is discussed here. The processor has been developed in the past, however, an update and new functionalities has been added to make it suitable for current computer systems and the amount of data handled.

The calculations for each subassembly result in axial distributions for each pin, which are detailed in Figure 2.

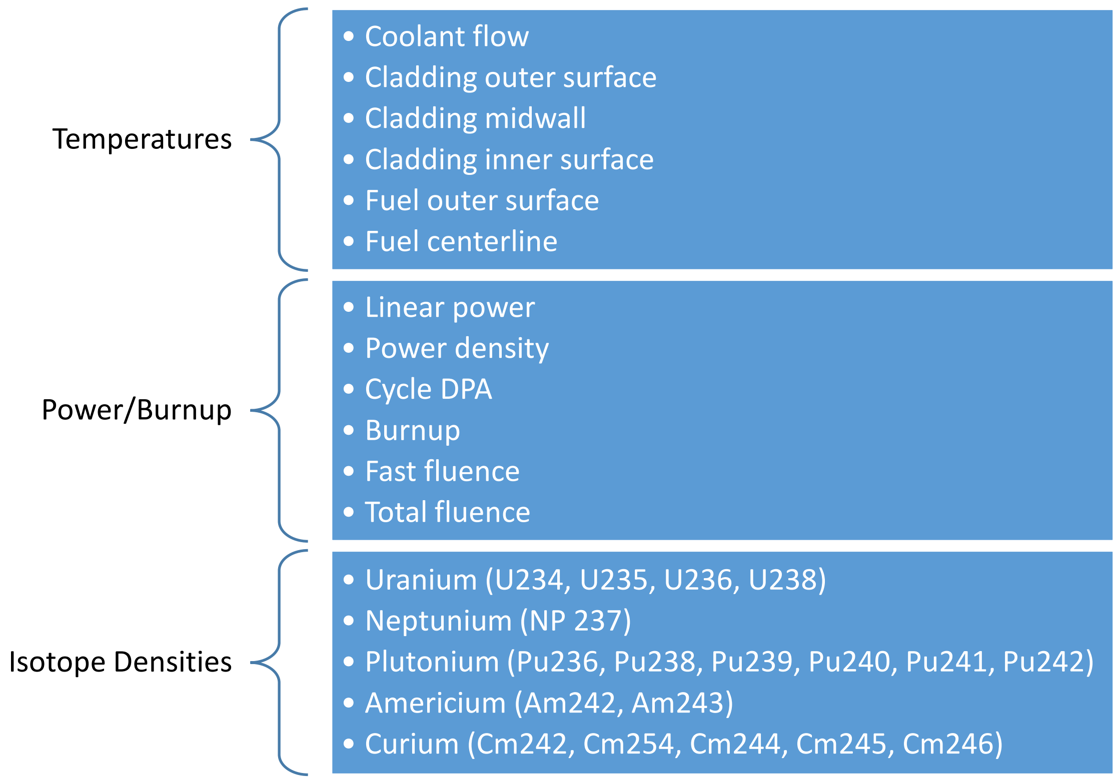


Figure 2: Calculated data available in FIPD. Data is given as axial distributions for each pin in the assembly.

2.2 Measured Data

Fabrication and post-irradiation measurements were performed on a subset of fuel pins. Even on pins that were analyzed, not all pins were subject to the same analysis. If a pin was measured in some way, the associated measured data is presented in the database. The available data is given in Figure 3.

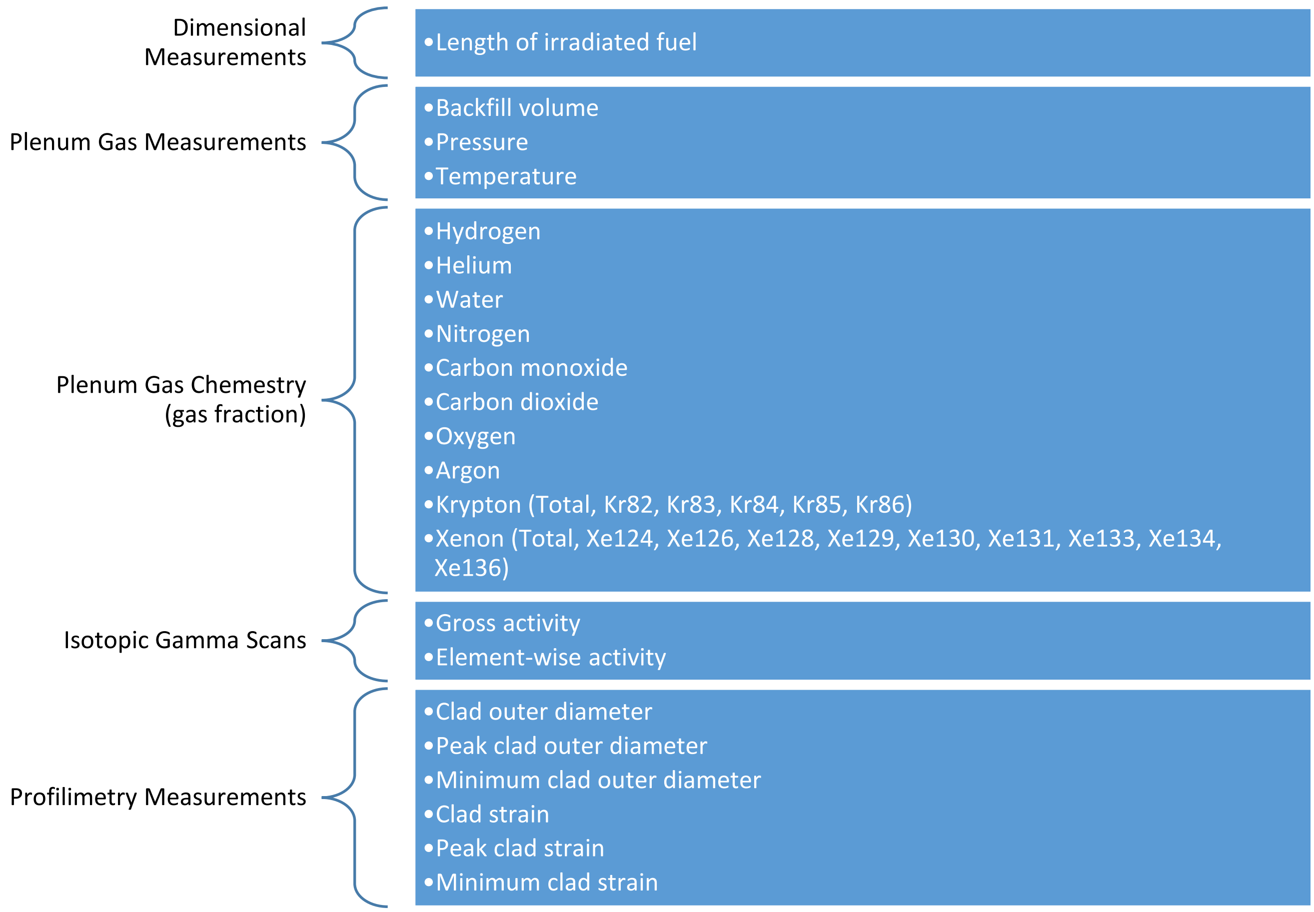


Figure 3: Measured data available for select pins. Not all data is available for all pins.

2.2.1 Bulk Measurements

The bulk pin measurements (dimensions, plenum gas measurements, plenum gas chemistry) were retrieved directly from the IMIS database [1]. Those measurements are verified against the original documents and PIE reports.

2.2.2 Digitized Profilometry Data

The profilometry measurements were performed as a non-destructive examination of the cladding dimensional changes. All of the profilometry measurements were recorded in hard-copy documents, where the quality of data varies for different experiments. In order to include digital data in the FIPD database, these plots were digitized using the Fast Reactor Data Digitalization System (FRDDS) code [6].

2.2.2.1 Contact Profilometry Data

Figure 4 shows a "low-quality" contact profilometry image, compared to a "high-quality" image shown in Figure 5. The "low-quality" image requires much more effort to digitize, primarily spent cleaning the image background (the contrasted points/grids beyond the real curve, which were either inherited from hard-copy gird or produced during the hard-copy data scanning), in order to interpret the curve that represents the fuel diameters as the function of fuel length. The "high-quality" image, on the other hand, can be readily digitized using FRDDS. Once digitized, FRDDS exports the curve data in CSV format.

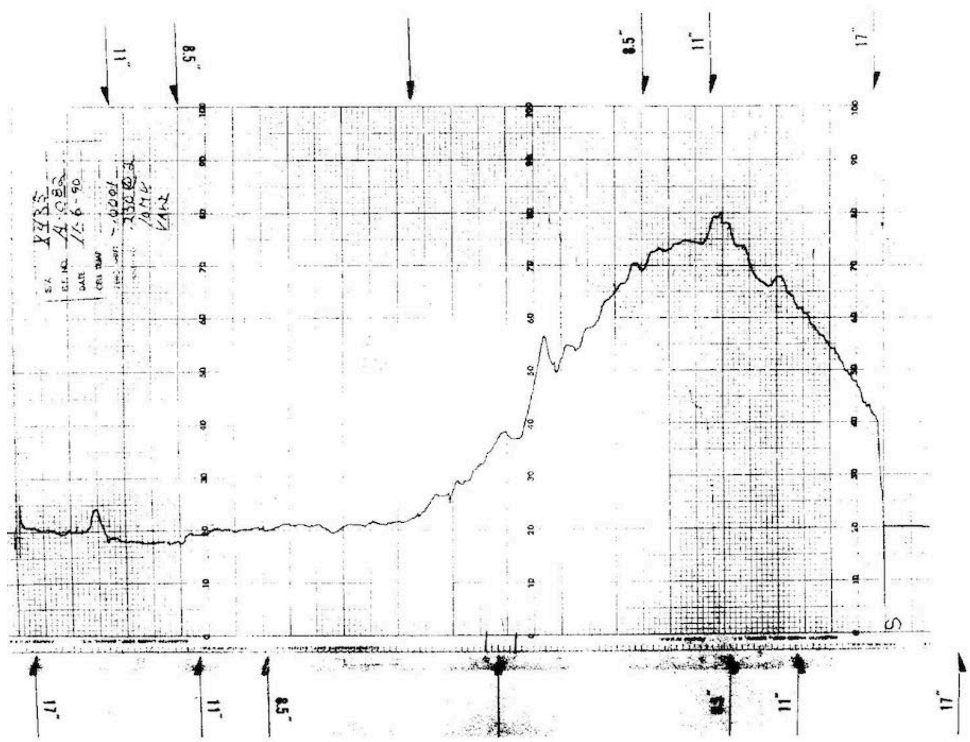


Figure 4: Fuel cladding contact profilometry data of element A082 in X435 experiment (raw hard-copy data).

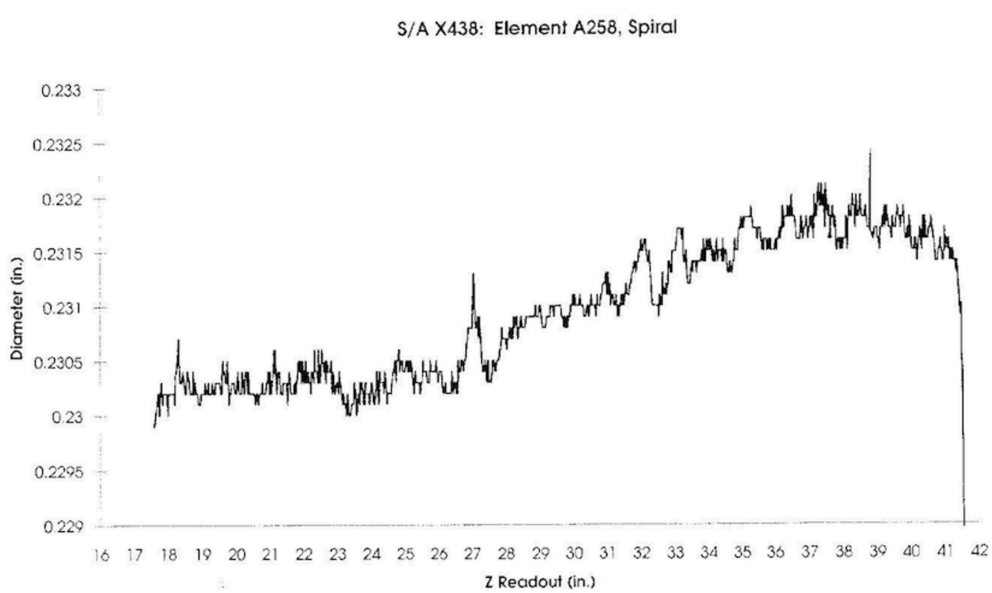


Figure 5: Fuel cladding contact profilometry of the element A258 in X438 experiment (raw hard-copy data).

Figure 6 and Figure 7 show two types of output files that can be accessed through FIPD, both of which were digitized from image shown in Figure 4. Figure 6 shows the raw digitized contact profilometry data that usually contains hundreds of data points (x-axis: fuel position from the bottom of the element; y-axis: the fuel cladding diameter). Figure 7 shows the data after it has been interpolated in order to compare to the thermal and neutronic operating data (section 2.1), which are calculated at 30 axial coordinates. One should note that the original data in Figure 4 has been "flipped" in Figure 6 and Figure 7, because the bottom of the element was set to be the beginning of the x-axis (x=0). More details about the methodologies and principles of data processing can be found in the related FY16 summary report [6].

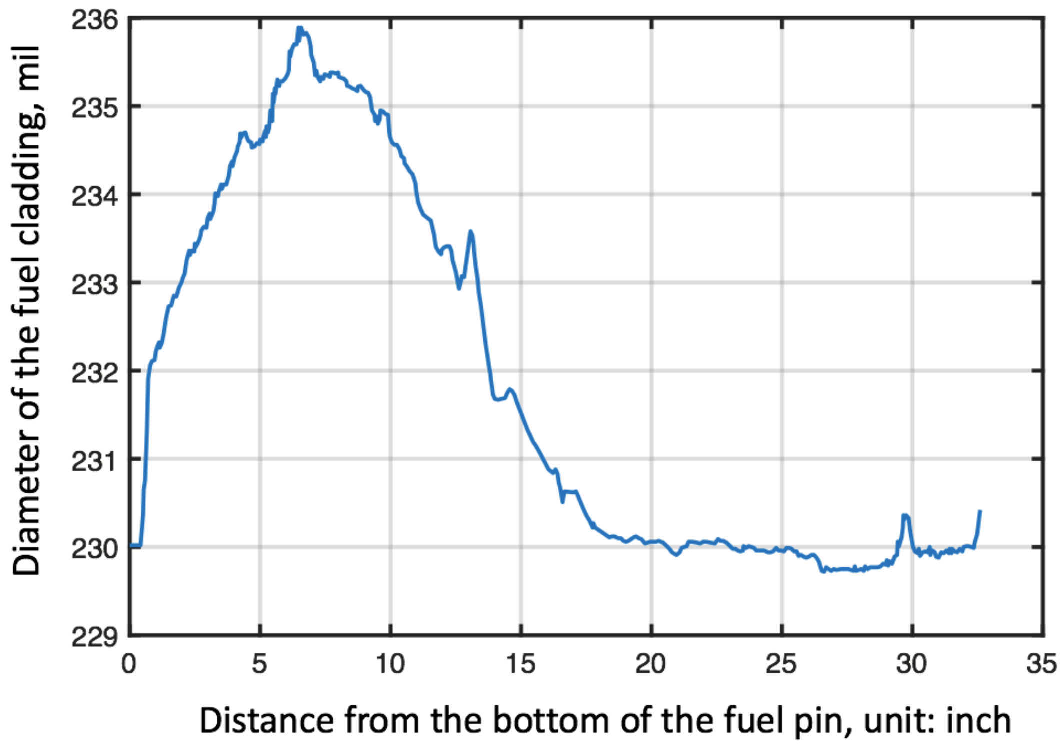


Figure 6: Fuel cladding contact profilometry of element A157 in X435 experiment (raw digitized data, stored in FIPD).

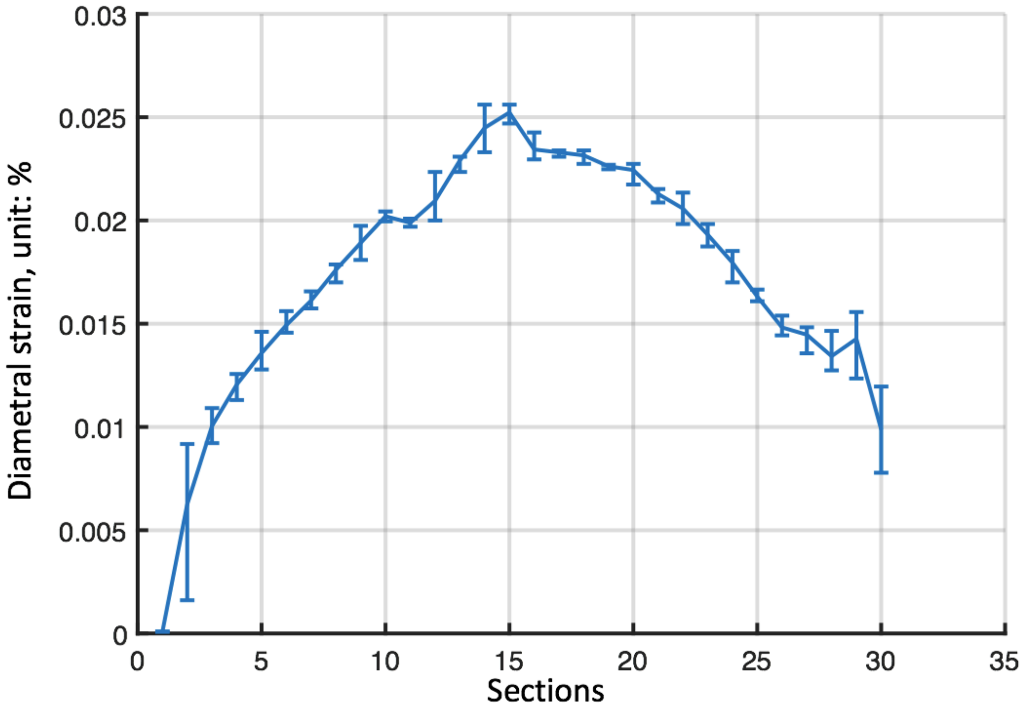


Figure 7: Fuel cladding contact profilometry of element A157 in X435 experiment (data was processed by averaging in sections, stored in FIPD).

2.2.2.2 Laser Profilometry Data

Compared to contact profilometry data, laser profilometry data are usually preserved in much higher-quality images. Here, “high-quality” refers to a data plot (a curve) with a better contrast with the background and less fluctuation, and contains more data points. Compared to the contact profilometry data, the laser profilometry data are not only much easier to digitize and analyze, but also more reliable, as it contains multiple measurements (at different scanning angles) for one single fuel element [6].

The raw data, as with the contact profilometry data, were given in scanned PDF files. Figure 8 and Figure 9 respectively show examples of raw and digitized laser profilometry data for element T116 in experiment X421A. Note that this measurement was performed at a measurement angle of 90 degrees. Usually for one fuel element, laser profilometry measurement at multiple angles were conducted. For fuel design and licensing purposes, the mean values of measurements at different angles are needed. A function has been developed in FRDDS to compute the mean values measured at different angles. Both the raw digitized data at different angles as well as the average data are calculated and exported for inclusion in FIPD. More details about the methods and principles of data processing can be found in the related summary report for FY16 [6].

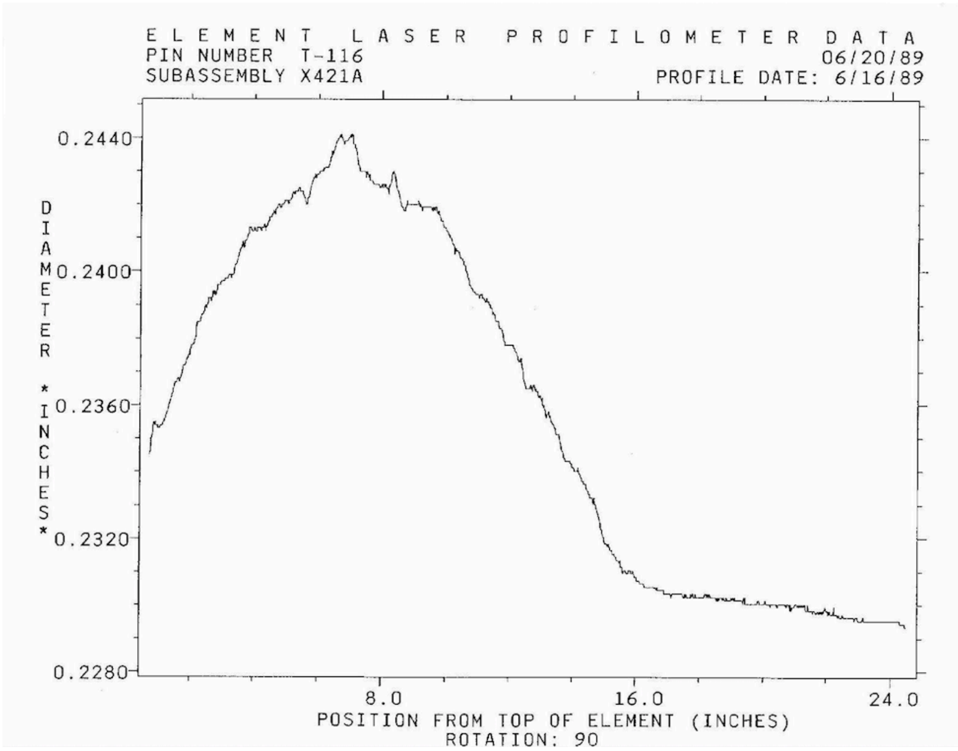


Figure 8: Raw hard-copy laser profilometry data of element T116 in experiment X421A (measurement angle: 90 degrees).

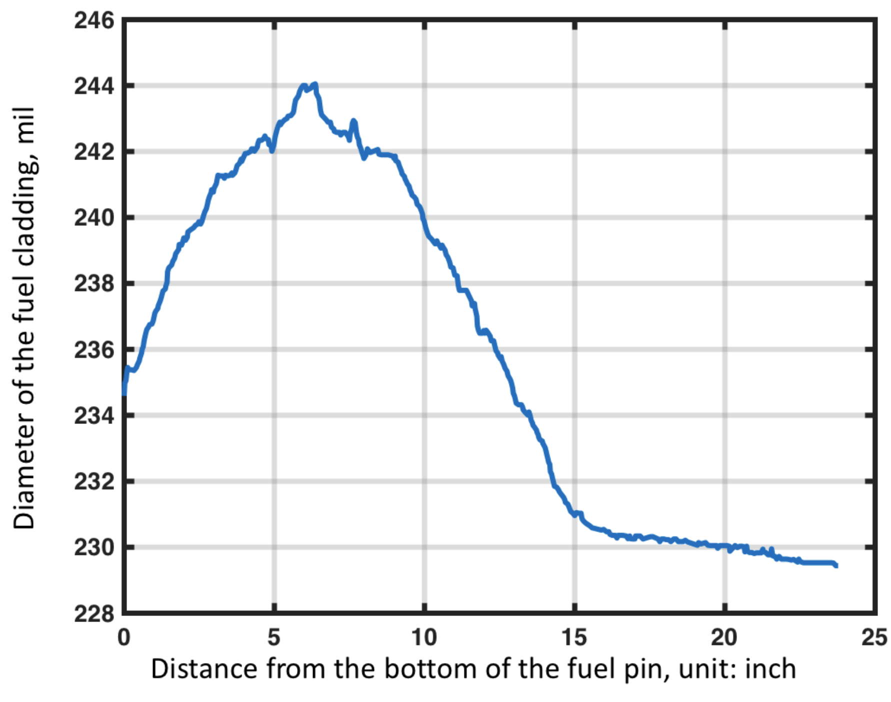


Figure 9: Plot of the digitized laser profilometry data of element T116 in experiment X421A (measurement angle: 90 degrees).

2.2.3 Digitized Gamma Scan Data

Among all types of PIE data, the amount of isotopic gamma scan data is the largest in terms of the number of scanned images in archived documentations. The isotopic gamma scan data of each fuel element usually contain gamma scan data for specific isotopes (e.g., CS134, CS137, MN54, NB95, RH106, and ZR9), and a measurement of gross activity. This isotopic gamma scan data can be used to determine the length of irradiated fuel element, which can be compared to length determined by NRAD (neutron radiography) data. The gamma scan data also provides important information to study the burnup level calculated by neutronics code.

All of the isotopic gamma scan legacy data were preserved in hardcopy, and have since been scanned into PDF files. As with the profilometry data, the digitization of the gamma scan PDF files was performed using FRDDS. Figure 10 shows an example of raw hard-copy isotopic gamma scan data image. The scan was conducted on element DP17 in experiment X441. The gamma scan energy is 796 keV, targeting the isotope of CS134. Figure 11 shows the plot of digitized data of Figure 10. As shown, all small details of the original curve (Figure 10) were caught in the digitized data. Figure 12 shows an example of raw isotopic gamma scan data of gross activity of fuel element DP16 in experiment X441. The digitization of Figure 12 is shown in Figure 13.

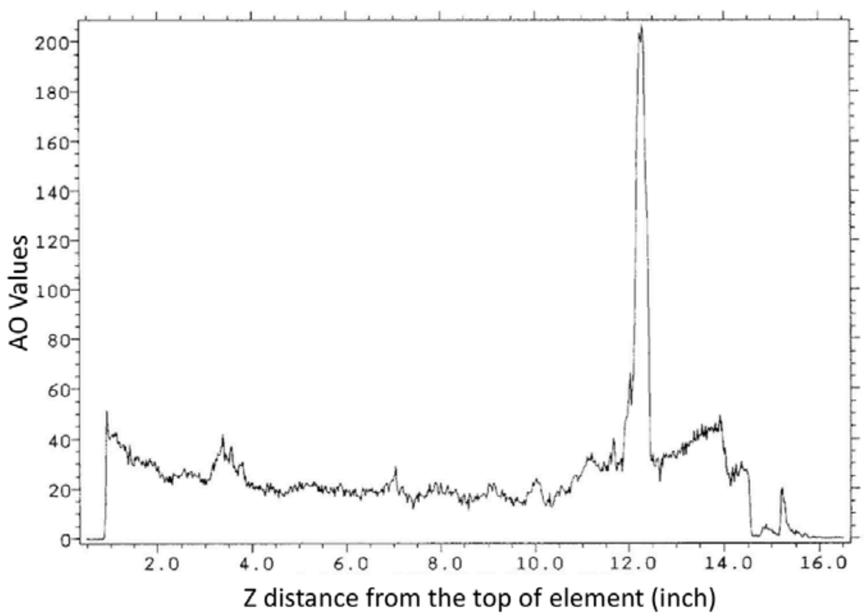


Figure 10: Raw hard-copy isotopic gamma scan data (isotope: CS134, gamma scan energy: 796 keV); the gamma scan was conducted on element DP17 in experiment X441.

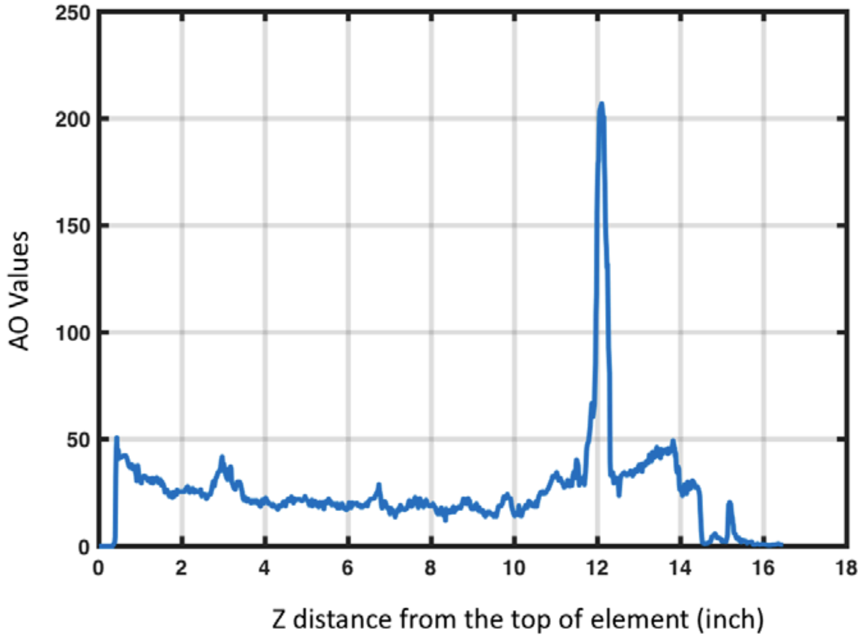


Figure 11: Plot of digitized isotopic gamma scan data (isotope: CS134, gamma scan energy: 796 keV); the gamma scan was conducted on element DP17 in experiment X441.

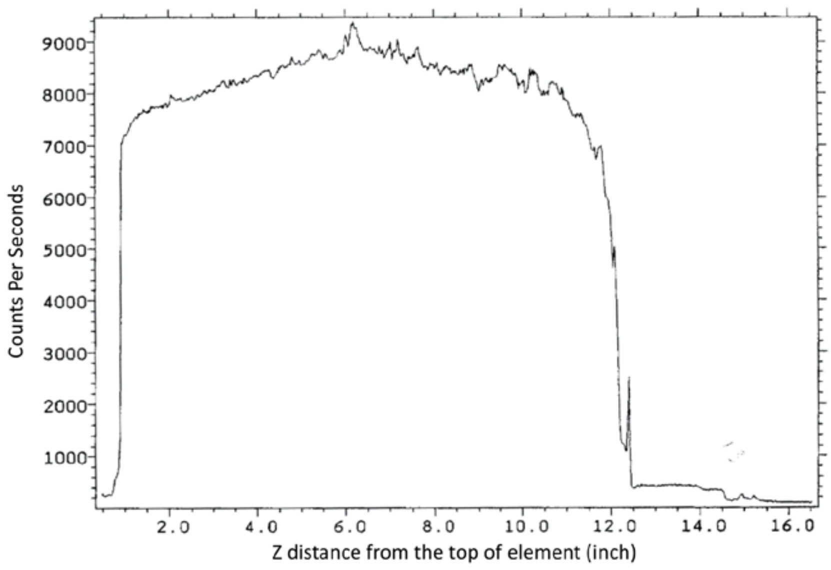


Figure 12: Raw hard-copy isotopic gamma scan data (gross activity); the gamma scan was conducted on element DP17 in experiment X441.

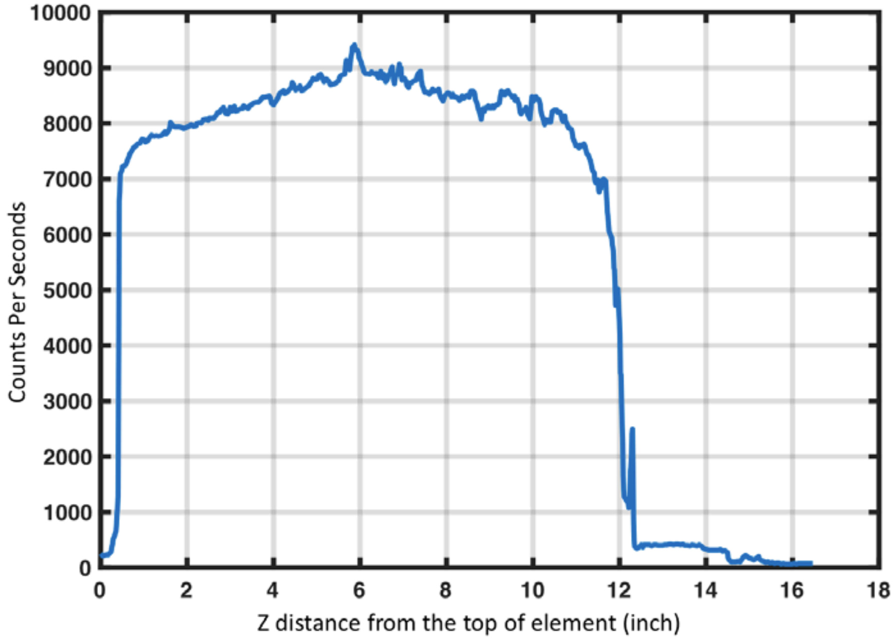


Figure 13: Plot of digitized isotopic gamma scan data (gross activity); the gamma scan was conducted on element DP17 in experiment X441.

2.3 Documents

Collections of documents are available for each experiment, some of which describe one or several of the pins in the experiment, as well as the experiment as a whole. Document contents include:

- design descriptions
- loading diagrams
- safety analyses
- operational memos
- Photographs/micrographs
- PIE results
    - Profilometry traces
    - Gamma scans
    - GASR data
    - Weight data
    - Plenum gas analyses
    - Chemical analyses

3 MYSQL DATABASE STRUCTURE AND DATA STORAGE

This section covers the low-level "database" description.

3.1 Database Usage

The relationships between data, pins, experiments, etc. are strored in an SQL database to facilitate cross-referencing and quick access. Much of the calculated data is also strord in the database, so that it can be quickly filtered and displayed appropriately.

3.2 Filesystem Usage

The FIPD document library is stored as part of the filesystem, with relevant metadata stored in the database. Many of the digitized datasets (e.g., profilometry, gamma scans, etc.) are also stored as files for convenience, as this more quickly facilitates incremental additions of newly scanned data to the website. In the future when the data digitization efforts are complete, this structure may be revisited and modified.

3.3 User and Authorization Information

The user details, and authorization information are stored in a collection of database tables so that they may be related back to the experiment metadata to which they refer.

3.4 Document Information

3.4.1 General Assembly/Pin Documents

Most documents relate to experimental details or PIE data, are generally accessible to users of the system, and are stored collectively in the primary document location. What is then presented to specific users depends on their authorization level.

3.4.2 Group-restricted Documents

The application can also be used to give specific groups of users access to special documenst that only pertain to them and their work. These documents are stored separately in a restricted document location.

Like the general experiment documentation, the metadata for the group-restricted documents is also stored in the database, with relations to the specific users that are allowed to access the information.

3.5 Measured Data

3.5.1 Bulk measurements

The bulk pin measurements described in section 2.2.1 were retrieved directly from the IMIS database [1]. The dimensions, plenum gas measurements, and plenum gas chemistry are unchanging, and are stored in the database for quick retrieval.

3.5.2 Digitized Profilometry Data

The digitized profilometry is stored in a directory on the filesystem, as this is an ongoing effort, and new profolometry data is being added as the work is complete. When the work is complete, this data will likely be reformatted and added to the database to speed up retrieval.

3.5.3 Digitized Gamma Scan Data

The digitized gamma scan data is stored in a directory on the filesystem, as this is an ongoing effort, and new gamma scan data are being added as the work is complete. When the work is complete, this data will likely be reformatted and added to the database to speed up retrieval.

3.6 Operating Parameters

The calculated operating parameters described in section 2.1 are all stored in the database, so that they can be quickly filtered and displayed properly in the various views in the application.

4 USER ACCESS CONTROL

4.1 Authentication and Site-wide Authorization

Authentication is currently handled using ANL account credentials, which allows the management and storage of password to be handled centrally by ANL IT services. As such, all users must have an Argonne username/password. For users which are not Argonne employees, basic authentication accounts can be requested through the ANL Cyber Gate Pass system [11]. This system only handles authentication and overall authenticated access to the application. Once a user has been authenticated, the application itself manages content authorization.

4.2 User-level Authorization

As things currently stand, there is currently no "public" access to the FIPD web interface. Only users which have been preapproved and added to the site's authorization list can access the site at all. This access list is linked to ANL user accounts, and thus each user of the system must an ANL account (username/password).

Access to content in FIPD is separated by experiment, based on the content of the experiment. Different users with different levels of access may not be able to see all of the experiments stored in FIPD, if those experiments contain information that has not been authorized for release at their access level. It was also decided that users that were given access to an experiment would be given access to all of the reloadings in the experiment (e.g., X425, X425A, X425B, etc.).

The views in the application are generated dynamically, and take the current user's access to content into account. Users with restricted access are presented with subsets of data instead of the full sets available to unrestricted users, as shown below.

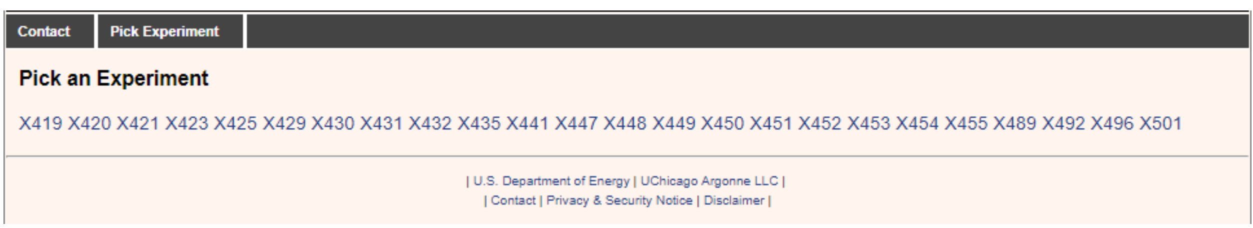


Figure 14: Unrestricted experiment picker.

Figure 15: Restricted experiment picker. The access group for the current user is restricted to experiments X419-X435.

5 FIPD WEB INTERFACE

This section covers the experience-focused "database" description, describing the web-based interface used to access all available information.

5.1 Site Map

The basic layout of the FIPD site is given in Figure 16. More detailed descriptions of views that make up the site are given in section 5.2.

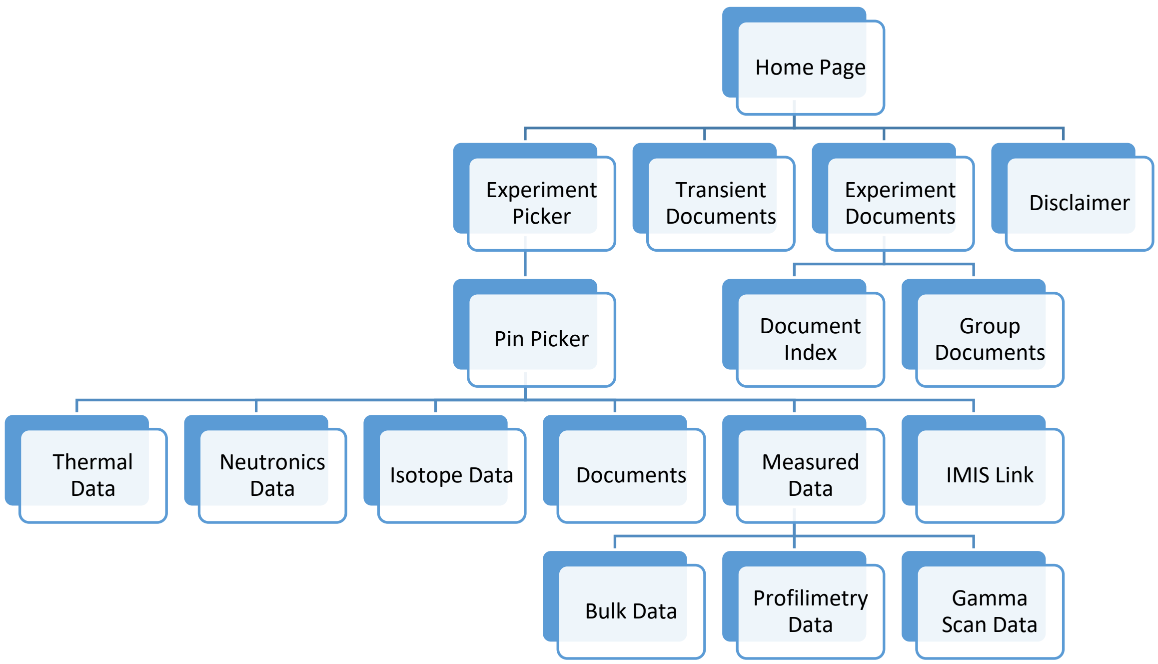


Figure 16: FIPD site map.

5.2 Views

The main contents of each view are generated using different subroutines, and are described here.

5.2.1 Home page (home.html)

This is the main home page for the web site, and is used to provide a starting point for the user, as well as provide background information on the EBR-II experiments. From the home page (and any other page), there are three primary sections available to browse, accessible from the navigation bar near the top of the page. These are Steady State Data (see section 5.2.3), Out-of-pile Transient Data (see section 5.2.16), and Documents (see section 2.3).

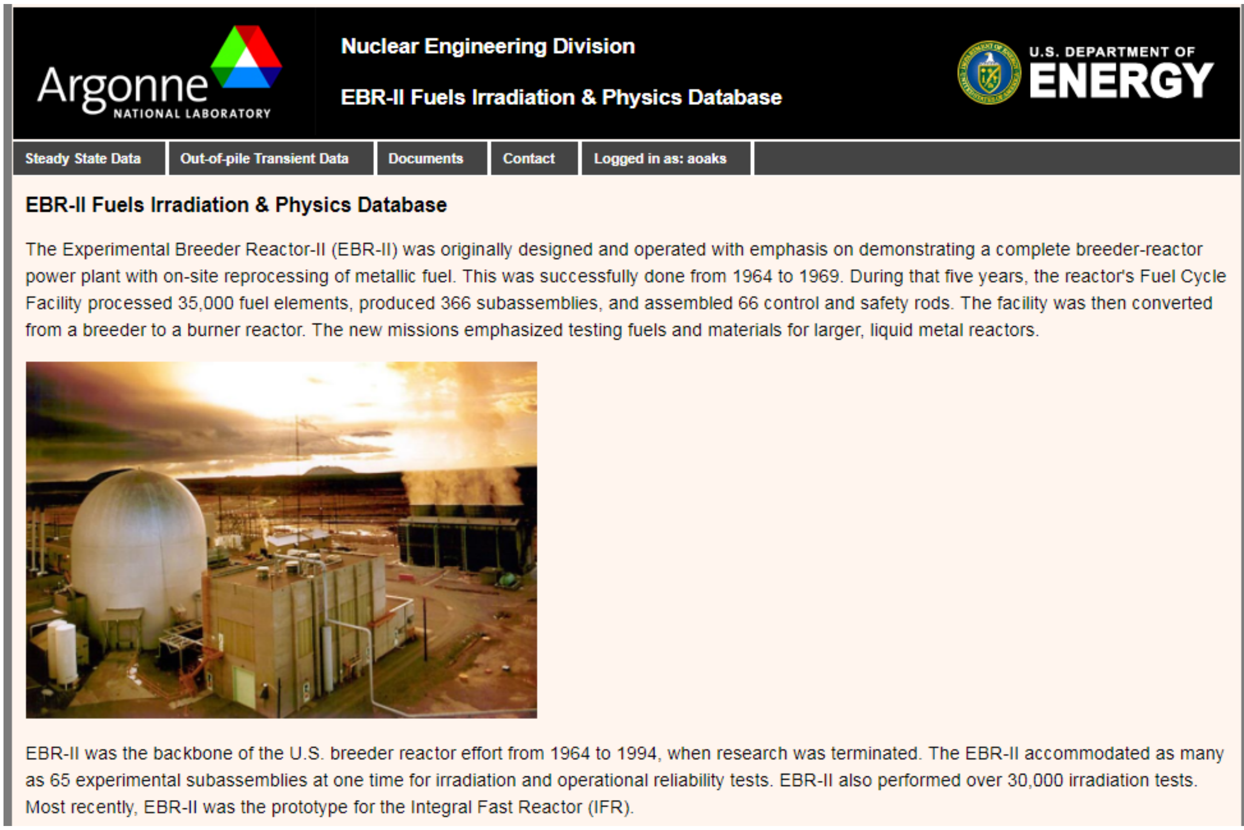


Figure 17: FIPD Home page.

5.2.2 Government Work Disclaimer (disclaimer.html)

This page displays the standard disclaimer for accessing government work. This is one of the static pages on the site, and does not involve a subroutine call. The disclaimer is as follows:

> *This web site was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.*

5.2.3 Experiment selector (pick_experiment)

This view lists the experiments/subassemblies for which the user is able to access data. This list will vary based on which access group the user has been assigned. The experiments are listed by primary name, with all reloadings of the experiment available once a primary name is chosen. For example, for experiment X419, only "X419" will be shown, not "X419A" or "X419B".

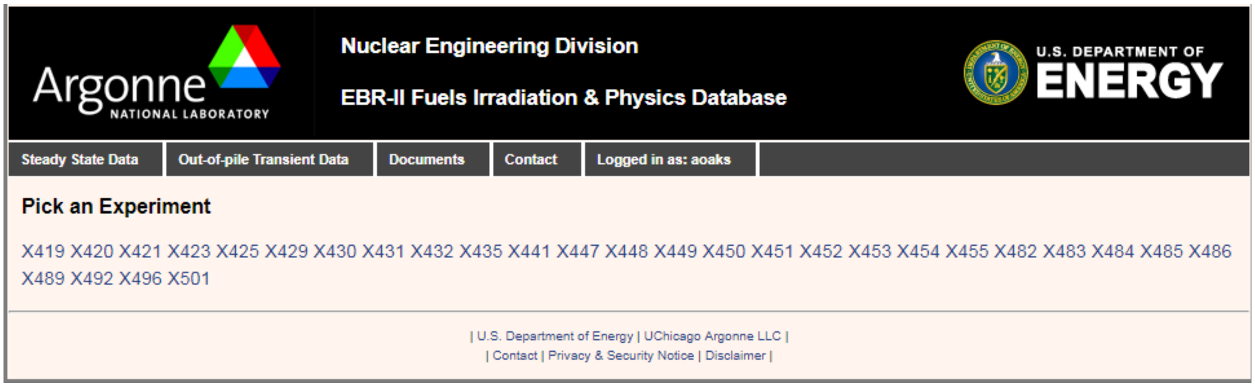


Figure 18: FIPD experiment selector view.

5.2.4 Pin selector (pick_pin)

This view lists all of the pins associated with a given experiment primary name. For example, for experiment X419, this will display pins from any of X419, X419A, or X419B. When one is selected, the same view is used to display which information is available for each subassembly in the experiment set. Due to how the relations are handled in the web code, only experiments/pins which have calculated operating parameters (see section 2.1) in the database (thermal, neutrons, and isotope data) will be displayed. A link to documents related to the specific subassembly (see section 2.3), as well as a link to the corresponding subassembly in the IMIS database [1] will always be provided. Checks are also done on the existence of related measured data (see section 2.2), and if any data is available, a link to measured data will be provided as well.

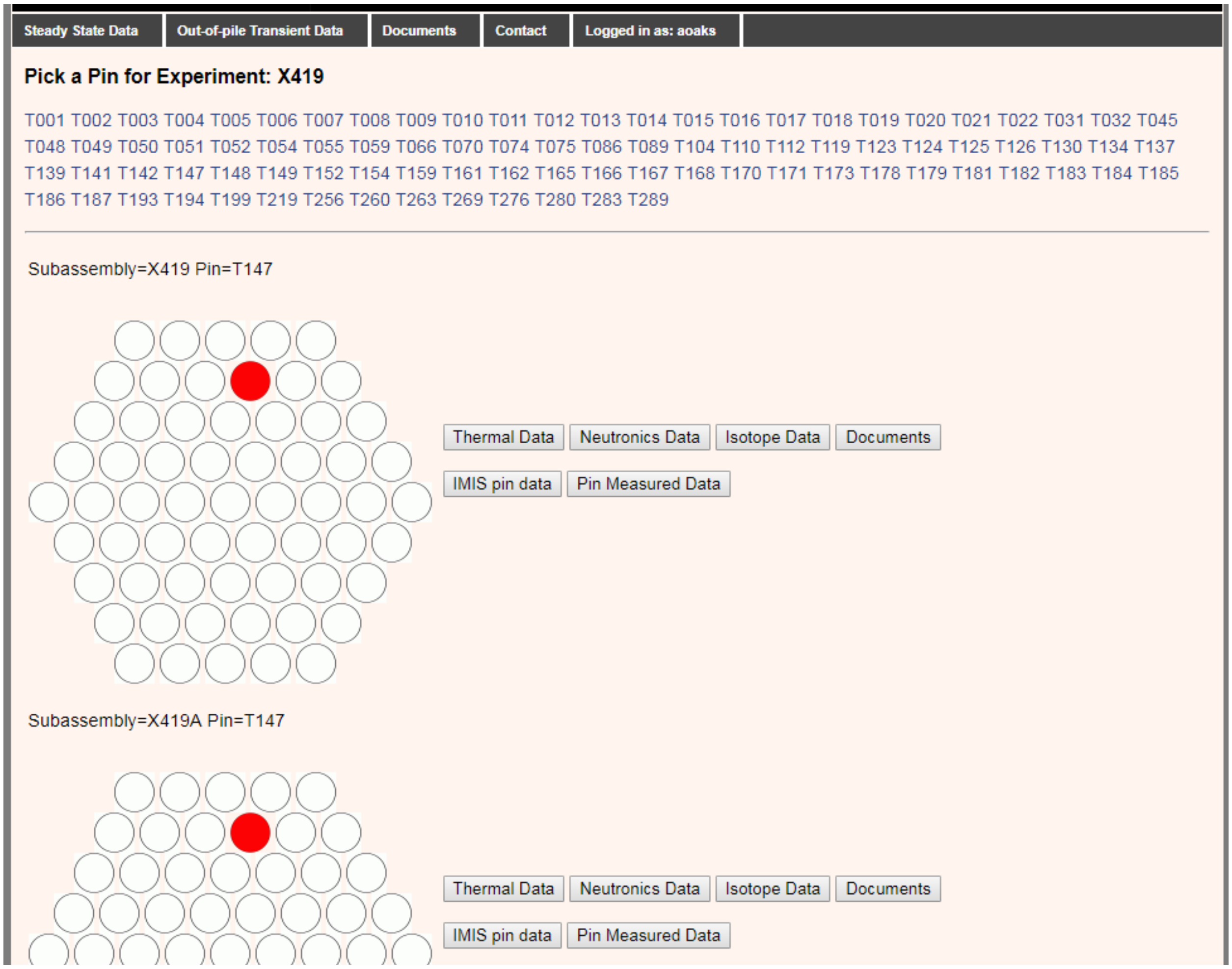


Figure 19: FIPD pin selection view.

5.2.5 Pin measured data list (list_pinmeasured)

This view lists available related measured data for the selected experiment/pin combination. What bulk measurement data (section 2.2.1) is available is displayed directly in this view (see Figure 20). If profilometry data (section 2.2.2) and or isotopic gamma scan data (section 2.2.3) are available, links are provided to corresponding views (section 5.2.6 and section 5.2.10) (see Figure 21).

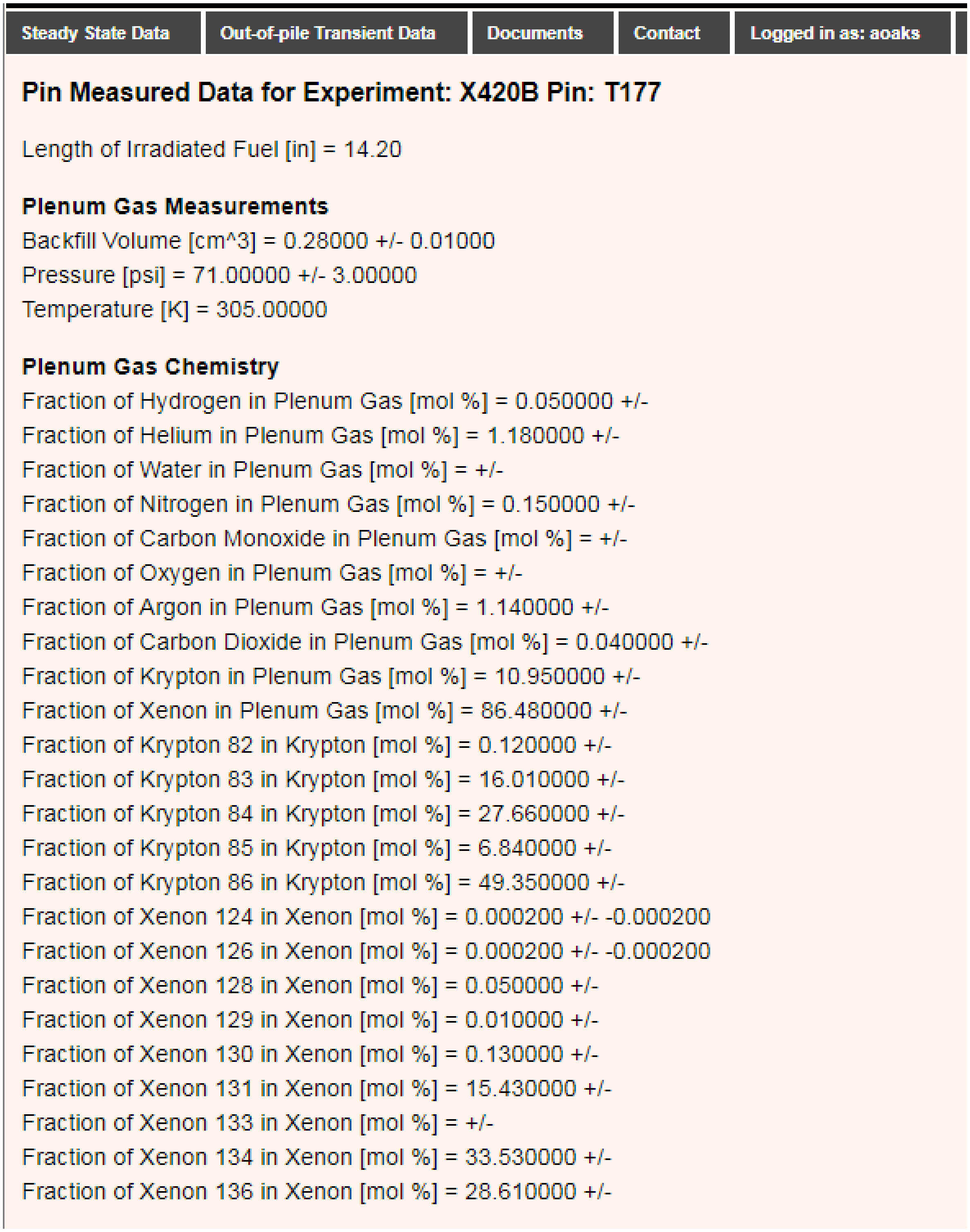


Figure 20: FIPD measured bulk data view.

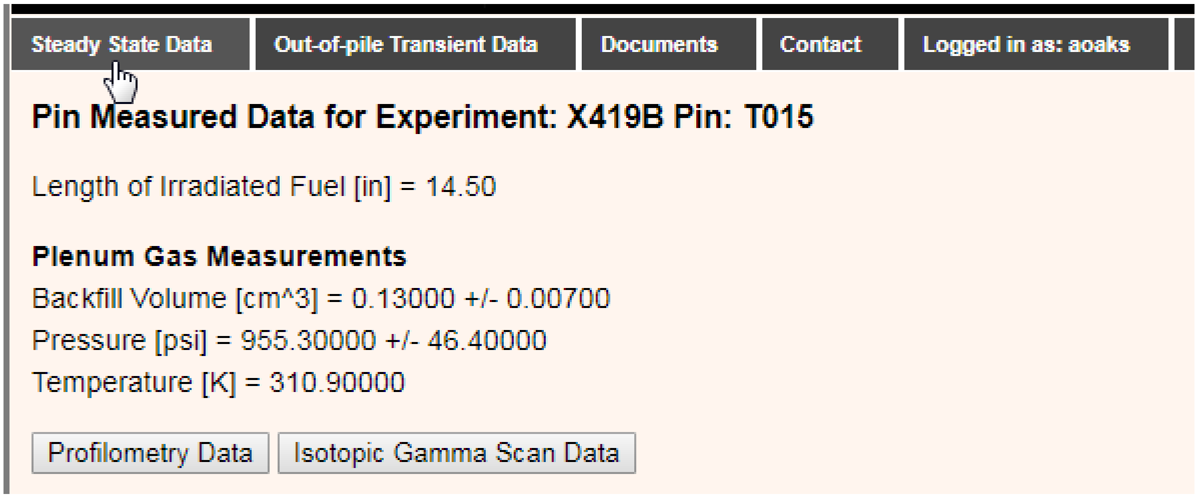


Figure 21: FIPD measured data links to profilometry and/or isotopic gamma scan data.

5.2.6 Gamma scan list (gammascan)

This view lists the available isotope gamma scan results for the selected experiment/pin combination. A link is provided for gross activity (section 5.2.7), as well as for each isotope scan available (section 5.2.8).

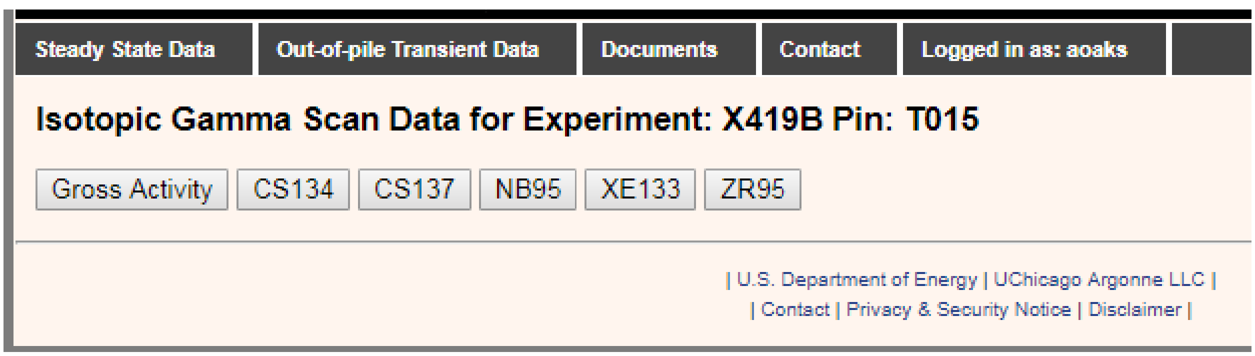
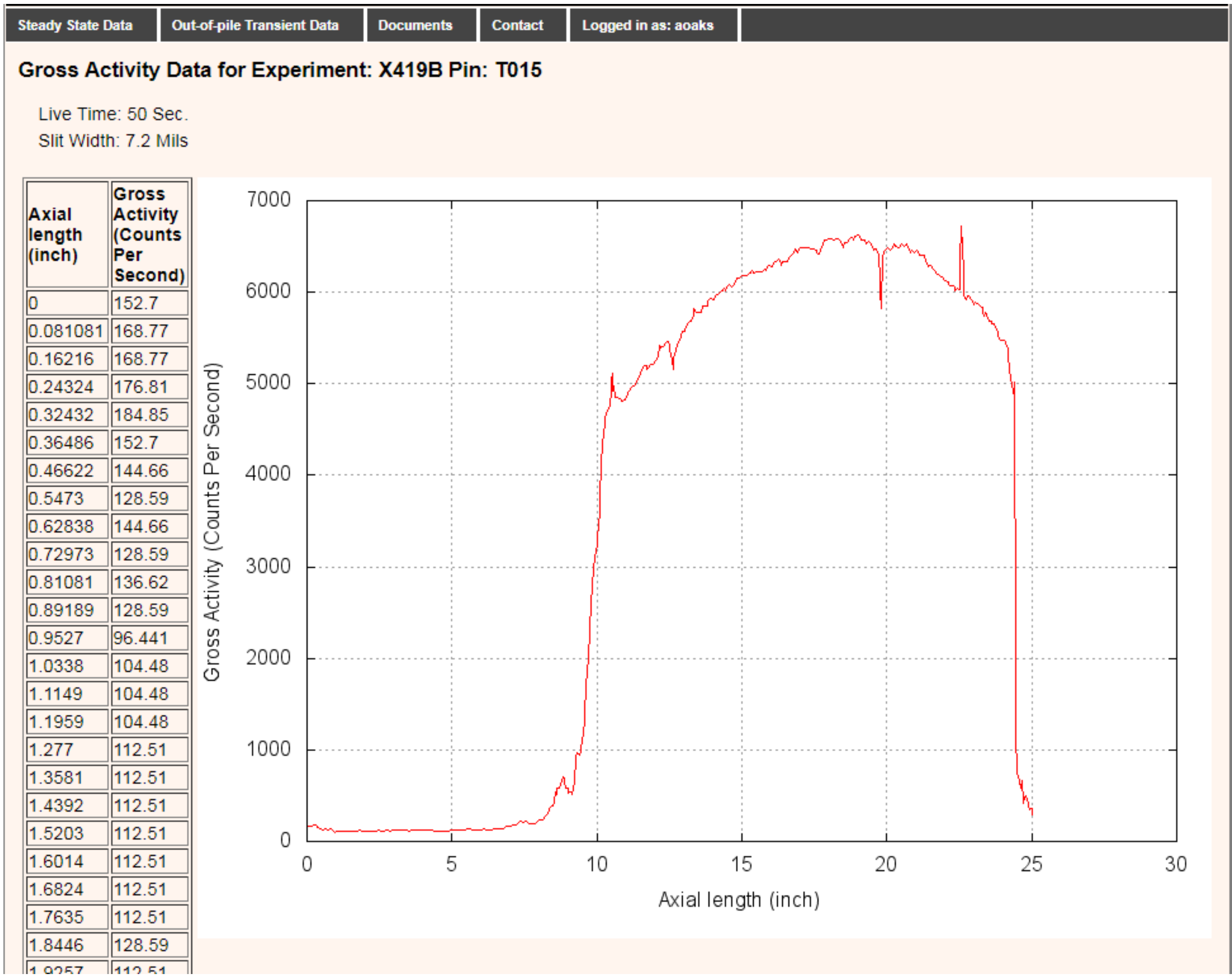


Figure 22: FIPD gamma scan listings.

5.2.7 Gamma scan gross activity (gammagross)

This view shows the gamma scan gross activity raw data, as well as a generated plot of the data for the selected experiment/pin combination.



Axial length (inch)	Gross Activity (Counts Per Second)
0	152.7
0.081081	168.77
0.16216	168.77
0.24324	176.81
0.32432	184.85
0.36486	152.7
0.46622	144.66
0.5473	128.59
0.62838	144.66
0.72973	128.59
0.81081	136.62
0.89189	128.59
0.9527	96.441
1.0338	104.48
1.1149	104.48
1.1959	104.48
1.277	112.51
1.3581	112.51
1.4392	112.51
1.5203	112.51
1.6014	112.51
1.6824	112.51
1.7635	112.51
1.8446	128.59

Figure 23: FIPD gamma scan gross activity view.

5.2.8 Gamma element data list (gammaelem)

This view shows the gamma scan parameters for the selected experiment/pin/isotope combination, and provides links to the data view (section 5.2.9) for AO values and AT values.

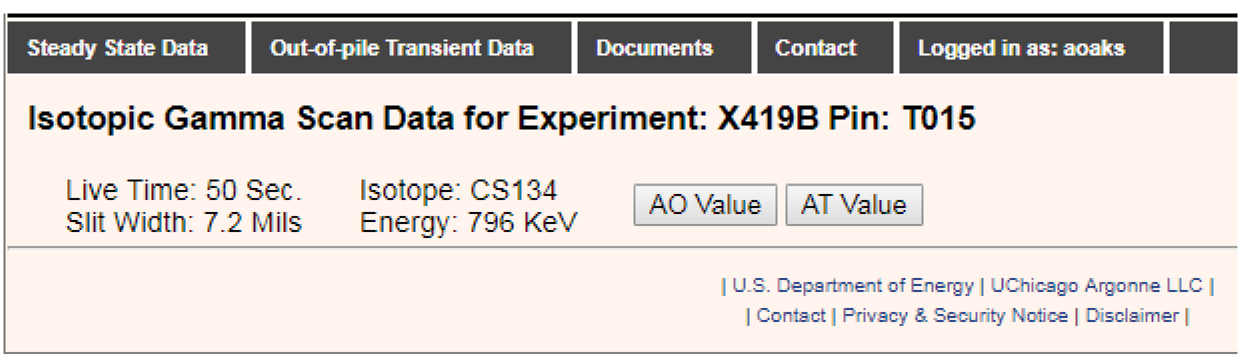


Figure 24: FIPD gamma scan element data list view.

5.2.9 Gamma element data listing and plot (gammaA)

This view shows gamma scan results for a particular isotope, giving both the raw data values and a generated plot of the raw data for the selected experiment/pin/isotope combination.

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Isotopic Gamma Scan Data for Experiment: X419B Pin: T015

Live Time: 50 Sec.
Slit Width: 7.2 Mils

Isotope: NB95
Energy: 766 KeV

Axial length (inch)	AT Values
0	2.5253
0.081287	0
0.16257	0
0.26418	0
0.34547	1.2626
0.42676	0
0.52837	1.2626
0.60965	1.2626
0.69094	0
0.77223	1.2626
0.85351	0
0.9348	0
1.0161	0
1.0974	0
1.1787	0
1.2599	0
1.3412	0
1.4225	0
1.5038	0
1.5851	1.2626
1.6664	1.2626
1.7477	0
1.829	0
1.9102	0
2.0119	0
2.0931	0
2.1948	1.2626

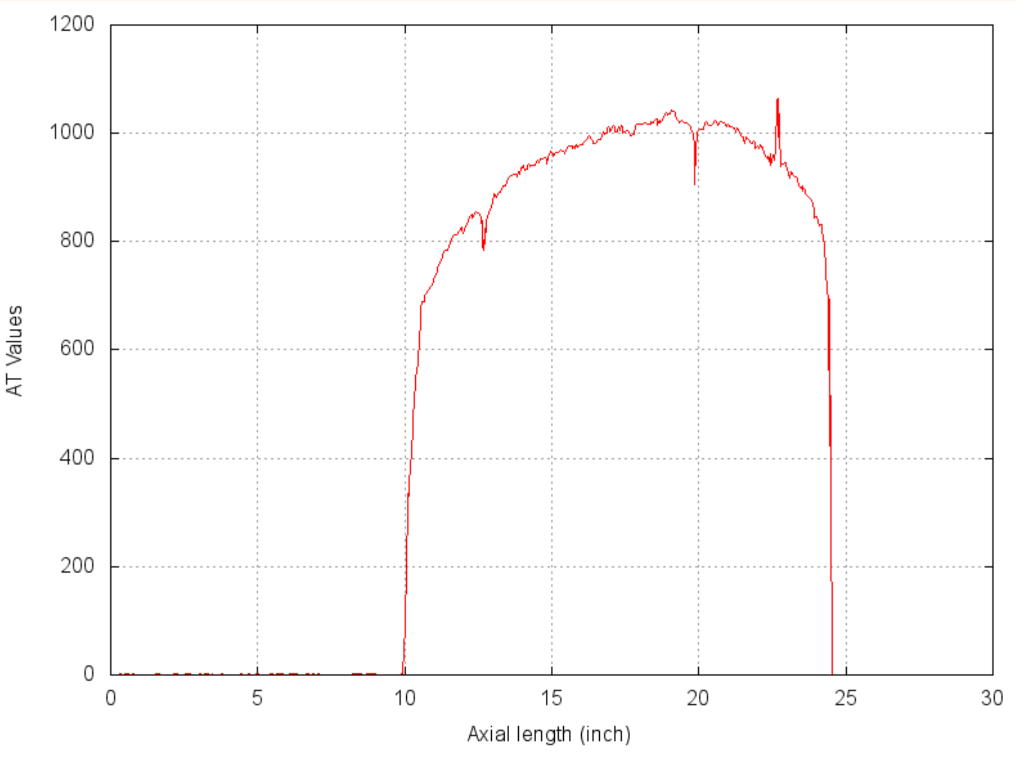

Figure 25: FIPD gamma scan elemental data listing and plot view.

5.2.10 Pin profilometry listing (profilometry)

This view presents a data table of all related profilometry data, interpolated to the same evaluation points as the calculated operating data (section 5.2.12), and presented with the corresponding thermal data for comparison. Links are presented to allow the user to download the data in CSV format, and to view the raw profilometry data (section 5.2.11). Each column header provides a link to a view (section 5.2.14) to generate a plot of the data in the column.

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Profilometry Data for Experiment: X419B Pin: T015 Raw Profilometry Data

Note: The profilometry data was processed according to the length of irradiated fuel.

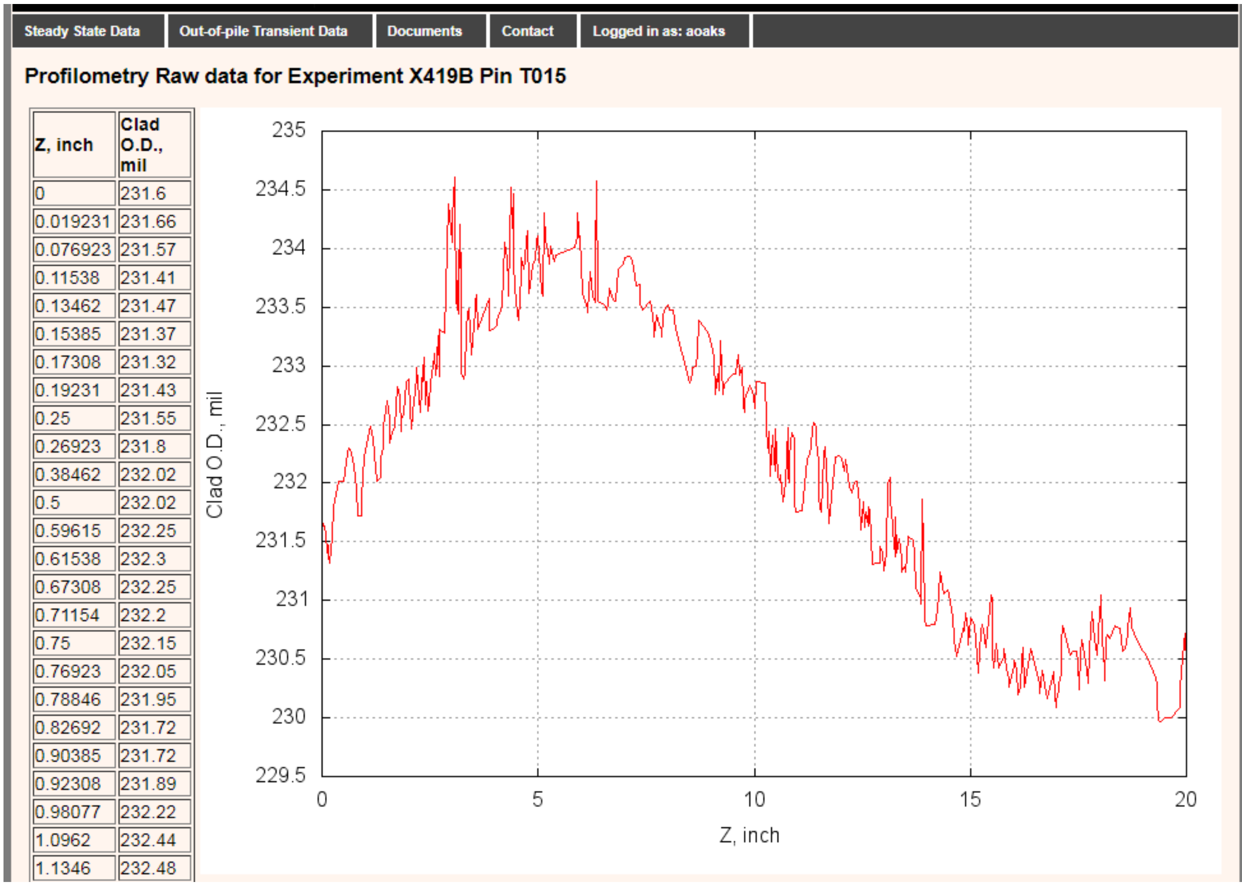
Right click Here and select 'Save link as' to download the .csv file

(Z/L):relative axial position along pin	Coolant temperature, C	Clad outer surface temperature, C	Clad mid-wall temperature, C	Clad inner surface temperature, C	Fuel surface temperature, C	Fuel center temperature, C	Linear power, kW/ft	Clad O.D., in.	Peak Clad O.D., in.	Min Clad O.D.,, in.	Clad Strain	Peak Clad Strain	Min Clad Strain
0.017	371	381	397.6	415.6	426	531.6	9.3	0.23171	0.23202	0.23132	0.0074475	0.0087956	0.0057471
0.05	371	381	398	416.5	427.5	535	9.5	0.23203	0.2323	0.23172	0.008838	0.009995	0.0074963
0.083	371	381	399	417	429	538	9.7	0.23228	0.23255	0.23202	0.0098979	0.011094	0.0087956
0.117	371	381	399	418	430	541	9.9	0.2326	0.23282	0.23234	0.011297	0.012244	0.010195
0.15	371	382	400	419	431	544	10.1	0.23278	0.23307	0.23246	0.012104	0.013343	0.010695
0.183	371	382	400	420	432	546.4	10.2	0.23307	0.23331	0.23262	0.013328	0.014393	0.011394
0.217	371	382	401	421	433	549	10.4	0.23373	0.23461	0.23289	0.016217	0.02004	0.012544
0.25	371	382	401	422	434	551.5	10.6	0.2334	0.23361	0.23309	0.014789	0.015692	0.013443
0.283	371	383	402	422.4	435	554	10.7	0.23355	0.23405	0.2333	0.015431	0.017591	0.014343
0.317	371.6	383	402	423	436	556	10.8	0.23387	0.23452	0.23339	0.016822	0.01964	0.014743
0.35	372	383	403	424	437	558	10.9	0.23392	0.2343	0.23359	0.017037	0.018691	0.015592
0.383	378.9	390.3	409.9	430.9	443.9	564.9	11	0.23394	0.23397	0.23389	0.017128	0.017241	0.016892
0.417	391.1	402.7	422.1	443.1	456.1	576.1	11	0.23381	0.2343	0.23345	0.016583	0.018691	0.014993
0.45	403.5	415	434	455	468	586.5	11	0.23362	0.23457	0.23347	0.015756	0.01989	0.015092
0.483	415.9	427.3	446.3	466.9	480.3	596.9	11	0.23385	0.23393	0.23355	0.01672	0.017091	0.015442
0.517	428.1	440.1	458.7	479.1	492.1	607.1	10.9	0.23351	0.23369	0.23325	0.015248	0.016042	0.014143
0.55	440	451	470	490	503	616	10.8	0.23342	0.23352	0.23325	0.014854	0.015292	0.014143
0.583	450.9	461.9	479.9	499.9	512.9	623.4	10.8	0.2329	0.2331	0.23285	0.012608	0.013493	0.012394
0.617	457	468	486	505	518.6	627	10.6	0.23319	0.23339	0.23276	0.013854	0.014743	0.011994
0.65	457	468	486	505	518	625	10.5	0.23296	0.23321	0.23276	0.012884	0.013943	0.011994

Figure 26: FIPD profilometry data listing view.

5.2.11 Pin profilometry raw data and plot (profilometry_raw)

This view shows the raw profilometry trace data, as well as a plot of the data, for the selected experiment/pin combination.

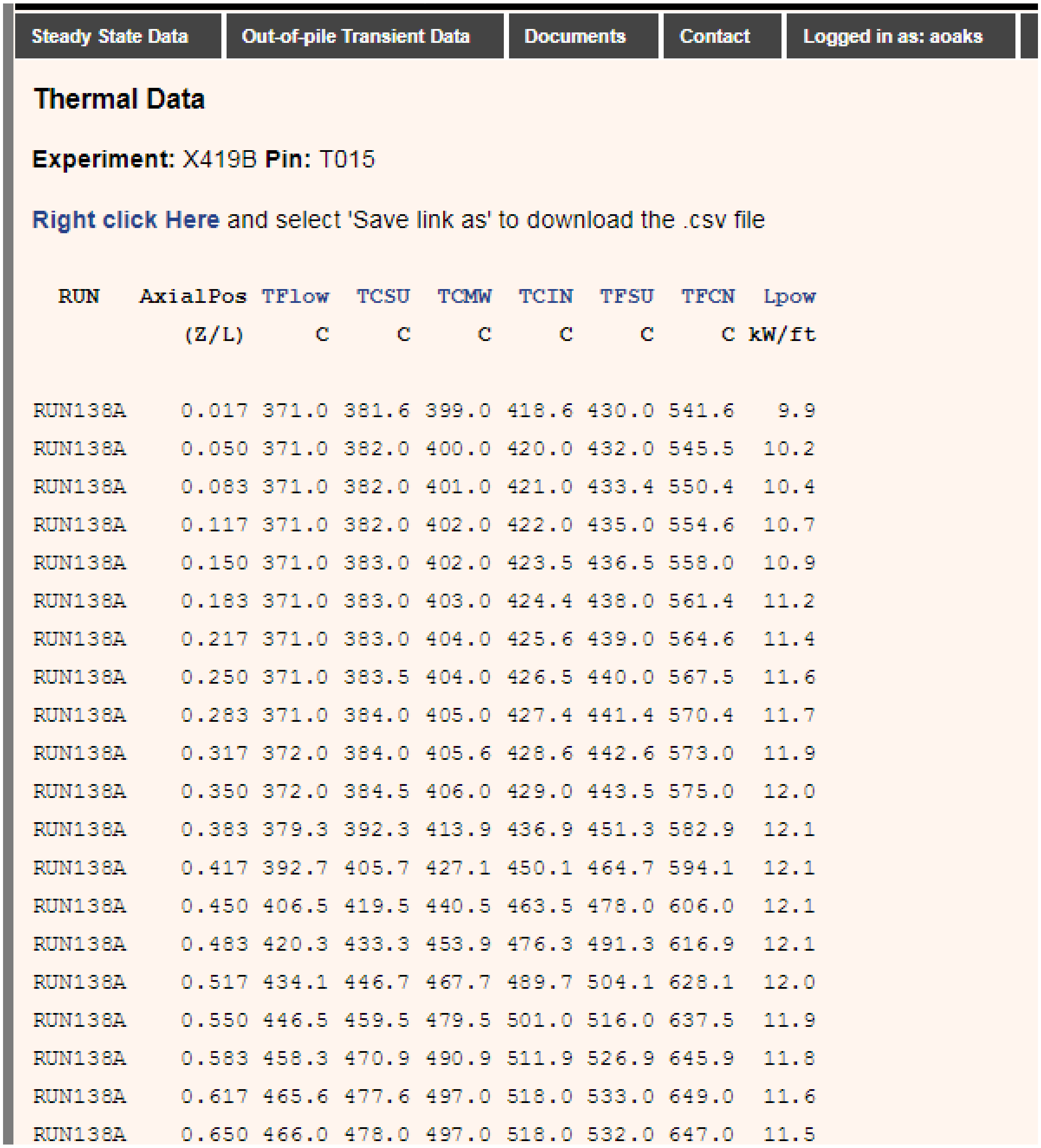


Z, inch	Clad O.D., mil
0	231.6
0.019231	231.66
0.076923	231.57
0.11538	231.41
0.13462	231.47
0.15385	231.37
0.17308	231.32
0.19231	231.43
0.25	231.55
0.26923	231.8
0.38462	232.02
0.5	232.02
0.59615	232.25
0.61538	232.3
0.67308	232.25
0.71154	232.2
0.75	232.15
0.76923	232.05
0.78846	231.95
0.82692	231.72
0.90385	231.72
0.92308	231.89
0.98077	232.22
1.0962	232.44
1.1346	232.48

Figure 27: FIPD profilometry raw data view.

5.2.12 Pin operating data listing (list_data)

This view presents a data table of the calculated operating data for the selected experiment/pin combination. Operating data is split into three categories: thermal data (Figure 28), neutronics data (Figure 29), and isotopic density data (Figure 30). This view is used for all three categories, and selected the data to view based on the category parameter passed to the view with the request. All columns headers provide a link to a view (section 5.2.13) to plot the values in the column for all related runs.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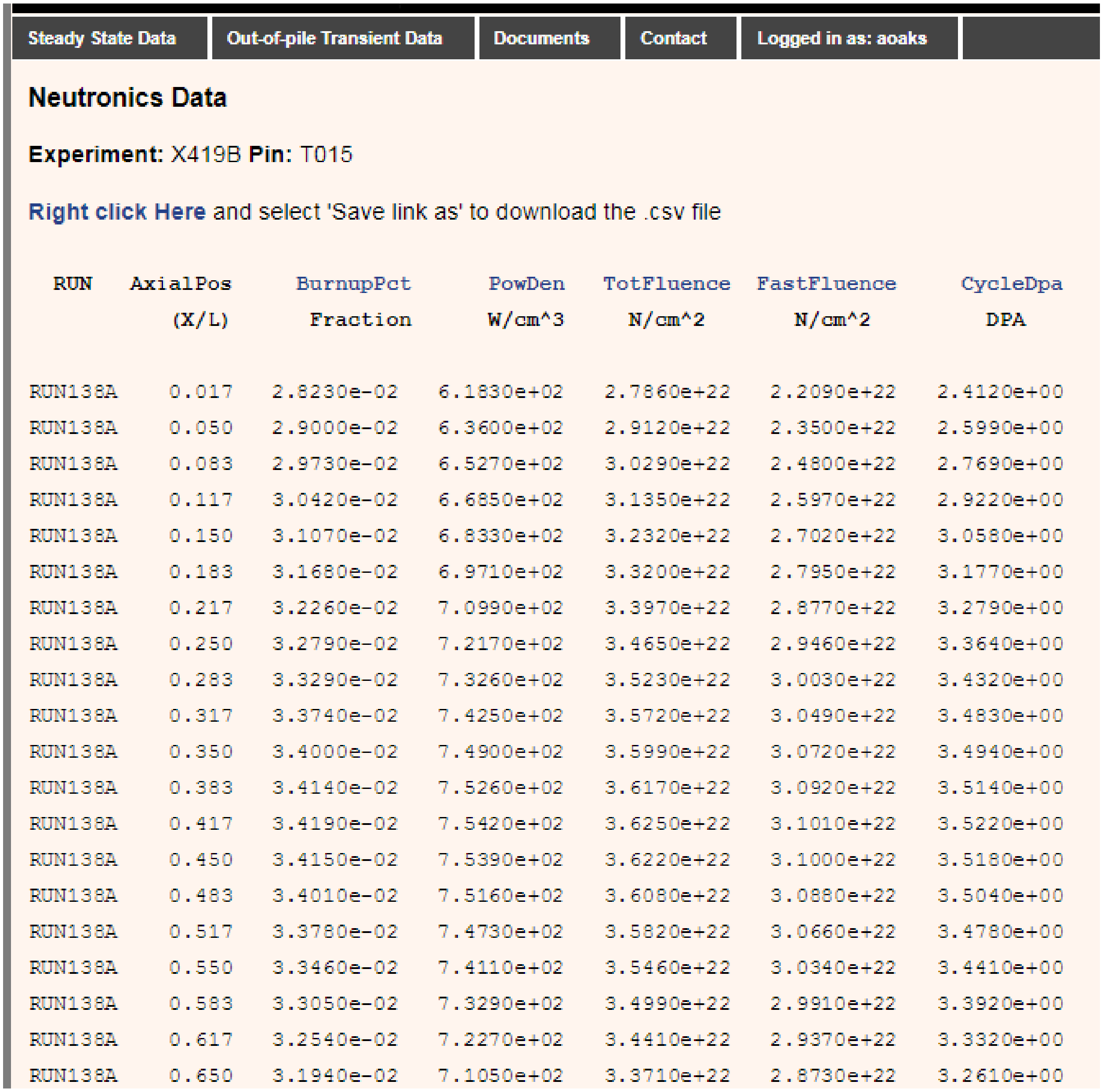
Thermal Data

Experiment: X419B **Pin:** T015

Right click Here and select 'Save link as' to download the .csv file

RUN	AxialPos (Z/L)	TFlow C	TCSU C	TCMW C	TCIN C	TFSU C	TFCN C	Lpow kW/ft
RUN138A	0.017	371.0	381.6	399.0	418.6	430.0	541.6	9.9
RUN138A	0.050	371.0	382.0	400.0	420.0	432.0	545.5	10.2
RUN138A	0.083	371.0	382.0	401.0	421.0	433.4	550.4	10.4
RUN138A	0.117	371.0	382.0	402.0	422.0	435.0	554.6	10.7
RUN138A	0.150	371.0	383.0	402.0	423.5	436.5	558.0	10.9
RUN138A	0.183	371.0	383.0	403.0	424.4	438.0	561.4	11.2
RUN138A	0.217	371.0	383.0	404.0	425.6	439.0	564.6	11.4
RUN138A	0.250	371.0	383.5	404.0	426.5	440.0	567.5	11.6
RUN138A	0.283	371.0	384.0	405.0	427.4	441.4	570.4	11.7
RUN138A	0.317	372.0	384.0	405.6	428.6	442.6	573.0	11.9
RUN138A	0.350	372.0	384.5	406.0	429.0	443.5	575.0	12.0
RUN138A	0.383	379.3	392.3	413.9	436.9	451.3	582.9	12.1
RUN138A	0.417	392.7	405.7	427.1	450.1	464.7	594.1	12.1
RUN138A	0.450	406.5	419.5	440.5	463.5	478.0	606.0	12.1
RUN138A	0.483	420.3	433.3	453.9	476.3	491.3	616.9	12.1
RUN138A	0.517	434.1	446.7	467.7	489.7	504.1	628.1	12.0
RUN138A	0.550	446.5	459.5	479.5	501.0	516.0	637.5	11.9
RUN138A	0.583	458.3	470.9	490.9	511.9	526.9	645.9	11.8
RUN138A	0.617	465.6	477.6	497.0	518.0	533.0	649.0	11.6
RUN138A	0.650	466.0	478.0	497.0	518.0	532.0	647.0	11.5

Figure 28: FIPD thermal operating data view.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Neutronics Data

Experiment: X419B **Pin:** T015

Right click Here and select 'Save link as' to download the .csv file

RUN	AxialPos (X/L)	BurnupPct Fraction	PowDen W/cm^3	TotFluence N/cm^2	FastFluence N/cm^2	CycleDpa DPA
RUN138A	0.017	2.8230e-02	6.1830e+02	2.7860e+22	2.2090e+22	2.4120e+00
RUN138A	0.050	2.9000e-02	6.3600e+02	2.9120e+22	2.3500e+22	2.5990e+00
RUN138A	0.083	2.9730e-02	6.5270e+02	3.0290e+22	2.4800e+22	2.7690e+00
RUN138A	0.117	3.0420e-02	6.6850e+02	3.1350e+22	2.5970e+22	2.9220e+00
RUN138A	0.150	3.1070e-02	6.8330e+02	3.2320e+22	2.7020e+22	3.0580e+00
RUN138A	0.183	3.1680e-02	6.9710e+02	3.3200e+22	2.7950e+22	3.1770e+00
RUN138A	0.217	3.2260e-02	7.0990e+02	3.3970e+22	2.8770e+22	3.2790e+00
RUN138A	0.250	3.2790e-02	7.2170e+02	3.4650e+22	2.9460e+22	3.3640e+00
RUN138A	0.283	3.3290e-02	7.3260e+02	3.5230e+22	3.0030e+22	3.4320e+00
RUN138A	0.317	3.3740e-02	7.4250e+02	3.5720e+22	3.0490e+22	3.4830e+00
RUN138A	0.350	3.4000e-02	7.4900e+02	3.5990e+22	3.0720e+22	3.4940e+00
RUN138A	0.383	3.4140e-02	7.5260e+02	3.6170e+22	3.0920e+22	3.5140e+00
RUN138A	0.417	3.4190e-02	7.5420e+02	3.6250e+22	3.1010e+22	3.5220e+00
RUN138A	0.450	3.4150e-02	7.5390e+02	3.6220e+22	3.1000e+22	3.5180e+00
RUN138A	0.483	3.4010e-02	7.5160e+02	3.6080e+22	3.0880e+22	3.5040e+00
RUN138A	0.517	3.3780e-02	7.4730e+02	3.5820e+22	3.0660e+22	3.4780e+00
RUN138A	0.550	3.3460e-02	7.4110e+02	3.5460e+22	3.0340e+22	3.4410e+00
RUN138A	0.583	3.3050e-02	7.3290e+02	3.4990e+22	2.9910e+22	3.3920e+00
RUN138A	0.617	3.2540e-02	7.2270e+02	3.4410e+22	2.9370e+22	3.3320e+00
RUN138A	0.650	3.1940e-02	7.1050e+02	3.3710e+22	2.8730e+22	3.2610e+00

Figure 29: FIPD neutronics operating data view.

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Isotopes Data

Experiment: X419B **Pin:** T015

Right click Here and select 'Save link as' to download the .csv file

RUN	AxialPos	U234	U235	U236	U238	NP237	PU236	PU238	PU239	PU240	PU241
	(X/L)	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm	atom/barn.cm
RUN138A	0.017	4.0430e-05	5.5120e-03	7.5780e-05	3.0810e-03	6.9830e-07	5.8050e-13	1.8100e-08	7.6660e-04	5.2600e-05	2.8540e-06
RUN138A	0.050	4.0410e-05	5.5080e-03	7.4970e-05	3.0810e-03	7.2260e-07	6.8400e-13	1.9530e-08	7.6530e-04	5.2260e-05	2.8390e-06
RUN138A	0.083	4.0380e-05	5.5030e-03	7.4330e-05	3.0800e-03	7.4570e-07	7.8090e-13	2.0850e-08	7.6400e-04	5.1980e-05	2.8270e-06
RUN138A	0.117	4.0360e-05	5.4990e-03	7.3870e-05	3.0800e-03	7.6780e-07	8.7130e-13	2.2050e-08	7.6290e-04	5.1740e-05	2.8170e-06
RUN138A	0.150	4.0340e-05	5.4950e-03	7.3580e-05	3.0790e-03	7.8860e-07	9.5510e-13	2.3130e-08	7.6180e-04	5.1550e-05	2.8090e-06
RUN138A	0.183	4.0320e-05	5.4900e-03	7.3460e-05	3.0790e-03	8.0840e-07	1.0320e-12	2.4090e-08	7.6090e-04	5.1400e-05	2.8030e-06
RUN138A	0.217	4.0300e-05	5.4860e-03	7.3520e-05	3.0780e-03	8.2710e-07	1.1030e-12	2.4920e-08	7.6010e-04	5.1300e-05	2.7990e-06
RUN138A	0.250	4.0280e-05	5.4820e-03	7.3740e-05	3.0780e-03	8.4460e-07	1.1670e-12	2.5640e-08	7.5940e-04	5.1250e-05	2.7980e-06
RUN138A	0.283	4.0270e-05	5.4780e-03	7.4140e-05	3.0770e-03	8.6100e-07	1.2250e-12	2.6240e-08	7.5870e-04	5.1240e-05	2.7980e-06
RUN138A	0.317	4.0250e-05	5.4730e-03	7.4720e-05	3.0770e-03	8.7620e-07	1.2760e-12	2.6730e-08	7.5820e-04	5.1280e-05	2.8000e-06
RUN138A	0.350	4.0240e-05	5.4710e-03	7.5110e-05	3.0770e-03	8.8430e-07	1.2980e-12	2.6940e-08	7.5800e-04	5.1320e-05	2.8020e-06
RUN138A	0.383	4.0230e-05	5.4700e-03	7.5140e-05	3.0770e-03	8.8840e-07	1.3130e-12	2.7110e-08	7.5780e-04	5.1300e-05	2.8020e-06
RUN138A	0.417	4.0230e-05	5.4690e-03	7.5090e-05	3.0770e-03	8.8960e-07	1.3190e-12	2.7170e-08	7.5770e-04	5.1280e-05	2.8010e-06
RUN138A	0.450	4.0230e-05	5.4700e-03	7.4960e-05	3.0770e-03	8.8780e-07	1.3160e-12	2.7130e-08	7.5770e-04	5.1260e-05	2.8000e-06
RUN138A	0.483	4.0240e-05	5.4710e-03	7.4750e-05	3.0770e-03	8.8300e-07	1.3050e-12	2.6980e-08	7.5780e-04	5.1250e-05	2.7990e-06
RUN138A	0.517	4.0240e-05	5.4730e-03	7.4450e-05	3.0770e-03	8.7540e-07	1.2850e-12	2.6720e-08	7.5810e-04	5.1230e-05	2.7980e-06
RUN138A	0.550	4.0260e-05	5.4760e-03	7.4070e-05	3.0770e-03	8.6480e-07	1.2570e-12	2.6360e-08	7.5850e-04	5.1220e-05	2.7970e-06
RUN138A	0.583	4.0270e-05	5.4800e-03	7.3600e-05	3.0770e-03	8.5130e-07	1.2200e-12	2.5900e-08	7.5890e-04	5.1210e-05	2.7960e-06
RUN138A	0.617	4.0290e-05	5.4850e-03	7.3050e-05	3.0780e-03	8.3480e-07	1.1740e-12	2.5330e-08	7.5950e-04	5.1200e-05	2.7940e-06
RUN138A	0.650	4.0310e-05	5.4900e-03	7.2420e-05	3.0780e-03	8.1540e-07	1.1200e-12	2.4650e-08	7.6020e-04	5.1190e-05	2.7930e-06

Figure 30: FIPD isotopic density operating data view.

5.2.13 Pin operating data plot (plot_data)

This view plots the operating data for a specific parameter (e.g., cladding surface temperature, power density, U-235 atom density, etc.) for runs related to the selected experiment/pin combination.

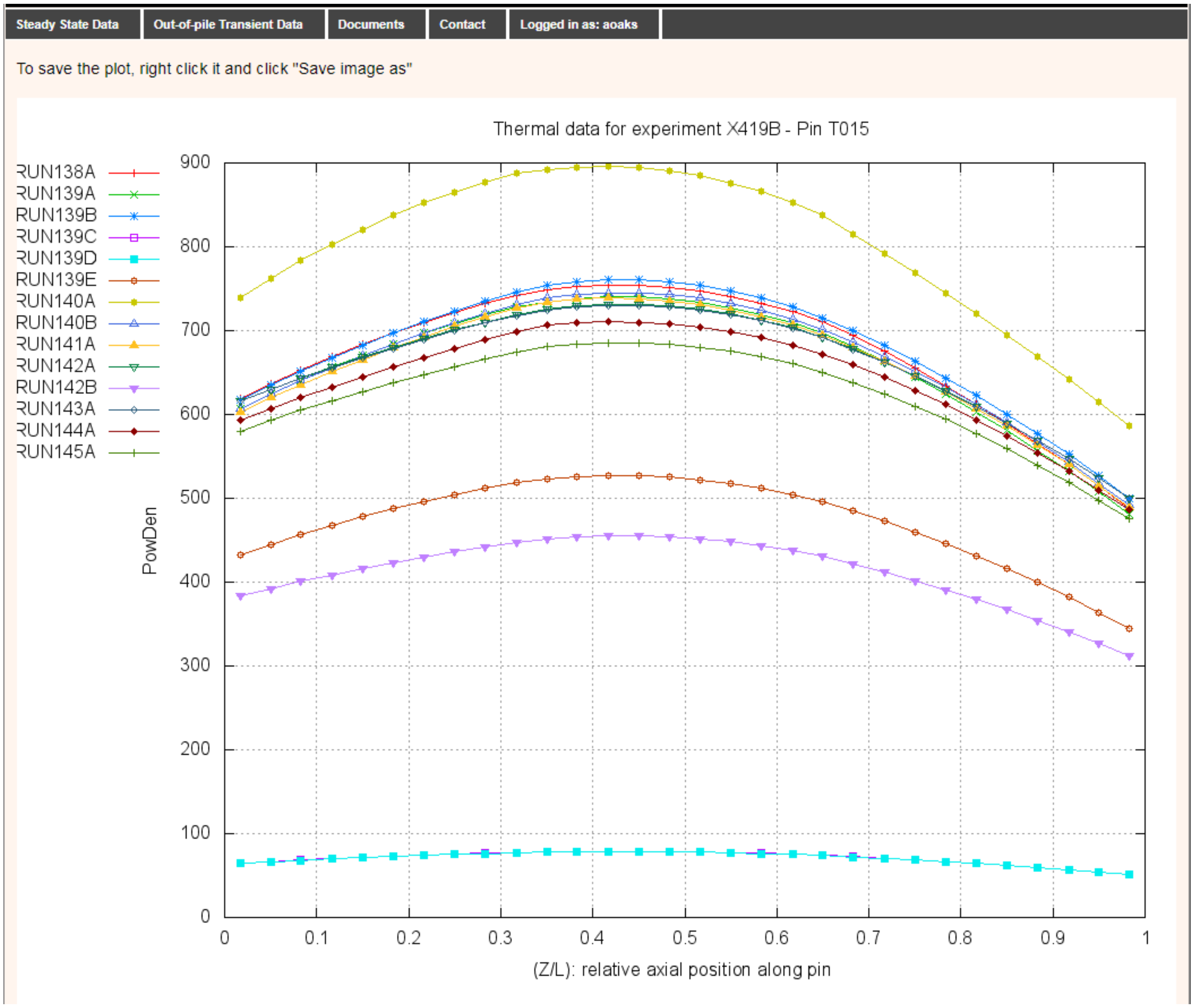


Figure 31: FIPD operating data run comparison plot.

5.2.14 Pin data single-data plot (plot1)

This view generates a single line plot for the requested data column of a given experiment/pin combination.

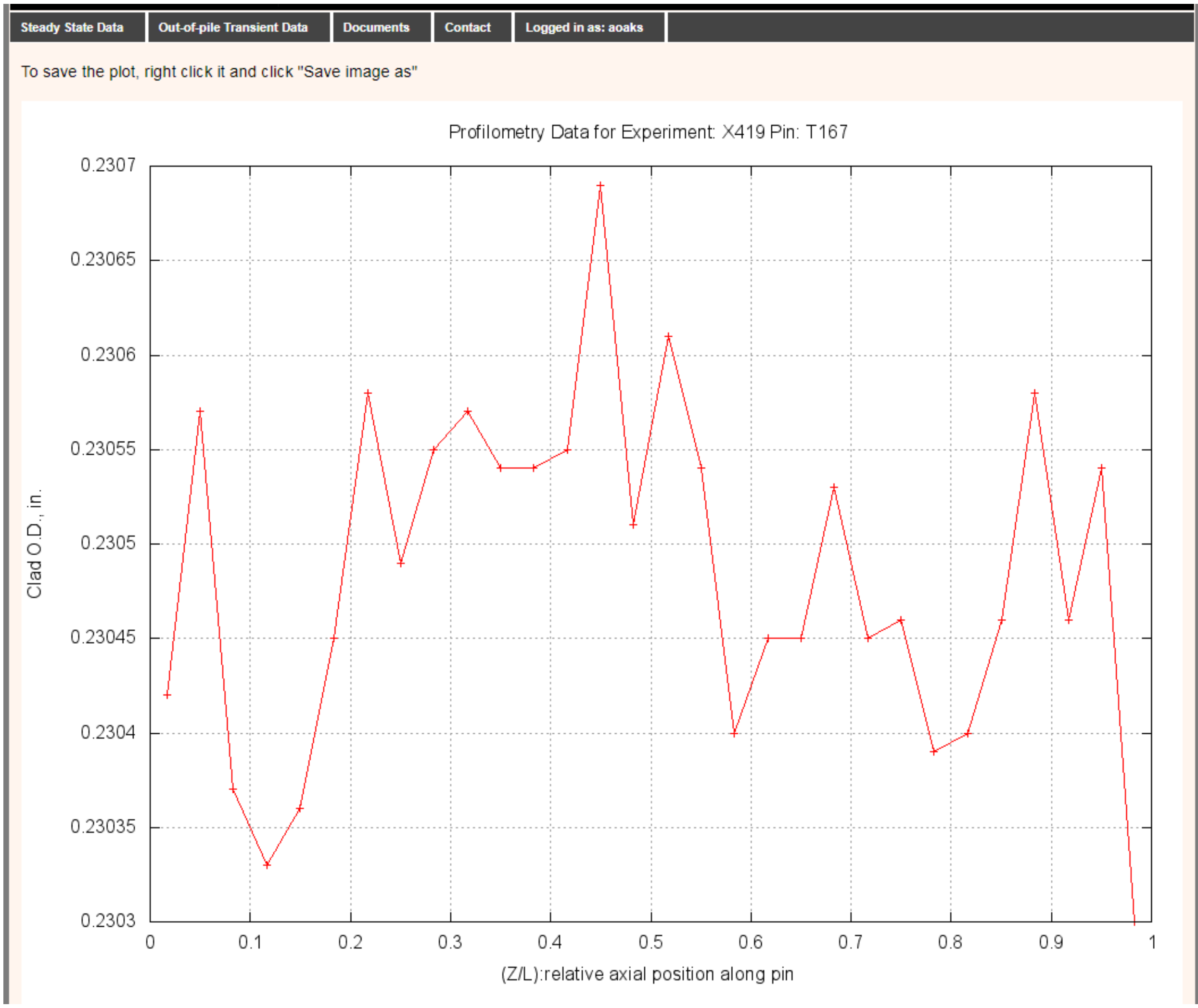


Figure 32: FIPD single data column plot view.

5.2.15 Experiment document listing (list_docs)

This view shows a list of related documents (see section 2.3) for the selected subassembly. The view displays the date and title of each document, and provides a link for each document.

Figure 33: FIPD experiment document view.

5.2.16 Transient documents (transient_docs)

This view shows a list of documents related to out-of-pile FBTA transient tests. The view displays the date and title of each document, and provides a link for each document.

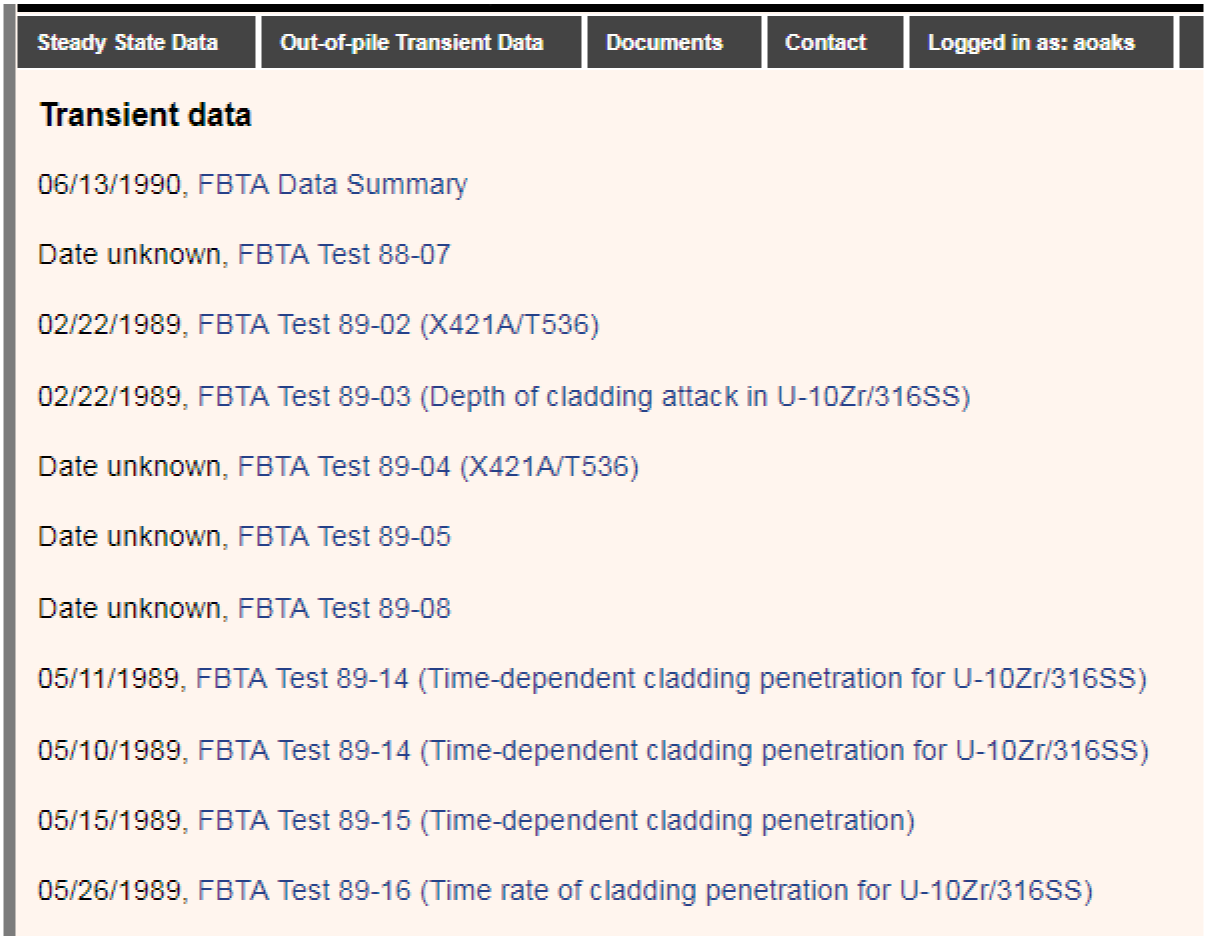


Figure 34: FIPD transient documents view.

5.2.17 Documents index / group documents (all_docs)

This view provides a direct link to all available subassembly-based document listings (Figure 35), as well and group-restricted documents that are available to the current user's access group (Figure 36).

Figure 35: FIPD documents index view.

Data Qualification Documents

Data and Software QA plans & related forms

Date unknown, Data Evaluation Form

Date unknown, Data Evaluation Form

09/09/2016, Process and Procedure for Historical SFR Metalic Fuel Data Qualification

07/05/2017, Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification

06/05/2017, Software Quality Assurance Program Plan for Nuclear Fuel Codes and Data

PIE data (databooks and memos)

01/02/1988, Fuel Element Databook for X419, Pins T012, T014, T134, T162, T179, T193

02/22/1989, Fuel Element Databook for X421A/T536

07/30/1985, Fuel Element Databook for X423, Pins T304, T317, T336

07/30/1985, Fuel Element Databook for X423, Pins T320, T341, T349

08/23/1988, Fuel Element Databook for X423A/T332

03/27/1989, Fuel Element Databook for X423C/T323

Legacy QA Documents

06/29/1989, AGHCF Operators Manual / Procedures

06/22/1989, Quality Assurance Plan for Irradiation Performance Section Activities

10/30/1986, Quality Assurance Plan for Irradiation Performance Section Activities

03/07/2002, Quality Assurance Plan for Irradiation Performance Section Activities

Figure 36: FIPD group-restricted documents view.

6 QUALITY ASSURANCE PLAN

A plan has been developed, with support from the DOE Advanced Reactor Technology program, to qualify data in the FIPD, so it can be used in future licensing activities. This plan is applicable to data from the different sources of metallic fuel data. An example of the plan implementation with a limited set of experimental data is provided in references [12, 13]. While the QA plan implementation described in the report was focused on data from the Alpha Gamma Hot Cell Facility (AGHCF) at Argonne, as an example, the QA plan can be applied to data generated at other facilities. The plan is applicable to all historical metallic fuel data that are pertinent to future licensing of SFRs. In addition to the plan to qualify the data, another plan has been developed to qualify the software associated with the database. Significant effort went into the development of a quality assurance plan to govern the database application and the data that feeds into it. This plan is designated the Nuclear Fuel Codes and Data (NFD) Software Quality Assurance Program Plan (SQAPP) [14]. Schematic shown in Figure 37 provides a summary of the QA environment for the FIPD. The following sections describe in more details the SQAPP to be used with the FIPD.

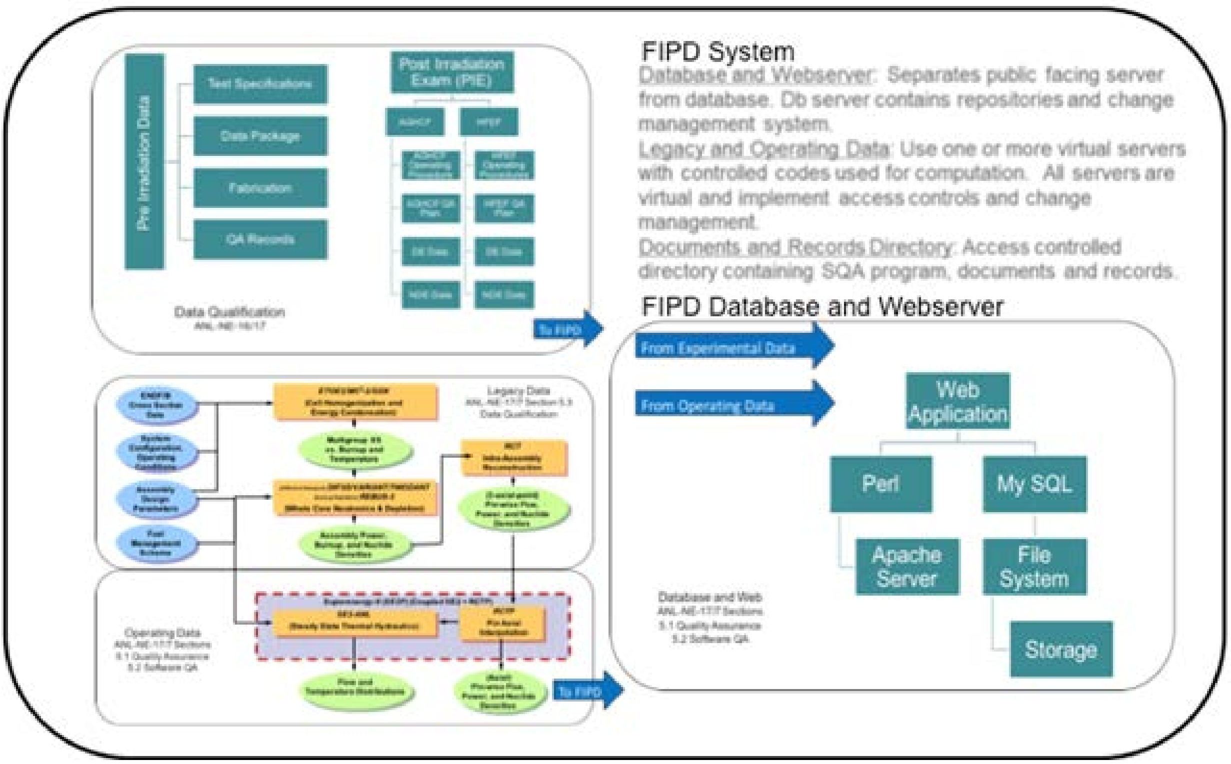


Figure 37: Schematic diagram of FIPD QA environment.

6.1 Overview

Argonne National Laboratory develops nuclear software, codes and data. In some cases, the intended user does not implement U.S. Department of Energy (DOE) regulations but instead must satisfy nuclear plant licensing regulations and standards. These may include regulations issued by the U.S. Nuclear Regulatory Commission (NRC) under 10CFR50 or 10CFR52 conforming to 10CFR50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel

Reprocessing Plants." They may also include other agencies seeking licensing under regulatory requirements issued by their host government.

Accordingly, this Nuclear Fuel Codes and Data (NFD) Software Quality Assurance Program Plan (SQAPP) was developed using the standards of ASME NQA-1-2008/2009 addenda without regard to DOE regulations. In some cases, specific provisions and measures have been prepared to meet some aspects of 10CFR50 Appendix B or IEEE. The intent is to make the software, code, and data available in a form that is appropriate for use by fuels and reactors analysts and modelers as well as its use for reactor licensing.

This SQAPP governs the following activities:

- Qualification of input data, where necessary to support subsequent code and data analysis
- Development and use of software for fuel analysis
- Control and operation of databases and webserver systems
- Development, control and operation of the NFD Data Repository containing all data, software, and configuration management elements

The SQAPP implements ASME NQA-1-2008, "Quality Assurance Requirements for Nuclear Facility Applications," (NQA-1) as it pertains to software quality assurance and data qualification. That ASME standard was endorsed by the NRC in Regulatory Guide 1.28 "QUALITY ASSURANCE PROGRAM CRITERIA (DESIGN AND CONSTRUCTION)," Revision 4.

SQAPP Appendix 7.4, NQA-1 Applicability, contains a detailed selection of the pertinent requirements and their applicability. In general, NQA-1 requirements apply as follows:

Quality Assurance Program	ASME NQA-1 Part I (selected aspects)
Software QA Program	ASME NQA-1 Part II, Subpart 2.7, "Quality Assurance Requirements for Computer Software for Nuclear Facility Applications."
Data Qualification	ASME NQA-1 Part III, Subpart 3.3, "Nonmandatory Guidance on Quality Assurance Program Requirements for Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories," Nonmandatory Appendix 3.1, "Guidance on Qualification of Existing Data."

Table 1: SQAPP NQA-1 requirements.

This SQAPP and associated procedures are permitted by provisions of the ANL QAPP which allow departments to issue QA programs so long as they are compatible in intent and do not compromise the ANL QAPP. Whereas the ANL QAPP is intended to fulfill DOE Order 414.1D, this SQAPP is intended implement selected aspects of NQA-1 to support advanced reactor developers pursuing licensing through the NRC. Accordingly, where the ANL QAPP suffices to implement NQA-1 this SQAPP makes no provisions and relies on the ANL QAPP. Where there are necessary departures to meet the needs of NRC licensees, this SQAPP provides its own measures separate from those of the ANL QAPP.

6.2 QA Provisions

The full document describes all of the roles in detail. It covers the following provisions based on NQA-1, part 1, which relate to all quality assurance programs:

- Organization
- Quality Assurance Program
- Design Control
- Procurement Document Control
- Instructions, Procedures and Drawings
- Document Control
- Control of Purchased Items and Services
- Control of Special Processes
- Inspection
- Test Control
- Control of Measuring and Test Equipment
- Handling, Storage, and Shipping
- Inspection, Test, and Operating Status
- Control of Nonconforming Items
- Corrective Action
- Quality Assurance Records
- Audits

The plan covers the following provisions based on NQA-1 part 2, subpart 2.7, which relate to software quality assurance:

- Software Engineering
- Software Configuration Management
- Problem Reporting and Corrective Actions
- Software Acquisition
- Software Design Requirements
- Software Design
- Implementation
- Acceptance Testing
- Operation
- Maintenance
- Retirement
- Standards and Conventions
- Support Software

The plan covers the following provisions based on NQA-1 part 3, subpart 3.3, which relate to the qualification of legacy data:

- Selecting Data Sets for Qualification
- Data Qualification Planning
- Data Qualification Preparation
- Data Qualification Attributes
- Qualification Methods
- Documentation of Results

6.3 QA Documents

In addition to the overall quality assurance plan document, the plan references a number of procedures and forms that were also created as part of the effort.

6.4 Secure Document Repository

The plan documents, procedures, forms, and records are located in a secure storage location hosted by the ANL NE IT section, which provides read access to all members of the project team, but write access only to the project Quality Assurance Representative. All revisions and additions of records go through the designated review process, but can only be added to the secure document repository by the Quality Assurance Representative.

7 SUMMARY OF PREVIOUS YEARS' ACTIVITIES

This section summarizes the work activities performed up to the current fiscal year (FY17).

7.1 Website Development

The majority of the FIPD web interface described in section 5 was performed in previous years, with the notable except of the user-restricted access scheme, which was implemented in FY17, as described in section 8.5.

7.2 Experiment Documents

Almost all of the experimental documents described in section 2.3 were categorized and added to FIPD in years prior to FY17. The number of documents associated with each experiment are given in Table 2.

Experiment	Documents		Experiment	Documents
X419	80		X432	23
X419A	23		X435	34
X419B	26		X435A	9
X420	45		X441	30
X420A	31		X441A	31
X420B	41		X447	32
X421	61		X447A	35
X421A	37		X448	21
X423	59		X448A	11
X423A	23		X449	6
X423B	21		X450	6
X423C	17		X451	11
X425	48		X452	10
X425A	21		X453	15
X425B	21		X454	8
X425C	20		X455	7
X429	35		X489	24
X429A	13		X492	29
X429B	34		X492A	11
X430	26		X492B	8
X430A	16		X496	34
X430B	18		X501	21
X431	23			

Table 2: Documents added to FIPD in years prior to FY17.

7.3 Digitization Software Development

The Fast Reactor Data Digitalization System (FRDDS) code was developed in FY15 to facilitate the digitization of PIE data in this effort. The software is described in detail in a separate report [6].

7.4 PIE Data Digitization

A significant amount of experimental data in hard-copy format was converted into digital format. This effort included the digitization of contact profilometry, laser profilometry, and isotopic gamma scan data. All the digitization work was performed using FRDDS [6]. The listing of contract profilometry data (as described in section 2.2.2.1) digitized and added to FIPD in years prior to FY17 is given in Table 3. The listing of laser profilometry data (as described in section 2.2.2.2) digitized and added to FIPD in years prior to FY17 is given in Table 4.

Experiment	Number of images
X419	61
X419A	9
X419B	60
X420A	57
X421	61
X423C	37
X425A	54
X425B	26
X425C	60
X430	37
X441	53
X441A	49
X447A	47
X448	7
X489	7
X492	4

Table 3: Contact profilometry scans digitized in years prior to FY17.

Experiment	Number of images
X419A	7
X419B	27
X421	40
X425	5
X441	129
X441A	117
X447	15

Table 4: Laser profilometry scans digitized in years prior to FY17.

7.5 Operating Parameter Calculations

The operating parameters in the FIPD database were mostly calculated before FY17. The experiments and corresponding EBR-II runs for which operating parameter calculations were run are listed in Table 5. All of the thermal, neutronic, and isotopic information described in section 2.1 are available for each of these experiment/run combinations.

Experiment	Runs Calculated
X419	133A, 133B, 134B, 134C
X419A	136A, 136B, 136C, 136D
X419B	138A, 139A, 139B, 139C, 139D, 139E, 140A, 140B, 141A, 142A, 142B, 143A, 144A, 145A
X420	133A, 133B, 134B, 134C, 135A, 135B, 135C, 135D, 135E, 136A, 136B, 136C, 136D, 137A, 137B, 137C, 138A, 138C
X420A	140A, 140B, 141A, 142A, 142B, 143A, 144A, 145A, 146A, 146B, 147A
X421	133A, 133B, 134B, 134C, 135A, 135B, 136C, 136D, 137A, 137B, 137C, 138A, 139A, 139B, 139C, 139D, 139E, 140A, 140B, 141A, 142A, 142B
X421A	144A, 145A, 146A, 147A, 147B, 149A
X423	135A, 135B, 135C
X423A	136A, 136B, 136C, 136D
X423B	138A, 139A, 139B, 139D, 139E
X423C	141A, 142A, 142B, 143A, 144A
X425	138A, 139A, 139B, 139C, 139D, 139E, 140A, 140B
X425A	142A, 142B, 143A, 144A, 145A, 146A, 146B, 147A
X425B	149A, 150A, 150B, 151A, 151B, 152C, 152D, 153A
X425C	156A, 156B, 157D, 157H, 157J, 158A, 158B
X429	142A, 142B, 143A, 144A, 145A, 146A, 146B
X429A	148B, 149A
X429B	151A, 151B, 152C, 152D, 153A, 154B
X430	144A, 145A, 146A, 146B, 147A, 148A, 148B
X430A	150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D
X430B	155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 161A
X431	149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D
X431A	155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A, 162A, 163A, 164A, 166A
X432	149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A
X432A	155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A, 162A, 163A, 164A, 166A
X435	144A, 145A, 146A, 146B, 147A, 148A, 148B, 149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D
X435A	157D, 157H, 157J, 158A, 158B, 161A
X441	146A, 146B, 147A, 148A, 148B
X447	146B, 147A, 148A, 148B

X447A	151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B
X448	152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B
X448A	158A, 158B, 160A, 160B, 160C, 161A, 162A, 163A, 164A, 166A
X449	152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A, 162A, 163A, 164A
X450	152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A
X451	152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A
X451A	164A, 165A, 166A, 167A, 167B, 167C, 168A
X452	147A
X452A	149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A
X453	147A, 148A, 148B, 149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154F, 155A
X454	148A, 148B, 149A, 150B, 152A, 152B, 152C, 153A, 154A
X455	148A, 148B, 149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A
X489	156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A
X492	156A, 156B
X492A	157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A
X492B	164A, 165A, 166A, 167A, 167B, 167C, 168A
X496	163A, 164A, 165A, 166A, 167A, 167B, 167C, 168A
X501	163A, 164A, 165A, 166A, 167A, 167B, 167C, 168A

Table 5: Subassembly operating parameter calculations performed in years prior to FY17.

8 SUMMARY OF FY17 ACTIVITIES

This section summarizes the work activities performed during FY17.

8.1 Quality Assurance Plan Development

The entirety of the NQA-1-compliant software quality assurance plan (SQAPP) described in detail in section 6 was developed and approved for use in FY17. This will be used to cover all software applications used to calculate or generate data that goes into FIPD. It also provides procedures to quality legacy data generated outside of the plan, where regeneration of the data is not practical.

8.2 PIE Data Digitization

A significant amount of experimental data in hard-copy format was converted into digital format. This effort included the digitization of contact profilometry, laser profilometry, and isotopic gamma scan data. All the digitization work was performed using FRDDS [6]. The listings of contract profilometry data (as described in section 2.2.2.1), laser profilometry data (as described in section 2.2.2.2), and isotopic gamma scan data (as described in section 2.2.3) digitized and added to FIPD in FY17 are given in Table 6, Table 7, and Table 8, respectively.

Experiment	Number of images
X420B	1
X421A	7
X435B	16
X438	6
X452A	23
X483	12
X486	6

Table 6: Contact profilometry scans digitized in FY17.

Experiment	Number of images
X420A	25
X420B	52
X421A	85
X429B	5
X435	14

Table 7: Laser profilometry scans digitized in FY17.

Experiment	Number of images
X419A	61
X441	277
X432	65

Table 8: Isotopic gamma scan data digitized in FY17.

8.3 Experiment Documents

This section describes new experimental documentation added to FIPD in FY17, listed in Table 9.

Experiment	Documents
X423	1
X447A	3
X482	6
X482A	6
X482B	10
X483	16
X483A	1
X484	4
X485	4
X486	15
X486A	6

Table 9: Documents added to FIPD in FY17.

8.3.1 New Fuel Swelling Data

Fuel swelling data is currently limited in the documents available in FIPD. Due to the importance of fuel swelling behavior for fuel qualification and design, the data from two experiments (six fuel elements in experiment X423, and six fuel elements in experiment X486) were provided by INL. These are high resolution neutron radiography (NRAD) images. Figure 38 shows the NRAD images of six elements in experiment X423.

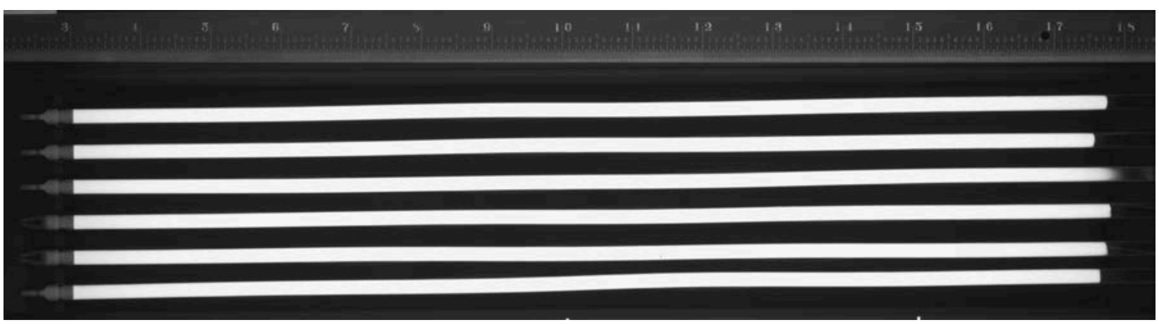


Figure 38: Raw neutron radiography data of six elements: J596, J651, J658, J630, J555, and J776, in experiment X486.

Two important types of PIE data can be extracted from the raw NRAD images: (1) fuel length after irradiation (i.e., fuel axial swelling data), and (2) fuel diameter as a function of length (i.e., fuel diametral swelling data). For most of the experiments, axial fuel length data has been measured and stored in FIPD. However, for some relative new experiments (e.g., X486), the measured axial fuel length data is not yet available. For this reason, digitization was performed on the newly acquired NRAD images to interpret the axial fuel length after irradiation for experiment X486. The acquired images have also been added to FIPD. Both diametral and axial fuel swelling behaviors are important to evaluate the metallic fuel performance, which can be calculated by the LIFE-METAL code [15].

8.3.2 High Resolution Metallography Data

In the documents available in FIPD, image quality of some documents was not sufficiently high. The interpretation of such "low" image quality documents is difficult for some cases. Although the image quality does not impact the usage of scanned documents with only words or plots, it causes problems when interpreting metallographic data (optical and electronic microscopic images) which contain detailed microstructural information.

The metallographic images for element DP69 in experiment X447 (approx. 5 at.-% burnup), as well as for elements DP04, DP70 (failed), and DP75 (failed) in experiment X447A (approx. 10 at.-% burnup) are of main interest to understand the fuel cladding chemical interaction. Idaho National Laboratory provided high-quality (600 dpi) scans of reports containing images of those elements have been received by Argonne. These additional reports/images are a significant improvement over what was available in FIPD. Figure 39 shows a comparison of the image quality between the original scanned image and the recent acquired scans for element DP70 in experiment X447A. These new image documents have been added to FIPD.

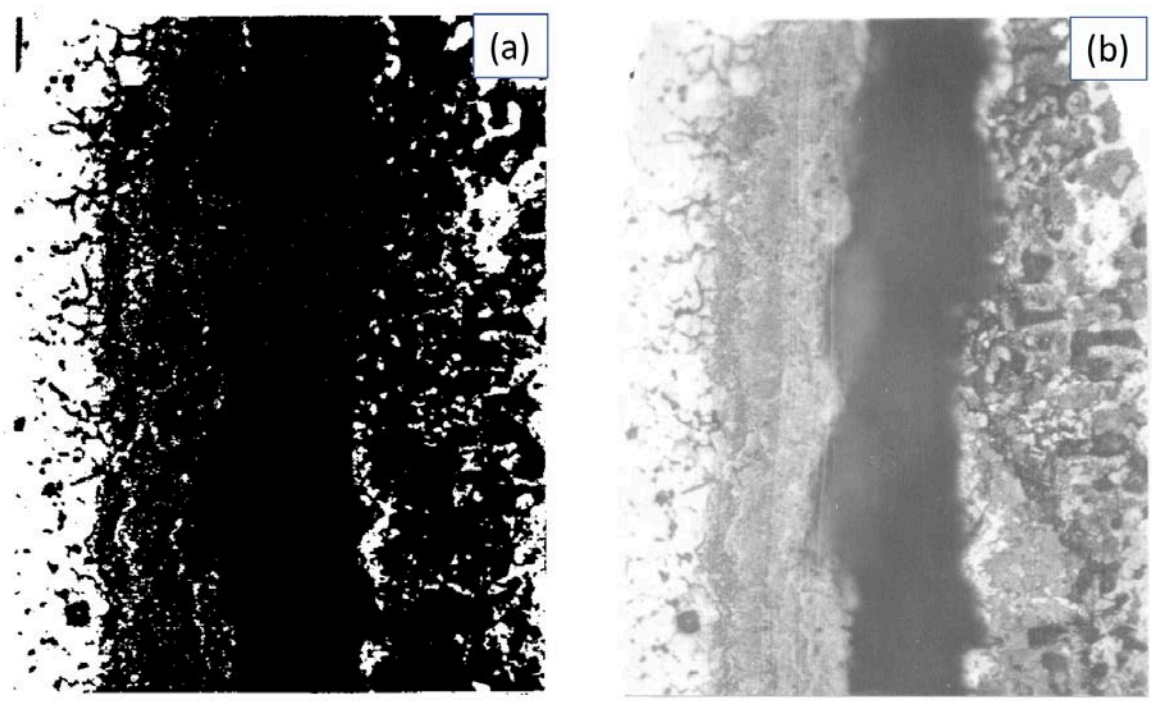


Figure 39: Comparison of image quality of (a) the original metallographic image in FIPD, and (b) the recent acquired metallographic image from INL; the microstructure was examined in element DP70 in experiment X447A.

8.4 Operating Data Calculations

In FY17, five key experiments were identified to be added to FIPD namely: X482, X483, X484, X485, and X486. The experiments and corresponding EBR-II runs for which operating parameter calculations were run are listed in Table 10. All of the thermal, neutronic, and isotopic information described in section 2.1 are available for each of these experiment/run combinations.

Experiment	Runs Calculated
X482	149A, 150A, 150B
X482A	152A, 152C, 153A
X482B	154B, 154C, 154E, 154F, 155A
X483	151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B,
X483A	158A, 158B, 159A, 159B, 160A, 160B, 160C, 161A, 162A, 163A, 164A, 166A
X484	151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A, 162A, 163A, 164A
X485	151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C, 161A
X486	151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 160A, 160B, 160C
X486A	164A, 165A, 166A, 167A, 167B, 167C, 168A, 170A

Table 10: Subassembly operating parameter calculations performed in FY17.

8.4.1 Experiment X482

The purpose of experiment X482 was to conduct the first in a series of open core Run-Beyond-Cladding-Breach (RBCB) tests using IFR prototypical fuel and hardware. X482 consisted of a D-61 subassembly placed in the open core, row 5, for two reactors run (EBR-II runs 149 and 150). The 61-pin fuel bundle contained six new standard MK-III fuel elements (U-10Zr) and one pre-thinned U-19Pu-10Zr test element (T139) from experiment X419B that sustained a planned cladding breach. The subassembly was removed from EBR-II at the end of run 150B then it was transferred without wash to HFEF and given a brief through-window examination. The pre-defected element T139 showed evidence of breach.

Element T045 (U-10Zr) from experiment X419B was pre-defected for the reconstruction of RBCB subassembly X482A. Pre-defecting required milling a 7/16-in. wide slot at fuel centerline. The defected element T045 was milled to a depth of 0.013 in. without breach. Post-defecting examination included laser profilometry, close visual examination and weighing.

The RBCB experimental subassembly was then reconstructed as X482B with 60 MK-IIIA, U-10Zr elements and one U-19Pu-10Zr test element with HT-9 cladding (T464) which was previously irradiated in X425B. The test element (T464) was pre-thinned to enhance the potential of breach.

8.4.2 Experiments X483-X486

Experiments X483, X484, X485, and X486 were Mark-IIIA qualification subassemblies which represented the first of the standard production subassemblies and operated in various locations to demonstrate that this design is suitable for use as a standard driver fuel in EBR-II. The Mark-IIIA fuel element design incorporates 316 S.S. cladding of the same O.D. and wall thickness as the MARK-III. The Mark-IIIA fuel is identical to the Mark-III 66.9% U-235 enriched U-10Zr and thus operation of the Mark-IIIA elements were expected to be very similar to the MARK-III elements. The Mark-IIIA were planned to be used when the supply of Mark-III is depleted and continue for approximately a year, allowing the Mark-IV fuel elements and subassembly designs to be irradiated in qualification subassemblies prior to routine use.

Subassembly X483 was a core type subassembly that utilized D-61 core driver type subassembly hardware and contained sixty-one new, unirradiated, U-10Zr fuel elements. The subassembly reached its goal exposure and was removed from the EBR-II core at the end of run 156. Following the required basket cooldown period, the subassembly was transferred to HFEF for disassembly and examination. For the reconstruction of X483A, 46 elements from subassembly X483 were replaced with new unirradiated MK-IIIA elements.

Subassembly X484 was a normal flow inner-blanket driver that was irradiated in row six in a corner position (6E1) with sixty-one new, unirradiated, U-10Zr fuel elements with 316 S.S. cladding. The subassembly was inserted in the EBR-II core in run 151A and achieved its exposure goal by the end of run 164A.

Similarly, subassembly X485 was an increased flow inner-blanket driver that was irradiated in a row 6 flat position (6A3). It contained sixty-one new, unirradiated, U-10Zr fuel elements with 316 S.S. cladding as well. The subassembly was inserted in the EBR-II core starting run 151A and achieved its exposure goal by the end of EBR-II run 161A.

Finally, subassembly X486 was irradiated at elevated temperatures which bound the EBR-II uncertainties on power and flow. The subassembly contained sixty-one 316 S.S. clad, U-10Zr fuel element and utilized D-61 inner blanket driver type subassembly hardware with a D-9 hex can. Subassembly X486 was irradiated in row 6 and was orificed to produce a change in coolant temperature about 120% of the nominal hot driver.

Subassembly X486A was reconstructed by replacing forty-eight elements from X486 with new unirradiated MK-IIIA spare elements whereas the remaining thirteen irradiated elements, previously irradiated in X486, were at approximately 10.47 at.-% burnup.

8.5 Website interface user-restricted access functionality

A major work effort for FY17 was making experimental data in the FIPD database available to external (non-ANL) users and groups, which could include other national labs, universities, and industry partners. The biggest hurdle to deployment was user-level security, where some users/partners needed to be restricted from accessing certain sets of experimental data. This was a problem as the web interface as designed did not allow user-level security; if a user was given access to the database, they were given access to the entire database. To accommodate this security requirement, the web interface design and implementation was first audited to determine what changes would need to be made, and these changes were then implemented.

8.6 Web Application Modernized Prototype

While the current web script has been upgraded and secured as best as possible, the entire web interface was written in an older and fairly restricted style. Even with the additional user-level access restrictions, the coding is such that it will only function securely in a read-only context. If the application is ever to be extended to support the submission of information/data from users for interactivity, many portions of the application needed to be rewritten. A prototype replacement interface that would support this interactivity with users has been developed and is described in part here.

8.6.1 Redesign benefits

The prototype was written using the popular Django web application framework for Python [16]:

> *Django is a high-level Python Web framework that encourages rapid development and clean, pragmatic design. Built by experienced developers, it takes care of much of the hassle of Web development, so you can focus on writing your app without needing to reinvent the wheel. It's free and open source.*

There are many important benefits to using an established framework over attempting to implement an in-house solution:

- Fully featured components are already available – Django includes dozens of extras you can use to handle common Web development tasks. Django takes care of user authentication, content administration, site maps, database interaction, and many more tasks, right out of the box.
- The ever-expanding problems of security are handled by professionals in the field – Django takes security seriously and helps developers avoid many common security mistakes, such as SQL injection, cross-site scripting, cross-site request forgery and clickjacking.
- General design allows applications to be versatile and scalable – Companies, organizations and governments have used Django to build all sorts of things, from content management systems to social networks to scientific computing platforms.
- Complete and detailed documentation is available for the entire platform – Django's platform documentation is extensive and rich, with descriptions and examples for all common and complex tasks, along with a sizable development community available to help.
- The platform is actively developed and maintained – The Django Software Foundation supports the continued development and maintenance of the platform, keeping the system up to date with modern web design and security standards.

- Model-View-Controller framework design separates data, presentation, and web logic, so that each can be logically documented and updated.

The prototype uses the popular Bootstrap frontend design framework [17], which is highly customizable, but at this point uses the default style. The prototype is still under active development, so all designs are subject to change, but several examples are given here for comparison.

8.6.2 Experiment selection

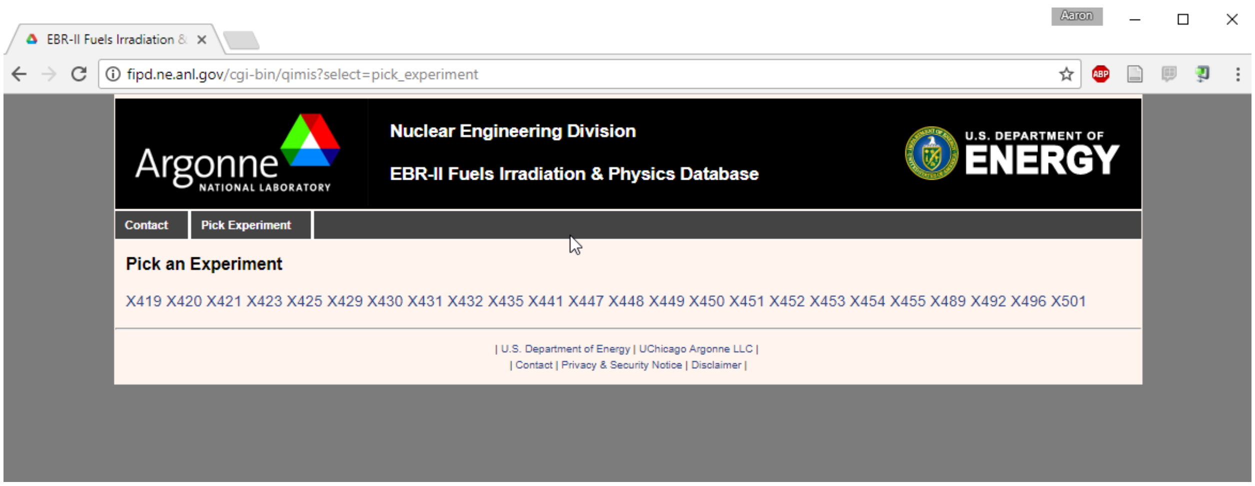


Figure 40: Experiment selection in current application.

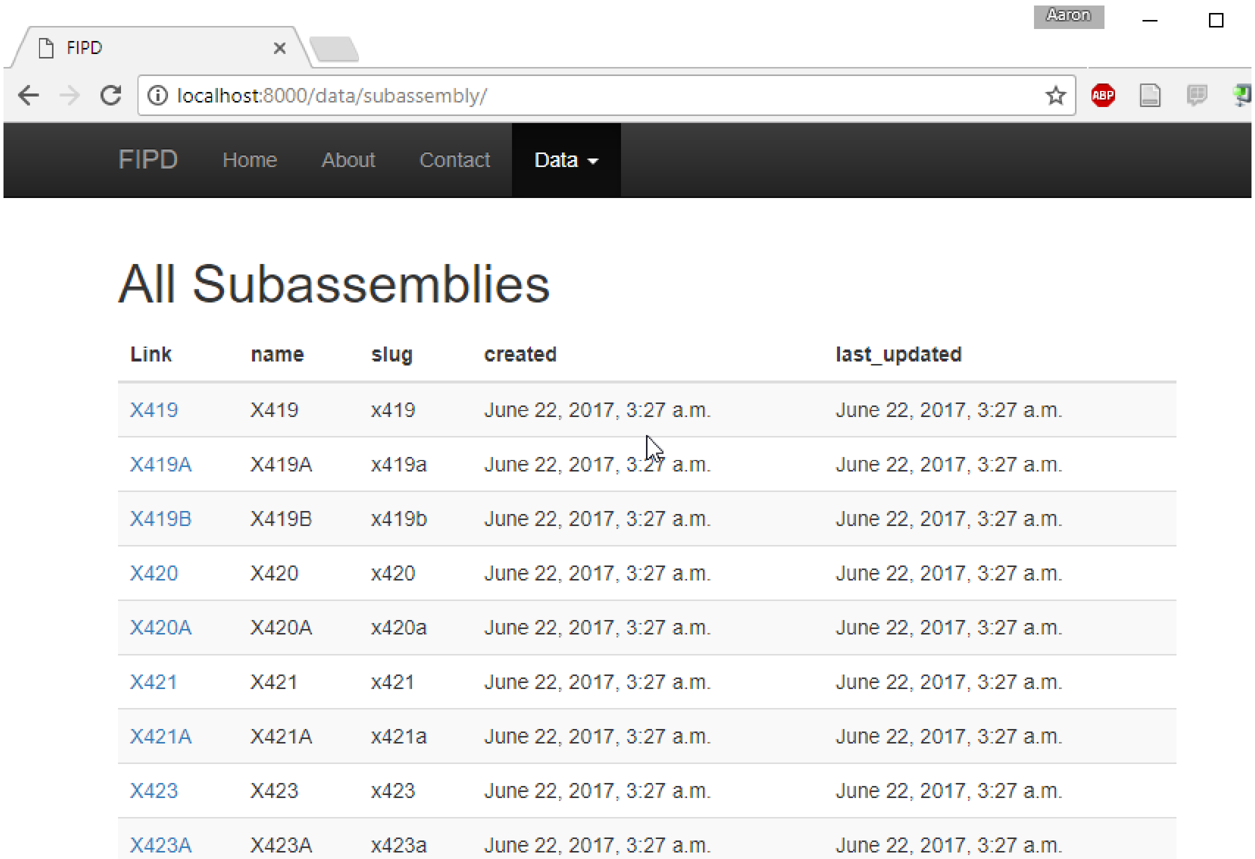
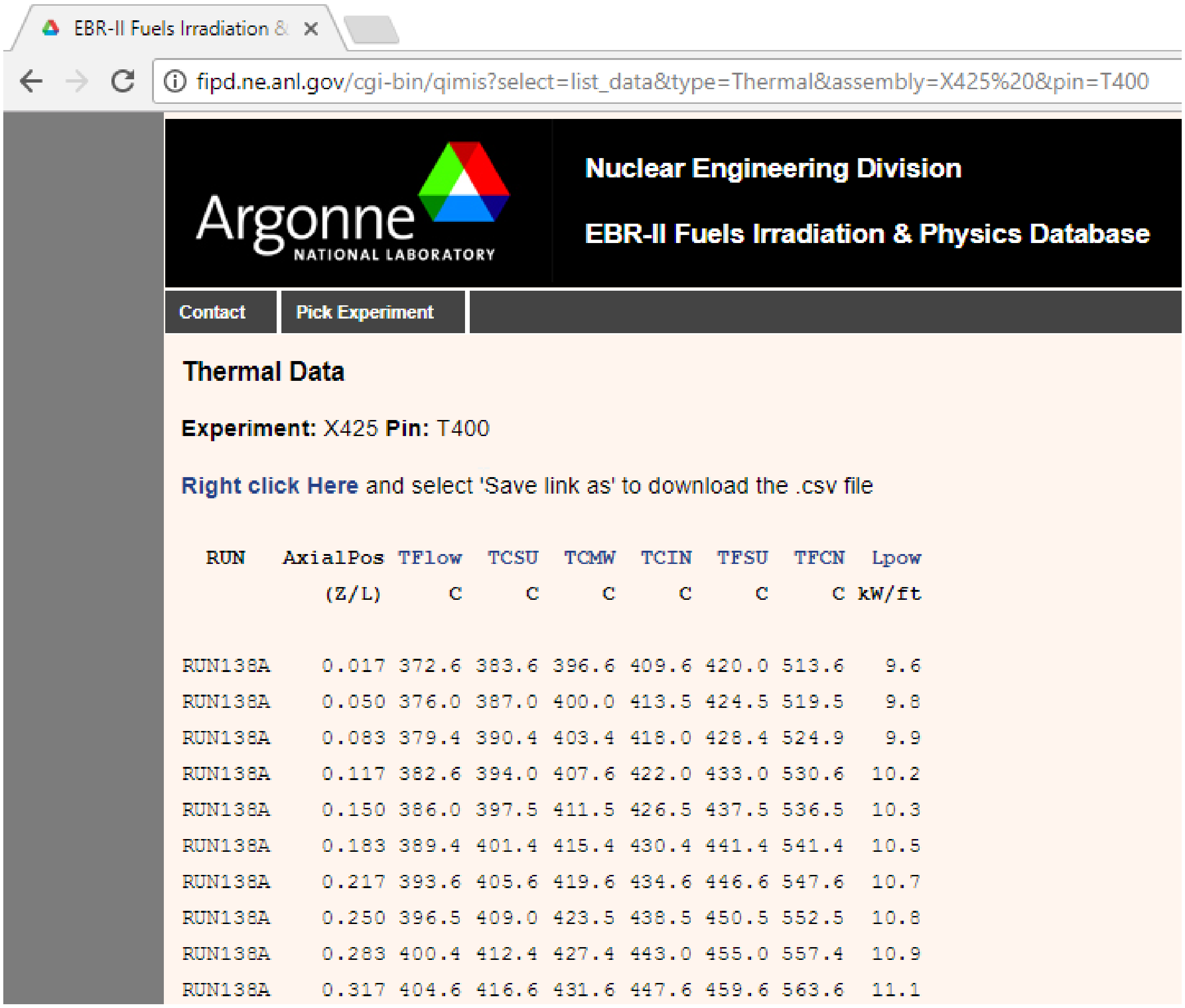


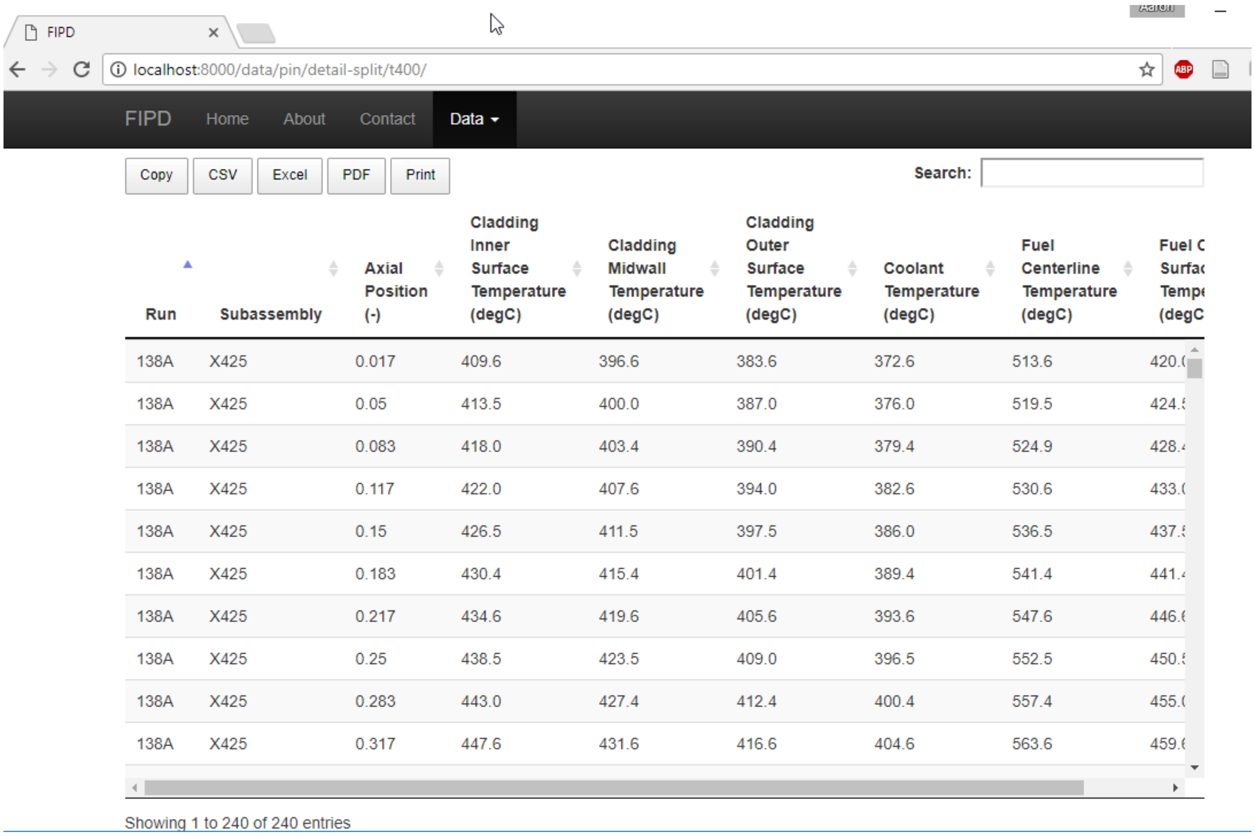
Figure 41: Experiment selection in prototype.

8.6.3 Pin Data



RUN	AxialPos (Z/L)	TFlow C	TCSU C	TCMW C	TCIN C	TFSU C	TFCN C	Lpow kW/ft
RUN138A	0.017	372.6	383.6	396.6	409.6	420.0	513.6	9.6
RUN138A	0.050	376.0	387.0	400.0	413.5	424.5	519.5	9.8
RUN138A	0.083	379.4	390.4	403.4	418.0	428.4	524.9	9.9
RUN138A	0.117	382.6	394.0	407.6	422.0	433.0	530.6	10.2
RUN138A	0.150	386.0	397.5	411.5	426.5	437.5	536.5	10.3
RUN138A	0.183	389.4	401.4	415.4	430.4	441.4	541.4	10.5
RUN138A	0.217	393.6	405.6	419.6	434.6	446.6	547.6	10.7
RUN138A	0.250	396.5	409.0	423.5	438.5	450.5	552.5	10.8
RUN138A	0.283	400.4	412.4	427.4	443.0	455.0	557.4	10.9
RUN138A	0.317	404.6	416.6	431.6	447.6	459.6	563.6	11.1

Figure 42: Pin thermal data in current application.



Run	Subassembly	Axial Position (-)	Cladding Inner Surface Temperature (degC)	Cladding Midwall Temperature (degC)	Cladding Outer Surface Temperature (degC)	Coolant Temperature (degC)	Fuel Centerline Temperature (degC)	Fuel C Surfac Tempe (degC
138A	X425	0.017	409.6	396.6	383.6	372.6	513.6	420.
138A	X425	0.05	413.5	400.0	387.0	376.0	519.5	424.
138A	X425	0.083	418.0	403.4	390.4	379.4	524.9	428.
138A	X425	0.117	422.0	407.6	394.0	382.6	530.6	433.
138A	X425	0.15	426.5	411.5	397.5	386.0	536.5	437.
138A	X425	0.183	430.4	415.4	401.4	389.4	541.4	441.
138A	X425	0.217	434.6	419.6	405.6	393.6	547.6	446.
138A	X425	0.25	438.5	423.5	409.0	396.5	552.5	450.
138A	X425	0.283	443.0	427.4	412.4	400.4	557.4	455.
138A	X425	0.317	447.6	431.6	416.6	404.6	563.6	459.

Showing 1 to 240 of 240 entries

Figure 43: Pin thermal data in prototype. Data tables now include download links in several standard formats.

8.6.4 Data plots

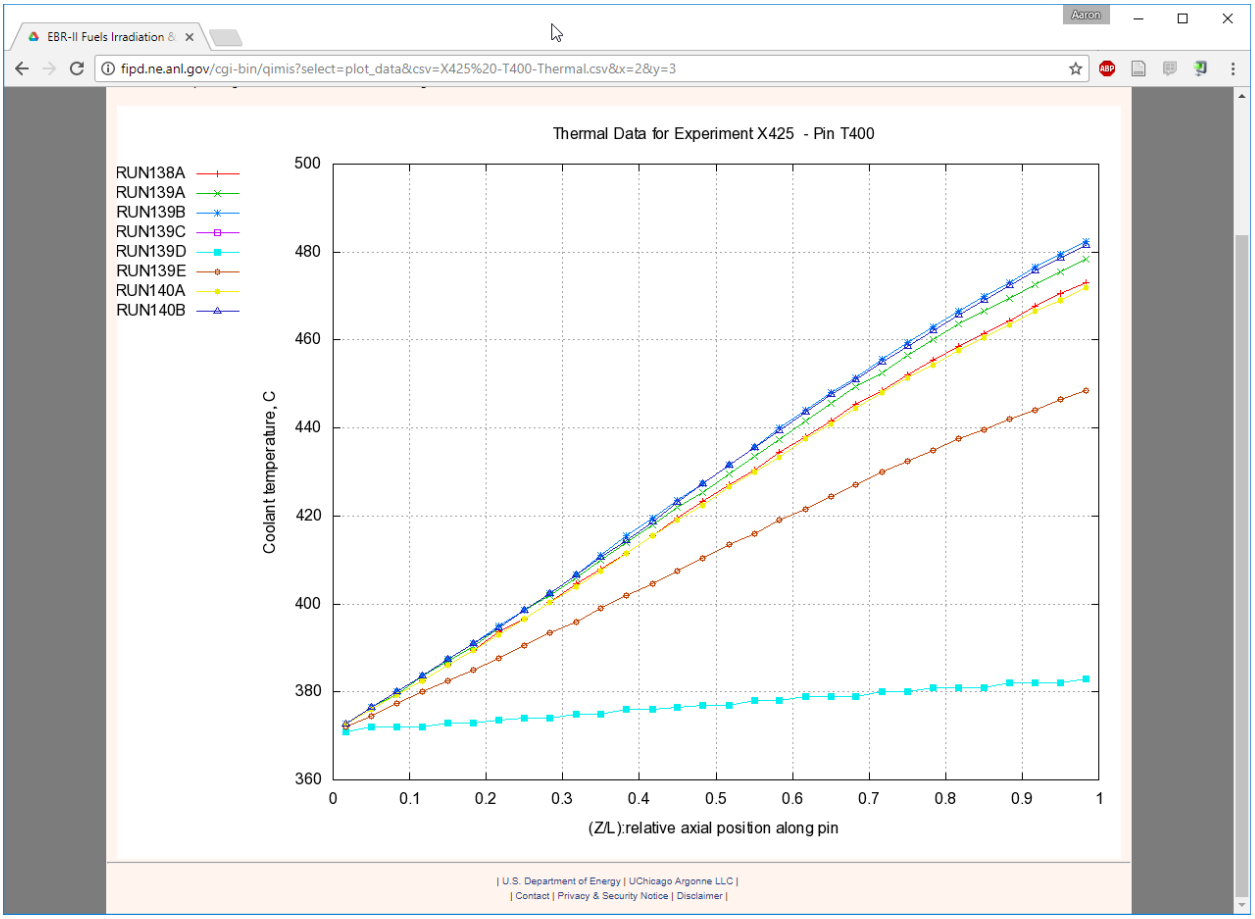


Figure 44: Flow temperatures for all runs of X425/T400 in current application.

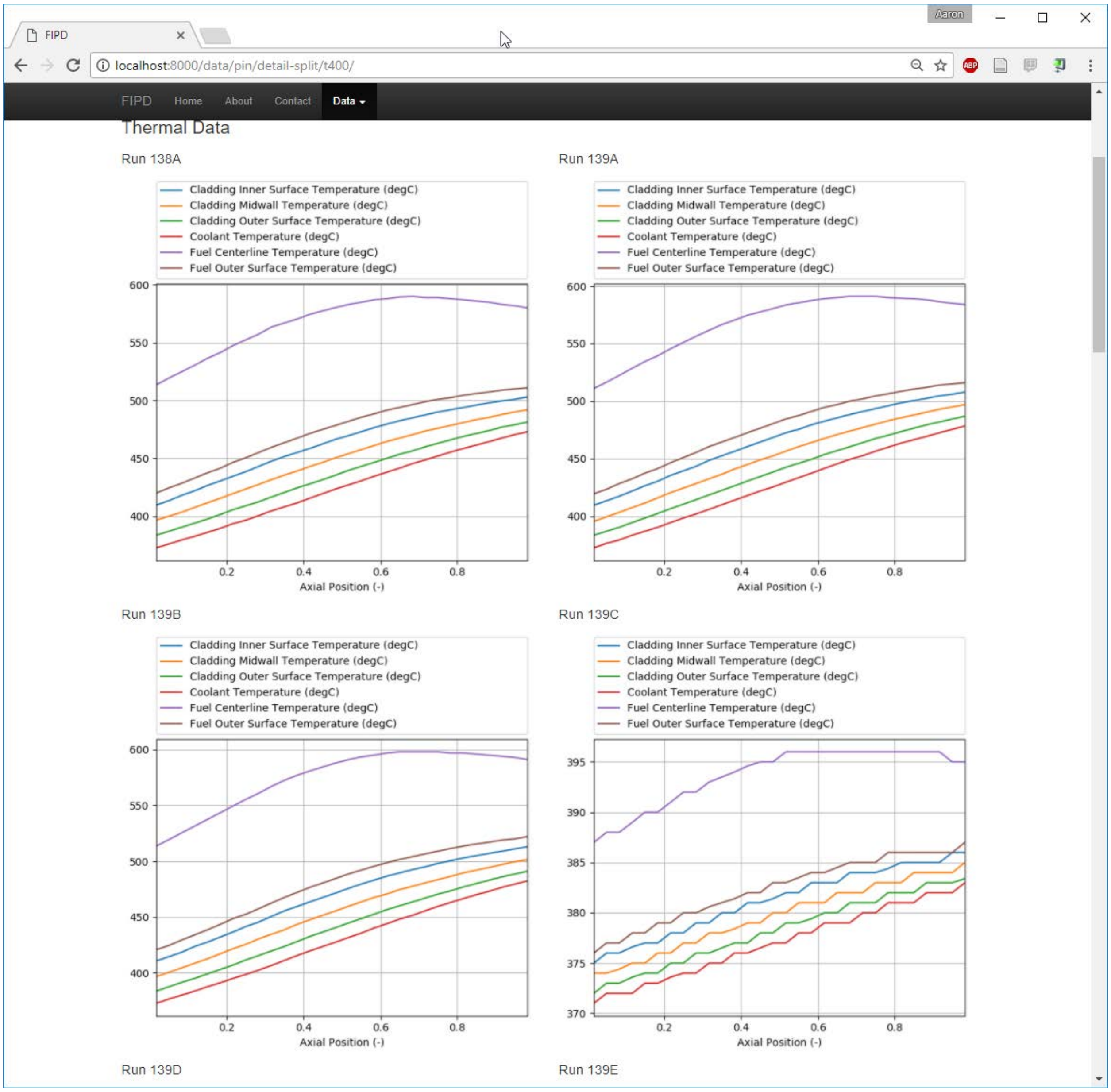


Figure 45: All thermal data plotted for each run for X425/T400 in prototype.

8.7 Transition of Operating Parameter Software to Modern Hardware

The SE2-RCTP (SE2P) code is a specific version of the Superenergy-II and RCTP software maintained at Argonne National Laboratory. Superenergy-II is used for steady state thermal fluids analysis of sodium cooled fast reactors while RCT is used in conjunction with a DIF3D-Nodal solution (assembly homogenized) to reconstruct the detailed flux and power distribution within a sub-assembly. RCTP is used to further reconstruct the subassembly distributions given by RCT into pin-wise distributions.

Most of the fast reactor analysis codes were maintained together in a common SCCS repository which includes DIF3D, Superenergy-II and RCT. This ensured that any developments in one code would lead to simultaneous usage and updates across the entire code system. The SE2P software was not original to the fast reactor code system and thus was not included in the transition process to move all of the reactor analysis software from the deprecated Sun operating system to the Linux operating system carried out in 2008 to 2009. In addition, the software quality assurance documentation (manual) and example problems were not present. Thus as part of the software quality assurance work, we need to transition the software from sun to Linux and put together the basics of source code comparisons. Based upon the personnel doing the work, the SE2P was added to the main fast reactor analysis SVN repository (update from the older SCCS repository) and thus becomes a maintained and consistent component with the rest of the ANL software termed ARC (Argonne Reactor Codes).

8.7.1 SE2P Modifications

The Sun operating system was not too dissimilar from Linux and thus while the executables have to be reconstructed to work with the more open framework of Linux, the main issue was that Sun allowed non-standard Fortran treatments which, when combined with the non-standard programming practices, made the transition tedious. During the OS transition, only a few minor source code updates were made to deal with the deprecated Sun compiler. A single non-fatal memory leak was also identified which was easy to remedy. The software was also hooked up to the latest versions of SEGLIB and SYSLIB, which managed all dynamic memory allocation in RCT and ARC.

8.7.2 Conversion of Binary Data Files

Aside from the code's initial incompatibility with x86 architecture, the other major hurdle was that the source data for power/flux/isotope distributions calculated by RCT were all stored in unformatted (binary) files for use on SPARC (big endian) hardware, which could not be read properly by the code when compiled on x86 (little endian) hardware. To solve this issue, a converter program was written which could read all of the data from original big endian files into memory and write them out to an ASCII text file. The ASCII files can then be copied to a little endian machine and run through the converter in reverse, converting the ASCII data back into the corresponding binary format. These converted binary files can then be properly read in by the SE2P code.

This software was verified manually by checking multiple read/write/print of the same data file to ensure consistency of the data in each operation. Combined with the transition, this allows all work to smoothly transition from the sun to modern Linux workstations.

At the time of this writing, the binary input data for the following experiments have been converted: 133B, 134B, 134C, 135A, 135B, 135C, 135D, 135E, 136A, 136B, 136C, 136D, 137A, 137B, 137C, 138A, 138C, 139A, 139B, 139C, 139D, 139E, 140A, 140B, 141A, 141B, 141C, 142A, 142B, 143A, 144A, 145A, 146A, 146B, 147A, 148A, 148B, 149A, 150A, 150B, 151A, 151B, 152A, 152B, 152C, 152D, 153A, 154A, 154B, 154C, 154D, 154E, 154F, 155A, 155B, 156A, 156B, 157A, 157C, 157D, 157H, 157J, 158A, 158B, 159A, 159B, 160A, 160B, 160C, 161A, 162A, 163A, 164A, 165A, 166A, 167A, 167B, 167C, 168A, 168B, 169A, 170A

8.7.3 Software Verification

The last aspect of discussion is the verification process. The ARC code repository includes source code tracking and a ticket system that is used to track bugs and their resolution. Figure 46 shows examples of the repository directory path (left) along with example source code changes (right).

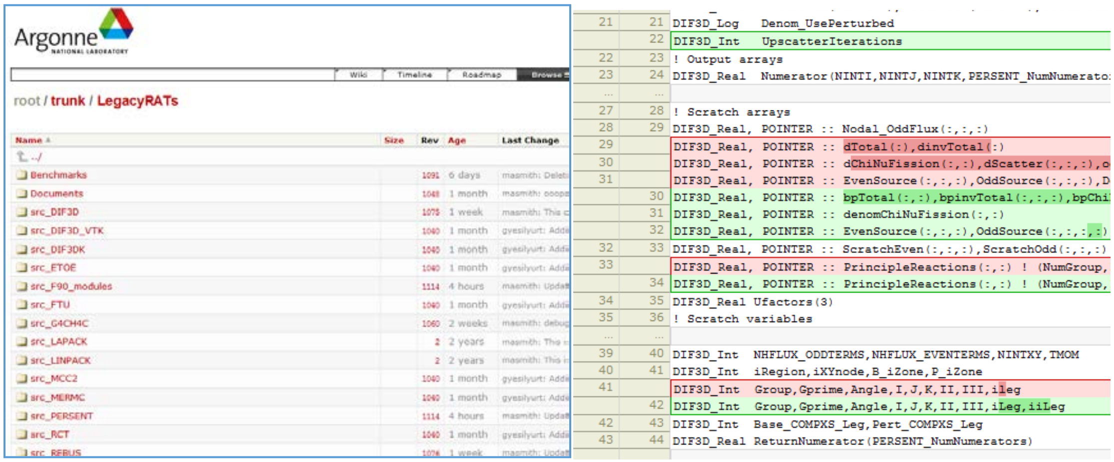


Figure 46: ARC Repository Directory View (left) and Example Code Markup (right).

In addition to improved software tracking, the ARC code repository includes a nightly regression system called BuildBOT. Figure 47 shows a snapshot of the BuildBOT web interface which allows users to review the outcome of nightly executions of the ARC software. The BuildBOT software is Python-based and runs continuously on a dedicated server which only performs this function. Each day, BuildBOT will checkout the full dependencies of each software component of ARC from the repository, compile the source code and all necessary utilities, and execute a series of benchmark problems, the success/failure of which informs BuildBOT of whether the software satisfies the stated SQA. The history of each night's work is maintained on the server for a period of 2 years, after which it is purged. Thus, the web interface allows the user to look backwards over a 2-year period and see how any source code change impacts any specific software piece.

Figure 47: BuildBOT Web Interface Monitoring of the ARC code repository.

The key to the BuildBOT service is the benchmark system. As the bulk of the output from SE2P is identical to Superenergy-II, an existing comparison script from Superenergy-II was duplicated and modified to satisfy the checking requirements for SE2P. This comparison process, a python script, required an expert user to go through the output file and identify every table of important data and prescribe an acceptable tolerance due to compiler and OS related changes (normally just round off errors).

At present, the SE2P software is under source control along as part of the greater ARC code repository. A series of verification problems were chosen by an expert user and a comparison script used to discriminate errors due to compiler changes or operating system changes was created. At present the software undergoes nightly regression testing through the BuildBOT service and any notable problems are brought to the attention of the responsible software developers.

8.8 Development of SE2P data file parsing module

The original SE2 and modified SE2P both output data in a collection of files in text formats designed for printing visual human consumption. Since all existing data is already saved in this style, it was decided that developing a parser for the format would be more useful than modifying to code source to output in a more useful format.

Reviewing the output files, all files were found to be in one of four formats:

Format	File(s)
Thermal	TCIN (cladding inner temp) TCMW (cladding midwall temp) TCSU (cladding outer temp) TFCE (fuel centerline temp) TFSU (fuel surface temp) TFLW (coolant flow temp) LINPW (linear power)
Power	AVPK
Burnup	BUPWF
Isotope Density	ATDEN

Table 11: SE2P output formats.

A sample of each format is given here:

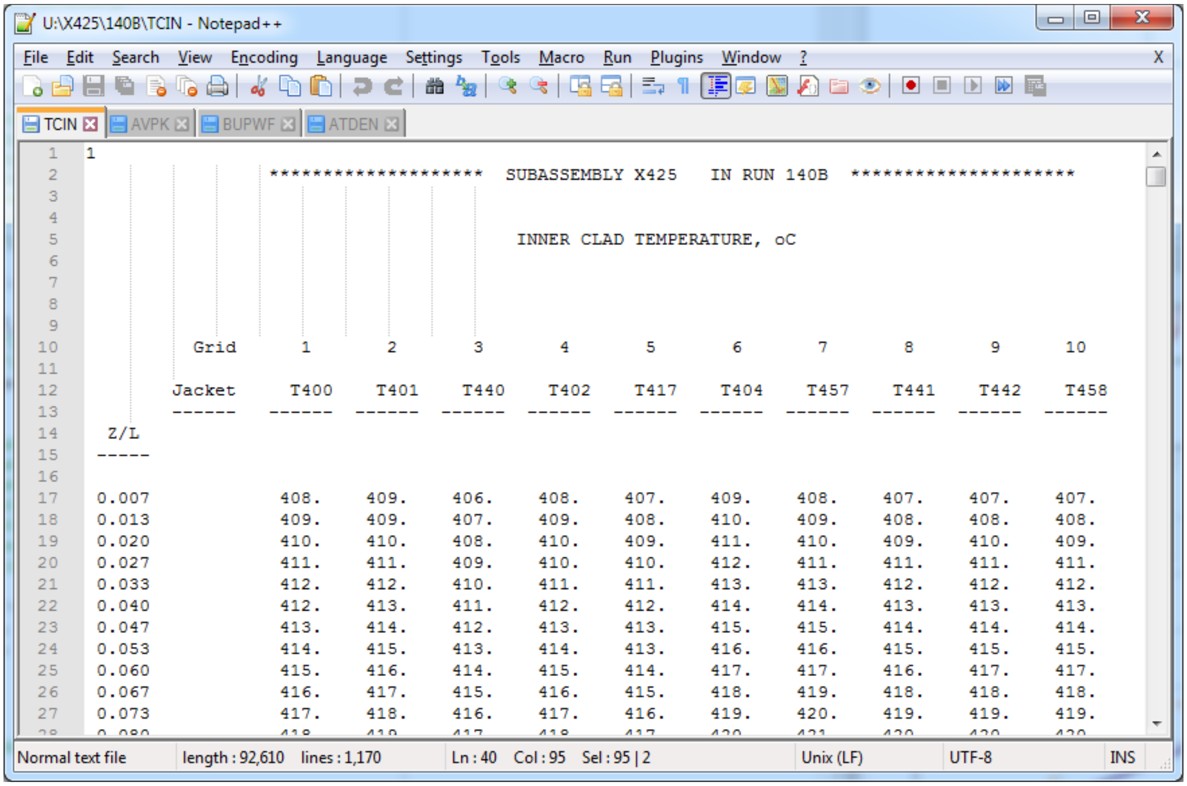


Figure 48: Thermal data text format.

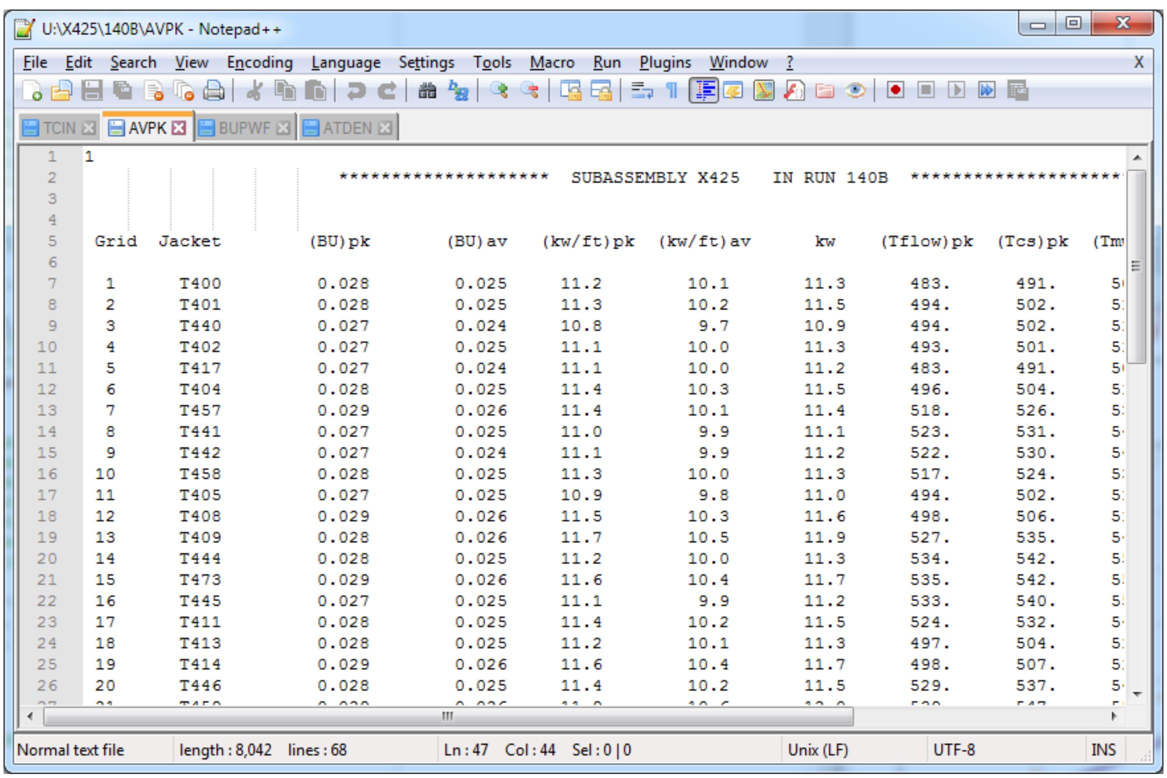
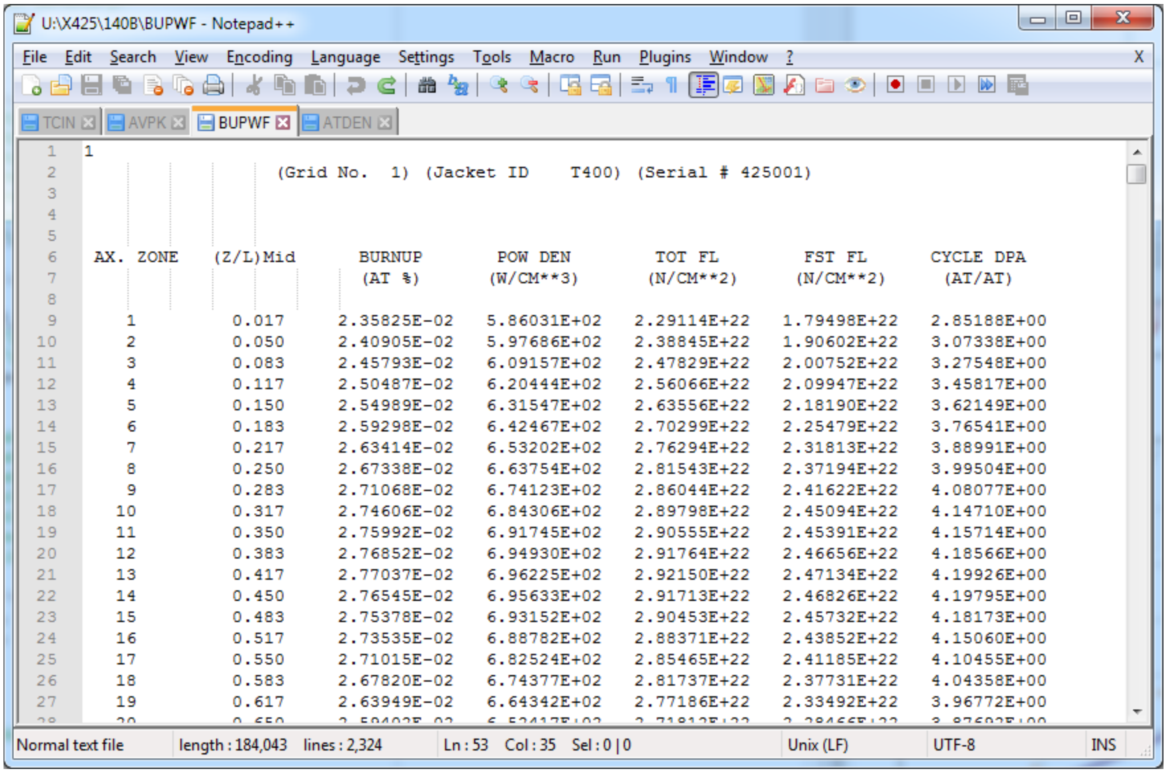


Figure 49: Power data text format.

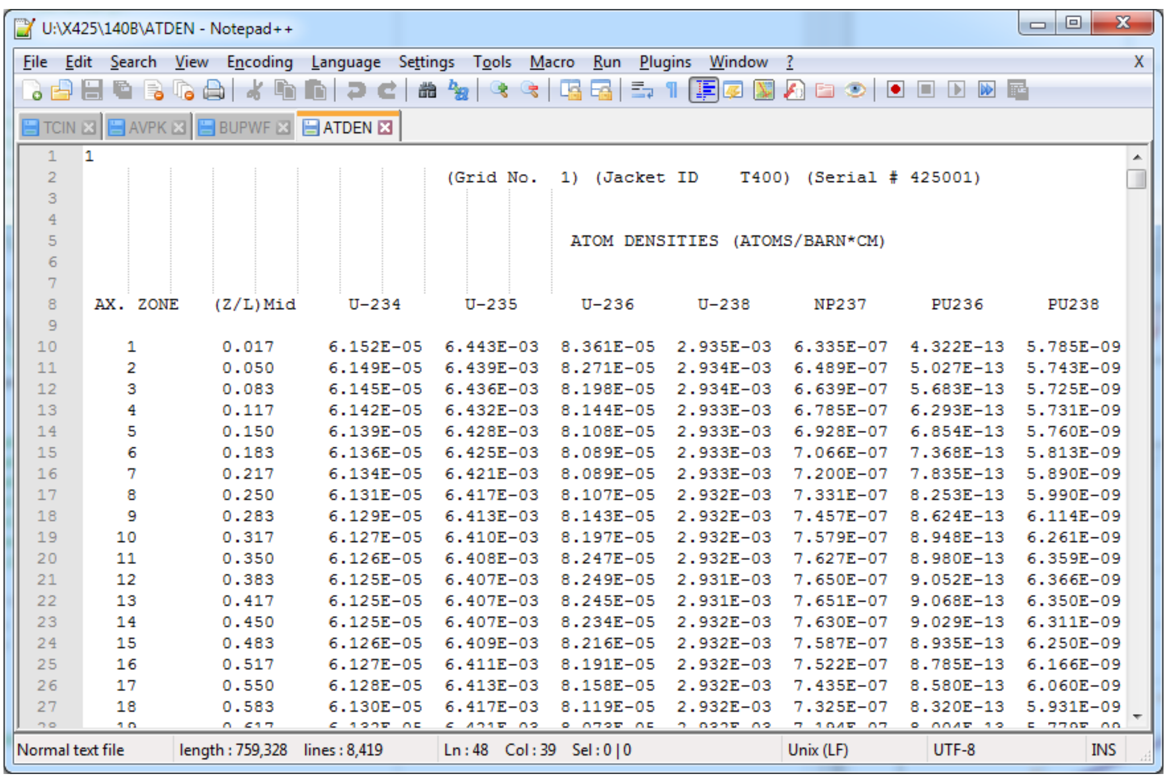


1

(Grid No. 1) (Jacket ID T400) (Serial # 425001)

AX. ZONE	(Z/L)Mid	BURNUP (AT %)	POW DEN (W/CM**3)	TOT FL (N/CM**2)	FST FL (N/CM**2)	CYCLE DPA (AT/AT)
1	0.017	2.35825E-02	5.86031E+02	2.29114E+22	1.79498E+22	2.85188E+00
2	0.050	2.40905E-02	5.97686E+02	2.38845E+22	1.90602E+22	3.07338E+00
3	0.083	2.45793E-02	6.09157E+02	2.47829E+22	2.00752E+22	3.27548E+00
4	0.117	2.50487E-02	6.20444E+02	2.56066E+22	2.09947E+22	3.45817E+00
5	0.150	2.54989E-02	6.31547E+02	2.63556E+22	2.18190E+22	3.62149E+00
6	0.183	2.59298E-02	6.42467E+02	2.70299E+22	2.25479E+22	3.76541E+00
7	0.217	2.63414E-02	6.53202E+02	2.76294E+22	2.31813E+22	3.88991E+00
8	0.250	2.67338E-02	6.63754E+02	2.81543E+22	2.37194E+22	3.99504E+00
9	0.283	2.71068E-02	6.74123E+02	2.86044E+22	2.41622E+22	4.08077E+00
10	0.317	2.74606E-02	6.84306E+02	2.89798E+22	2.45094E+22	4.14710E+00
11	0.350	2.75992E-02	6.91745E+02	2.90555E+22	2.45391E+22	4.15714E+00
12	0.383	2.76852E-02	6.94930E+02	2.91764E+22	2.46656E+22	4.18566E+00
13	0.417	2.77037E-02	6.96225E+02	2.92150E+22	2.47134E+22	4.19926E+00
14	0.450	2.76545E-02	6.95633E+02	2.91713E+22	2.46826E+22	4.19795E+00
15	0.483	2.75378E-02	6.93152E+02	2.90453E+22	2.45732E+22	4.18173E+00
16	0.517	2.73535E-02	6.88782E+02	2.88371E+22	2.43852E+22	4.15060E+00
17	0.550	2.71015E-02	6.82524E+02	2.85465E+22	2.41185E+22	4.10455E+00
18	0.583	2.67820E-02	6.74377E+02	2.81737E+22	2.37731E+22	4.04358E+00
19	0.617	2.63949E-02	6.64342E+02	2.77186E+22	2.33492E+22	3.96772E+00

Figure 50: Burnup data text format.



1

(Grid No. 1) (Jacket ID T400) (Serial # 425001)

ATOM DENSITIES (ATOMS/BARN*CM)

AX. ZONE	(Z/L)Mid	U-234	U-235	U-236	U-238	NP237	PU236	PU238
1	0.017	6.152E-05	6.443E-03	8.361E-05	2.935E-03	6.335E-07	4.322E-13	5.785E-09
2	0.050	6.149E-05	6.439E-03	8.271E-05	2.934E-03	6.489E-07	5.027E-13	5.743E-09
3	0.083	6.145E-05	6.436E-03	8.198E-05	2.934E-03	6.639E-07	5.683E-13	5.725E-09
4	0.117	6.142E-05	6.432E-03	8.144E-05	2.933E-03	6.785E-07	6.293E-13	5.731E-09
5	0.150	6.139E-05	6.428E-03	8.108E-05	2.933E-03	6.928E-07	6.854E-13	5.760E-09
6	0.183	6.136E-05	6.425E-03	8.089E-05	2.933E-03	7.066E-07	7.368E-13	5.813E-09
7	0.217	6.134E-05	6.421E-03	8.089E-05	2.933E-03	7.200E-07	7.835E-13	5.890E-09
8	0.250	6.131E-05	6.417E-03	8.107E-05	2.932E-03	7.331E-07	8.253E-13	5.990E-09
9	0.283	6.129E-05	6.413E-03	8.143E-05	2.932E-03	7.457E-07	8.624E-13	6.114E-09
10	0.317	6.127E-05	6.410E-03	8.197E-05	2.932E-03	7.579E-07	8.948E-13	6.261E-09
11	0.350	6.126E-05	6.408E-03	8.247E-05	2.932E-03	7.627E-07	8.980E-13	6.359E-09
12	0.383	6.125E-05	6.407E-03	8.249E-05	2.931E-03	7.650E-07	9.052E-13	6.366E-09
13	0.417	6.125E-05	6.407E-03	8.245E-05	2.931E-03	7.651E-07	9.068E-13	6.350E-09
14	0.450	6.125E-05	6.407E-03	8.234E-05	2.932E-03	7.630E-07	9.029E-13	6.311E-09
15	0.483	6.126E-05	6.409E-03	8.216E-05	2.932E-03	7.587E-07	8.935E-13	6.250E-09
16	0.517	6.127E-05	6.411E-03	8.191E-05	2.932E-03	7.522E-07	8.785E-13	6.166E-09
17	0.550	6.128E-05	6.413E-03	8.158E-05	2.932E-03	7.435E-07	8.580E-13	6.060E-09
18	0.583	6.130E-05	6.417E-03	8.119E-05	2.932E-03	7.325E-07	8.320E-13	5.931E-09

Figure 51: Atomic density data text format.

Each of the text formats where analyzed for patterns and a Python module was written to automatically parse all of the data files in an SE2P run directory into Pandas Dataframes. By default, since the different formats correspond to different types of data and have different dimensions of information, the results from each format parse are stored independently in a Python dictionary.

```
os.chdir('U:\X425\140B')
all_data = se2parse.parse_run()
```

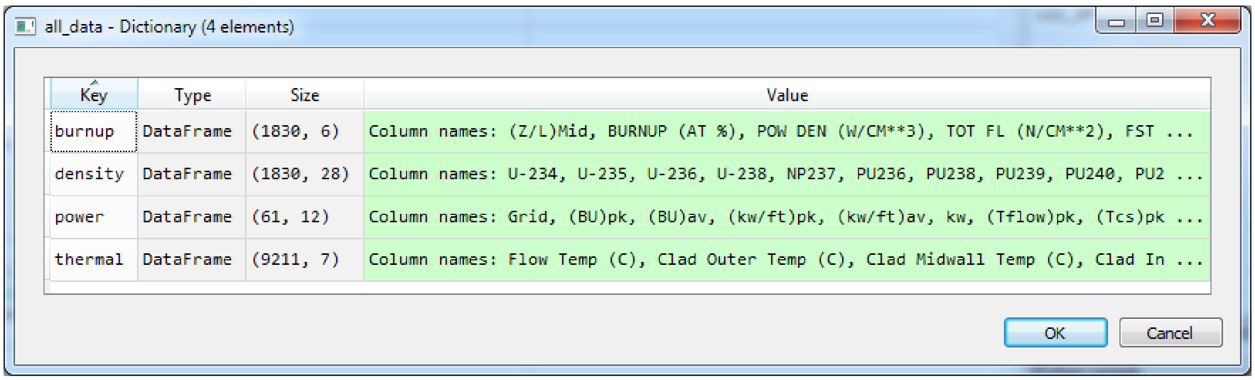


Figure 52: Python dictionary of all data returned by SE2P parsing module.

These dataframes are indexed by pin name and by axial position, with each measured variable (e.g., cladding outer temp, fuel surface temp, etc.) stored as a column of the dataframe.

thermal - DataFrame

Index	Flow Temp (C)	Clad Outer Temp (C)	Clad Midwall Temp (C)	Clad Inner Temp (C)	Fuel Surface Temp (C)	Fuel Center Temp (C)	Linear Power (kw/ft)
('T400', 0.007)	372	385	401	418	430	543	11.8
('T400', 0.013)	372	386	402	419	431	545	11.9
('T400', 0.02)	373	387	403	420	432	546	11.9
('T400', 0.027)	374	387	403	421	433	548	12
('T400', 0.033)	375	388	404	422	434	549	12
('T400', 0.04)	375	389	405	423	436	551	12.1
('T400', 0.047)	376	390	406	423	437	552	12.2
('T400', 0.053)	377	391	407	424	438	554	12.2
('T400', 0.06)	377	391	408	425	439	555	12.3
('T400', 0.067)	378	392	409	426	440	557	12.4
('T400', 0.073)	379	393	410	427	441	558	12.4
('T400', 0.08)	380	394	410	428	442	560	12.5
('T400', 0.087)	380	395	411	429	443	561	12.5
('T400', 0.093)	381	395	412	430	444	562	12.6
('T400', 0.1)	382	396	413	431	445	564	12.7
('T400', 0.107)	382	397	414	432	446	565	12.7
('T400', 0.113)	383	398	415	433	447	567	12.8
('T400', 0.12)	384	398	416	434	448	568	12.8
('T400', 0.127)	385	399	416	435	449	569	12.9

Format Resize Background color Column min/max OK Cancel

Figure 53: Thermal data in Python Pandas dataframe.

Once in dataframe form, all of the data analysis tools available from Python's Pandas library can be applied. For example, calculating descriptive statistics for the thermal data of the T400 pin:

```
thermal.loc['T400'].describe()
```

all_data - DataFrame

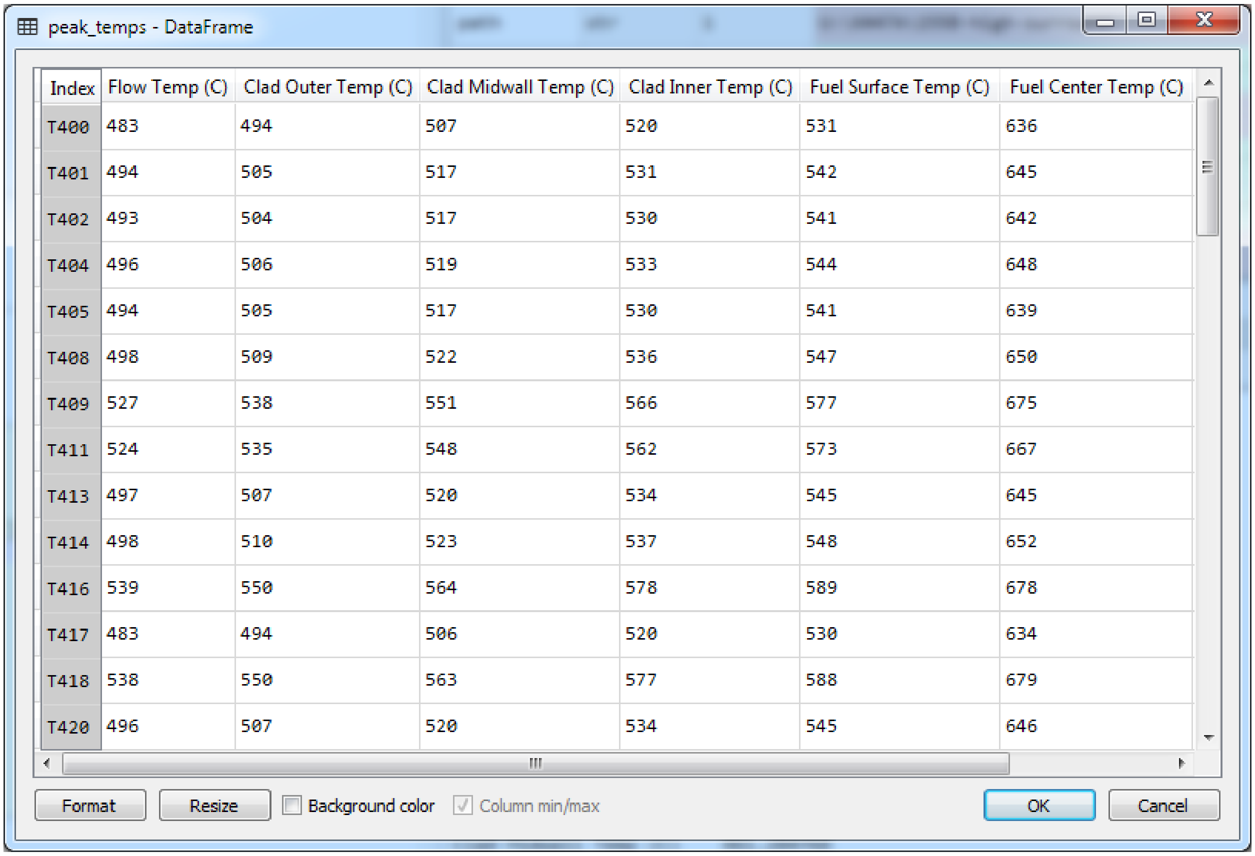
Index	Flow Temp (C)	Clad Outer Temp (C)	Clad Midwall Temp (C)	Clad Inner Temp (C)	Fuel Surface Temp (C)	Fuel Center Temp (C)	Linear Power (kw/ft)
count	151	151	151	151	151	151	151
mean	429	444	461	480	494	611	13
std	33.7	33	32.2	31.4	31.2	26.6	1.41
min	372	385	401	418	430	543	9.4
25%	400	416	434	454	468	596	12.1
50%	430	446	466	486	503	622	13.3
75%	460	474	490	508	523	632	14.2
max	483	494	507	520	531	636	14.5

Format Resize Background color Column min/max OK Cancel

Figure 54: Descriptive statistics of thermal data from Python Pandas dataframe.

Or calculating the peak temperatures for each pin:

```
thermal.groupby(level='Jacket').max()
```



Index	Flow Temp (C)	Clad Outer Temp (C)	Clad Midwall Temp (C)	Clad Inner Temp (C)	Fuel Surface Temp (C)	Fuel Center Temp (C)
T400	483	494	507	520	531	636
T401	494	505	517	531	542	645
T402	493	504	517	530	541	642
T404	496	506	519	533	544	648
T405	494	505	517	530	541	639
T408	498	509	522	536	547	650
T409	527	538	551	566	577	675
T411	524	535	548	562	573	667
T413	497	507	520	534	545	645
T414	498	510	523	537	548	652
T416	539	550	564	578	589	678
T417	483	494	506	520	530	634
T418	538	550	563	577	588	679
T420	496	507	520	534	545	646

Figure 55: Fuel pin peak temperatures calculated by Python Pandas dataframe.

Or visualizing the Pin T400 data in the table by plotting it:

```
thermal.loc['T400'].plot()
```

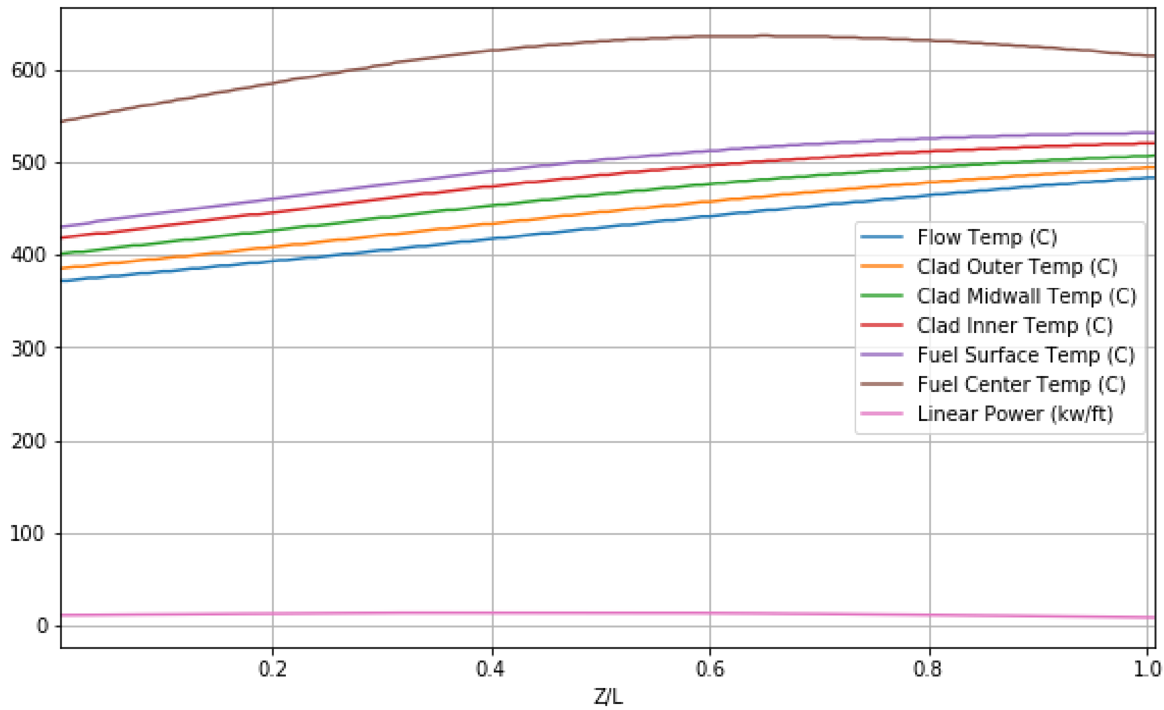


Figure 56: Dataframe data as plotted by Python Pandas library.

9 FUTURE ACTIVITIES

Currently, the FIPD contains majority of the key metallic fuel experiments data needed for supporting fuel behavior analysts and reactor designers, as well as supporting industry licensing activities for fast reactor designs that are based on metallic U-Zr fuels. The current mature state of the database will allow its immediate utilization to support those areas, as activities in both areas are expected to accelerate in the near future.

For example, adaptation of the advanced fuel performance code BISON [18] to metallic fuel is at the state where it will require detailed validation and verification effort, especially as it is identified as a code of interest to both NRC and industry. The detailed data provided through the database is the type of data needed for BISON V&V activities, as well as, supporting improvements in the code physics based models. In addition, the recent consideration of the deployment of a US test fast reactor (Versatile Test Reactor – VTR [19]) that is based on metallic U-Zr fuel, highlights the importance of the database and the quality of its data.

Recently, there has been industry stake holders who are promoting different types of advanced fast reactor designs that are based on the US experience with metallic fuels in fast reactors. Those industries include TerraPower, GE Hitachi Nuclear Energy, Oklo Inc., and Advanced Reactor Concepts (ARC), where some are already engaged in licensing discussions with the NRC. For example, Oklo Inc. is currently engaged in pre-application activities with the NRC for licensing their specific design, where metallic fuel performance and the qualification of metallic fuel data in the FIPD is key part of the discussion.

Based on the above discussion, it is clear that the quality of the data accumulated in the FIPD is important to both analysts and industry, and QA will need to be a major part of future database related activities. The following is a summary of potential future FIPD activities:

- Continue revising data, including PIE images and graphs, in the database as original images become available from the original databook at ANL or INL
- Include databooks for all available experiments from AGHCF and databooks from HFEF (as it become available), and QA related documents (especially HFEF related documents).
- Continue security improvements of the database and access control activities to provide the database to wider audience.
- Maintenance of the database software as described in the SQAPP.
- Make data available to analysts in NEAMS or other DOE supported programs
- Support industry specific requests for data, and support the qualification of the data to meet NRC requirements for use in licensing related activities.
- Implement all data relevant to metallic fuel experiments in IMIS database into the FIPD, so that the data tables can be queried directly within the FIPD
- Include all relevant data from the whole pin furnace experiments (WPF) and the fuel behavior test apparatus (FBTA) into the database to make it available for transient simulations and licensing support, and link the data to the relevant operating experience of each fuel pin.

REFERENCES

[1] A. Yacout and T. Sofu, Argonne National Laboratory, unpublished information , Sep. 2011.
[2] A. M. Yacout *et al.*, Argonne National Laboratory, unpublished information, Sep. 2012.
[3] A. M. Yacout *et al.*, Argonne National Laboratory, unpublished information , Aug. 2013.
[4] W. Mohamed *et al.*, Argonne National Laboratory, unpublished information, Aug. 2014.
[5] T. Sofu *et al.*, Argonne National Laboratory, unpublished information, Sep. 2015.
[6] T. Sofu *et al.*, Argonne National Laboratory, unpublished information, Sep. 2016.
[7] K. L. Basehore and N. E. Todreas, "SUPERENERGY-2: A multiassembly, steady-state computer code for LMFBR core thermal-hydraulic analysis," Pacific Northwest Laboratory, PNL-3379, Aug. 1980.
[8] T. Fei, *et al.*, Argonne National Laboratory, unpublished information, Sep. 2014.
[9] A. M. Yacout, Argonne National Laboratory, unpublished information, 20-Nov-1992.
[10] E. A. Hoffman, "Neutron Transmutation of Nuclear Waste," Georgia Institute of Technology, 2002.
[11] Argonne National Laboratory, unpublished information, September 2017.
[12]A. M. Yacout and M. C. Billone, "Pre-Licensing Evaluation of Legacy SFR Metallic Fuel Data," Argonne National Laboratory, ANL-ART-76, Sep. 2016.
[13] "Quality Assurance Program Plan for SFR Metallic Fuel Data Qualification (QAPP)," Argonne National Laboratory, ANL/NE-16/17, Rev. 0.
[14] A. Young, Argonne National Laboratory, unpublished information, June 2017.
[15] A. M. Yacout and M. C. Billone, "Current Status of the LIFE Fast Reactors Fuel Performance Codes," presented at the FR13: International Conference on Fast Reactors and Related Fuel Cycles, Paris, France, 04-Mar-2013.
[16] Django Software Foundation, "Django: The Web framework for perfectionists with deadlines." [Online]. Available: https://www.djangoproject.com/. [Accessed: 06-Sep-2017].
[17] M. Otto, J. Thornton, and Bootstrap Contributors, "Bootstrap: The most popular HTML, CSS, and JS library in the world." [Online]. Available: http://getbootstrap.com. [Accessed: 06-Sep-2017].
[18] R. L. Williamson *et al.*, "Multidimensional multiphysics simulation of nuclear fuel behavior," *Journal of Nuclear Materials*, vol. 423, no. 1, pp. 149–163, Apr. 2012.
[19] Nuclear Energy Advisory Committee (NEAC) Assessment of Missions and Requirements for a New U.S. Test Reactor," February 2017.

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