FCT Quality Assurance Program Document

Appendix E
FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	Complete Prototype UNF Database and Associated Documentation
Work Package Title and Number	UNF Data and M&S Toolset Development and Demonstration – ORNL FT-12OR082202
Work Package WBS Number	1.02.08.22
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Quality Rigor Level for Deliverable/Milestone	☐ QRL-3	☐ QRL-2	☐ QRL-1 ☐ Nuclear Data	☒ N/A*

This deliverable was prepared in accordance with Oak Ridge National Laboratory
(Participant/National Laboratory Name)

QA program which meets the requirements of
☒ DOE Order 414.1 ☐ NQA-1-2000

This Deliverable was subjected to:

☒ Technical Review

☐ Peer Review

Technical Review (TR)

Review Documentation Provided

☐ Signed TR Report or,

☒ Signed TR Concurrence Sheet or,

☐ Signature of TR Reviewer(s) below

Peer Review (PR)

Review Documentation Provided

☐ Signed PR Report or,

☐ Signed PR Concurrence Sheet or,

☐ Signature of PR Reviewer(s) below

Name and Signature of Reviewers

*Note: In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity along with the Document Cover Sheet is sufficient to demonstrate achieving the milestone. QRL for such milestones may be also be marked N/A in the work package provided the work package clearly specifies the requirement to use the Document Cover Sheet and provide supporting documentation.

A Comprehensive Database and Automation Tool for Used Nuclear Fuel Safety Analyses

Fuel Cycle Research & Development

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Used Fuel Disposition Campaign
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EXECUTIVE SUMMARY

This technical letter report documents work performed supporting the Department of Energy (DOE) Office of Nuclear Energy (NE) Fuel Cycle Technologies Used Fuel Disposition Campaign (UFDC) under work breakdown structure element 1.02.08.22, *Used Nuclear Fuel Assessment Capabilities*. In particular, this report fulfills the M3 milestone M3FT-12OR08220213, *Complete Prototype UNF Database and Associated Documentation*, within work package FT-12OR082202 – UNF Data and M&S Toolset Development and Demonstration. This report documents prototype development of the database system that will subsequently be refined and expanded upon.

A centralized, comprehensive, and integrated data and analysis tool system is being developed to facilitate modeling and analysis capabilities for existing storage and transportation cask systems. The analysis system is referred to as the used nuclear fuel (UNF) Integrated Data, Experiments, and Analysis System (IDEAS). Initial work documented in this report is focused on building the system infrastructure and integrating existing data and analysis capabilities that form the nucleus of UNF-IDEAS. The nucleus is referred to as Comprehensive Database and Automation Tool (CDAT) for Used Nuclear Fuel Safety Analyses. CDAT will provide key technical data and real-time analysis capabilities for demonstrating compliance with regulatory requirements and assessing technical issues related to the aging and safety of discharged nuclear fuel. The objective of CDAT is to develop and integrate UNF data and analysis capabilities and apply the initial version to streamline the characterization of UNF inventory, determine realistic safety margins and conditions, and assess risks and uncertainties. CDAT is instrumental to demonstrating the power and value of UNF-IDEAS for application to: (1) developing technical basis for UNF extended storage and transport after extended storage; (2) evaluating and prioritizing the needs for fundamental research, engineering solutions, and regulatory guidance changes; and (3) providing data and systems assessments to help inform decision makers and future policy actions. The development of the UNF-IDEAS is a multi-year, multi-laboratory effort led by Oak Ridge National Laboratory.

The UNF database and the modeling and simulation automation tool are developed simultaneously in a consistent manner. Technical data collection and its synthesis into appropriate formats are based on the SCALE and COBRA-SFS input requirements for depletion, criticality, and thermal analysis, whereas model templates for the computer codes utilize fuel assembly and storage cask information from the UNF database. Currently, the UNF database contains the RW-859 data, basic fuel assembly data such as assembly design parameters for representative assembly types, reactor- and cycle-specific data, and cask data, which are organized in relational structured query language data tables.

TRITON model templates have been developed for assembly types representative of the pressurized water reactor (PWR) Westinghouse (W) 14×14, 15×15, 17×17, Babcock and Wilcox 15×15, and Combustion Engineering 14×14 assemblies. Initial CSAS6 model templates have been developed for the TROJAN MPC 24E/EF storage cask and the W17×17 assembly types. These templates will be improved to accommodate different assembly types, different cladding materials, non-fuel components typically inserted into assembly guide tubes, damaged fuel cans, etc. For fast-running depletion calculations with ORIGEN, ARP cross-section libraries have been generated for representative PWR and boiling water reactor (BWR) assembly types. A modeling and simulation automation tool has been developed to streamline UNF nuclear safety evaluations. The current version of the tool has the capability to autonomously generate PWR ARP cross-section libraries and CSAS6 input files as well as access pre-generated BWR ARP cross-section libraries. Each of these libraries is retained within the database system and used to generate thermal source terms and used fuel composition data for each discharged fuel assembly identified in the RW-859 database.

Collection of additional data from the nuclear industry has been initiated with the help of the Nuclear Energy Institute. Reactor operating data for the Sequoyah Nuclear Plant, Units 1 and 2, and Watts Bar Nuclear Plant Unit 1 has been provided by the Tennessee Valley Authority (TVA) along with cask loading information for the Independent Spent Fuel Storage Installation (ISFSI) sites. TVA also provided Brown's Ferry Nuclear Power Plant ISFSI data, and Duke Energy has provided data for the Catawba and McGuire nuclear sites. ISFSI site data has also been collected for the decommissioned reactors Connecticut Yankee, Maine Yankee, and Yankee Rowe. These data are being evaluated and incorporated into the centralized UNF database.

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FIGURES (continued)

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TABLES

LIST OF ACRONYMS AND UNITS

ANF	Advanced Nuclear Fuel
APSR	axial power shaping rods
B&W	Babcock & Wilcox
BPRA	burnable poison rod assembly
BWR	boiling water reactor
CDAT	Comprehensive Database and Automation Tool
CFR	Code of Federal Regulations
CE	Combustion Engineering
COBRA–SFS	COolant Boiling in Rod Arrays–Spent Fuel Storage
DOE	U.S. Department of Energy
DPCs	dual purpose canisters
EOC	end of cycle
UFDC	Fuel Cycle Technologies Used Fuel Disposition Campaign
GC	(U.S. DOE Office of the) General Counsel
GE	General Electric
GUI	graphical user interface
IDEAS	Integrated Data, Experiments, and Analysis System
ISFSI	Independent Spent Fuel Storage Installation
k_{eff}	effective neutron multiplication factor
LOPAR	low parasitic (fuel)
M&S	modeling and simulation
NE	(U.S. DOE) Office of Nuclear Energy
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PWR	pressurized water reactor
QA	quality assurance
RCCA	control cluster assembly
SQL	relational structured query language
SS	stainless steel
SSCs	structures, systems, and components
TVA	Tennessee Valley Authority
UNF	used nuclear fuel
WABA	wet annular burnable absorber (rod)
W	Westinghouse

Used Fuel Disposition Campaign *A Comprehensive Database and Automation Tool for Used Nuclear Fuel Safety Analyses*

1. INTRODUCTION

Used nuclear fuel (UNF) is expected to be stored at reactor sites for longer time intervals than originally foreseen. Extended storage over long periods of time may affect the integrity of important-to-safety structures, systems, and components (SSCs), thus potentially compromising the safety of fuel storage units. Current dry cask licensing experience has been based on the use of conservative modeling approximations and UNF assemblies with an average burnup up to 45 GWd/MTU to meet relatively short storage periods where temporal effects on material properties could be justified as relatively negligible. As documented in the *Gap Analysis to Support Extended Storage of Used Nuclear Fuel* (Ref. 1), the ability of the SSCs to continue to meet safety functions over extended times and for subsequent transportation must be maintained and demonstrated. Uncertainties associated with the physical characteristics of the fuel assemblies at discharge will necessarily propagate and compound with increased storage times resulting in increases in UNF shipping, handling, and disposal costs. For most SSCs important to safety, additional data are required, often because there are limited data on new materials used in more modern fuel assemblies or dry storage cask systems, or because the effects of high burnup and extended storage are not fully known.

The key storage and transportation safety functions and gaps identified in Ref. 1 span many different technical disciplines. As indicated in *Used Nuclear Fuel Storage and Transportation Research, Development, and Demonstration Plan* (Ref. 2), addressing these functions requires a number of different modeling and simulation (M&S) and experimental efforts to be performed by a variety of experts. To address the technical issues associated with UNF storage, transportation, and disposal and to generate the technical data to support licensing and periodic relicensing activities in a timely and cost-effective manner, a centralized system is being developed that provides a predictive simulation capability and uncertainty quantification to enable extrapolation of results to extended storage timeframes. The centralized system is illustrated in Figure 1, and is known as the UNF Integrated Data, Experiments, and Analysis System (UNF-IDEAS). UNF-IDEAS will ensure that individual efforts are integrated and coordinated to accomplish the Department of Energy (DOE) Office of Nuclear Energy (NE) Fuel Cycle Technologies Used Fuel Disposition Campaign (UFDC) goals, identify and prioritize data and analysis needs based on impact to safety margins, inform future experimental demonstration programs to maximize return on investment, as well as establish an invaluable UNF archive.

Initial work documented in this report is focused on building the system infrastructure and integrating existing data and analysis capabilities forming the nucleus of UNF-IDEAS. A more complete discussion of UNF-IDEAS will be provided in a subsequent update of this report. The analysis system developed in this report is referred to as the UNF Comprehensive Database and Analysis Tool (CDAT) in the remainder of this document. The purpose of CDAT is to provide a comprehensive resource with key technical data and real-time analysis capabilities for demonstrating compliance with regulatory requirements and assessing technical issues related to aging and safety of discharged nuclear fuel. The objective of the CDAT is to develop and integrate UNF data and analysis capabilities and apply the initial version to streamline characterization of UNF inventory, determination of realistic safety margins and conditions, and assessment of risks and uncertainties. Thus, the system is instrumental to demonstrating the power and value of UNF-IDEAS for application to: (1) developing technical bases for UNF extended storage and transport after extended storage; (2) evaluating and prioritizing needs for fundamental research, engineering solutions, and regulatory guidance changes; and (3) providing data and systems assessments to help inform decision makers and future policy actions.

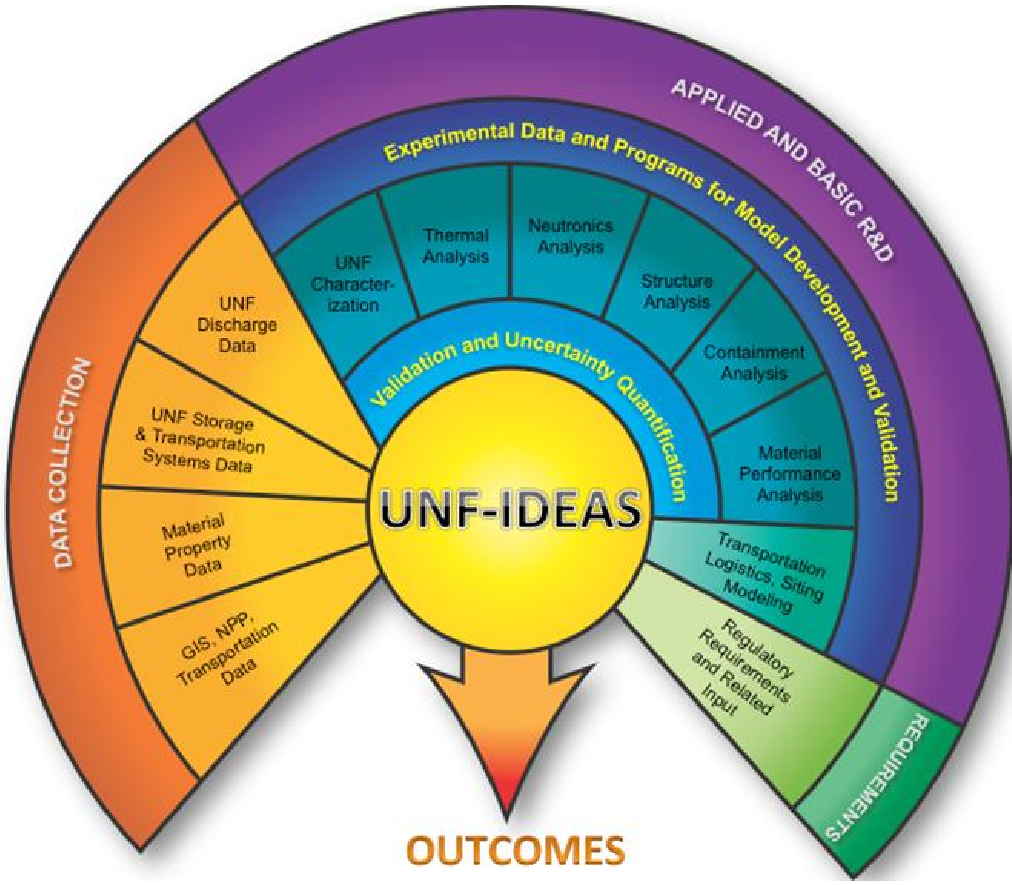

Figure 1. Illustration of UNF-IDEAS.

The development of CDAT is part of a larger program goal and is a multi-laboratory effort, led by Oak Ridge National Laboratory (ORNL), that includes:

- integration of existing modeling and simulation (M&S) tools and inventory data for UNF characterization, criticality safety, and thermal analyses;
- development of computational models to support UNF characterization, criticality safety, and thermal analyses;
- analysis of existing loaded canisters of interest to the Used Fuel Disposition Program; and
- validation of the developed analysis capabilities and data.

A comprehensive UNF database and associated documentation are key components of CDAT. The development of the UNF database includes the following activities:

- identification of technical data to be collected based on the input requirements to computer codes dedicated to out-of-reactor nuclear safety analyses (i.e., depletion, criticality, and thermal analyses);

- documentation of the scope and requirements of the database;

- development of a data request questionnaire to collect supplemental information that is not collected as part of the General Counsel (GC)-859 data collection activity;

- development of an archive database for the UNF discharge data using an appropriate data format;

- collection of UNF discharge data, with a focus on operational history information;

- data processing (e.g., review for acceptance, reformat, etc.) and incorporation into database system;

- data analysis for observations relative to safety analyses, including identification of any gaps and/or limitations of the data; and

- development of model templates for depletion, criticality, and thermal analyses.

Collection of additional data from the nuclear industry has been initiated with the help of the Nuclear Energy Institute (NEI). Reactor operating data for the Sequoyah Nuclear Plant, Units 1 and 2, and Watts Bar Nuclear Plant Unit 1 has been provided by Tennessee Valley Authority (TVA) along with cask loading information for the Independent Spent Fuel Storage Installation (ISFSI) sites. TVA also provided Brown's Ferry Nuclear Power Plant ISFSI data, and DUKE Energy has provided data for the Catawba and McGuire nuclear sites. ISFSI site data has also been collected for the decommissioned reactors Connecticut Yankee, Maine Yankee, and Yankee Rowe. These data are being evaluated and incorporated into the centralized UNF database.

Currently, CDAT consists of the following components:

- a database of fuel assembly discharge and storage information as of December 2002 (Ref. 3) and basic fuel assembly design and generic operating data collected from publicly available documents such as *Characteristics of Spent Fuel, High-Level waste, and other Radioactive Wastes which may Require Long-Term Isolation* (Ref. 4) and commercial reactor criticality data summary reports (e.g., Ref. 5);

- a collection of model templates for depletion and criticality analyses; and

- a computer modeling and simulation tool used to automate the variety of safety analyses.

The benefits of a comprehensive UNF database for safety analyses are described in Sect. 2. Section **Error! Reference source not found.** provides a description of the current CDAT components, including the centralized UNF database, the safety analysis computer codes, the developed fuel assembly and cask templates for depletion and criticality calculations, and the current modeling and simulation automation tool. The UNF database schema is provided in Appendix A. An example of data source documentation developed for traceability purposes is provided in Appendix B. A questionnaire developed for reactor operating data, which is supplemental information not collected as part of the GC-859 data collection activity, is presented in Appendix C. Examples of model templates for the depletion and criticality calculations are included in Appendices D and E, respectively.

2. BENEFITS OF A COMPREHENSIVE DATABASE FOR UNF CHARACTERIZATION

There are many potential benefits to having improved UNF characterization such as streamlining current cask loading operations, decreased used fuel assembly pool cooling time periods required, and increased fuel assembly payloads in casks. Two immediately recognizable benefits with substantial potential cost implications that will be discussed further are: (1) allowing direct disposal of dual purpose canisters (DPCs) and transport of DPCs after long-term storage; and (2) preventing premature implementation of compensatory/corrective measures due to overly conservative analysis approximations.

2.1 Direct Disposal of DPCs and Transport after Extended Storage

A limited number of studies have been conducted regarding the feasibility of direct disposal of DPCs. These studies have concluded that, although it is possible, demonstrating criticality control over the disposal time period is one of the primary challenges (Refs. 6 and 7). Similar constraints may also be present for meeting transportation requirements after extended storage periods.

Existing DPCs were not loaded considering the issues for disposal and as such, do not have neutron absorbers with the corrosion-resistant properties necessary to meet potential disposal criticality control needs. However, a significant amount of uncredited safety margin was incorporated at the time of loading. For example, a fresh fuel assumption or other similar conservative assumptions were used in place of the specific loaded contents. Development of the technical basis to enable direct disposal of DPCs and transport of DPCs after extended periods of storage as well as transport of high-burnup fuel is expected to require more realistic safety margin estimates. Improved safety margin estimates allow a decrease in the uncredited margin. Detailed assembly operating history information allows improved UNF characterization that may allow credit for some previously uncredited margin that is present to account for effects of corrosion on neutron absorber panels. Reducing the amount of uncredited margin enables the benefits of burnup credit to be maximized in meeting subcriticality requirements while maintaining adequate safety margin.

2.2 Prevent Premature Implementation of Compensatory/Corrective Measures

Overly conservative analysis approximations may be used for UNF characterization where detailed operating history data is unavailable. Overly conservative analysis approximations could lead to prematurely invoking compensatory measures, such as repackaging bare fuel, canisterizing a significant fraction of UNF prior to storage, or requiring additional criticality control prior to transport and disposal (e.g., inserting disposal control rod assemblies). Therefore, a significant benefit of operating history data availability is prevention or reduction of the compensatory measures that would be justified based on overly conservative analysis approximations.

Corrosion and degradation—aging—of the overall storage system (i.e., fuel, canister, and overpack), and especially of the closure systems (e.g., welds, bolts, seals), is temperature dependent. Hence, it is crucial to accurately model the temperature-dependent degradation mechanisms to identify if/when a cask system should be replaced or repackaged, as well as to facilitate mitigation strategies. More detailed UNF characterization data coupled with thermal analysis capabilities will enable: (1) reduced conservatism for mechanisms that are worse at higher temperatures; and (2) enhanced safety through accurate modeling of degradation mechanisms that are worse at lower temperatures (e.g., deliquescence).

Current methods in use typically over-predict the time-dependent temperature profiles by an unknown amount. This can hinder efforts to accurately predict confinement breaches due to low temperature degradation phenomena and over-predict the number of fuel rods that may potentially fail during extended storage. Two of the primary phenomena of concern related to maintaining fuel integrity during and following extended storage periods are hydride reorientation/embrittlement and delayed hydride cracking (Ref. 1). Detailed assembly service history information supports predictions of the susceptibility and extent of the stored fuel to potential hydride reorientation. Similarly, this information can be used in conjunction with dry storage cask system loading patterns to determine when the assemblies have cooled sufficiently such that the cladding may undergo a ductile-to-brittle transition. CDAT allows more accurate peak temperatures during assembly drying to be calculated, as well as more accurate low temperatures to be estimated during extended storage, preventing a gross overestimation of the number of rods that could potentially fail during storage which could result in compensatory measures (e.g., canisterizing all fuel assemblies prior to storage) being imposed for future cask loading campaigns.

3. COMPREHENSIVE DATABASE AND AUTOMATION TOOL

The comprehensive database and automation tool system has been developed with the capability to completely automate depletion, criticality, and thermal analyses using fuel depletion conditions that are either bounding or nominal with respect to criticality/thermal analyses. In addition, the automation tool has been designed to perform either: (1) a fast-running but moderately-accurate depletion calculation using fuel assembly design and irradiation history data representative of generic assembly classes, or (2) a highly-accurate but slower-running depletion calculation using detailed fuel assembly-specific design and irradiation history data. User's input is limited to selecting the type of evaluation, the depletion conditions, and the fuel assemblies/cask system for the analysis.

The overall data base system is in the developmental stage. The current components of the database are hosted on an ORNL server and interface capability is provided through a separate application that will be transitioned to a web portal. The current components of CDAT are:

- a centralized database containing technical information about discharged commercial UNF, assembly design and operating parameters, and cask loading patterns for use as inputs to the various safety analyses (see Sect. 3.1);
- established computer codes for depletion, criticality, and thermal calculations (see Sect. 3.2);
- a collection of fuel assembly and cask model templates for depletion and criticality calculations (see Sect. 3.3);
- a collection of cross-section libraries representative of assembly types for fast depletion calculations (see Sect. 3.4);
- a computer code that has the capabilities to automate model development for depletion, criticality, and thermal calculations, execute the nuclear safety analysis codes, and provide the calculation results (e.g., nuclide concentration values, the effective neutron multiplication factor k_{eff} for a spent fuel storage cask, and temperature distribution for a spent fuel storage/transport cask) (see Sect. 3.5).

A general representation of CDAT is provided in Figure 2. As illustrated in the figure, four different data sets are combined with nuclear safety analysis models to develop inputs to out-of-reactor nuclear safety analyses (i.e., depletion, criticality, and thermal analyses). The analysis system components and the process for automating UNF safety analyses are described further in the report.

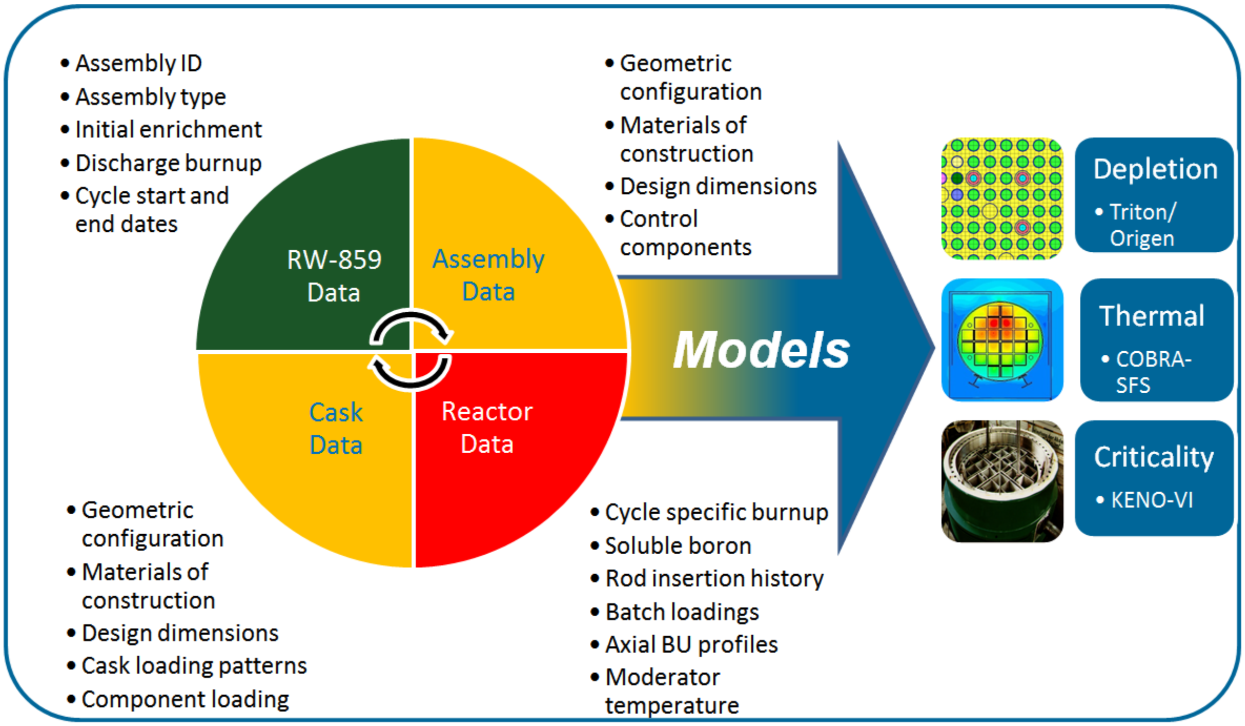

Figure 2. General representation of CDAT.

3.1 Combined UNF Database

Available spent fuel discharge data (Ref. 3) has not been updated since 2002, and collection and availability of useful and relevant data pertaining to used fuel irradiation histories are not consolidated or readily available to support the analyses that will be required prior to UNF transport. Additional data related to spent fuel characteristics, particularly reactor exposure conditions and physical fuel conditions, could be used to reduce current analysis conservatisms (which would correspond to cost savings) and positively influence decision making related to design and licensing. Hence, a comprehensive and integrated database for supporting real-time safety analysis capabilities of UNF is needed.

The combined UNF database under development is an electronic database that functions within the CDAT. The purpose of the database is to supply all the technical data identified as input parameters to the various safety analyses, such as cask loading pattern, assembly design characteristics, initial enrichment, final burnup, initial uranium content, discharge date, reactor- and cycle-specific data, etc. There are four different types of data in the centralized database: (1) the GC-859 data, currently consisting of the RW-859 fuel assembly discharge information from Ref. 3; (2) fuel assembly design data (e.g., technical data collected from Ref. 4); (3) reactor-specific operation data; and (4) cask design and loading data. The RW-859 database does not include detailed assembly-specific and reactor cycle-specific information needed for safety analyses. Therefore, it has been supplemented with basic assembly design data and generic reactor data collected from other publicly available sources. These data are referred to as surrogate (i.e., substitute) data, which is representative of generic reactor and assembly classes. Surrogate data will be periodically updated and expanded as detailed assembly-specific and reactor cycle-specific information becomes available.

The fuel characterization data in the centralized database is organized in Structured Query Language (SQL) relational database tables that store the various data. Database schema and established data relationships are illustrated in Appendix A. Note that the database consists of numerous tables and the schema has been subdivided into six parts from the top to the bottom and from the left side to the right side of the schema for the purpose of readability. A primary key is used to uniquely identify a data table. Each table contains a set of related parameters, each parameter being identified with a verbose name that explicitly describes that parameter. For example, the table identified as *assembly* contains general assembly design characteristics from the RW-859 database such as assembly identifier denoted as *assembly_id*, initial uranium mass per assembly denoted as *initial_uranium*, initial average ^{235}U enrichment denoted as *initial_enrichment*, and assembly final burnup denoted as *max_burnup*. The parameter names are used consistently throughout CDAT. Appropriate relationships among the variables in the SQL data tables have been implemented so that all the relevant parameters are automatically made available for use in a safety analysis, based on the analysis type, reactor identifier, assembly type, and cask type.

Technical data traceability is being documented in PDF files, which were included in the database and linked to the corresponding SQL data tables. An example of a documentation sheet for the pressurized water reactor (PWR) Westinghouse 17×17 LOPAR assembly design data is provided in Appendix B. Dimension values expressed in the English System of Units in the reference documents, dimension values converted to the International System of Units, the source documents, and the pages providing the original parameter values are all described in the documentation sheet.

3.1.1 RW-859 Data

The most recent nuclear fuel discharge and storage data covers UNF discharged from commercial reactors as of December 31, 2002 (Ref. 3). These data, referred to as the RW-859 database, contain basic discharge information for 70,292 PWR UNF assemblies and 93,351 boiling water reactor (BWR) assemblies. The UNF assemblies in the RW-859 database are categorized into assembly classes based on assembly outside dimensions, which are further subdivided by assembly type for a total of 134 individual fuel assembly types discharged from both U.S. PWRs and BWRs as of December 31, 2002 (Ref. 8). Currently, the data collection authorization is under the auspices of the U.S. DOE Office of the General Counsel and the nuclear data survey has been redesignated as Form GC-859.

UNF discharge data available in the RW-859 database for use in the UNF safety analyses include:

- reactor and fuel assembly identifiers;
- assembly type;
- initial ^{235}U enrichment;
- initial uranium content;
- assembly discharge burnup;
- reactor cycle corresponding to assembly discharge; and
- reactor cycle start and end dates.

Fuel assembly initial enrichment, final burnup, and discharge date are essential parameters for determining nuclide concentrations and associated source terms. However, these parameters are insufficient for modeling purposes because a depletion calculation model requires far more input parameters (e.g., fuel pin dimensions, fuel temperature and specific power, moderator density and temperature, etc.). Therefore, technical data beyond that available in the RW-859 database, including basic fuel assembly and reactor cycle-specific data, has been collected to facilitate model development for UNF safety analyses.

3.1.2 Basic Fuel Assembly Data

Currently, the combined UNF database contains basic design data for representative fuel assembly types collected from publicly available sources (e.g., Ref. 4). Assembly design data include:

- assembly array size, rod pitch, and assembly pitch;
- number of guide tubes/water rods and their assembly locations;
- fuel pellet and clad dimensions;
- assembly reactivity control components;
- design dimensions for assembly guide tube, instrument tube, water rod, or assembly channel;
- design dimensions for burnable poison and control rods; and
- construction materials.

It is expected that the current data will be supplemented in the future with detailed assembly-specific information such as exposure to removable burnable poison, the enrichment of the burnable poison, fuel temperature, etc.

3.1.3 Reactor Cycle-specific Data

Limited reactor cycle-specific data for selected reactors and cycles is available from commercial reactor criticality data summary reports (e.g. Refs. 5, 9, 10). These data include:

- cycle specific burnup;
- soluble boron concentration as a function of time;
- control rod insertion history;
- batch loadings;
- axial burnup profiles; and
- moderator temperature.

Additional reactor cycle-specific data is expected to be provided by the nuclear industry for operational or decommissioned U.S. commercial nuclear reactors. Currently, reactor operating data for the Sequoyah Nuclear Plant, Units 1 and 2, and Watts Bar Nuclear Plant Unit 1 has been provided by TVA. These data are being evaluated and incorporated into the centralized UNF database. A questionnaire developed for reactor operating data, which is supplemental information not collected as part of the GC-859 data collection activity, is presented in Appendix C.

3.1.4 Cask Data

As of January 2011, 90 facilities have placed used fuel in dry storage (Ref. 11) using a variety of casks with different loading capacities. Cask data consists of cask design data (i.e., cask geometry configuration, materials of construction, and design dimensions), which typically is provided in safety analysis reports for spent fuel dry storage systems, and cask loading data (i.e., cask loading patterns and component loading), which is specific to a storage facility and is not readily available. General dry storage and cask information, such as the information shown in Table 1 for selected nuclear power plants, is being collected for inclusion in the combined UNF database for general information purposes. Cask loading information for Brown's Ferry, Sequoyah, Catawba, and McGuire nuclear plants as well as for the ISFSIs at the sites of the decommissioned reactors Connecticut Yankee, Maine Yankee, and Yankee Rowe is currently available. These data are being evaluated and incorporated into the centralized UNF database.

3.1.5 Surrogate Data

Some of the depletion modeling parameters are not directly available and need to be derived from the available technical data. These modeling parameters are referred to as surrogate data. An example of such a modeling parameter is assembly average specific power. This parameter is assembly- and irradiation-cycle specific and is typically calculated as the assembly burnup for an irradiation cycle divided by the cycle length. However, the current RW-859 database does not provide end-of-cycle assembly burnup values for use in specific power calculations. Only assembly final burnup and the assembly discharge cycle are available from the database. Therefore, an assumption has been made concerning the number of cycles in which a fuel assembly has been irradiated. It has been assumed that an assembly with a final burnup smaller than 30 GWd/MTU has been irradiated for two consecutive cycles and an assembly with a final burnup greater than 30 GWd/MTU has been irradiated for three consecutive cycles. This assumption is used to calculate irradiation time and specific power for assembly-specific depletion calculations. The impact of this assumption on the cask k_{eff} values is considered to be small based on the results of previous parametric studies (Refs. 12 and 13).

Table 1. Example of dry storage information

Utility	Exelon	Duke	Dominion
Reactor	LaSalle	McGuire	Surry
Type	BWR	PWR	PWR
License type	General license	General license	General license
Year of first load[a]	2010	2001	2007
Vendor	Holtec	NAC	TN
Cask system	HI-STORM	NAC-UMS	NUHOMS
Canister or cask type	MPC-68	UMS-24	32PTH
Docket number	HI-STORM 100 (71-1014)	NAC-UMS (71-1015)	NUMOMS HD-32PTH (71-1030)
Total canisters or casks loaded	6	28	15
Assemblies stored	408	672	480
Storage configuration	Canister in vertical concrete overpack	Canister in vertical concrete overpack	Canister in horizontal concrete overpack
Minimum lead time for shipment[b]	14 months	24 months	24 months
Inside diameter (in)	67.375	65.81	68.75
Outside diameter (in)	68.375	67.06	69.75
Length (in)	190.3125	191.8	185.75
Gross weight (lbs)	282,000	251,492	N/A
Assembly capacity	68	24	32
Maximum loaded mass	87,171	72,900	108,760
Maximum thermal output for storage (kW)	18.5	23	34.8
Maximum thermal output for transportation (kW)	18.5	20	N/A
Maximum design-basis burnup (MWd/MTU)	30,000	45,000	60,000
Maximum enrichment (wt% ^{235}U)	4.2	4.2	5.0
Minimum cooling time (years)	5	5	5
Canister outer material composition	stainless steel (SS)	SS	SS
Canister internal materials and structural design	SS, Al, Boral	SS, Al, Boral	SS, Al, Boral
Basket materials	SS, Al, Boral	SS, Al, Boral	SS, B-Al, Al
Neutron absorber materials	Boral	SS, Al, Boron	SS, Al, Boron
Spacer and thermal shunts	Alloy X, SS	SS	steel
Shield plug	SS	SS	steel
Method for criticality control	Fixed borated neutron absorber	Flux trap principle	Borated aluminum (Boralyn)
Reference	14, 15	16	17

[a]For multiple cask ISFSI sites the earliest load date applies to all casks.
[b]Lead time due to primary cask not yet fabricated.

3.2 Nuclear Analysis Computer Codes

The computer code for depletion and criticality calculations is the SCALE (Ref. 18) code system. A depletion calculation determines actinide and fission product nuclide concentrations in discharged nuclear fuel assemblies and the associated decay heat source terms, which are used as part of the input to subsequent criticality and thermal calculations, respectively. Depletion calculations are performed with the TRITON sequence or ORIGEN/ARP computer codes in the SCALE code system. A criticality calculation determines the effective neutron multiplication factor (k_{eff}). Criticality calculations are performed with the CSAS6 sequence in the SCALE code system. The computer code for thermal analysis is the thermal-hydraulic analysis code COBRA-SFS (Ref. 19). Fuel assembly and cask model templates for depletion, criticality, and thermal analyses are currently being developed and integrated into CDAT.

The executable and supporting data files for SCALE and COBRA–SFS are integrated into CDAT. The computer program dedicated to calling and executing the nuclear analysis computer codes through the data system is being developed. A description of the computer program will be discussed in a future revision of this report.

3.2.1 SCALE

SCALE is a system of computer codes for depletion, decay, criticality, and shielding analyses. This computer code system has been developed by Oak Ridge National Laboratory and distributed for more than 30 years through the Radiation Safety Information Computational Center and the Nuclear Energy Agency Data Bank under license agreement. SCALE has been used for safety analysis and design by regulators, licensees, and research institutions around the world. This code is accepted by the U.S. Nuclear Regulatory Commission for criticality safety applications (Ref. 20). SCALE 6.1 is the most recent release version of the SCALE code system. The SCALE computer codes/sequences used by CDAT are described further.

The SCALE code system has a highly accurate depletion analysis capability with TRITON (Ref. 18, Sect. T01) and a moderately accurate but fast-running depletion analysis capability with ORIGEN using pre-generated problem-specific ARP cross sections. TRITON has the capability of using a two-dimensional representation of a fuel assembly and simulating the depletion of multiple mixtures in the fuel assembly model. The TRITON two-dimensional (2-D) depletion calculation sequence employs CENTRM (Ref. 18, Sect. F18) for multi-group cross-section processing, NEWT (Ref. 18, Sect. F21) for 2-D discrete ordinates transport calculations, and ORIGEN (Ref. 18, Sect. F07) for depletion and decay calculations. The ARP computer code uses an interpolation algorithm and pre-generated one-group cross sections for generic assembly/reactor specific classes and a range of initial enrichment, burnup, and moderator density to rapidly generate cross sections for specific fuel initial enrichment, burnup, and moderator density values, which are subsequently used in ORIGEN depletion calculations. Within CDAT, the TRITON depletion sequence is used to perform either: (1) assembly-specific detailed depletion calculations that provide actinide and fission product nuclide concentrations in discharged nuclear fuel assemblies or (2) depletion calculations that generate ARP cross-section libraries for generic assembly/reactor specific classes and a range of initial enrichment, burnup, and moderator density.

Within CDAT, the CSAS6 criticality analysis sequence in the SCALE code system is used to perform resonance cross-section processing and a Monte Carlo criticality transport calculation with KENO VI.

3.2.2 COBRA-SFS

COolant **B**oiling in **R**od **A**rrays–Spent Fuel Storage (COBRA–SFS) is a thermal-hydraulic code used to perform calculation of flow and temperature distributions in spent fuel storage systems under a wide range of flow conditions, including mixed and natural convection. The COBRA software series was originally designed for thermal-hydraulic analysis of nuclear fuel rod bundles in reactor cores. COBRA–SFS uses the same subchannel formulation, but has been extensively modified and improved for application to single phase analysis of spent fuel storage and transportation systems with radiative, convective, and conductive heat transfer. Several features specific to UNF storage analyses are incorporated in COBRA–SFS, including the capability to model a detailed radiation heat transfer model, which includes individual fuel rods and boundary conditions that simulate radiation and natural convection heat transfer from storage system surfaces, and calculate three-dimensional conduction heat transfer through fuel basket and cask body. Within CDAT, COBRA–SFS is used to determine the spatial distribution of the temperature within the cask.

3.3 Fuel Assembly and Cask Model Templates for Depletion, Criticality, and Thermal Calculations

As a result of the large number of spent fuel assemblies and cask loading patterns that may require detailed modeling of fuel depletion, a fast, reliable, and quality-assurable method of input model creation has been developed. Assembly and cask model templates are currently being developed for depletion, criticality, and thermal calculations. The fuel assembly and cask model templates as well as input parameters from the combined UNF database are used by a Java-based template engine to develop complete input files for depletion, criticality, and thermal calculations. Model templates contain three basic components: (1) input data blocks that do not vary as a function of fuel assembly characteristics (e.g., description of cask dimensions and construction materials for criticality or thermal calculations); (2) input parameters that vary as a function of assembly characteristics (e.g., fuel pin dimensions in an assembly model for depletion calculations or nuclide concentrations in a cask model for criticality calculations); and sub-templates to be imported (e.g., templates describing fuel pin arrays for depletion or criticality calculations). Model template development, update, and review are conducted using the Mercurial distributed source control management tool, which is widely used for version control of files.

3.3.1 TRITON Model Templates

TRITON models are stored in a compact form as a set of templates, for each type of fuel assembly, which permits an automated method of input file assembly with verified dimensions and conditions stored in a single location. TRITON model templates have been developed for assembly types representative of the PWR Westinghouse (W) 14×14, W15×15, W17×17, Babcock & Wilcox (B&W) 15×15, and Combustion Engineering (CE) 14×14 assemblies. The assembly-specific parameters supplied include fuel pin, guide tube, and removable absorber rod patterns, dimensions, materials, and temperatures, fuel and removable absorber initial enrichments, moderator temperature and density, cycle-dependent specific power and irradiation time, and soluble boron concentration. A description of the TRITON model templates for depletion calculations for the assembly type W17×17 LOPAR is provided in Appendix D.

3.3.2 CSAS6/KENO-VI Model Templates

CSAS6 models are stored in a compact form as a set of templates for each type of cask, which permits an automated method of input file assembly with verified dimensions and conditions stored in a single location. Currently, CSAS6 model templates for the MPC24E/EF cask have been developed. This cask has been loaded with W17×17 fuel assemblies discharged from the TROJAN reactor (Ref. 14). The assembly-specific parameters supplied include assembly pattern description, which depends on the assembly type, and nuclide concentrations in fuel mixtures, which depend on assembly characteristics such as final burnup, initial enrichment, axial burnup profile, and decay time. A description of the CSAS6 model templates for the MPC24E/EF cask and the W17×17 fuel assembly type is provided in

Appendix E. The cask model includes a very large number of fuel mixtures because each fuel assembly and each axial burnup zone in the model has a unique fuel composition. For example, the cask model for the MPC24E/EF cask has a total of 432 different fuel mixtures, which is determined as the product between the number of fuel assemblies in the cask (i.e., 24 fuel assemblies) and the number of axial burnup zones modeled (e.g., 18 axial zones for the PWR active fuel region). The ENDF/B-VII continuous-energy cross-section library is used for the CSAS6 criticality calculations.

3.3.3 COBRA-SFS Model Templates

COBRA-SFS cask model templates are in the development stage. Assembly-specific parameters include average fuel decay heat per cubic foot, scaling factors to be applied to the average decay heat to obtain assembly-specific decay heat per cubic foot, and scaling factors to be applied to the assembly-specific decay heat to represent the variation of assembly decay heat as a function of position along the fuel axial height.

3.3.4 ARP/ORIGEN Input File Generation and FT71f0001 File Post-processing

A computer program has been developed that is dedicated to ARP/ORIGEN input file generation and calculation of mixture nuclide concentrations and decay heat source terms as a function of fuel assembly and axial burnup zone for use in subsequent cask criticality and thermal calculations. This computer program is referred to as "Orella."

3.3.5 Template Engine

A template engine (or template processor) is used to combine UNF technical data with the model templates developed for depletion, criticality, and thermal calculations to produce complete input files for those calculations. A template engine is a string substitution program designed to take advantage of repeated structures in text files. The template engine takes the input parameters data structures represented by a JavaScript Object Notation (JSON) data structure and the root template file. With these two components, the template engine conducts attribute replacement and sub-template imports. Template engine also performs evaluations for an input parameter and inserts the evaluated value in the appropriate place within a model template. These evaluations are performed using simple mathematical expressions that define relationships between input parameters and other parameters with available data in the UNF database.

3.4 ARP Cross-section Libraries

Due to the large number of discharged fuel assemblies and axially varying burnup, a fast-running depletion calculation method using pre-generated problem-specific cross-section libraries is used to enable the numerous depletion calculations required by the UNF characterization, criticality, and thermal analyses. For comparison, an ORIGEN depletion calculation using pre-generated cross sections requires less than a minute of computer time per assembly, whereas a detailed TRITON depletion calculation for the same assembly may require up to two days of computer time using a single processor. The fast-running method is slightly less accurate than the highly-accurate but slower-running TRITON depletion calculation method. As more detailed assembly-specific technical information is incorporated into the database, detailed TRITON depletion analyses can be completed as needed. The results of the detailed depletion analyses will also be retained within the database and used for specific assembly characterization.

As previously described, the RW-859 data base provides the commercial UNF inventory as of 2002. The UNF assemblies are categorized into assembly classes which are further subdivided by assembly type for a total of 134 individual fuel types. The majority of the fuel types within a given class have similar characteristics that can be represented by a fuel type within that class. For example, the CE Fort Calhoun assembly types XFC14A, XFC14C, and XFC14W, and the generic CE 14×14 assembly type (CE1414C) differ primarily with respect to assembly length. These assembly types have the same pellet diameter, rod diameter, rod pitch, and clad material, that is, the two-dimensional representations of these assemblies are identical and can be represented by the CE1414C assembly type. Therefore, ARP cross-section libraries are generated for representative assemblies within assembly classes or specific reactors as described in Table 2 through Table 5.

ARP cross-section library interpolation parameters are fuel initial enrichment, fuel burnup, and moderator density. The initial enrichment and moderator density values and the burnup range to be used in the ARP cross-section library generation process are provided in Table 6. Two sets of ARP cross-section libraries were generated, one set using nominal (i.e., average) operating parameters and the other set using operating parameters that are bounding with respect to criticality analyses. Depletion parameters for nominal analyses are calculated as the average values of reactor-specific operating data available in the centralized database. Bounding depletion parameters for criticality analyses are parameters that increase discharged fuel reactivity. For bounding criticality analyses, decreased moderator density than typical values, higher fuel and moderator temperatures than typical values, burnable absorber rod insertion, and a constant soluble boron concentration (e.g., 1000 ppm) throughout the irradiation time period for PWR assemblies (see Table 7) increase discharge fuel reactivity (Refs. 12 and 13). These parameters harden the neutron spectrum, which in effect reduces the utilization of initial ^{235}U fissile material and generates higher actinide nuclide concentrations. The burnup profiles presented in Table 8, which have been previously demonstrated to be bounding with respect to criticality (Refs. 21 and 22), are used to calculate nuclide concentrations for bounding criticality analyses. A nominal burnup profile is based on average burnup values for fuel axial zones provided in an axial burnup profile database (e.g., Ref. 23). For thermal analyses, a pointed axial burnup profile is more conservative than a flat axial burnup profile.

Table 2. ARP libraries for PWR generic assembly classes

Generic assembly class	Array size	Version	Assembly type	Representative assembly type
B&W 15×15	15×15	B&W Mark B	B1515B	B1515B4
	15×15	B&W Mark B10	B1515B10	
	15×15	B&W Mark B3	B1515B3	
	15×15	B&W Mark B4	B1515B4	
	15×15	B&W Mark B4Z	B1515B4Z	
	15×15	B&W Mark B5	B1515B5	
	15×15	B&W Mark B5Z	B1515B5Z	
	15×15	B&W Mark B6	B1515B6	
	15×15	B&W Mark B7	B1515B7	
	15×15	B&W Mark B8	B1515B8	
	15×15	B&W Mark B9	B1515B9	
	15×15	B&W Mark BGD	B1515BGD	
	15×15	B&W Mark BZ	B1515BZ	
	15×15	W	B1515W	
	14×14	ANF	C1414A	CE1414C
CE 14×14	14×14	CE	C1414C[a]	
	14×14	W	C1414W	
	14×14	CE	XFC14A[a]	
	14×14	CE	XFC14C[a]	
	14×14	CE	XFC14W[a]	
CE 16×16[b]	16×16	CE	C1616CSD	CE1616CSD
	16×16	CE System 80	C8016C	
	16×16	CE	XSL16C	
	14×14	ANF	W1414A	W1414WL
	14×14	ANF Top Rod	W1414ATR	
W 14×14	14×14	B&W	W1414B	
	14×14	W LOPAR	W1414WL	
	14×14	W OFA	W1414WO	
	14×14	W Std	W1414W	
	15×15	ANF	W1515A	W1515WL
	15×15	ANF HT	W1515AHT	
	15×15	ANF Part Length	W1515APL	
W 15×15	15×15	W LOPAR	W1515WL	
	15×15	W OFA	W1515WO	
	15×15	W Standard	W1515W	
	15×15	W Vantage 5	W1515WV5	
	17×17	ANF	W1717A	W1717WL
	17×17	W	W1717WRF	
	17×17	W	W1717WVJ	
	17×17	W LOPAR	W1717WL	
W 17×17	17×17	W Vantage 5H	W1717WVH	
	17×17	South Texas[c]	WST17W	
	17×17	B&W Mark B	B1717B	
	17×17	W OFA	W1717WO	W1717WO
	17×17	W Pressurized	W1717WP	
	17×17	W Vantage	W1717WV	
	17×17	W Vantage +	W1717WV+	
	17×17	W Vantage 5	W1717WV5	

[a]CE14×14 assembly types with different lengths, but same pellet diameter, rod diameter and pitch, and clad material (Ref. 4).

[b]CE16×16 assembly types with different assembly lengths and number of non-fueled rods, but same pellet diameter, rod diameter and pitch, and clad material (Ref. 4).

[c]The W17×17 South Texas and LOPAR assembly types have same pellet diameter, rod diameter and pitch, and clad material, but different lengths (Ref. 4).

Table 3. ARP libraries for BWR generic assembly classes

Generic assembly class	Array size	Version	Assembly type	Representative assembly type
GE BWR/2,3	7×7	ANF	G2307A	G4607G3B
	7×7	GE-2a	G2307G2A	
	7×7	GE-2b	G2307G2B	
	7×7	GE-3	G2307G3	
	8×8	ANF	G2308A	G4607G4B
	8×8	ANF Pressurized	G2308AP	
	8×8	GE-10	G2308G10	
	8×8	GE-4	G2308G4	
	8×8	GE-5	G2308G5	
	8×8	GE-7	G2308G7	
	8×8	GE-8a	G2308G8A	
	8×8	GE-8b	G2308G8B	
	8×8	GE-9	G2308G9	
	8×8	GE-Barrier	G2308GB	
	8×8	GE-Pressurized	G2308GP	
	9×9	ANF	G2309A	G4609A
	9×9	ANF IX	G2309AIX	
	9×9	GE-11	G2309G11	
	9×9		9X9IXQFA	
GE BWR/4-6	7×7	GE-2	G4607G2	G4607G3B
	7×7	GE-3a	G4607G3A	
	7×7	GE-3b	G4607G3B	
	8×8	ANF-Pressurized	G4608AP	G4608G4B
	8×8	GE-10	G4608G10	
	8×8	GE-11	G4608G11	
	8×8	GE-12	G4608G12	
	8×8	GE-4a	G4608G4A	
	8×8	GE-4b	G4608G4B	
	8×8	GE-5 (Retrofit Fuel)	G4608G5	
	8×8	GE-8	G4608G8	
	8×8	GE-9	G4608G9	
	8×8	GE-Barrier	G4608GB	
	8×8	GE-Pressurized	G4608GP	
	8×8	WE	G4608W	
	9×9	ANF	G4609A	G4609A
	9×9	ANF 9-5	G4609A5	
	9×9	ANF 9X	G4609A9X	
	9×9	ANF IX	G4609AIX	
	9×9	ANF X+	G4609AX+	
	9×9	GE-11	G4609G11	
	9×9	GE-13	G4609G13	
	10×10	ANF	G4610A	G4610G14
	10×10	ANF IX	G4610AIX	
	10×10	CE	G4610C	
	10×10	GE-12	G4610G12	
	10×10	GE-14	G4610G14	
	10×10	ATRIUM10	ATRIUM10	

Table 4. Representative assembly types for reactor-specific PWR ARP libraries

Reactor-specific assembly class	Array size	Version	Assembly type	Representative assembly type
Palisades	15×15	ANF CE	XPA15A XPA15C	XPA15C
Yankee Rowe	15×16	ANF CE UNC W	XYR16A XYR16C XYR16U XYR18W	XYR16C
San Onofre-1	14×14	W W D W M	XSO14W XSO14WD XSO14WM	XSO14W
Haddam Neck	15×15	B&W SS B&W Zir Gulf SS Gulf Zir NUM SS NUM Zir W W Zir	XHN15B XHN15BZ XHN15HS XHN15HZ XHN15MS XHN15MZ XHN15W XHN15WZ	XHN15B
Indian Point-1	13×13	W	XIP14W	XIP14W

Table 5. Representative assembly types for reactor-specific BWR ARP libraries

Reactor-specific assembly class	Array size	Version	Assembly type	Representative assembly type
Dresden-1 Humboldt Bay	6×6 6×6 7×7 8×8 6×6 6×6 6×6 6×6 6×6 6×6 7×7	ANF GE GE SA-1 GE PF Fuels GE Tpe III-B GE Type III-F GE Type V UNC 6x6 ANF GE GE Type II	XDR06A XDR06G XDR07GS XDR08G XDR06G3B XDR06G3F XDR06G5 XDR06U XHB06A XHB06G XHB07G2	XDR06G5
LaCrosse [a]	10×10 10×10	AC ANF	XLC10L XLC10A	XLC10A
Big Rock Point	9×9 11×11 7×7 8×8 8×8 11×11 11×11	ANF ANF GE GE GE GE NFS	XBR09A XBR11A XBR07G XBR08G XBR09G XBR11G XBR11N	XBR11A

[a]LaCrosse was an Allis Chalmers (AC) reactor; fuel rod cladding material is stainless steel 348H.

Table 6. Range of ^{235}U initial enrichment, fuel final burnup, and moderator density values for ORIGEN/ARP libraries

Parameter	Bounding operating conditions	Nominal operating conditions
Initial enrichment values (wt % ^{235}U)	1.0; 1.5; 2.0; 3.0; 4.0; 5.0; 6.0	1.0; 1.5; 2.0; 3.0; 4.0; 5.0; 6.0
Burnup range for a PWR ARP library (GWd/MTU)	0 - 90	0 - 90
Burnup range for a BWR ARP library (GWd/MTU)	0 - 72	0 - 72
PWR moderator density values (g/cm^3)	See Table 7	0.60; 0.75; 0.80
BWR moderator density values (g/cm^3)	See Table 7	0.10; 0.30; 0.50; 0.65; 0.80

Table 7. Bounding depletion modeling parameters for ORIGEN/ARP libraries

Parameter/Reactor type	B&W PWR[a]	W PWR[b]	CE PWR[c]	GE BWR[d]
Fuel rod mixture[e]	UO_2	UO_2	UO_2	UO_2
Fuel density (g/cm^3)[f]	10.741	10.741	10.741	10.741
Specific Power (MW/MTU)[g]	30	30	30	22.38
Fuel temperature (K)[g]	1144.1	1157	1171.6	1200
Moderator temperature (K)[g]	588.7	598.2[h]	598.55	560.7
Moderator density (g/cm^3)[g]	0.6905	0.6668[h]	0.6656[i]	0.3[j]
Soluble boron concentration (ppm)[g]	1000	1000	1000	N/A
Burnable absorber exposure[k]	All assembly guide tubes contain burnable poison rods fully inserted throughout irradiation time	All assembly guide tubes contain pyrex rods fully inserted throughout irradiation time	None	Full-length control blade insertion
Type of absorber	Al_2O_3-B_4C	SiO_2-B_2O_3	N/A	B_4C
B_4C wt %	3.5[l]	12.5[m]	N/A	70[n,o]
Axial burnup profile	See Table 8	See Table 8	See Table 8	Uniform

[a]Ref. 24.
[b]Ref. 5 except for specific power and soluble boron concentration which are the same as for B&W.
[c]Ref. 25, assembly AH1, except for specific power and soluble boron concentration which are the same as for B&W.
[d]Ref. 26.
[e]NUREG/CR-6760 (Ref. 27) has demonstrated that use of UO_2 rods in place of integral burnable absorber rods made of either UO_2-Gd_2O_3, UO_2-Er_2O_3, or Al_2O_3-B_4C generates nuclide concentration values that are bounding for criticality analyses.
[f]Value given as 98% UO_2 theoretical density.
[g]For bounding conditions, this parameter is constant throughout the irradiation time.
[h]Based on 155 bar operating pressure and 325 °C outlet temperature for the McGuire nuclear power plant.
[i]Based on the 598.55 K moderator temperature and 154.94 bar operating pressure for the Saint Lucie 2 nuclear power plant.
[j]For both the in-channel and by-pass flow moderator regions.
[k]NUREG/CR-6761 (Ref. 28) has demonstrated that use of burnable poison rods in the PWR depletion simulations is conservative with respect to criticality. Similarly for the BWR fuel (Ref. 26).
[l]B_4C weight percent in Al_2O_3-B_4C.
[m]B_2O_3 weight percent in SiO_2-B_2O_3.
[n]Ref. 29.
[o]Percent of B_4C theoretical density (2.52 g/cm^3, Ref. 18).

Table 8. PWR bounding axial burnup profiles[21]

Axial zone no.	Fraction of active fuel height	Burnup < 18 GWd/MTU	18 ≤ Burnup < 30 GWd/MTU	Burnup ≥ 30 GWd/MTU
		1	2	3
1	0.0278	0.649	0.668	0.652
2	0.0833	1.044	1.034	0.967
3	0.1389	1.208	1.150	1.074
4	0.1944	1.215	1.094	1.103
5	0.2500	1.214	1.053	1.108
6	0.3056	1.208	1.048	1.106
7	0.3611	1.197	1.064	1.102
8	0.4167	1.189	1.095	1.097
9	0.4722	1.188	1.121	1.094
10	0.5278	1.192	1.135	1.094
11	0.5833	1.195	1.140	1.095
12	0.6389	1.190	1.138	1.096
13	0.6944	1.156	1.130	1.095
14	0.7500	1.022	1.106	1.086
15	0.8056	0.756	1.049	1.059
16	0.8611	0.614	0.933	0.971
17	0.9167	0.481	0.669	0.738
18	0.9722	0.284	0.373	0.462

3.5 Modeling and Simulation Automation Tool

The purpose of the M&S automation tool is to streamline nuclear safety evaluations for discharged commercial nuclear fuel assemblies using UNF technical data and model templates from an integrated UNF database. The capabilities of the M&S automation tool are described in Sect. 3.5.1. User interaction with CDAT is accomplished through a graphical user interface that provides the option for the type of analysis to be performed and graphically displays the results of the analysis (see Sect. 3.5.2). The architecture of the analysis processes implemented into the M&S automation tool is described in Sect. 3.5.3.

3.5.1 Modeling and Simulation Automation Tool Capabilities

The M&S automation tool has the following capabilities:

(1) ARP cross-section library generation for representative assembly types. The ARP cross-section libraries are used in fast-running depletion calculations with ORIGEN.

(2) Depletion analysis to provide UNF nuclide inventories. Nuclide inventory information is needed for burnup credit criticality safety analyses, for developing nuclear reprocessing and safeguards technologies, and for radiological dose assessments. Options are implemented for a highly-accurate depletion calculation with TRITON (which is appropriate if detailed fuel assembly-specific design and irradiation history data are available), and a fast-running depletion calculation with ORIGEN using ARP cross sections generated for fuel assemblies representative of generic assembly classes. In addition, the fast-running depletion calculation path provides the option for

using ARP cross-section libraries generated with either nominal (i.e., average) or bounding irradiation history parameters with respect to criticality.

(3) CSAS6 nuclear criticality safety evaluations for spent fuel in transport and dry storage casks to demonstrate compliance with regulatory requirements in 10 CFR Part 71 and Part 72. A total of 28 actinide and fission product nuclides are considered in the fuel compositions for burnup credit criticality safety analyses, as recommended in the Draft Interim Staff Guidance – 8, Revision 3, *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks* (Ref. 30).

(4) COBRA-SFS thermal analysis for spent fuel in storage/transport casks to demonstrate compliance with regulatory requirements in 10 CFR Part 71 and Part 72.

3.5.2 Graphical User Interface

The graphical user interface (GUI) has the capability to provide options for the user to select the type of evaluation (e.g., criticality analysis) and the type of analysis (e.g., analysis using bounding depletion parameters respect to criticality) to be performed, and to update the existing set of ARP cross-section libraries, as illustrated in Figure 3.

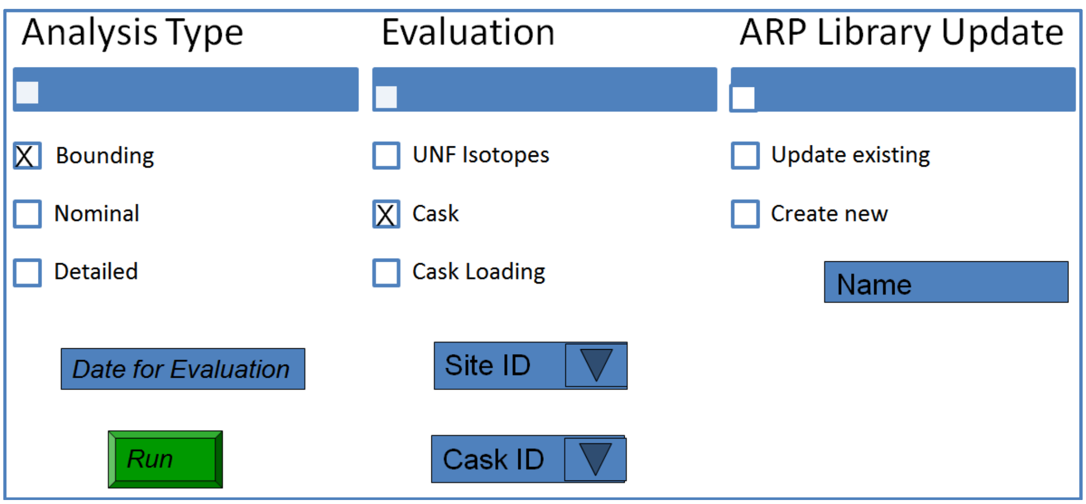

Figure 3. Analysis options provided by GUI.

Additional GUI features will be developed so that the results of the depletion, criticality, and thermal calculations can be displayed graphically. Examples of graphs for nuclide inventory evaluations are scatter plots where the X-axis can be different functions in the database such as assembly average burnup, initial enrichment, or initial U content. In the scatter plots, there will be options for: (1) using different symbol colors to identify assemblies with different parameters such as discharge date, initial enrichment, burnup range, etc.; (2) plotting nuclide concentrations for assemblies of the same reactor type, assembly type, reactor ID, etc. A post processor capability allows the user to manipulate the data with equations such as the ratio of $^{235}U/^{239}Pu$ or $^{239}Pu+^{241}Pu+^{242}Pu$, ^{239}Pu equivalence (i.e., reactivity worth of a fuel component is expressed in terms of ^{239}Pu worth), etc., and then plot the results. An option will be available to dump out the user selected data to a CSV or SQLITE file.

3.5.3 Automated Processes

Component interaction and process flow for the various calculations are depicted in the flow charts shown in this section.

3.5.3.1 *ARP Cross-Section Library Generation*

ARP cross-section libraries are generated for fuel assembly types that are representative of generic assembly classes and for reactor-specific assembly types (see Table 2 through Table 5). These libraries reside in the UNF CDAT data repository and are used in fast-running depletion calculations with ORIGEN. The process flow charts for ARP cross-section library generation using bounding and nominal operating parameters are illustrated in Figure 4 (a) and (b), respectively. To generate ARP cross-section libraries for a representative assembly type, a TRITON input file is generated for each fuel initial enrichment and moderator density value identified in Table 6. The burnup values used in the TRITON input files for PWR and BWR assemblies are 90 and 72 GWd/MTU, respectively.

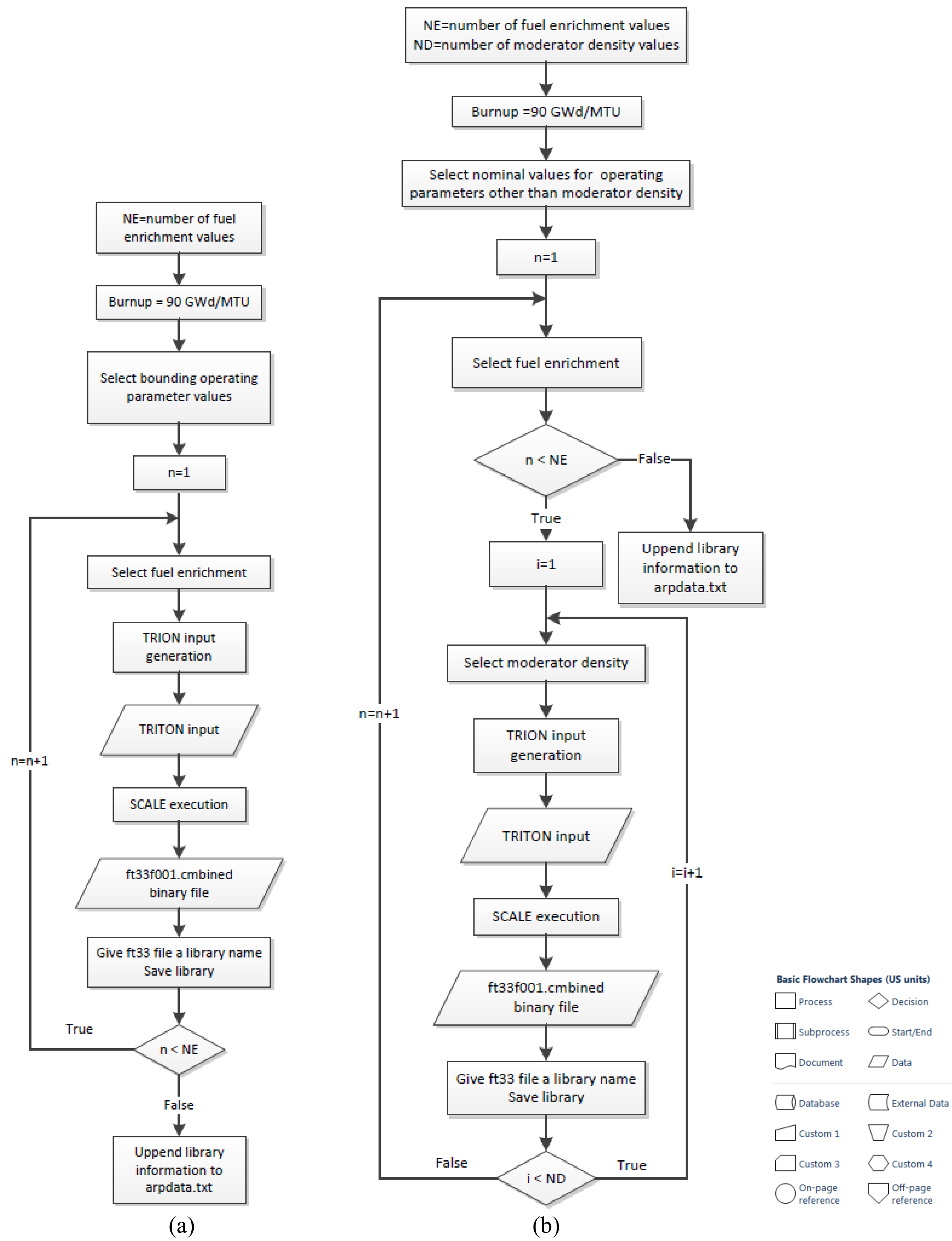

Figure 4. Flow chart illustrating generation of ARP cross-section libraries using (a) bounding operating parameters; (b) nominal operating parameters.

3.5.3.2 *Cask Nuclear Safety Analyses*

The process flow for cask thermal and criticality safety analyses is depicted in Figure 5. This process includes three sub-processes denoted as sub-process A, B, and C, which are dedicated to calculating nuclide concentration and the decay source term as a function of fuel assembly and axial burnup zone (see Sect. 3.5.3.3), CSAS6 input file generation (see Sect. 3.5.3.4); and COBRA-SFS input file generation (see Sect. 3.5.3.5), respectively. The automatically generated CSAS6 and COBRA-SFS output files are retained within the CDAT data repository.

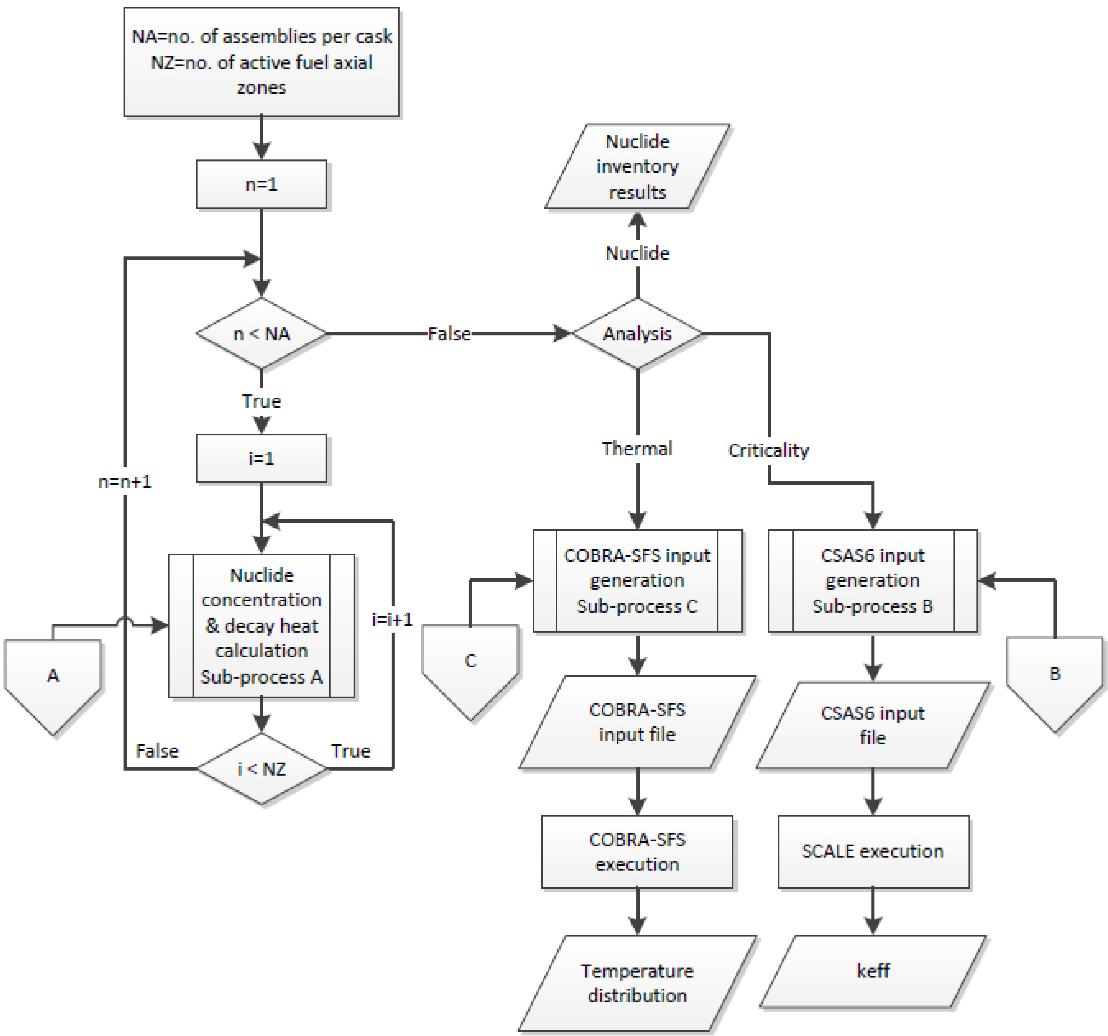

Figure 5. Flow chart illustrating cask safety analysis processes.

3.5.3.3 *Nuclide Concentration and Decay Heat Source Term Calculation*

Nuclide concentration values and associated decay source terms for use in criticality and thermal calculations, respectively, are calculated as a function of fuel assembly and axial burnup zone, as described in Figure 6.

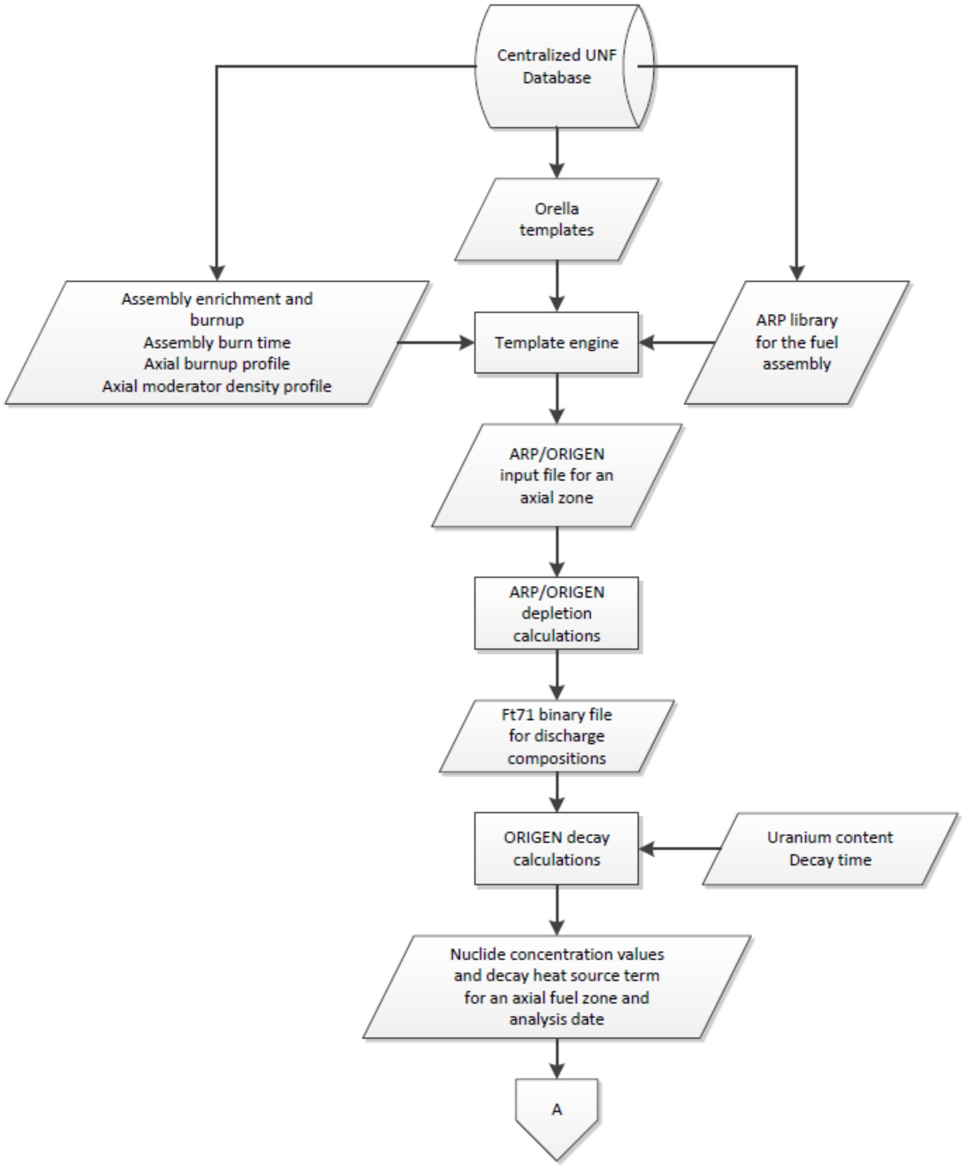

Figure 6. Flow chart illustrating the processes for nuclide concentration and decay heat source term calculations.

For an assembly type, the Orella template engine within the M&S automation tool uses the Orella templates, the ARP library corresponding to the assembly type, and a set of input parameters to generate a complete Orella input file. The assembly-dependent Orella input parameters include assembly enrichment and burnup, assembly burn time, the burnup axial profile, and the axial moderator density profile. Orella generates a series of input files for ARP/ORIGEN depletion calculations. The result of the ARP/ORIGEN calculations is an ft71 binary file containing discharge fuel compositions, which is retained within the CDAT repository. The binary file is then used to calculate the nuclide concentrations and fuel decay heat source term corresponding to the decay time of interest. These calculations are automatically performed according to an established calculation sequence resulting in nuclide concentration and decay heat values being passed to the next sub-processes dedicated to CSAS6 and COBRA-SFS input file generation.

3.5.3.4 *CSAS6 Input File Generation*

The flow chart for generating a CSAS6 input file for criticality calculations is illustrated in Figure 7. The template engine assembles a CSAS6 input file using the CSAS6 model templates for the evaluated cask, the assembly- and axial burnup zone-dependent nuclide concentration values previously determined with ORIGEN, and the JSON with parameter values selected for the evaluated fuel assemblies.

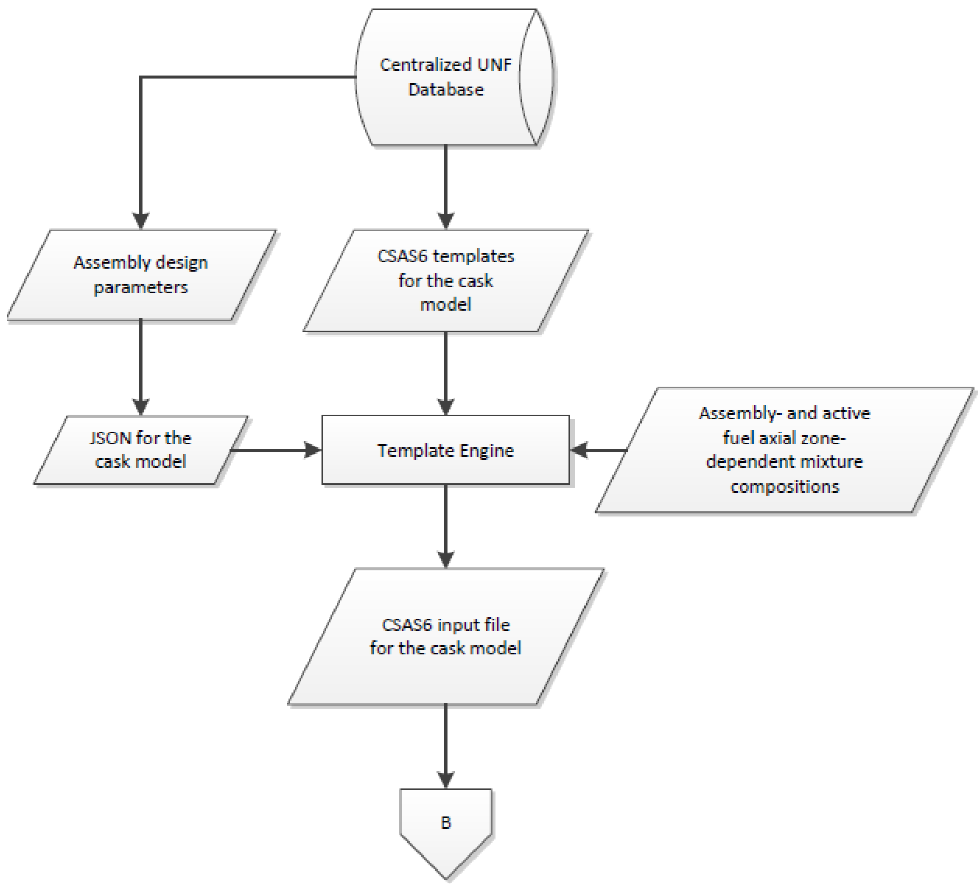

Figure 7. Flow chart illustrating the generation of a CSAS6 input file for cask criticality calculations.

3.5.3.5 *COBRA-SFS Input File Generation*

The flow chart for generating a COBRA-SFS input file for thermal calculations is illustrated in Figure 8. The template engine assembles a COBRA-SFS input file using the COBRA-SFS model templates for the evaluated cask, the decay heat values previously determined with ORIGEN, and the JSON with parameter values selected for the evaluated fuel assemblies.

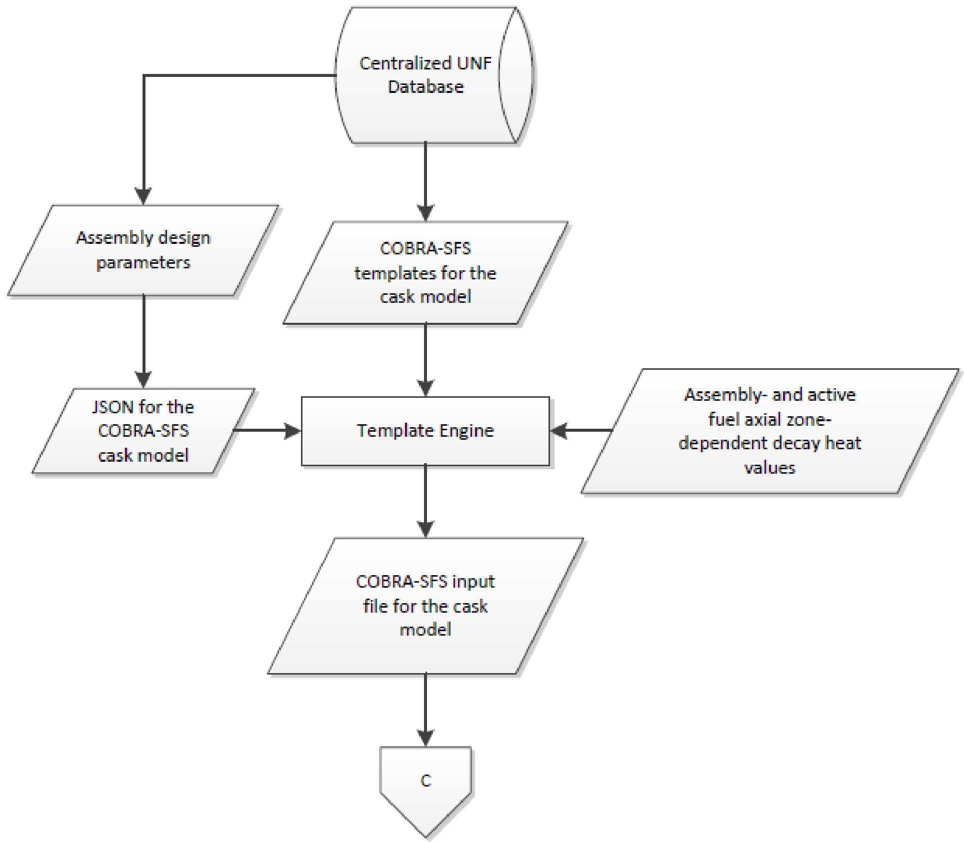

Figure 8. Flow chart illustrating generation of a COBRA-SFS input file for cask thermal calculations.

4. SUMMARY

To facilitate modeling and analysis capabilities for existing storage and transportation cask systems a centralized, comprehensive and integrated data and analysis tool system is currently being developed. The analysis system is referred to as UNF-IDEAS. CDAT is the nucleus of UNF-IDEAS with a purpose to provide key technical data and analysis capabilities for demonstrating compliance with regulatory requirements and assessing technical issues related to aging and safety of discharged nuclear fuel.

The development of CDAT is a multi-laboratory effort, led by Oak Ridge National Laboratory, that includes:

- integration of existing modeling and simulation tools and inventory data for UNF characterization, criticality safety, and thermal analyses;
- development of computational models to support UNF characterization, criticality safety, and thermal analyses;
- analysis of existing loaded canisters of interest to the UFD program; and
- validation of the developed analysis capabilities and data.

The UNF database and the modeling and simulation automation tool are developed simultaneously in a consistent manner. Technical data collection and its synthesis into appropriate formats are based on the SCALE and COBRA-SFS input requirements for depletion, criticality, and thermal analysis, whereas model templates for the computer codes utilize fuel assembly and storage cask information from the UNF database. Currently, the UNF database contains RW-859 data, basic fuel assembly data such as assembly design parameters for representative assembly types, reactor- and cycle-specific data, and cask data, which are organized in relational SQL data tables.

TRITON model templates have been developed for assembly types representative of the PWR W14×14, W15×15, W17×17, B&W15×15, and CE14×14 assemblies. Initial CSAS6 model templates have been developed for the TROJAN MPC 24E/EF storage cask and the W17×17 assembly types. These templates will be further improved to accommodate different assembly types, different cladding materials, non-fuel components typically inserted into assembly guide tubes, damaged fuel cans, etc. For fast-running depletion calculations with ORIGEN, ARP cross-section libraries have been generated for representative PWR and BWR assembly types. An M&S automation tool has been developed to streamline UNF nuclear safety evaluations. The current version of the tool has the capability to automate generation of PWR ARP cross-section libraries, calculation of discharge assembly nuclide concentrations based on the UNF characteristics provided by the RW-859 database, and generation of CSAS6 input files. The generated ARP libraries and discharge fuel assembly compositions have been processed into CDAT. Collection of additional data from the nuclear industry has been initiated with the help of NEI. These data are being evaluated and incorporated into the centralized UNF database. The data structure and relationships have been developed and the SQL data tables are starting to be populated with data that has been collected.

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14. *Final Safety Analysis Report for the Holtec International Storage, Transport, and Repository Cask System (HI-STAR 100 Cask System)*, Rev. 3, Docket No. 72-1008, Holtec International (2004).

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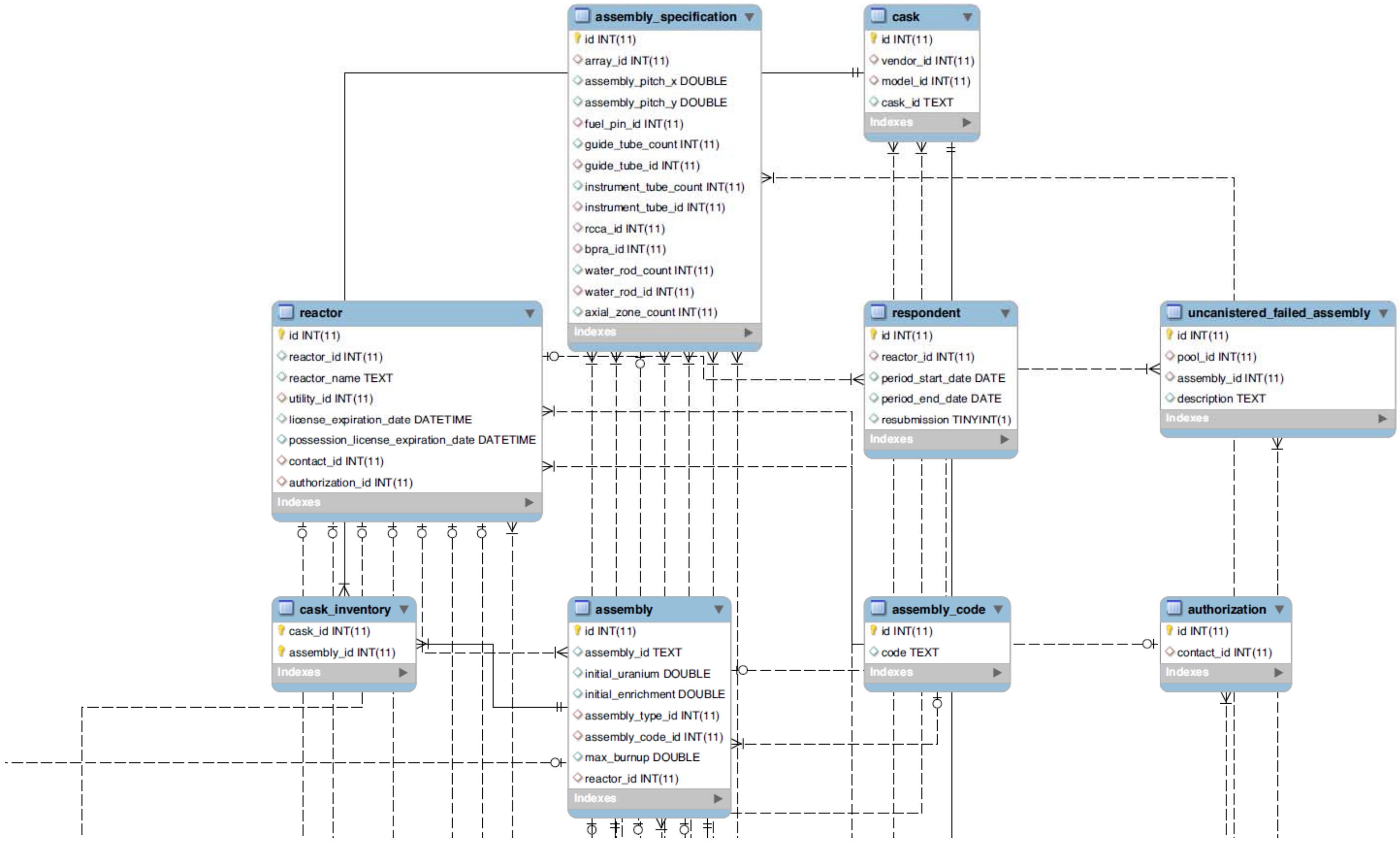
Appendix A

Database Schema



Part 1
Part 2 Part 3
Part 4 Part 5
Part 6

Figure A-1. Database schema – Part 1.

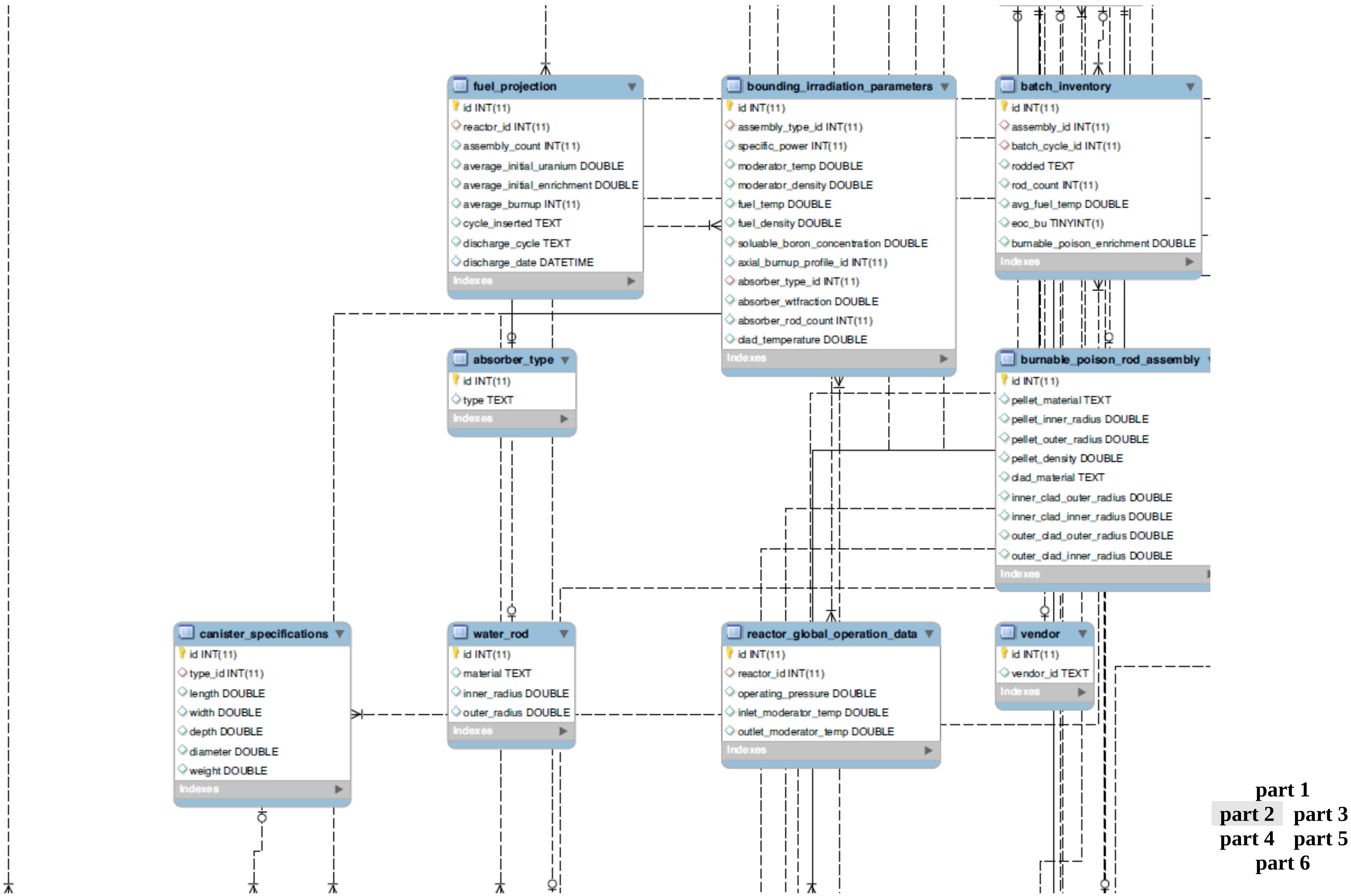


Figure A-2. Database schema – Part 2.

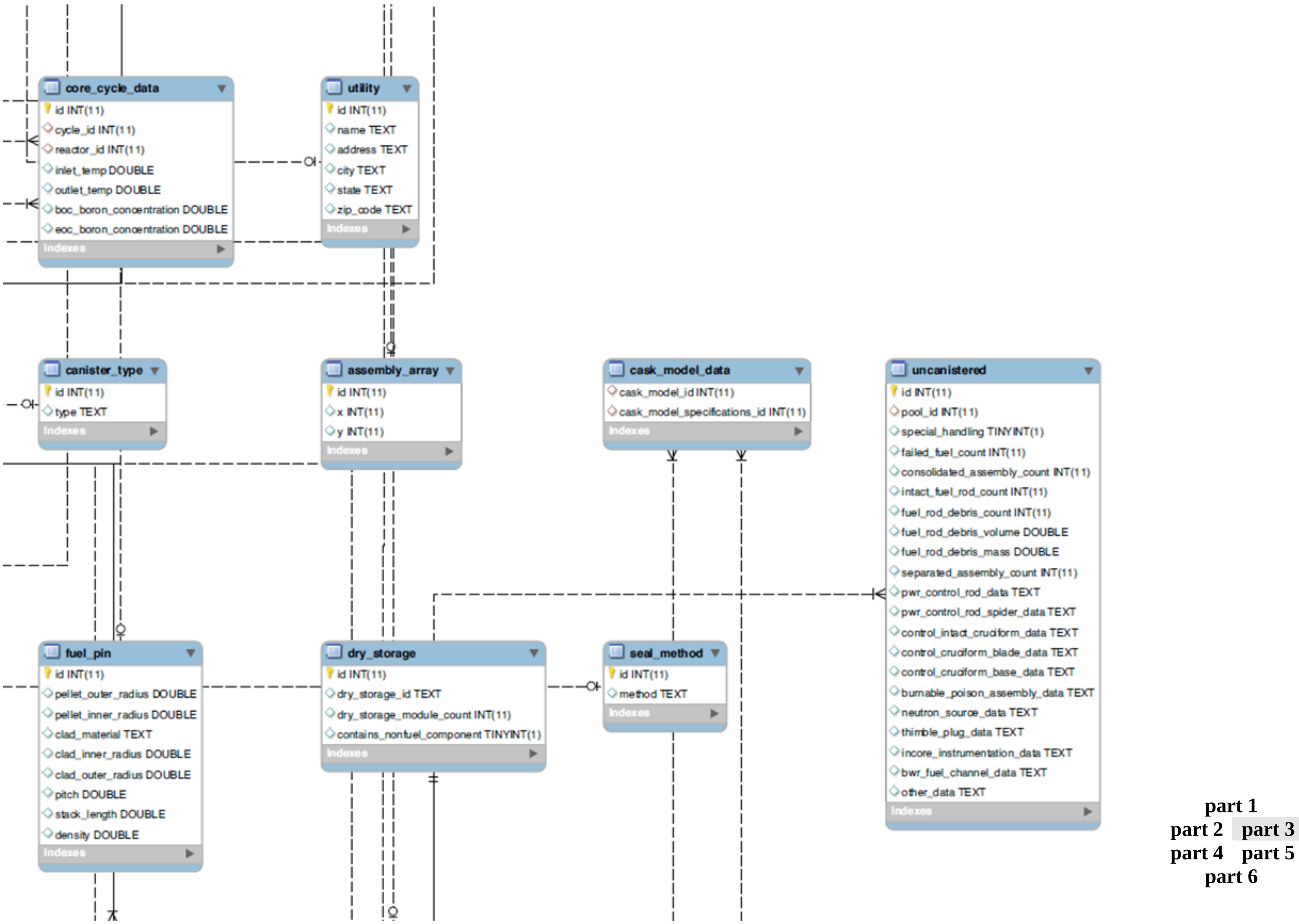
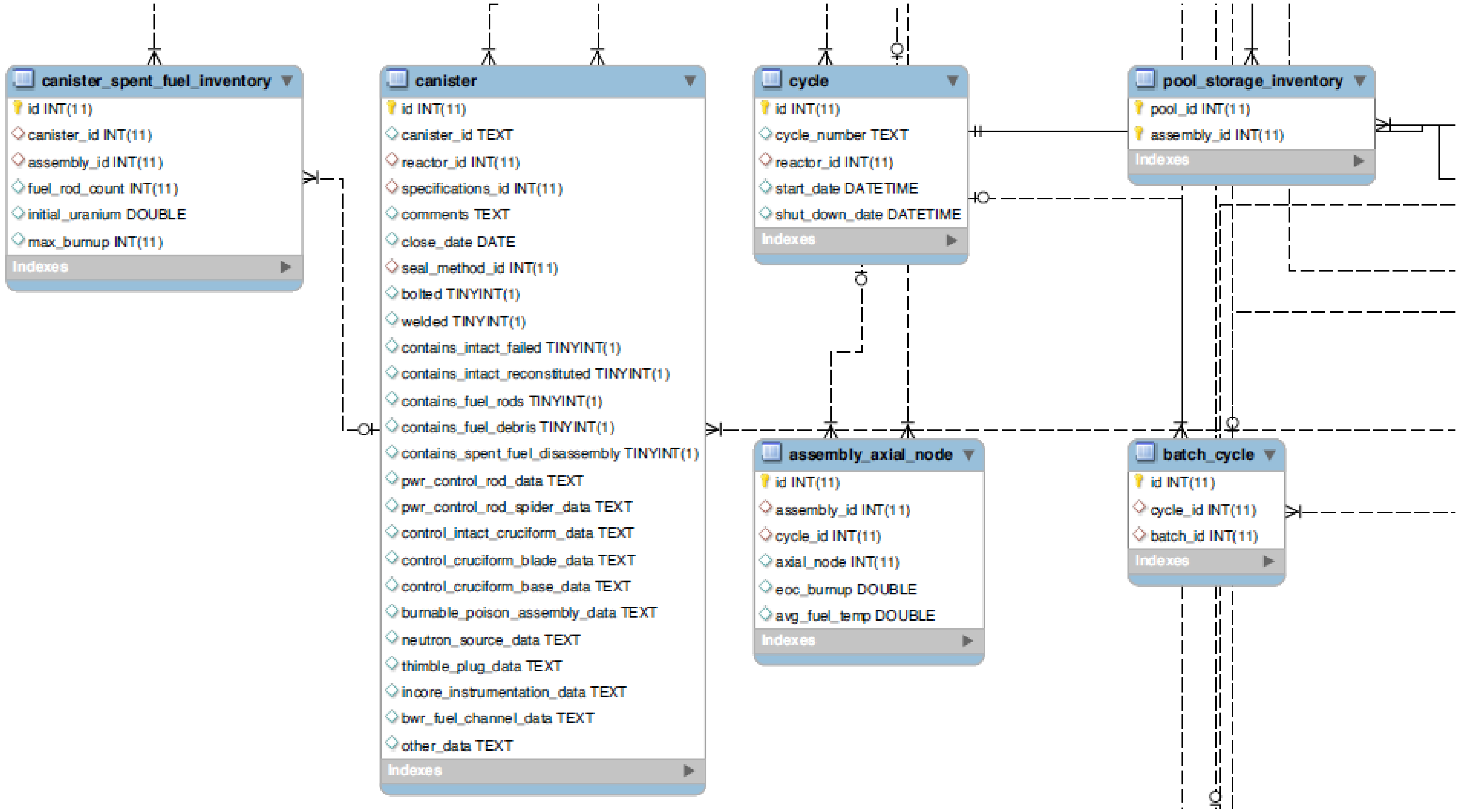


Figure A-3. Database schema – Part 3.



part 1
part 2 part 3
part 4 part 5
part 6

Figure A-4. Database schema – Part 4.

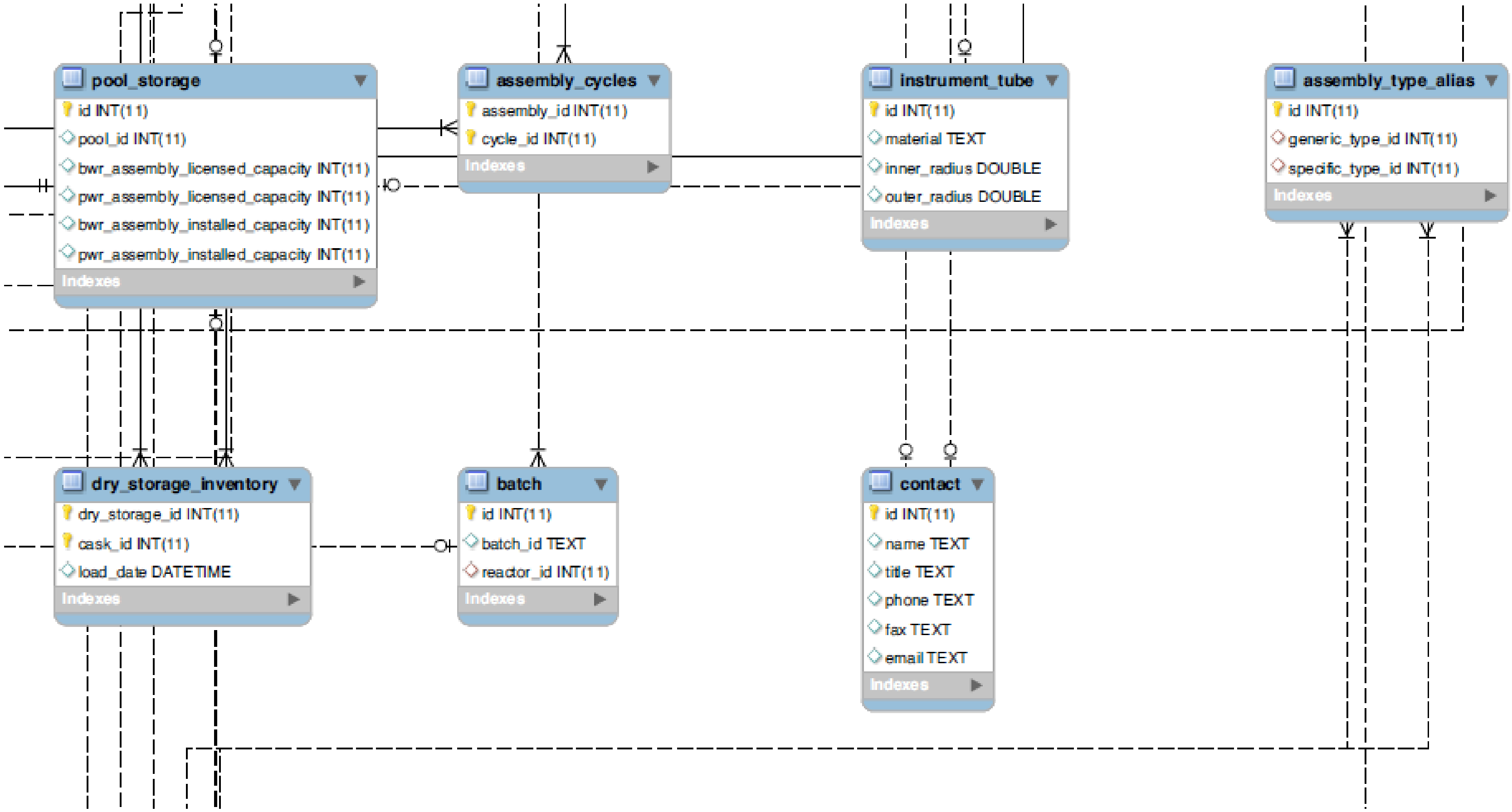
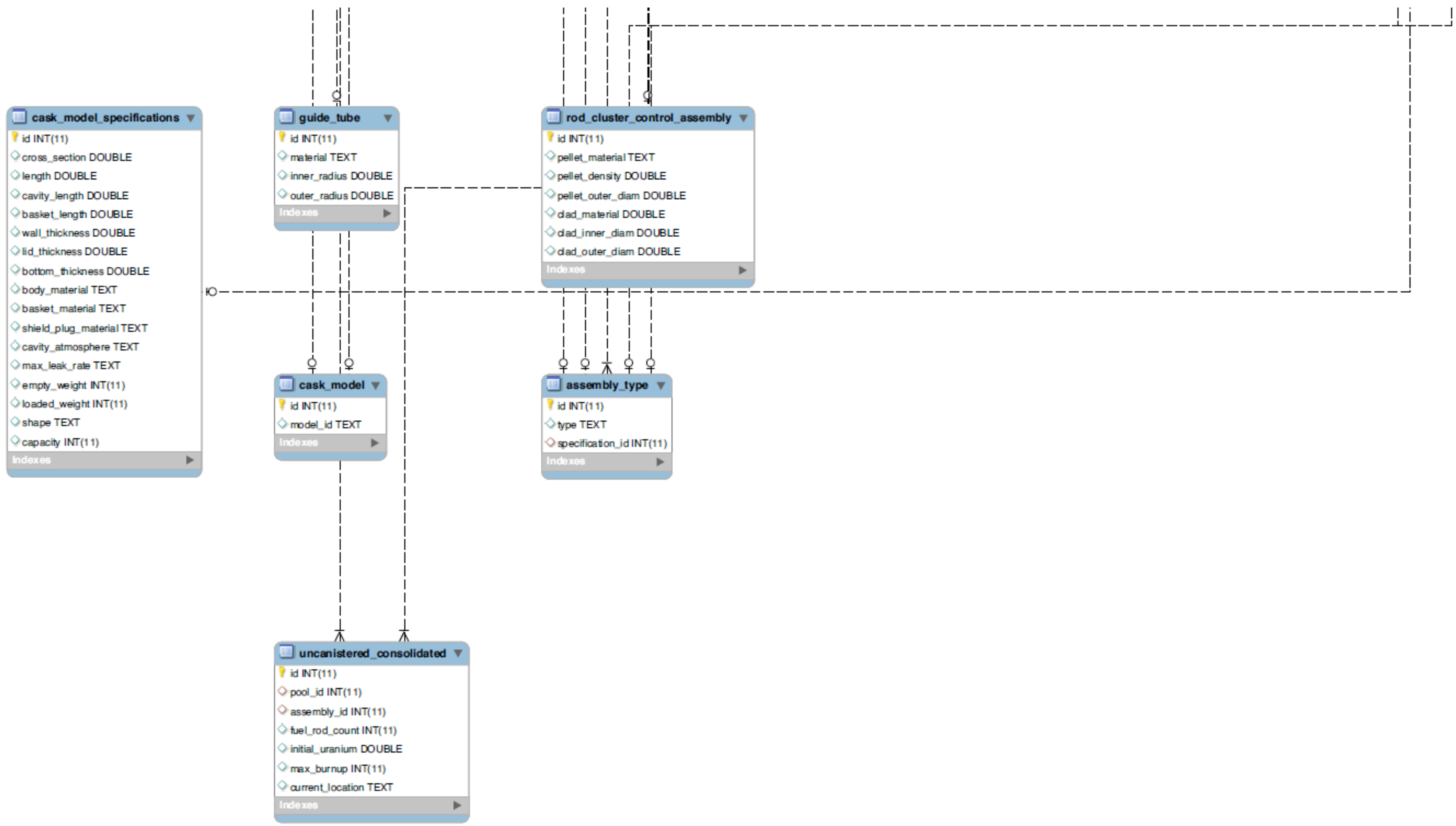


Figure A-5. Database schema – Part 5.



part 1
part 2 part 3
part 4 part 5
part 6

Figure A-6. Database schema – Part 6.

Appendix B

Example of Data Source Documentation

Table B-1. Generic assembly design data for PWR W1717WL

Assembly design data	English unit		Value		Source	Comment
Reactor class			PWR			
Assembly class			WE 17x17			
Assembly type			W1717WL			
Lattice geometry						
Lattice (assembly) pitch (cm)			21.50364			
Assembly width (cm)	8.424 in				[2] DWG-1465F30	
Rod pitch (cm)	0.4960 in		1.25984		[1]A1-5-7	
Number of fuel rods			264		[2]2A-345	
Number of guide/instrument tubes			25		[2]2A-345	
Active fuel rod length (cm)	144 in		365.76		[2]2A-345	Length of fuel within fuel rod
Fuel pellet diameter (cm)	0.3225 in		0.81915		[1]A1-5-7	
Total fuel pin length (cm)	151.635 in		385.1529		[2]DWG-1465F30	Upper end of range for thermal models
Pin length above active fuel (cm)	5.77 in		14.656		N/A	Derived from total and below active fuel length
Pin length below active fuel (cm)	1.865 in		4.7374		[6]	Derived value from source
Typical mass of (U) in assembly (kg)			460		[6]	
Clad data						
Clad material	Zircaloy-4		Zirc4		[2]2A-345	
Clad inner diameter (cm)	0.329 in		0.83566		[1]A1-5-7	Derived from reported nominal thickness of 0.0225 inches
Clad outer diameter (cm)	0.3740 in		0.94996		[1]A1-5-7	
Fill gas	Helium		He		[2]2A-345	
Guide Tube data	Upper	Lower	Upper	Lower		Only upper GT data modeled
Material	Zircaloy-4		Zirc4	Zirc4	[6]	
Inner diameter (cm)	0.450 in	0.397 in	1.143	1.00838	[6]	
Outer diameter (cm)	0.482 in	0.429 in	1.22428	1.08966	[6]	

Table B-1 (continued)

Assembly design data	English unit	Value	Source	Comment
Instrument Tube Data				
Material	Zircaloy-4	Zirc4	[6]	
Inner diameter (cm)	0.450 in	1.143	[6]	
Outer diameter (cm)	0.482 in	1.22428	[6]	
Hardware				
Upper end-fitting length (cm)	3.67 in	9.322	[2] DWG-1465F30	
Lower end-fitting length (cm)	2.738 in	6.954	[2] DWG-1465F30	
Intermediate spacer grid material		Inconel	[6]	
Upper spacer grid material		Inconel	[6]	
Bottom spacer grid material		Inconel	[6]	
Intermediate grid length (cm)	1.322 in	3.35788	[6]	
Upper grid length (cm)	1.322 in	3.35788	[6]	
Bottom grid length (cm)	1.322 in	3.35788	[6]	
Total number of spacer grids		8	[6]	

[1] Westinghouse Electric Company LLC Nuclear Fuel, Application for Approval of Packaging of Fissile Radioactive Material, Revision 1, October 2011

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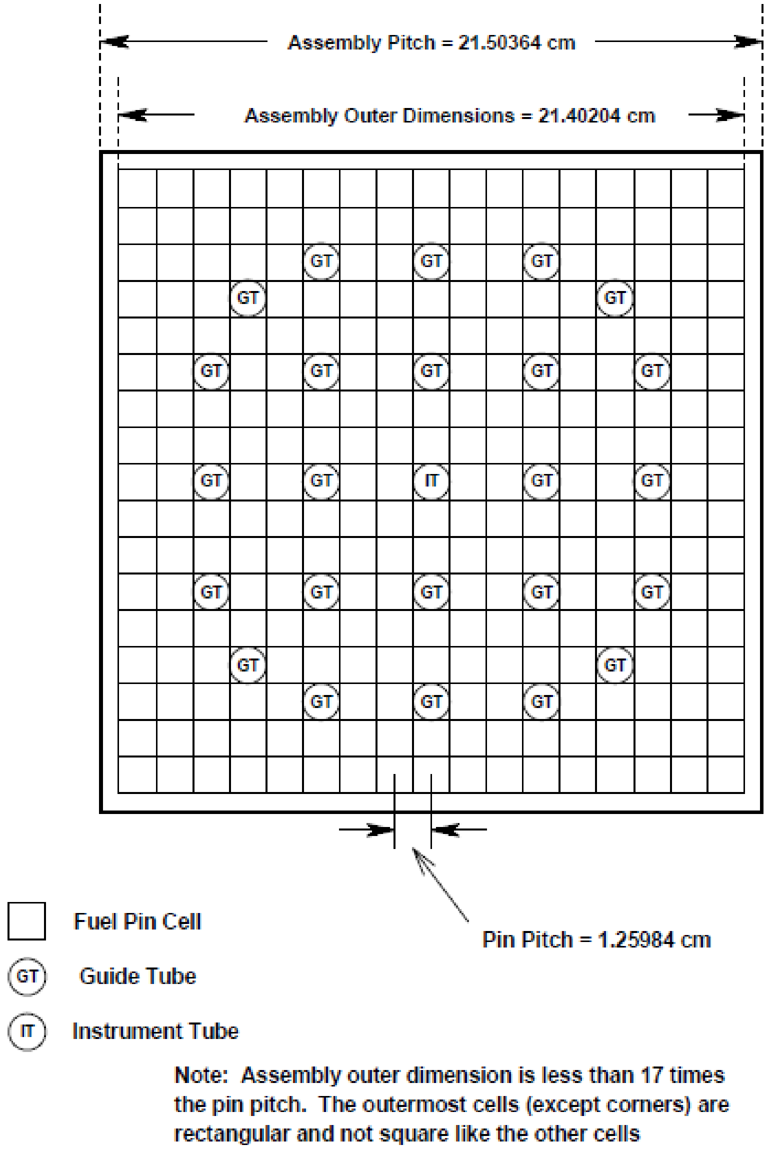


[6]

Figure B-1. Horizontal cross-section representation of a W1717WL assembly.

Appendix C

Reactor Operating Data Questionnaire

Supplemental Used Fuel Data Questionnaire
Date: 10 September 2012

The *objective of this Questionnaire* is to collect additional data to the GC-859 process relevant to nuclear safety analyses involving domestic commercial used nuclear fuel (UNF). The data collected from this Questionnaire will be used to develop an extensive database of UNF operating history data that are representative of domestic UNF assemblies discharged from U.S. pressurized water reactors (PWRs) and boiling water reactors (BWRs).

The *intended use* of the database is to provide a credible technical resource for selection of values for reactor operating parameters that are input data to out-of-reactor nuclear safety analyses involving UNF, including burnup credit criticality safety analyses, source term predictions, thermal analyses, shielding analyses and off-site dose calculations, fuel/cladding integrity studies, and other aging management aspects associated with extended storage, subsequent transportation, and disposal.

The *beneficial outcomes* anticipated from developing this database include: a credible resource for selecting input data for out-of-reactor nuclear safety analyses involving UNF, use of more realistic and appropriately conservative parameters depending on the specific application, improved defensibility in used fuel licensing activities, and improved accuracy associated with safety margin estimates. In this regard, it is anticipated that the dry cask transportation vendors and the DOE could use this database to increase the fraction of UNF assemblies that are acceptable for transportation and disposal after extended storage periods, as well as facilitate justification for potential direct disposal of existing dual-purpose canisters (DPCs).

The *request* is to provide, to the extent possible, the data items listed below. For data submitted, a description of the source and relative pedigree of the data should also be provided. While QA data is preferred, non-QA data is also acceptable. The category levels associated with each data item are as follows: 1=high value data that is anticipated to be easily collected and provided; 2=high-value data that is recognized as potentially being more difficult to collect and provide. Tabulated views of the information requested are provided in Tables 1 and 2, followed by illustrative examples of the types of data requested. Note that data can be provided in any format including raw data, and partial data submittals are also acceptable.

The *point-of-contact* for this activity is:

Marcus Nichol
Senior Project Manager, Used Fuel Storage and Transportation
Nuclear Energy Institute
1776 I Street, NW, Suite 400, Washington, DC 2006
(202) 739-8031
mrn@nei.org

Requested Used Fuel Data

Table 1. Category 1 Data

Parameter	Comments
1.1 Reactor Data	
A) Reactor identification	Consistent with GC-859 nomenclature
B) Control rod/blade design group ID (e.g., CBD), and core locations	Provide a full-core figure showing the location of the various control elements. Provide description of rod insertion limits (RILs).
C) Reactor power history over time	Percent full power
1.2 Cycle data (provide for each cycle)	
A) Cycle number, start and end date	Provided on GC-859, only post 2002 data requested
B) Soluble boron concentration (ppm B) at HFP w/Eq. Xe - Measured (preferred) or design values at BOC, MOC, EOC	Desirable to have data at least every 1,000 MWd/MTHM where possible
C) Nominal moderator temperatures (F, C or K - specify),	T_{in}, T_{avg} & T_{out} at HFP
D) Nominal reactor operating pressure (psia)	at HFP
E) Actual uranium loading (MTHM) per cycle	Full core load
1.3 Fuel Assembly-Specific Data	
A) Assembly ID	Consistent with RW-859 nomenclature
B) Fuel assembly type(s) (e.g., W1717L)	Provided on GC-859, only post 2002 data requested
C) Control rod/blade designs used (e.g. Ag-In-Cd RCCAs)	Specify type and material (See 2.1[a]).
D) Active fuel exposure to control rod or blade insertions (Yes/No)	If yes, identify control rod/blade design type as specified in 1.3(c). (desirable to have additional information as identified in 2.2[b])
E) Nominal initial enrichment	Provided on GC-859, only post 2002 data requested
F) Provide assembly batch identifier	Assembly fresh fuel batch identifier (see pp. 6 or 8 for examples)
G) Identify use of axial blankets (Yes/No)	If yes, provide length and composition
H) Assembly average burnup at EOC	Inferred from in-core measurements (axial profile desired)
I) Assembly location in core per cycle	Full core map or map based on symmetry (1/8, ¼, or ½)
1.4 Burnable absorbers and other power/flux shaping devices used	Identify which are used in which assemblies
A) Type (e.g., APSR, IFBA, WABA, Gd, Hf rods, etc.)	Specify types used. See 2.4(a).
B) Number of burnable poison rods and absorber content (e.g., wt% B_4C)	If all guide tubes are not filled then need orientation (map) within assembly
C) Number and location of poisoned fuel rods per assembly (e.g., number of pins, material, and enrichment)	These are for fixed fuel rods that are not expected to be removed in a subsequent cycle
D) Assembly exposure to removable burnable poison rods (yes/no)	If yes, need number of cycles exposed, and, if practical, link to information in 1.4(b).
1.5 Canister/Cask Specific Data	
A) Unique cask serial number	A copy of the dry storage certification record should contain all necessary information
B) Assembly IDs contained in cask	--
C) Cask used-fuel loading pattern	--
D) Additional non-fuel components present in cask or inserted in assembly guide tubes, e.g., control rod assemblies, burnable poison rods, etc. (Yes/No)	If yes, identify type. See 2.5(f) for additional information that is desirable.
E) Canister backfill material	e.g., He
F) As loaded decay heat (MW)	Includes assemblies and components

Table 2. Category 2 Data

Parameter	Comments
2.1 Reactor Data	
a) Actual design data for rod inserts and control components used, e.g., dimensional and material specifications.	It is recognized that design details may be proprietary and need to be supplied by the vendor.
2.2 Cycle data (provide for each cycle)	
A) Unusual events impacting assembly burnup	Intended to be a catch all to describe unusual events that can cause significant variation from nominal expectations. (e.g. extended operation with a dropped control rod, power suppressed regions in BWR core, large spatial power deviations, significant core quadrant power tilts, etc).
B) Control rod/blade usage at power (insertion history; depth & duration) (rods for PWRs, blades for BWRs)	Provide a table or figure showing the axial position as a function of burnup of all control rods inserted while at power (see p. 11 for example).
2.3 Fuel Assembly-Specific Data	
A) Cycle average moderator density axial distribution (BWRs)	From models or inferred using reactor instrumentation.
B) Accumulated axial burnup distribution (MWd/MTHM) (EOC)	From models or inferred using reactor instrumentation.
C) Actual assembly dimensions, e.g., fuel pitch, pellet diameter, cladding thickness, etc.	--
D) Masses and composition of nonfuel rod hardware, e.g., end-fittings, nozzles, grids, etc.	--
E) Within assembly quadrant burnup variation	From models, provide minimum quadrant burnup divided by assembly average burnup for each assembly.
2.4 Burnable absorbers and other power/flux shaping devices used	
A) Length/location, dimensional details	For example 108" total length, center 3" above midplane of active fuel. It is recognized that this information may be proprietary and would need to be supplied by the vendor.
2.5 Canister/Cask Specific Data	
A) Backfill pressure	As measured
B) Drying method	--
C) Total drying time (hours)	--
D) Number of drying cycles	--
E) Total occupational dose (mRem)	As measured
F) Additional non-fuel components present in cask or inserted in assembly guide tubes, e.g., control rod assemblies, burnable poison rods, etc.	Provide details on materials, number, cask layout, which assembly guide tubes are filled,component masses, and component irradiation history information
Canister/cask history after emplacement	The following pertain to after the dry storage cask system has been placed out on the pad or in the storage module.
G) Has canister ever been reopened (yes/no)	--
H) Has canister been rewetted (yes/no)	--
I) Has canister ever had a loss of inert gas (yes/no)	--
J) Has there ever been a loss of gas from the secondary seal (yes/no)	--

HFP = hot full power BOC = near beginning of cycle MOC = near middle of cycle
CBD = Control Bank D Eq. Xe = equilibrium xenon EOC = near end of cycle

The following are illustrative examples of formats for providing the requested information

Reactor data

Parameter	Data
Reactor identification - name & unit number	McGuire Unit 1
Plant design (e.g. WE 4-Loop, GE BWR type 6)	WE 4-Loop
Core loading (i.e., number of assemblies)	193 assemblies
Number of control locations	28
Utility or plant contact (name, e-mail address, phone number & mailing address)	Ms. J. Jones
Reactor power history over time	January 1980 0.96 February 1980 0.95 March 1980 0.90 April 1980 0.91 May 1980 0.93 … …

Example Table of Boron Letdown Data for Plant ID XYZ **(provide for each cycle)**

Cycle 1A		Cycle 1B		Cycle 2		Cycle 3		…Cycle x	
EFPD	**ppmB**	**EFPD**	**ppmB**	**EFPD**	**ppmB**	**EFPD**	**ppmB**	**EFPD**	**ppmB**
0.0	1147	269.4	843	0.6	930	0.7	1090	data	data
7.2	968	269.8	783	0.8	930	2.0	1020	data	data
18.6	912	272.0	748	0.9	930	4.0	947	data	data
55.2	934	280.2	558	2.1	826	6.7	951	data	data
63.8	909	287.2	571	3.0	809	12.6	908	data	data
69.9	909	306.2	513	4.4	778	26.8	891	data	data
94.9	884	313.2	441	11.4	809	32.6	843	data	data
184.7	705	337.2	419	15.8	735	50.7	822	data	data
192.3	683	345.7	346	22.5	709	66.0	757	data	data
216.0	627	364.2	309	29.3	683	69.9	746	data	data
224.8	610	377.6	246	35.3	666	85.0	692	data	data
228.5	666	389.5	279	42.3	644	100.2	666	data	data
238.0	584	401.7	290	50.0	623	111.2	636	data	data
244.0	575	419.3	272	55.8	614	130.5	562	data	data
250.8	614	427.1	229	60.8	592	143.8	528	data	data
254.7	588	431.8	231	69.1	571	163.9	467	data	data
--	--	437.1	229	75.2	558	174.0	432	data	data
--	--	440.1	242	83.1	528	184.2	394	data	data
--	--	--	--	89.8	506	212.9	324	data	data
--	--	--	--	97.8	480	227.5	272	data	data
--	--	--	--	104.7	463	246.4	229	data	data
--	--	--	--	116.4	441	262.9	250	data	data
--	--	--	--	122.5	406	283.8	190	data	data
--	--	--	--	129.1	385	304.0	130	data	data
--	--	--	--	135.9	372	322.0	86	data	data
--	--	--	--	139.9	346	--	--	data	data
--	--	--	--	148.6	333	--	--	data	data
--	--	--	--	156.4	320	--	--	data	data
--	--	--	--	161.4	316	--	--	data	data

Cycle data (provide for each cycle)

Example Table of Cycle Summary Information for Plant ID XYZ

Cycle	Startup Date	Shutdown Date	Cycle Length (calendar days)	Cycle Length (EFPD)	Downtime at EOC (days)	Nominal Reactor Full Power (MWt)	Moderator temperature			Soluble Boron Concentration[a]			System Pressure (psia)
							Inlet (˚C)	Outlet (˚C)	Core (˚C)	BOC (ppm)	MOC (ppm)	EOC (ppm)	
1A	01/14/77	03/03/78	413	268.80	195	3000	280	340	310	1147	820	588	1900
1B	09/15/78	04/23/79	220	171.30	97	3000	280	340	310	843	328	242	1900
2	07/29/79	02/26/80	212	166.50	164	3000	280	340	310	930	543	316	2100
3[b]	08/08/80	09/28/81	416	323.00	73	3000	280	340	310	1090	473	86	2100
4	12/10/81	03/19/83	464	336.60	127	3000	280	340	310	A	B	C	2250
5[c]	07/24/83	03/08/85	593	484.40	163	3300	280	340	310	A	B	C	2250
6	08/18/85	09/18/87	761	412.07	112	3300	280	340	310	A	B	C	2250
7	01/08/88	03/14/90	796	497.90	99	3300	280	340	310	A	B	C	2250
…	…	…	…	…	…	…	…	…	…	…	…	…	…
Up to current cycle data													

[a] Not needed if cycle letdown data is provided
[b] Downtime of 403 hours and 296 hours occurred after 168.5 EFPD and 250 EFPD, respectively
[c] Downtime of 119 hours occurred after 388.5 EFPD

Fuel Assembly-Specific Data **(provide for each fuel batch)**

Fresh Fuel Cycle	Assembly Batch	Assembly Type	wt% U235	kgU/ Assembly	FP Pellet OD (cm)	FP Clad OD (cm)	FP Clad ID (cm)	FA Grid Material	BPRA Type
1	1	STD	2.108	458.93	0.819150	0.94996	0.83566	Inconel	None
	2	STD	2.601	458.97	0.819150	0.94996	0.83566	Inconel	Pyrex
	3	STD	3.106	460.39	0.819150	0.94996	0.83566	Inconel	Pyrex
2	4	OFA	3.204	424.28	0.784352	0.91440	0.80010	zircaloy	Pyrex
3	5	OFA	3.204	424.39	0.784352	0.91440	0.80010	zircaloy	Pyrex
4	6A	OFA	3.20	423.12	0.784352	0.91440	0.80010	zircaloy	Pyrex
	6B	OFA	3.40	423.12	0.784352	0.91440	0.80010	zircaloy	Pyrex
5	7A	OFA	3.40	423.12	0.784352	0.91440	0.80010	zircaloy	WABA
	7B	OFA	3.60	423.12	0.784352	0.91440	0.80010	zircaloy	WABA
	7C	MKBW	2.92	456.20	0.811530	0.94996	0.82804	zircaloy	WABA
6	8	OFA	3.60	423.12	0.784352	0.91440	0.80010	zircaloy	WABA
7	9	OFA	3.75	423.12	0.784352	0.91440	0.80010	zircaloy	WABA

FP - Fuel Pin; FA - Fuel Assembly; BPRA - Burnable Poison Rod Assembly
OD - outer diameter; ID - inner diameter

RCCAs

Pellet Material	Ag-In-Cd
Fraction of Pellet Materials	Ag(80%), In(15.0%), Cd(5.0%)
Pellet Density	10.16 g/cc
Pellet OD	0.86614 cm
Clad Material	SS304
Clad OD	0.96774 cm
Clad ID	0.87376 cm

BPRAs (Annular)	Pyrex	WABA
Material	B_2O_3-SiO_2	B_4C-Al_2O_3
Boron Loading	12.5 wt% B_2O_3	14.0 wt% B_4C
	0.00624 g/cm (B-10)	0.006165 g/cm (B-10)
Absorber OD	0.85344 cm	0.8077 cm
Absorber ID	0.48260 cm	0.7061 cm
Absorber length	108”, 3” above midplane	134”, 4” above midplane
Clad Material	SS304	zircaloy
Outer Clad OD	0.96774 cm	0.96774 cm
Outer Clad ID	0.87376 cm	0.83570 cm
Inner Clad OD	0.46101 cm	0.67820 cm
Inner Clad ID	0.42799 cm	0.57150 cm

Control Blade Technical Information

Neutron absorber material	B_4C (natural boron)
Percent of B_4C theoretical density	70
Total blade span tip to tip	24.902 cm
Total blade support span	3.937 cm
Active absorber length	364.998 cm (min) 365.76 cm (typical)
Sheath material	304 stainless steel
Sheath thickness	0.1143 cm
Blade thickness	0.8331 cm
Number of B_4C rods per blade	72
B_4C cladding material	304 stainless steel
B_4C rod OD	0.5588 cm
B_4C rod ID	0.4216 cm
B_4C rod wall thickness	0.06858 cm

<u>Example Table of axial profile information for Assembly ID: AAAAAA</u> **<u>(provide for each assembly)</u>**

Axial	Node	Burnup			Burnup			Burnup		
Node	**Height (cm)**	**EOC 1**	**T-Fuel**	**Spec.Vol**	**EOC 2**	**T-Fuel**	**Spec.Vol**	**EOC 3**	**T-Fuel**	**Spec.Vol**
1 (top)	17.78	5.191	912.6	0.0237	7.992	974.1	0.0231	12.28	1006.3	0.0232
2	20.0025	8.429	1033.5	0.0236	12.84	1120.5	0.0231	19.411	1108	0.0231
3	20.0025	10.599	1084.4	0.0235	15.827	1189.6	0.023	23.509	1126.5	0.023
4	20.0025	11.995	1168.3	0.0234	17.481	1209.5	0.0229	25.524	1111.8	0.0229
5	20.0025	12.77	1428.3	0.0233	18.282	1211.3	0.0227	26.395	1093.3	0.0228
6	20.0025	13.19	1490.9	0.0232	18.646	1205.6	0.0226	26.737	1079.3	0.0227
7	20.0025	13.318	1501.4	0.023	18.721	1201.9	0.0225	26.797	1071.7	0.0226
8	20.0025	13.341	1504.9	0.0229	18.702	1199.5	0.0224	26.793	1068.2	0.0225
9	20.0025	13.329	1507.4	0.0227	18.662	1196.7	0.0223	26.815	1067.3	0.0224
10	20.0025	13.308	1510.2	0.0225	18.63	1191.9	0.0222	26.893	1068	0.0223
11	20.0025	13.294	1512.9	0.0224	18.616	1183.6	0.0221	27.016	1069.3	0.0222
12	20.0025	13.297	1513.2	0.0223	18.619	1171.5	0.022	27.148	1070.6	0.0221
13	20.0025	13.332	1505.7	0.0221	18.633	1155.5	0.0219	27.247	1072	0.022
14	20.0025	13.535	1478.7	0.022	18.754	1132.8	0.0219	27.358	1071.6	0.0219
15	20.0025	14.814	1390.7	0.0219	19.753	1084	0.0218	28.056	1054.6	0.0218
16	20.0025	17.321	1233.5	0.0217	21.717	1005.7	0.0217	29.285	1012.1	0.0217
17	20.0025	16.644	1128.2	0.0217	20.47	957.9	0.0216	27.15	985.7	0.0217
18	22.352	10.859	974.7	0.0216	13.47	866.9	0.0216	18.111	923.6	0.0216
Average/total	360.172	12.73	1327	0.0226	17.58	1125	0.0223	25.17	1058	0.0224

Burnup - GWd/MTU
T-Fuel - ^{o}F
Spec. Vol. - ft^3 / lbm

<u>Example Figure of eighth core-map for Cycle 3</u> **(provide for each cycle)**

	H	G	F	E	D	C	B	A
8	B10 * F(1) 1	B13 F(2) 4	D8 F(1) 3	F(3) 5	C11 * F(1) 1	A8 F(2) 4	F8 F(1) 3	B13 F(2) 4
9		D12 F(1) 3	A9 F(2) 4	F9 F(1) 3	F(3) 5	D11 F(1) 3	F(3) 5	A11 F(2) 4
10			E11 F(1) 3	F(3) 5	D9 F(1) 3	F(3) 5	C12 F(1) 3	B12 F(2) 4
11				F10 F(1) 3	F(3) 5	E10 F(1) 3	F(3) 5	B11 F(2) 4
12					D10 * F(1) 1	F(3) 5	B9 F(2) 4	
13						G9 F(1) 3	A10 F(2) 4	

*** = Cycle 1 Location**

CR	= Previous FA position Column/Row (C/R) - 1/8th Core
F	= Cycle FA was Fresh (F)
B	= Fuel Batch (B)

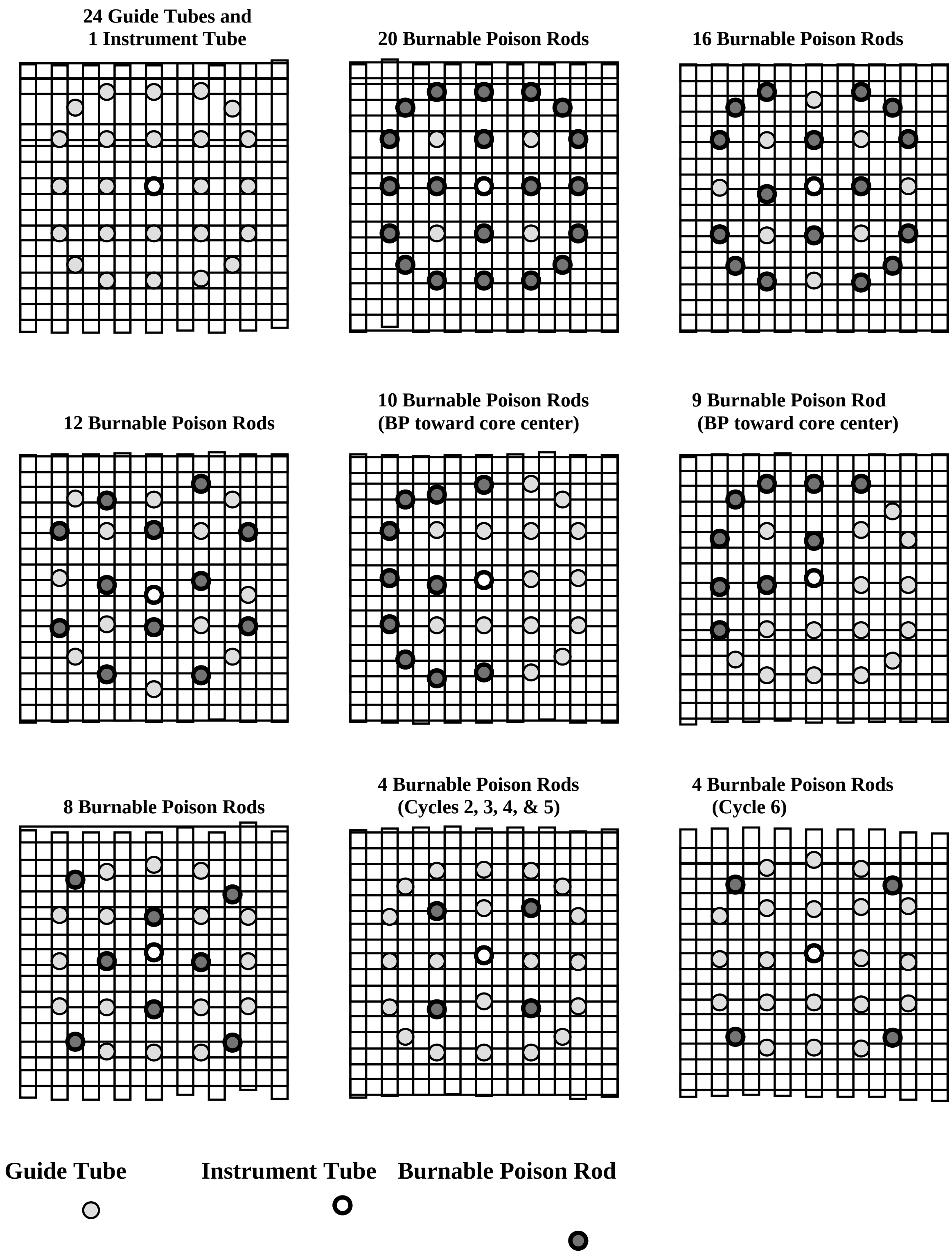
Cycle	Batch	Wt% U-235
3	1	2.108
	2	2.601
	3	3.106
	4	3.204
	5	3.204

BPRA Loading

Fuel Assembly Location	Number BP Rods/ Assembly
B9, C12	4
E8, D9, E10, C10, D11	8

Control Rod Bank	Core Location
CA	F8
CB	B10
CC	B8, F10
CD	H8, D12

Example Figure of Burnable Poison Rod Locations within a Fuel Assembly **(provide for each pattern)**



<u>Example Table for Fuel Assembly Locations by Cycle</u> **(provide for all cycles)**

Assembly Number/Batch	Assembly Location in Cycle 1	2	3	4	5	6	7	Comments
B25b/4		B11	A11			H8		**Cycle 2**
B31a/4		B13	A8	B13			H8	
C25/5			B11	A9	B13	D10		**Cycle 3**
D8/6B				A8	C8	D12		**Cycle 4**
D14/6B				B9	B12	B8		
D14a/6B				-	-	G9		
D17a/6B				E10	C13	E11		
D21/6B				A10	C10	E9		
D25/6B				B11	B10	F8		
D28/6B				C12	A9	C9		
E2/7C					G8	F10	G9*	**Cycle 5**
E8/7B					A8	C8	D8	* For cycle 7, assembly
E10/7A					F9	A9	D10	E2 represents 3 batch 7C
E12/7A					D9	D8	G9*	assemblies in a full core
E12a/7A					-	C13		representation (I.e.,
E14/7A					B9	B13	F10	symmetric to location G9).
E14a/7A					-	-	D12	Assembly E12 represents
E17/7A					E10	A11	B8	1 batch 7A assembly
E17a/7A					-	-	E11	in location G9. BOC cycle 7
E21/7A					A10	F9		should be examined with a
E23/7A					D11	B10		full core representation to
E25/7B					B11	B12	E9	examine asymmetry effects.
E28/7A					C12	C11		

<u>Example Table for Control Rod and Burnable Absorber Loading by Cycle</u> **(provide for all cycles)**

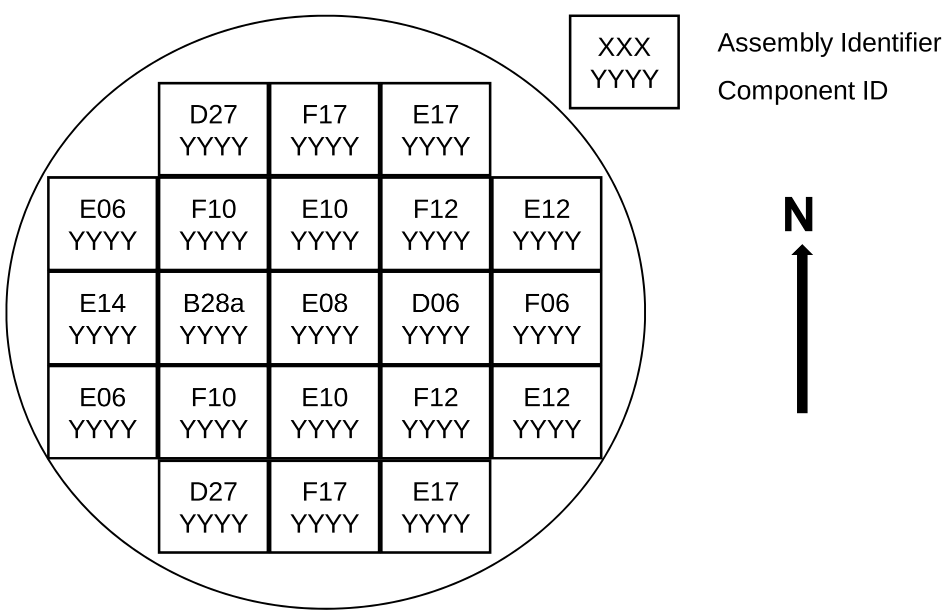
Assembly Number/Batch	Number of BA Rods or Rod Bank ID# / Assembly Location in Cycle 1	2	3	4	5	6	7	Cycle Burnable Absorber Type
B25b/4		**4/B11**	X			**CD/H8**		**Cycle 2**
B31a/4		X	X	X			**CD/H8**	**BA => Pyrex**
	CD=> Rod bank; X=> Assembly also present in cycle indicated							
D8/6B				X	X	**CD/D12**		**Cycle 4**
D14/6B				**4/B9**	X	X		**BA => Pyrex**
D14a/6B				**4/B9**	X	X		
D17a/6B				**12/E10**	X	X		
D28/6B				**4/C12**	X	X		
E2/7C					**4/G8**	X	X	**Cycle 5**
E10/7A					**8/F9**	X	X	**BA => WABA**
E12/7A					**8/D9**	X	X	
E12a/7A					**8/D9**	X		
E14/7A					**8/B9**	X	X	
E14a/7A					**8/B9**	X	**CD/D12**	
E17/7A					**8/E10**	X	X	
E17a/7A					**8/E10**	X	X	
E23/7A					**8/D11**	X		
E25/7B					**4/B11**	X	X	
E28/7A					**4/C12**	X		

<u>Example Table for Rod Insertion Time by Axial Node for Assembly B25b</u> **(provide for each rodded assembly)**

Axial Node	Time Rod Inserted (EFPD) BOC6 to EOC6
1	62.4
2	33.4
3	0.0
4	0.0
5	0.0
6	0.0
7	0.0
8	0.0
9	0.0
10	0.0
11	0.0
12	0.0
13	0.0
14	0.0
15	0.0
16	0.0
17	0.0
18	0.0

Canister/Cask Specific Data

Example Figure showing cask IJK loading and component locations



Example Table on cask component information for Cask IJK

Component ID	cycle(s) irradiated	Assy ID irradiated in	Cycle shutdown	Assy Enr (wt% U-235)	Assy Burnup (MWd/MTU)	Initial U loading (kgU)	component description
YYYY	8	B25b	2/26/1980	3.204	17580	424.28	Burnable poison rod assembly
????	????	????	????	????	????	????	????

Appendix D

TRITON Template Description

As a result of the large number of spent fuel assemblies that may require detailed modeling of fuel depletion, a fast, reliable and quality-assurable method of input model creation has been developed. The method adopted for this project is described below. The discussion assumes a basic knowledge of SCALE/TRITON and NEWT depletion calculations. The modeling relies on features of SCALE 6.1.

TRITON models are stored in a compact form as a set of templates, for each type of fuel assembly, which permits an automated method of input file assembly with verified dimensions and conditions stored in a single location. This method also supports the insertion into guide tubes and removal of burnable poison rods, such as rod control cluster assemblies (RCCAs), PYREX, wet annular burnable absorber (WABA), burnable poison rod assemblies (BPRAs), and black and gray axial power shaping rods (APSRs), in a variety of numbers and patterns and the use of fixed burnable poison fuels containing Gd_2O_3 or Er_2O_3.

The format of the TRITON input files is verbose, i.e., every fuel and non-fuel site in a fuel assembly is represented individually in the model to permit the description of the contents of each site such as a distribution of U235 enrichments, the presence or absence of burnable poison rods or the distribution of poisoned fuel rods. Such models can run to approximately 2000 lines of input with dimensions and densities and temperatures spread throughout. The template structure takes advantage of requiring the storage of only one replication of repeated structures which contain pre-defined parameter names that are the same for all assemblies. Thus, the volume of material stored for a model is much less than 2000 lines and the verified numerical values applicable to a specific fuel assembly are stored as a data vector in the database.

Fuel and poison-fuel materials and unit numbers are based on the (i, j) position of each rod in the 2D array, e.g., (row 1 contains materials 11 12 13 14…, row 2 contains 21 22 23 24… etc). Hence, unit 11 will contain material 11 etc. This explicit notation thus avoids any confusion about the location of a particular material. Since different assembly types contain differing numbers, locations and shapes of water rods (guide and instrument tubes in PWRs or water rods in BWRs), a comment block is supplied with each set of templates showing the array positions of fuel and water rods for a particular assembly type.

The input format makes extensive use of the TRITON functions “alias” and “assign” that are available in SCALE 6.1 to simplify the description of material distributions and to reduce the number of CENTRM (self-shielding) calculations required. In this method, a CENTRM calculation will be performed for a typical fuel rod and the self-shielded cross sections will be “assigned” to all similar rods. This method has been shown in past work for k-effective to deviate from a “CENTRM for every rod” calculation by a negligible quantity (approximately 10 pcm).

The models are assembled by a TemplateEngine written in java (versions 6 and later) using a main template that describes the structure of a TRITON deck and controls the order in which the functional pieces of the deck are placed in the input file. The main template calls for the importation of various sets of sub-templates that build the functional units of the file. Various flags signal whether a particular feature is present or not in a model e.g., if the flag “bpra_present” is set to “true”, this indicates to the TemplateEngine to include any structures and materials related to a specified number of a specified type of burnable poison rod. Typically, fuel assemblies may contain burnable poison rods on the first irradiation cycle but may have them removed on the second and subsequent cycles. The same type of logic controls the presence or not of RCCAs or poison-fuel rods in an assembly.

The template pieces do not contain numbers that govern the dimensions or conditions of operation of an assembly. These numbers are supplied by the database. A set of verbose parameter names has been defined that are the same for all assembly types. The verbosity removes ambiguity in what the parameter represents. This facilitates the re-usability of input file pieces. Once an input file has been constructed, parameter names are used to locate the actual values of dimensions and conditions for an assembly in the data vector for that assembly and they are subsequently substituted into the input file to produce a functional TRITON input file. They are also used for "self-documenting" the input file. The entire process takes approximately 5 seconds.

There is a "save" template which will save output files such as "ft31f0001", "ft33f001.cmbined" and "StdComps". These files are named with fields for various characteristics of the calculation, thus relieving the user of the burden of inventing names. The ft31f001 and ft33f0001 files are used in subsequent calculations by other sections of the main M&S tool. The StdComps are the compositions at each burnup step of the calculation and may be used to initiate subsequent irradiation cycles perhaps after burnable poison rods have been removed.

These concepts are illustrated in the following section, which describes the templates for a Westinghouse 17×17 LOPAR (W1717WL) fuel assembly.

The Template Set

Figure D-1 presents the contents of the root directory of an off-line TRITON model calculation to illustrate the storage of template components. Figure 1 shows a number of subdirectories (alias, compositions, depletion etc), the main template TDepl.tmpl, and a "json" file TDepl_bounding_pyrex.json from which the TemplateEngine draws the numerical values and flags that control the model construction as well as some auxiliary files.

```
W1717WL/
Sub-directories
drwxr-xr-x  2 hs7 users   4096 Aug 16 09:36 aliases
drwxr-xr-x  2 hs7 users   4096 Aug 28 14:02 burn_data
drwxr-xr-x  2 hs7 users   4096 Aug 13 17:34 celldata
drwxr-xr-x  2 hs7 users   4096 Aug 14 17:00 compositions
drwxr-xr-x  2 hs7 users   4096 Aug 28 14:03 depletion_data
drwxr-xr-x  2 hs7 users   4096 Aug 13 17:34 keep_data
drwxr-xr-x  2 hs7 users   4096 Aug 13 17:34 lib
drwxr-xr-x  3 hs7 users   4096 Aug 13 17:34 model_data
drwxr-xr-x  2 hs7 users   4096 Aug 28 14:04 timetable_data
Template Engine components
-rw-r-----  1 hs7 users   2102 Aug 21 13:18 TDepl_bounding_pyrex.json
-rw-r-----  1 hs7 users   2127 Aug 10 09:52 TDepl.tmpl
Auxiliary files
-rw-r-----  1 hs7 users    209 Jul 24 08:05 TemplateHeader.tmpl
-rw-r-----  1 hs7 users   1057 Aug 16 09:35 W1717WL.layout.comment.tmpl
-rw-r-----  1 hs7 users   1555 Aug  1 14:30 W1717WL.opus_data.tmpl
-rw-r-----  1 hs7 users   2194 Aug  8 17:22 W1717WL.save_data.tmpl
```

Figure D-1. Template components for a W1717WL fuel assembly.

Main template TDepl.tmpl

The main template, TDepl.tmpl, presented in Figure D-2, is not assembly dependent, i.e., it applies to all TRITON models. It directs the flow of events to be implemented by the TemplateEngine. The first item to be placed in the model is the TemplateHeader.tmpl file. This file forms part of the QA trail and records who made the model, on which machine and on which date. The TemplateHeader.tmpl file is illustrated in Figure D-3.

```
#import TemplateHeader.tmpl

=t-depl parm=(centrm,addnux=4,weight)
#import <assembly.type>.title.tmpl
<xslib>
' -----------------------------------------
' -----------------------------------------
' ---  Rod array layout and naming   ---
' -----------------------------------------
' -----------------------------------------
#import <assembly.type>.layout.comment.tmpl
'
' half assembly pitch is #eval fmt=%6.4f (0.5*<assembly.pitch>) as hap# cm
' fuel rod half pitch is #eval fmt=%6.4f (0.5*<fuel_pin.pitch>) as frhp# cm
'
' -----------------------------------------
'  --- Alias Data ---
' -----------------------------------------
#import aliases/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Composition Data ---
' -----------------------------------------
#import compositions/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Cell Data ---
' -----------------------------------------
#import celldata/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Depletion Data ---
' -----------------------------------------
#import depletion_data/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Timetable Data -Tfuel, Cdens, Bconc etc ---
' -----------------------------------------
#import timetable_data/<assembly.type>.<reactor>.tmpl
' -----------------------------------------
'  ---  Burn Data ---
' -----------------------------------------
#import burn_data/<assembly.type>.<reactor>.tmpl
' -----------------------------------------
'  ---  Keep Data ---
' -----------------------------------------
#import keep_data/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Model Data ---
' -----------------------------------------
#import model_data/<assembly.type>.tmpl
' -----------------------------------------
'  ---  Opus Data ---
' -----------------------------------------
#import <assembly.type>.opus_data.tmpl
End
' -----------------------------------------
'  ---  Save Data ---
' -----------------------------------------
#import <assembly.type>.save_data.tmpl
```

Figure D-2. TDepl.tmpl.

```
' -------------------------------------------------------
- Author - <USER>
- Date   - <DATE>
- Created on a <OS> <ARCHITECTURE> machine named <MACHINE>
' -------------------------------------------------------
```

Figure D-3. TemplateHeader.tmpl.

The next line in the main template is to write the opening line of a TRITON tdepl calculation, followed by the title card (Figure D-4) and the cross section library to be used.

```
#ifdef pfuel_present
<assembly.type> <pfuel.u235_enrichment> wt% LEU,<pfuel_count>
<pfuel.u235_enrichment>Wt%LEU+<pfuel_type>,1/4 ass'y model-Reactor <reactor>
#endif
#ifndef pfuel_present
<assembly.type> <fuel.u235_enrichment> wt% LEU, 1/4 ass'y model - Reactor <reactor>
#endif
```

Figure D-4. W1717WL.title.tmpl.

The title template offers two options for a title depending on whether or not the assembly contains poison-fuel (pfuel) rods. The title file shows the first use of parameter names (enrichments, poison-fuel characteristics, reactor) which are substituted from the assembly data vector in the database or in this off-line case, the json file. An excerpt of the json file is presented in Figure D-5.

```
{
  "reactor" : 'generic_bounding'
  ,"fuel.u235_enrichment" : 1.00
  ,"xslib" : 'v7-238'
  ,"assembly.type" : 'W1717WL'

  ,'pfuel_present' : false
  ,'pfuel_type' : 'gd'
  ,'pfuel_pattern' : 'd'
  ,'pfuel_count' : '20'

  ,'bpra_present' : true
  ,'bpra_type' : 'pyrex'
  ,'bpra_count' : '24'

  ,'bpr.inner_clad_inner_radius': 0.21400
  ,'bpr.inner_clad_outer_radius': 0.23051
  ,'bpr.pellet_inner_radius'    : 0.24130
  ,'bpr.pellet_outer_radius'    : 0.42672
  ,'bpr.outer_clad_inner_radius': 0.43688
  ,'bpr.outer_clad_outer_radius': 0.48387
  ,'bpr.pellet_material'        : pyrex
  ,'bpr.pellet_density'         : 2.299
  ,'bpr.absorber_wtfraction'    : 0.125
  ,'bpr.clad_material'          : ss304


  ,'fuel_pin.pitch'             : 1.25984
  ,'fuel_pin.pellet_radius'     : 0.40575
  ,'fuel_pin.clad_inner_radius' : 0.41783
  ,'fuel_pin.clad_outer_radius' : 0.47498
  ,'fuel_pin.pellet_density'    : 10.741
  ,'fuel_pin.pellet_temperature' : 1157
  ,'fuel_pin.gap_temperature'   : 687
  ,'fuel_pin.clad_material'     : zirc4

  ,"pfuel.u235_enrichment" : 3.0
  ,"pfuel.poison_wtfraction" : 0.02
.
.
.
}
```

Figure D-5. Excerpt from TDepl_bounding_pyrex.json.

This data vector is the only place in which numerical values of dimensions, enrichments and operating conditions are presented, thus simplifying the effort to QA the model or to make adjustments to or parametrize the model e.g., for U235 enrichment)

The main template then inserts a comment block portraying the fuel material numbering scheme for the model. This is illustrated in Figure D-6 where the zeroes are the locations of guide tubes in the array.

```
' W1717L Assembly Layout
'        11 12 13 14 15 16 17 18 19
'        21 22 23 24 25 26 27 28 29
'         0 32 33  0 35 36 37 38 39
'        41 42 43 44 45  0 47 48 49
'        51 52 53 54 55 56 57 58 59
'         0 62 63  0 65 66  0 68 69
'        71 72 73 74 75 76 77 78 79
'        81 82 83 84 85 86 87 88 89
'         0 92 93  0 95 96  0 98 99
'
'-----------------DEFINE ALIAS------------------------
```

Figure D-6. W1717WL.layout.

Following the importation of the layout, there are two in-line evaluations. Typically, assembly pitch and rod pitch data is installed in the database. However, in the modeling, extensive use is made of the half-assembly pitch and the half-fuel-rod pitch. These “half pitch” values are calculated and given parameter names that are used subsequently in the models.

Alias

The main template then directs the importation of aliases/W1717WL.tmpl. This sub-template is presented in Figure D-7 and shows the construction of the alias data for TRITON depending on whether or not pfuel is present. The first task in the aliases/W1717WL.tmpl is to insert the aliasing for CENTRM calculations. The sub template will thus add W1717WL.centrm.fuel.tmpl or, if pfuel is present, W1717WL.centrm.fuel.tmpl and W1717WL.centrm.pfuel.tmpl.

The second task is to insert the aliasing for the depletion materials (i.e., those identified by array position). If there is no pfuel, then all sites are fuel as shown in W1717WL.depl.fuel.tmpl. If pfuel is present then a complementary pair of files is required for a specified pfuel pattern and number of pfuel rods (e.g., W1717WL.depl.fuel.gd.a.12.tmpl and W1717WL.depl.pfuel.gd.a.12.tmpl) as shown in Figure D-7. The separate description for pfuel is required because the pfuel is a different fuel and it is also modeled as five concentric rings to improve the representation of flux depression in the poison fuel rod. It is necessary to communicate where the normal fuel is located in the array and where the pfuel is located.

The third task is to insert the aliasing for other materials (clad, gap, moderator).

Composition

Figure D-8 presents the template set for inserting the material compositions. W1717WL.tmpl will insert W1717WL.fuel.tmpl or, if pfuel is present, W1717WL.fuel.tmpl and W1717WL.pfuel.tmpl. The templates receive the U235 enrichment for the fuel materials and calculate the corresponding weight fractions of U234, U236 and U238. In the case of the pfuel, the template also adds in the poison type (Gd or Er) and the weight fraction in the pfuel.

The next task is to add the compositions of other materials such as clad, gap, gt(guide tube), coolant. This section also imports the materials for any burnable poison rods and their cladding. The templates for the compositions of the burnable poison rods are presented in Figure D-9.

```
W1717WL.tmpl
' <assembly.type> alias data
read alias
#import <assembly.type>.centrm.fuel.tmpl
#ifdef pfuel_present
#import <assembly.type>.centrm.pfuel.tmpl
#endif
#ifndef pfuel_present
#import <assembly.type>.depl.fuel.tmpl
#endif
#ifdef pfuel_present
#import
<assembly.type>.depl.fuel.<pfuel_type>.<pfuel_pattern>.<pfuel_cou
nt>.tmpl
#import
<assembly.type>.depl.pfuel.<pfuel_type>.<pfuel_pattern>.<pfuel_co
unt>.tmpl
#endif
#import <assembly.type>.gap.clad.gt.cool.tmpl
end alias
```

```
W1717WL.centrm.fuel.tmpl
$1fl<fuel.u235_enrichment>      1 end
```

```
W1717WL.centrm.pfuel.tmpl
$1f<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction>  600 601 602 603 604   end
```

```
W1717WL.depl.fuel.tmpl
$fl<fuel.u235_enrichment>       11  12  13  14  15  16  17  18  19
                  21  22  23  24  25  26  27  28  29
                      32  33      35  36  37  38  39
                  41  42  43  44  45      47  48  49
                  51  52  53  54  55  56  57  58  59
                      62  63      65  66      68  69
                  71  72  73  74  75  76  77  78  79
                  81  82  83  84  85  86  87  88  89
                      92  93      95  96      98  99   end
```

```
W1717WL.depl.fuel.gd.a.12.tmpl
$fl<fuel.u235_enrichment>       11  12  13  14  15  16  17  18  19
                  21  22  23  24  25  26  27  28  29
                      32  33      35  36      38  39
                  41  42  43  44  45      47  48  49
                  51  52      54  55  56  57  58  59
                      62  63      65  66      68  69
                  71  72  73  74      76  77  78  79
                  81  82  83  84  85  86  87  88  89
                      92  93      95  96      98  99   end
```

```
W1717WL.depl.pfuel.gd.a.12.tmpl
$f<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction>   37  53  75
        371  531  751
        372  532  752
        373  533  753
        374  534  754   end
```

```
W1717WL.gap.clad.gt.cool.tmpl
$gap   101 102 103   end
$clad  121 122 123   end
$gt    131 132 133   end
$mod   141 142 143   end
$lclad  151  end
$<bpra_type>  200       end
```

Figure D-7. Alias template files.

The methods of specifying material composition for the PYREX and WABA rods differ from that for fuels because they are compound materials, i.e., PYREX is (SiO_2+B_2O_3). In the PYREX and WABA specifications, the format calls for the volume fraction of the component materials. Normally, the literature provides only the density. Hence, there is an in-line calculation of the volume fractions based on the densities of the components.

```
W1717WL.tmpl
' <assembly.type> composition data
read composition
#import <assembly.type>.fuel.tmpl
#ifdef pfuel_present
#import <assembly.type>.pfuel.tmpl
#endif
#import <assembly.type>.gap.clad.gt.cool.tmpl
end composition
```

```
W1717WL.fuel.tmpl
' Data for fuel pins in a <assembly.type> assembly
' Density:    <fuel_pin.pellet_density> g/cc  with 1.24% dishing loss
' Enrichment:  <fuel.u235_enrichment> Wt% enriched
' Temp:       <fuel_pin.pellet_temperature> K
 uo2   $1fl<fuel.u235_enrichment>    den=<fuel_pin.pellet_density> 1    <fuel_pin.pellet_temperature>
                    92234  #eval fmt=%6.4f (0.0089*<fuel.u235_enrichment>) as u4#
                    92235  <fuel.u235_enrichment>
                    92236  #eval fmt=%6.4f (0.0046*<fuel.u235_enrichment>)  as u6#
                    92238  #eval fmt=%6.4f (100-u4-<fuel.u235_enrichment>-u6)# end
```

```
W1717WL.pfuel.tmpl
' Data for poisoned fuel pins for <assembly.type> assembly pfuel
' Density:    <pfuel_pin.pellet_density>  g/cc with <pfuel.poison_wtfraction> <pfuel_type> and 1.24% dishing loss
' Enrichment:  <pfuel.u235_enrichment> Wt% enriched  LEU fraction is #eval fmt=%6.4f (1-<pfuel.poison_wtfraction>) as pfrac#
' Temp:       <pfuel_pin.pellet_temperature> K
 uo2   $1fl<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction> den=<pfuel_pin.pellet_density> <pfrac>
<pfuel_pin.pellet_temperature>
                    92234  #eval fmt=%6.4f (0.0089*<pfuel.u235_enrichment>) as pfu4#
                    92235  <pfuel.u235_enrichment>
                    92236  #eval fmt=%6.4f (0.0046*<pfuel.u235_enrichment>) as pfu6#
                    92238  #eval fmt=%6.4f (100-pfu4-<pfuel.u235_enrichment>-pfu6)# end
 gd2o3 $1fl<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction> den=<pfuel_pin.pellet_density> <pfuel.poison_wtfraction>
<pfuel_pin.pellet_temperature>  end
```

```
W1717WL.gap.clad.gt.cool
'----------------------Gap, he--------------------------------
'
' Density:    2.2218E-4 g/cc
 he  $gap    den=2.2218E-4 1.0000  <fuel_pin.gap_temperature>  end
'----------------------Clad--------------------------------
'
' Data for fuel clad
' Material:   <fuel_pin.clad_material>
' Density:    SCALE standard density assumed
' Temp:       <moderator.temperature> K
 <fuel_pin.clad_material> $clad 1      <moderator.temperature> end
'
'----------------------Guide Tube--------------------------------
'
' Data for guide tube
' Material:   <guide_tube.material>
' Density:    SCALE standard density assumed
' Temp:       <moderator.temperature> K
  <guide_tube.material> $gt    1 <moderator.temperature> end
'----------------------Water Moderator 0% Void--------------------------------
'
' LEU core has average <moderator.boron_concentration> ppm B from
rundown curve
' Temperature: <moderator.temperature> g/cc
  h2o    $mod     den=<moderator.density> 1.0000
<moderator.temperature> end
 wtptbor $mod         <moderator.density> 1 5000 100
<moderator.boron_concentration>e-6 <moderator.temperature> end

#ifdef bpra_present
#import <assembly.type>.<bpra_type>.tmpl
'----------------------BPRA Clad---------------------------------------------
'
' Data for fuel clad
' Material:   <bpr.clad_material>
' Density:    SCALE standard density assumed
' Temp:       <moderator.temperature> K
  <bpr.clad_material> $lclad  1 <moderator.temperature> end
#endif
```

Figure D-8. Composition template files.

```
W1717WL.pyrex.tmpl
'----------------------PYREX (SiO2-B2O3) -------------------------------------
'b2o3 volume fraction is #eval fmt=%6.4f (1.97*<bpr.absorber_wtfraction>/3.07) as  b2o3vf#
'sio2 volume fraction is #eval fmt=%6.4f (1-<b2o3vf>) as  sio2vf#
  atom-<bpr.pellet_material> $<bpra_type> <bpr.pellet_density> 2 14000 1 8016 2 #eval fmt=%6.4f (1-<b2o3vf>) as  sio2vf#
<moderator.temperature> end
  atom-<bpr.pellet_material> $<bpra_type> <bpr.pellet_density> 2  5000 2 8016 3 #eval fmt=%6.4f (1.97*<bpr.absorber_wtfraction>/3.07)
as  b2o3vf# <moderator.temperature> end
```

```
W1717WL.waba.tmpl
'----------------------WABA (Al2O3-B4C)--------------------------------------
' b4c volume fraction   is #eval fmt=%6.4f (3.7*<bpr.absorber_wtfraction>/2.52) as b4cvf#
' al2o3 volume fraction is #eval fmt=%6.4f (1-<b4cvf>) as al2o3vf#
 atom-<bpr.pellet_material> $<bpra_type> <bpr.pellet_density> 2 13027 2 8016 3 #eval fmt=%6.4f (1-<b4cvf>) as al2o3vf# <moderator.temperature> end
 atom-<bpr.pellet_material> $<bpra_type> <bpr.pellet_density> 2  5000 4 6000 1 #eval fmt=%6.4f (3.7*<bpr.absorber_wtfraction>/2.52) as b4cvf#
<moderator.temperature> end
```

```
W1717WL.rcca.tmpl
'----------------------RCCA------------------------------------------------
  wtpt<bpr.pellet_material> $<bpra_type> <bpr.pellet_density> 3
              47000 80.00
              48000  5.00
              49000 15.00  1 <moderator.temperature> end
```

Figure D-9. Burnable poison rod composition template files.

<u>Celldata</u>

Figure D-10 presents the templates for adding the celldata to the input file. Normal fuel is calculated using a latticecell calculation. Pfuel is calculated using a multiregion calculation with five subdividing rings.

```
W1717WL.tmpl
' <assembly.type> cell data
read celldata
#import <assembly.type>.fuel.tmpl
#ifdef pfuel_present
#import <assembly.type>.pfuel.tmpl
#endif
end celldata
```

```
W1717WL.fuel.tmpl
' <assembly.type> lattice cell definition
 latticecell squarepitch  hpitch= <frhp> 141
                fuelr=<fuel_pin.pellet_radius>    1
                gapr=<fuel_pin.clad_inner_radius> 101
                cladr=<fuel_pin.clad_outer_radius>  121    end
  centrmdata nmf6=-1 alump=0.03 demin=0.125 pmc_omit=1
pmc_dilute=5.0e5 end centrmdata
```

```
  W1717WL.pfuel.tmpl
   multiregion cylindrical right_bdy=white end
     600 0.18336
     601 0.25931
     602 0.31758
     603 0.36672
     604 <pfuel_pin.pellet_radius>
     103 <pfuel_pin.clad_inner_radius>
     123 <pfuel_pin.clad_outer_radius>
     143 <frhp>  end zone
   centrmdata alump=0.03 pmc_omit=1  end centrmdata
```

Figure D-10. Celldata template files.

Depletion
Figure D-11 presents the templates that add the TRITON instructions to define which materials are to be depleted and in what manner, i.e., regular fuel rods are depleted by power (default) whereas pfuel rods are depleted by flux. This template also carries out the "assign" function wherein the self-shielded cross sections of "CENTRM" fuels (indicated by a"1" flag in the name, e.g., $1fl.., as opposed to a depletion material $fl..) are assigned to various depletion materials.

```
W1717WL.tmpl
' <assembly.type> depletion data
read depletion
 $fl<fuel.u235_enrichment>
#ifdef pfuel_present
flux
 $fl<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction>
#endif
 end
 assign $1fl<fuel.u235_enrichment> $fl<fuel.u235_enrichment> end
#ifdef pfuel_present
#import
<assembly.type>.assign.pfuel.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.tmpl
#endif
end depletion
```

```
W1717WL.assign.gd.a.12.tmpl
 assign 600     37  53  75 end
  assign 601   371 531 751 end
  assign 602   372 532 752 end
  assign 603   373 533 753 end
  assign 604   374 534 754 end
```

Figure D-11. Depletion and assign template files.

Model_data
Figure D-12 presents the template, W1717WL.tmpl, that builds the model geometry. It starts with a declaration of the calculation parameters followed by material mixtures to be used.

The next task is to add in the descriptions of each unit in the assembly. This task is carried out by template units/W1717WL.fuel.rods.tmpl presented in Figure 13. Some of these units are fuel rods and some are guide tubes or the instrument tube. Since the model is a one quarter model assembly with an odd number of fuel rods per side (17), the symmetry lines cut fuel rods and guide tubes in half. They cut the centrally-located instrument into one quarter. The geometry descriptions of each unit are highly repetitive. Hence, a looping description has been used to build all similar units. It can be seen in Figure D-13 that the single fuel rod description, W1717WL.fuel.rod.tmpl has been used repetitively, substituting the listed fuel rod unit numbers. Similarly, the right half fuel rods and top half fuel rods half have been created with the appropriate unit numbers. This process was also used to create the guide tube units and the instrument tube unit. If burnable poison rods have been flagged as present, the template will add units that describe the burnable poison rod geometry as shown in Figure D-14. These units have numbers that are not array positions because they are inserted into guide tubes that have already been assigned those unit numbers. Having built all of the fuel rod, guide tube, instrument tube and burnable poison rod units, W1717WL.tmpl of Figure 12 now adds in the global unit shown in Figure D-14. The W1717WL.global.tmpl template places the array of units in the global unit and if burnable poison rods are present uses W1717WL.bpr.24 as shown in Figure D-15 to place the rods in guide tubes using the TRITON 'hole' function.

```
W1717WL.tmpl
' <assembly.type> model data
read model
#import ../<assembly.type>.title.tmpl
#import <assembly.type>.parameters.tmpl
read materials
 mix=$fl<fuel.u235_enrichment>      pn=1 com='<fuel.u235_enrichment> Wt%' end
#ifdef pfuel_present
 mix=$fl<pfuel.u235_enrichment><pfuel_type><pfuel.poison_wtfraction> pn=2
com='<pfuel.u235_enrichment> Wt%+<pfuel.poison_wtfraction> <pfuel_type>' end
#endif
 mix=$gap        pn=1  com='Helium'          end
 mix=$mod        pn=2  com='H2O'             end
 mix=$clad       pn=1  com='<fuel_pin.clad_material>' end
 mix=$lclad      pn=1  com='<bpr.clad_material>' end
 mix=$gt         pn=1  com='<guide_tube.material>'  end
 mix=200         pn=2  com='<bpra_type>'        end
end materials
' ------------------------------------------------------------
' --- Model Geometry Data ---
' ------------------------------------------------------------
read geometry
#import units/<assembly.type>.fuel.rods.tmpl
#import units/<assembly.type>.global.tmpl
end geometry
' ------------------------------------------------------------
' --- Model Array Data ---
' ------------------------------------------------------------
#import <assembly.type>.array.tmpl
read bounds
 all=refl
end bounds
end model
```

```
W1717WL.parameters
read parameters
 echo=yes drawit=yes run=yes prtflux=no solntype=b1
 cmfd=1 epsilon=1e-5 converg=mix inners=2 therm=yes therms=1
outers=9999 xycmfd=1
end parameters
```

```
W1717WL.array
' <assembly.type> array data
read array
 ara=1 nux=9 nuy=9 typ=cuboidal
 fill
 91  92  93  94  95  96  97  98  99
 81  82  83  84  85  86  87  88  89
 71  72  73  74  75  76  77  78  79
 61  62  63  64  65  66  67  68  69
 51  52  53  54  55  56  57  58  59
 41  42  43  44  45  46  47  48  49
 31  32  33  34  35  36  37  38  39
 21  22  23  24  25  26  27  28  29
 11  12  13  14  15  16  17  18  19  end fill
end array
```

Figure D-12. Model template files – part 1.

```
W1717WL.fuel.rods.tmpl
#ifdef pfuel_present
#import fuel/<assembly.type>.fuel.rod.units.<pfuel_type>.<pfuel_pattern>.<pfuel_count>
#endif
#ifndef pfuel_present
#import <assembly.type>.fuel.rod.tmpl using [{'unit' : '12'},{'unit' : '13'},{'unit' : '14'},{'unit' : '15'},{'unit' : '16'},{'unit' : '17'},{'unit' :
'18'},{'unit' : '19'},{'unit' : '22'},{'unit' : '23'},{'unit' : '24'},{'unit' : '25'},{'unit' : '26'},{'unit' : '27'},{'unit' : '28'},{'unit' : '29'},{'unit' :
'32'},{'unit' : '33'},{'unit' : '35'},{'unit' : '36'},{'unit' : '37'},{'unit' : '38'},{'unit' : '39'},{'unit' : '42'},{'unit' : '43'},{'unit' : '44'},{'unit' :
'45'},{'unit' : '47'},{'unit' : '48'},{'unit' : '49'},{'unit' : '52'},{'unit' : '53'},{'unit' : '54'},{'unit' : '55'},{'unit' : '56'},{'unit' : '57'},{'unit' :
'58'},{'unit' : '59'},{'unit' : '62'},{'unit' : '63'},{'unit' : '65'},{'unit' : '66'},{'unit' : '68'},{'unit' : '69'},{'unit' : '72'},{'unit' : '73'},{'unit' :
'74'},{'unit' : '75'},{'unit' : '76'},{'unit' : '77'},{'unit' : '78'},{'unit' : '79'},{'unit' : '82'},{'unit' : '83'},{'unit' : '84'},{'unit' : '85'},{'unit' :
'86'},{'unit' : '87'},{'unit' : '88'},{'unit' : '89'}]
#import <assembly.type>.fuel.rod.right.half.tmpl using [{'unit' : '11'},{'unit' : '21'},{'unit' : '41'},{'unit' : '51'},{'unit' : '71'},{'unit' : '81'}]
#import <assembly.type>.fuel.rod.top.half.tmpl using [{'unit' : '92'},{'unit' : '93'},{'unit' : '95'},{'unit' : '96'},{'unit' : '98'},{'unit' : '99'}]

#import <assembly.type>.guide.tube.tmpl using [{'unit' : '34'},{'unit' :'46'},{'unit' :'64'},{'unit' :'67'}]
#import <assembly.type>.guide.tube.right.half.tmpl using [{'unit' : '31'},{'unit' : '61'}]
#import <assembly.type>.guide.tube.top.half.tmpl using [{'unit' : '94'},{'unit' : '97'}]
#import <assembly.type>.instrument.tube.ne.quarter.tmpl using [{'unit' : '91'}]

#endif
#ifdef bpra_present
#import bpr/<assembly.type>.bpr.<bpra_type>.units.tmpl
#endif
```

```
W1717WL.fuel.rod.tmpl
unit <unit>
com='UO2 fuel rod for unit <unit>'
 cylinder 10 <fuel_pin.pellet_radius>
 cylinder 20 <fuel_pin.clad_inner_radius>
 cylinder 30 <fuel_pin.clad_outer_radius>
 cuboid   40  4p<frhp>
 media <unit> 1 10
 media 102 1 20 -10
 media 122 1 30 -20
 media 143 1 40 -30
 boundary 40 4 4
```

```
W1717WL.fuel.rod.right.half.tmpl
unit <unit>
com='right-half of UO2 fuel rod'
 cylinder 10 <fuel_pin.pellet_radius>  chord +x=0
 cylinder 20 <fuel_pin.clad_inner_radius> chord +x=0
 cylinder 30 <fuel_pin.clad_outer_radius>  chord +x=0
 cuboid   40  <frhp>  0.0 2p<frhp>
 media <unit> 1 10
 media 102 1 20 -10
 media 122 1 30 -20
 media 143 1 40 -30
 boundary 40 2 4
```

```
W1717WL.fuel.rod.top.half
unit <unit>
com='top-half of UO2 fuel rod'
 cylinder 10 <fuel_pin.pellet_radius>  chord +y=0
 cylinder 20 <fuel_pin.clad_inner_radius> chord +y=0
 cylinder 30 <fuel_pin.clad_outer_radius>  chord +y=0
 cuboid   40  2p<frhp> <frhp> 0.0
 media  <unit> 1 10
 media 102 1 20 -10
 media 122 1 30 -20
 media 143 1 40 -30
 boundary 40 4 2
```

Figure D-13. Model template files – part 2.

```
W1717WL.bpr.pyrex.units.tmpl
'Pyrex Rods
unit 200
com='bpr insert -whole rod-annular'
cylinder 10 <bpr.inner_clad_inner_radius>
cylinder 20 <bpr.inner_clad_outer_radius>
cylinder 30 <bpr.pellet_inner_radius>
cylinder 40 <bpr.pellet_outer_radius>
cylinder 50 <bpr.outer_clad_inner_radius>
cylinder 60 <bpr.outer_clad_outer_radius>
media 102 1 10
media 132 1 20 -10
media 102 1 30 -20
media 200 1 40 -30
media 102 1 50 -40
media 132 1 60 -50
boundary 60 4 4

unit 201
com='bpr insert -right-half rod'
cylinder 10 <bpr.inner_clad_inner_radius> chord +x=0
cylinder 20 <bpr.inner_clad_outer_radius> chord +x=0
cylinder 30 <bpr.pellet_inner_radius> chord +x=0
cylinder 40 <bpr.pellet_outer_radius> chord +x=0
cylinder 50 <bpr.outer_clad_inner_radius> chord +x=0
cylinder 60 <bpr.outer_clad_outer_radius> chord +x=0
media 102 1 10
media 132 1 20 -10
media 102 1 30 -20
media 200 1 40 -30
media 102 1 50 -40
media 132 1 60 -50
boundary 60 2 4

unit 202
com='bpr insert -top-half rod-annular'
cylinder 10 <bpr.inner_clad_inner_radius> chord +y=0
cylinder 20 <bpr.inner_clad_outer_radius> chord +y=0
cylinder 30 <bpr.pellet_inner_radius> chord +y=0
cylinder 40 <bpr.pellet_outer_radius> chord +y=0
cylinder 50 <bpr.outer_clad_inner_radius> chord +y=0
cylinder 60 <bpr.outer_clad_outer_radius> chord +y=0
media 102 1 10
media 132 1 20 -10
media 102 1 30 -20
media 200 1 40 -30
media 102 1 50 -40
media 132 1 60 -50
boundary 60 4 2


W1717WL.global.tmpl
global unit 10
 cuboid 10 <hap> 0.0 <hap> 0.0
 array 1 10 place 1 1 0 0
 media 142 1 10
#ifdef bpra_present
#import bpr_config/<assembly.type>.<bpr>.<bpra_count>
#endif
 boundary 10 36 36
```

Figure D-14. Model template files – part 3.

```
W1717WL.bpr.24.tmpl
'place rcca or bpr in 24 rod pattern'
'position 34
 hole 200 origin x=#eval fmt=%6.4f (3*<fuel_pin.pitch>) as pos3#
y=#eval fmt=%6.4f (6*<fuel_pin.pitch>) as pos6#
'position 46
 hole 200 origin x=#eval fmt=%6.4f (5*<fuel_pin.pitch>) as pos5#
y=<pos5>
'position 64
 hole 200 origin x=<pos3>  y=<pos3>
'position 67
 hole 200 origin x=<pos6>  y=<pos3>
'position 31
 hole 201 origin x=0.000   y=<pos6>
'position 61
 hole 201 origin x=0.000   y=<pos3>
'position 94
 hole 202 origin x=<pos3>  y=0.000
'position 97
 hole 202 origin x=<pos6>  y=0.000
```

Figure D-15. Model template files – part 4.

Auxiliary templates

W1717WL.save.tmpl, which is described in Figure C-16, adds instructions to save various files produced during the run such as the ft31f001 and ft33f001.cmbined which contain results for post-processing into, for example, "ARP" libraries. These files are named based on characteristics of the run for consistency and ease of identification. The template also creates a subdirectory named "exitcomps+characteristics of the run". These are fuel compositions for each fuel material at each burnup step and can be used to initiate a subsequent calculation under changed operational conditions.

Four optional printouts are shown in Figure D-16 for:

- Regular fuel only
- Regular fuel + burnable poison rods
- Regular fuel + poison fuel
- Regular fuel +poison fuel +poison rods.

```
W1717WL.save.tmpl
=shell
#ifndef pfuel_present
#ifndef bpra_present
  cp $TMPDIR/ft71f001         $RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.71.lib
  cp $TMPDIR/ft33f001.cmbined   $RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.33.lib
  mkdir $RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>
  cp $TMPDIR/Std*             $RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>/.
#endif
#ifdef bpra_present
  cp $TMPDIR/ft71f001         $RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<bpra_type>.<bpra_count>.71.lib
  cp $TMPDIR/ft33f001.cmbined   $RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<bpra_type>.<bpra_count>.33.lib
  mkdir $RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<bpra_type>.<bpra_count>
  cp $TMPDIR/Std*             $RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<bpra_type>.<bpra_count>/.
#endif
#endif
#ifdef pfuel_present
#ifndef bpra_present
  cp $TMPDIR/ft71f001         $RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.71.lib
  cp $TMPDIR/ft33f001.cmbined
$RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.33.lib
  mkdir $RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>
  cp $TMPDIR/Std*
$RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>/.
#endif
#ifdef bpra_present
  cp $TMPDIR/ft71f001
$RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.<bpra_type>.<bpra_count>.71.lib
  cp $TMPDIR/ft33f001.cmbined
$RTNDIR/<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.<bpra_type>.<bpra_count>.33.lib
  mkdir
$RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.<bpra_type>.<bpra_co
unt>
  cp $TMPDIR/Std*
$RTNDIR/exitcomps.<assembly.type>.<fuel.u235_enrichment>.<reactor>.<pfuel_type>.<pfuel_pattern>.<pfuel_count>.<bpra_type>.<bpra_co
unt>/.
#endif
#endif
end
```

Figure D-16. Save template file.

Appendix E

CSAS6/KENO-VI Cask Model Template

The canister/cask criticality models are developed for each storage site to be used with the SCALE/KENO-VI software, using the continuous energy option. The cask models are filled with water of full density, which is a typical approach for criticality computation. The material properties are constant for structural materials and for the water that fills the cask, but vary for fuel materials, depending on the fuel zone in the cask. In general, the cask models have $AN \times NN$ fuel material zones, where *AN* is the number of fuel assemblies (including damaged fuel canisters, if applicable) stored in the cask and *NN* is the number of axial nodes (burnup zones) along each fuel assembly. The fuel material zone number for assembly *A* and node *N* are computed using the formula $1000+(A-1) \times NN+N$. The assignment of the material compositions to a certain fuel material is performed by the GUI tool at the top of the computational chain.

These models have been designed in a modular fashion to facilitate ulterior additions and changes to the existing models. As a general feature, the fixed part of the canister is decoupled from the variable content, i.e., fuel assemblies and debris. This allows for automatic construction of a full model of the canister/cask with various contents. The fixed part of the canister/cask structure, containing the fuel rack together with the absorber panels as well as the canister hardware, including the wall and lid, is identical for many casks, whereas the fuel stored is different from one cask to the other. The fixed part of the canister/cask is therefore designated as a template which is filled with different fuel content for different cask loading patterns. The variable part of the SCALE/KENO-VI models employs a template language engine to build this part of the input, which typically has a repetitive structure. Different variables used in this template file are initialized in an input file to the template engine, called a JSON.

An example of a command that uses this template language to build the fuel pin units is:

```
#repeat pin_unit.tmpl using assembly=1,<assembly_count> node=1,<axial_node_count>
```

With this statement inserted at the proper place in the master template (the file containing the bare cask model), the template language will insert pin units (assumed similar) for each fuel assembly and for each axial node in the master template.

The CSAS6 model template for the MPC24E/EF (TROJAN) cask loaded with Westinghouse 17×17 fuel assemblies is provided in Sect. E.1. The JSON for the cask template is provided in Sect. E.2 and the cask sub-templates are provided in Sect. E.3.

E.1 Model Template for the MPC24E/EF (TROJAN) Cask

```
=csas26
KENO-VI model of MPC-24E/EF Trojan
ce_v7
read comp
' Stainless steel
ss304     1                  1    300    end
' Water in cask
h2o       2    den=1.0       1    300    end
'    - Boral- B-10 loading of 0.0372 g B-10/cm2, 2.66g/cc, 0.101 inch thick (nominal)
'      The B-10 concentration reduced to 75% of the nominal value
b-10      3  0  6.5409E-03   300.0  end
b-11      3  0  3.5172E-02   300.0  end
c         3  0  1.0968E-02   300.0  end
al        3  0  3.6904E-02   300.0  end
'
'    - Al as boral clad
al        4   den=2.7      1 300.0  end
'
'    - water in gt
h2o       5   den=1.0      1 300.0  end
'
'    - Zirc guide tubes
zirc4     6                1 300.0  end
'
'    - Zirc cladding for CE calculations
zirc4     12              1 300.0  end
'
'    - water for fuel pin cell moderator for CE calculations
h2o       13 den=1.0      1 300.0 end
'
'    - water for fuel pin cell pellet/clad gap for CE calculations
h2o       14 den=1.0      1 300.0 end

#repeat assembly_materials.tmpl using assembly=1,<assembly_count>

end comp

' ----------------------------------------------------------------
' Parameters
' ----------------------------------------------------------------
read parm
 sig=0.0001 gen=110 npg=10000 nsk=1 htm=no uum=no
end parm

' ----------------------------------------------------------------
' Geometry
' ----------------------------------------------------------------
read geom

#import geometry.tmpl using <assemblies>

unit 97001
  com='wide neutron absorber, [1] pag. 162, note1'
  cuboid    1     9.6549     -9.6549     0.47752     0.0     396.5424      0.0
  media       1     1     1    -6
  cuboid    2     9.5025     -9.5025     0.00889     0.0     396.3924      0.1524
  media       2     1     2
  cuboid    3     9.5025     -9.5025     0.03429     0.0     396.3924      0.1524
  media       4     1     3    -2
```

```
 cuboid    4     9.5025     -9.5025     0.29083     0.0     396.3924      0.1524
 media       3     1     4    -3
 cuboid    5     9.5025     -9.5025     0.31623     0.0     396.3924      0.1524
 media       4     1     5    -4
 cuboid    6     9.5025     -9.5025     0.32512     0.0     396.3924     0.1524
 media       2     1     6    -5
 boundary    1
unit 97002
 com='narrow neutron absorber, [1] pag. 162, note2'
 cuboid    1     8.0899     -8.0899     0.47752     0.0     396.5424     0.0
 media       1     1     1    -6
 cuboid    2     7.9375     -7.9375     0.00889     0.0     396.3924     0.1524
 media       2     1     2
 cuboid    3     7.9375     -7.9375     0.03429     0.0     396.3924     0.1524
 media       4     1     3    -2
 cuboid    4     7.9375     -7.9375     0.29083     0.0     396.3924     0.1524
 media       3     1     4    -3
 cuboid    5     7.9375     -7.9375     0.31623     0.0     396.3924     0.1524
 media       4     1     5    -4
 cuboid    6     7.9375     -7.9375     0.32512     0.0     396.3924     0.1524
 media       2     1     6    -5
 boundary    1
unit 97003
 com='mousehole, [1] pag. 162, note5'
 cuboid    1    10.16        0.0        0.79375     0.0       3.175      0.0
 media       2     1     1
 boundary    1

unit 97101
 com='cell  1'
 cuboid    1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid    2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid    3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid    4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30001 origin              z=25.15870001
 boundary    1
unit 97102
 com='cell  2'
 cuboid    1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid    2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid    3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid    4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30002 origin              z=25.15870001
 boundary    1
unit 97103
 com='cell  3'
 cuboid    1 12.60475000 -11.81100000 12.60475000 -11.81100000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid    2 12.60474999 -11.81100000 12.60474999 11.81100000 424.81499999 0.00000001
 media       1     1     2
 cuboid    3      12.60474999     11.81100000
                   12.60474999    -12.60474999
                  424.81499999      0.00000001
 media       1     1     3    -2
 cuboid    4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
```

```
  media       2     1     4
  hole 30003 origin             z=25.15870001
  boundary    1
 unit 97104
  com='cell  4'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
  media       2     1     4
  hole 30004 origin             z=25.15870001
  boundary    1
 unit 97105
  com='cell  5'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2  11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
  media       2     1     4
  hole 30005 origin             z=25.15870001
  boundary    1
 unit 97106
  com='cell  6'
  cuboid   1 12.60475000 -11.81100000 12.60475000 -11.81100000 424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 12.60474999 -11.81100000 12.60474999 11.81100000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 12.60474999 11.81100000 12.60474999 -12.60474999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30006 origin             z=25.15870001
  boundary    1
 unit 97107
  com='cell  7'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999  11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999  -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30007 origin             z=25.15870001
  boundary    1
 unit 97108
  com='cell  8'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000  424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30008 origin             z=25.15870001
  boundary    1
```

```
unit 97109
 com='cell  9'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999  -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30009 origin              z=25.15870001
 boundary    1
unit 97110
 com='cell 10'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30010 origin              z=25.15870001
 boundary    1
unit 97111
 com='cell 11'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30011 origin              z=25.15870001
 boundary    1
unit 97112
 com='cell 12'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999  0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30012 origin              z=25.15870001
 boundary    1
unit 97113
 com='cell 13'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30013 origin              z=25.15870001
 boundary    1
unit 97114
 com='cell 14'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
```

```
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30014 origin             z=25.15870001
  boundary    1
 unit 97115
  com='cell 15'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
  media       2     1     4
  hole 30015 origin             z=25.15870001
  boundary    1
 unit 97116
  com='cell 16'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30016 origin             z=25.15870001
  boundary    1
 unit 97117
  com='cell 17'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999  11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
  media       2     1     4
  hole 30017 origin             z=25.15870001
  boundary    1
 unit 97118
  com='cell 18'
  cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
  media       1     1     2
  cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
  media       1     1     3    -2
  cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
  media       2     1     4
  hole 30018 origin             z=25.15870001
  boundary    1
 unit 97119
  com='cell 19'
  cuboid   1 12.60475000 -11.81100000 12.60475000 -11.81100000  424.81500000 0.00000000
  media       2     1     1    -2    -3    -4
  cuboid   2 12.60474999 -11.81100000 12.60474999 11.81100000 424.81499999 0.00000001
  media       1     1     2
```

```
 cuboid   3 12.60474999 11.81100000 12.60474999 -12.60474999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
 media       2     1     4
 hole 30019 origin              z=25.15870001
 boundary    1
unit 97120
 com='cell 20'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30020 origin              z=25.15870001
 boundary    1
unit 97121
 com='cell 21'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
 media       2     1     4
 hole 30021 origin              z=25.15870001
 boundary    1
unit 97122
 com='cell 22'
 cuboid   1 12.60475000 -11.81100000 12.60475000 -11.81100000  424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 12.60474999 -11.81100000 12.60474999 11.81100000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 12.60474999 11.81100000 12.60474999 -12.60474999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
 media       2     1     4
 hole 30022 origin              z=25.15870001
 boundary    1
unit 97123
 com='cell 23'
 cuboid   1  11.90625000 -11.11250000 11.90625000 -11.11250000 424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000 424.81499998 0.00000002
 media       2     1     4
 hole 30023 origin              z=25.15870001
 boundary    1
unit 97124
 com='cell 24'
 cuboid   1 11.90625000 -11.11250000 11.90625000 -11.11250000  424.81500000 0.00000000
 media       2     1     1    -2    -3    -4
 cuboid   2 11.90624999 -11.11250000 11.90624999 11.11250000 424.81499999 0.00000001
 media       1     1     2
 cuboid   3 11.90624999 11.11250000 11.90624999 -11.90624999 424.81499999 0.00000001
 media       1     1     3    -2
 cuboid   4 11.11240000 -11.11240000 11.11240000 -11.11240000  424.81499998 0.00000002
```

```
  media       2     1     4
  hole 30024 origin              z=25.15870001
  boundary    1

 unit 97400
  com='upper half'
  cylinder  1     85.72498    430.02199998      0.00000001 chord +y=0.00000001
  media       2     1     1     -2     -3     -4  -101  -102  -103  -104
                           -201  -202  -203  -204  -205  -206  -207  -208
'    central post
  cuboid   2   3.4925   -3.4925    3.4925   0.0    430.02198   0.00002
  media       1     1     2     -3     -4  -101  -201  -202
'    location 10
  cuboid   3   2.66446    29.41955    2.66446   29.41955    430.02198    0.00002
  media       2     1     3
'    location 9
  cuboid   4  -29.41955   -2.66446    2.66446   29.41955    430.02198    0.00002
  media       2     1     4
'    rack walls along x (starting from y=0 midplane)
'    cell spacer #1
  cuboid  101     81.5721     -81.5721
                   0.79375      0.0
                 424.815        0.0        origin y=1.87071
  media       1     1   101
'    boral S of location 7
  hole 97001 origin x=-69.67855000 y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 9
  hole 97001 origin x=-13.77696000 y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 10
  hole 97001 origin x=13.77696000  y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 12
  hole 97001 origin x=69.67855000  y=1.87070999 z=9.84250000 rotate a1=180
'    cell spacer #2
  cuboid  102     79.5401     -79.5401
                   0.79375      0.0
                 424.815        0.0        origin y=29.41955
  media       1     1   102
'    boral N of location 8
  hole 97001 origin x=-41.32580000 y=30.21330001 z=9.84250000
'    boral S of location 4
  hole 97001 origin x=-18.30705000 y=29.41954999 z=9.84250000 rotate a1=180
'    boral S of location 5
  hole 97001 origin x=18.30705000  y=29.41954999 z=9.84250000 rotate a1=180
'    boral N of location 11
  hole 97001 origin x=41.32580000  y=30.21330001 z=9.84250000
'    cell spacer #3
  cuboid  103     58.42       -58.42
                   0.79375      0.0
                 414.655        0.0        origin y=57.7723
'    boral N of location 3
  hole 97001 origin x=-45.96130000 y=58.56605001 z=9.84250000
'    boral S of location 1
  hole 97001 origin x=-13.77696000 y=57.77229999 z=9.84250000 rotate a1=180
'    boral S of location 2
  hole 97001 origin x=13.77696000  y=57.77229999 z=9.84250000 rotate a1=180
'    boral N of location 6
  hole 97001 origin x=45.96130000  y=58.56605001 z=9.84250000
'          clip outer walls for locations 3,6
  cuboid  104     30.2133     -30.2133
                   0.79375      0.0
                 424.815      414.655      origin y=57.7723
  media       1     1   104
  media       1     1   103
```

```
'    rack walls along y (first right, then left, starting from x=0 midplane)
'    cell spacer #1 (right and left)
  cuboid  201      0.79375      0.0
                  81.5721       0.0
                 424.815        0.0        origin x=1.87071
  media       1     1   201  -101  -102  -103  -104
'    boral W of location 10
  hole 97001 origin x=1.87070999 y=13.77696000 z=9.84250000 rotate a1=90
'    boral W of location 2
  hole 97001 origin x=1.87070999 y=69.67855000 z=9.84250000 rotate a1=90
  cuboid  202      0.0         -0.79375
                  81.5721       0.0
                 424.815        0.0        origin x=-1.87071
  media       1     1   202  -101  -102  -103  -104
'    boral E of location 9
  hole 97001 origin x=-1.87070999 y=13.77696000 z=9.84250000 rotate a1=-90
'    boral E of location 1
  hole 97001 origin x=-1.87070999 y=69.67855000 z=9.84250000 rotate a1=-90
'    cell spacer #2 (right and left)
  cuboid  203      0.79375      0.0
                  79.5401       0.0
                 424.815        0.0        origin x=29.41955
  media       1     1   203  -101  -102  -103  -104
'    boral E of location 5
  hole 97001 origin x=30.21330001 y=41.32580000 z=9.84250000 rotate a1=-90
'    boral W of location 11
  hole 97001 origin x=29.41954999 y=18.30705000 z=9.84250000 rotate a1=90
  cuboid  204      0.0         -0.79375
                  79.5401       0.0
                 424.815        0.0        origin x=-29.41955
  media       1     1   204  -101  -102  -103  -104
'    boral W of location 4
  hole 97001 origin x=-30.21330001 y=41.32580000 z=9.84250000 rotate a1=90
'    boral E of location 8
  hole 97001 origin x=-29.41954999 y=18.30705000 z=9.84250000 rotate a1=-90
'    cell spacer #3 (right and left)
  cuboid  205      0.79375      0.0
                  58.42         0.0
                 414.655        0.0        origin x=57.7723
  media       1     1   205  -101  -102  -103  -104
'    boral W of location 12
  hole 97001 origin x=57.77229999 y=13.77696000 z=9.84250000 rotate a1=90
'    boral E of location 6
  hole 97001 origin x=58.56605001 y=45.96130000 z=9.84250000 rotate a1=-90
  cuboid  206      0.0         -0.79375
                  58.42         0.0
                 414.655        0.0        origin x=-57.7723
  media       1     1   206  -101  -102  -103  -104
'    boral E of location 7
  hole 97001 origin x=-57.77229999 y=13.77696000 z=9.84250000 rotate a1=-90
'    boral W of location 3
  hole 97001 origin x=-58.56605001 y=45.96130000 z=9.84250000 rotate a1=90
'          clip outer walls for locations 3,6
  cuboid  207      0.79375      0.0
                  30.2133       0.0
                 424.815      414.655      origin x=57.7723
  media       1     1   207
  cuboid  208      0.0         -0.79375
                  30.2133       0.0
                 424.815      414.655      origin x=-57.7723
  media       1     1   208
'    boral inside locations
'    horizontal ([1], pag 162)
```

```
'    ===========================================================================
'    boral N of cell 10
  hole 97001 origin x=13.77696000  y=25.68321001 z=9.84250000
'    boral N of cell 12
  hole 97002 origin x=69.67855000  y=25.68321001 z=9.84250000
'    boral N of cell 9
  hole 97001 origin x=-13.77696000 y=25.68321001 z=9.84250000
'    boral N of cell 7
  hole 97002 origin x=-69.67855000 y=25.68321001 z=9.84250000
'    ===========================================================================
'    boral S of cell 11
  hole 97001 origin x=41.32580000  y=6.40079999 z=9.84250000 rotate a1=180
'    boral S of cell 8
  hole 97001 origin x=-41.32580000 y=6.40079999 z=9.84250000 rotate a1=180
'    ===========================================================================
'    boral N of cell 5
  hole 97001 origin x=18.30705000  y=53.23205001 z=9.84250000
'    boral N of cell 4
  hole 97001 origin x=-18.30705000 y=53.23205001 z=9.84250000
'    ===========================================================================
'    boral S of cell 6
  hole 97001 origin x=45.96130000  y=33.35654999 z=9.84250000 rotate a1=180
'    boral S of cell 3
  hole 97001 origin x=-45.96130000 y=33.35654999 z=9.84250000 rotate a1=180
'    ===========================================================================
'    boral N of cell 2
  hole 97002 origin x=13.77696000  y=81.58480001 z=9.84250000
'    boral N of cell 1
  hole 97002 origin x=-13.77696000 y=81.58480001 z=9.84250000
'    vertical ([1], pag 162)
'    ===========================================================================
'    boral E of cell 10
  hole 97001 origin x=25.68321001  y=13.77696000 z=9.84250000 rotate a1=-90
'    boral E of cell 2
  hole 97002 origin x=25.68321001  y=69.67855000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral W of cell 9
  hole 97001 origin x=-25.68321001 y=13.77696000 z=9.84250000 rotate a1=90
'    boral W of cell 1
  hole 97002 origin x=-25.68321001 y=69.67855000 z=9.84250000 rotate a1=90
'    ===========================================================================
'    boral W of cell 5
  hole 97001 origin x=6.40079999   y=41.32580000 z=9.84250000 rotate a1=90
'    ===========================================================================
'    boral E of cell 4
  hole 97001 origin x=-6.40079999  y=41.32580000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral E of cell 11
  hole 97001 origin x=53.23205001  y=18.30705000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral W of cell 8
  hole 97001 origin x=-53.23205001 y=18.30705000 z=9.84250000 rotate a1=90
'    ===========================================================================
'    boral W of cell 6
  hole 97001 origin x=33.35654999  y=45.96130000 z=9.84250000 rotate a1=90
'    ===========================================================================
'    boral E of cell 3
  hole 97001 origin x=-33.35654999 y=45.96130000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral E of cell 12
  hole 97002 origin x=81.58480001  y=13.77696000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral W of cell 7
```

```
  hole 97002 origin x=-81.58480001 y=13.77696000 z=9.84250000 rotate a1=90
'    =========================================================================
'    =========================================================================
'    fuel
  hole 97101 origin x=-13.77696000 y=69.67855000 z=0.00000002 rotate a1=90
  hole 97102 origin x=13.77696000  y=69.67855000 z=0.00000002
  hole 97103 origin x=-45.96130000 y=45.96130000 z=0.00000002 rotate a1=-90
  hole 97104 origin x=-18.30705000 y=41.32580000 z=0.00000002
  hole 97105 origin x=18.30705000  y=41.32580000 z=0.00000002 rotate a1=90
  hole 97106 origin x=45.96130000  y=45.96130000 z=0.00000002 rotate a1=180
  hole 97107 origin x=-69.67855000 y=13.77696000 z=0.00000002 rotate a1=90
  hole 97108 origin x=-41.32580000 y=18.30705000 z=0.00000002 rotate a1=180
  hole 97109 origin x=-13.77696000 y=13.77696000 z=0.00000002 rotate a1=90
  hole 97110 origin x=13.77696000  y=13.77696000 z=0.00000002
  hole 97111 origin x=41.32580000  y=18.30705000 z=0.00000002 rotate a1=-90
  hole 97112 origin x=69.67855000  y=13.77696000 z=0.00000002
  boundary    1

 unit 97800
  com='lower half'
  cylinder  1     85.72498    430.02199998      0.00000001 chord +y=0.00000001
  media       2     1     1     -2     -3     -4  -101  -102  -103  -104
                             -201  -202  -203  -204  -205  -206  -207  -208
'    central post
  cuboid    2      3.4925      -3.4925
                   3.4925       0.0
                 430.02198      0.00002
  media       1     1     2     -3     -4  -101  -201  -202
'    location 10
  cuboid    3      2.66446     29.41955
                   2.66446     29.41955
                 430.02198      0.00002
  media       2     1     3
'    location 9
  cuboid    4    -29.41955     -2.66446
                   2.66446     29.41955
                 430.02198      0.00002
  media       2     1     4
'    rack walls along x (starting from y=0 midplane)
'    cell spacer #1
  cuboid  101     81.5721     -81.5721
                   0.79375      0.0
                 424.815        0.0        origin y=1.87071
  media       1     1   101
'    boral S of location 7
  hole 97001 origin x=-69.67855000 y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 9
  hole 97001 origin x=-13.77696000 y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 10
  hole 97001 origin x=13.77696000  y=1.87070999 z=9.84250000 rotate a1=180
'    boral S of location 12
  hole 97001 origin x=69.67855000  y=1.87070999 z=9.84250000 rotate a1=180
'    cell spacer #2
  cuboid  102     79.5401     -79.5401
                   0.79375      0.0
                 424.815        0.0        origin y=29.41955
  media       1     1   102
'    boral N of location 8
  hole 97001 origin x=-41.32580000 y=30.21330001 z=9.84250000
'    boral S of location 4
  hole 97001 origin x=-18.30705000 y=29.41954999 z=9.84250000 rotate a1=180
'    boral S of location 5
  hole 97001 origin x=18.30705000  y=29.41954999 z=9.84250000 rotate a1=180
```

```
'    boral N of location 11
  hole 97001 origin x=41.32580000  y=30.21330001 z=9.84250000
'    cell spacer #3
  cuboid  103     58.42       -58.42
                   0.79375      0.0
                 414.655        0.0        origin y=57.7723
'    boral N of location 3
  hole 97001 origin x=-45.96130000 y=58.56605001 z=9.84250000
'    boral S of location 1
  hole 97001 origin x=-13.77696000 y=57.77229999 z=9.84250000 rotate a1=180
'    boral S of location 2
  hole 97001 origin x=13.77696000  y=57.77229999 z=9.84250000 rotate a1=180
'    boral N of location 6
  hole 97001 origin x=45.96130000  y=58.56605001 z=9.84250000
'          clip outer walls for locations 3,6
  cuboid  104     30.2133     -30.2133
                   0.79375      0.0
                 424.815      414.655      origin y=57.7723
  media       1     1   104
  media       1     1   103
'    rack walls along y (first right, then left, starting from x=0 midplane)
'    cell spacer #1 (right and left)
  cuboid  201      0.79375      0.0
                  81.5721       0.0
                 424.815        0.0        origin x=1.87071
  media       1     1   201  -101  -102  -103  -104
'    boral W of location 10
  hole 97001 origin x=1.87070999 y=13.77696000 z=9.84250000 rotate a1=90
'    boral W of location 2
  hole 97001 origin x=1.87070999 y=69.67855000 z=9.84250000 rotate a1=90
  cuboid  202      0.0         -0.79375
                  81.5721       0.0
                 424.815        0.0        origin x=-1.87071
  media       1     1   202  -101  -102  -103  -104
'    boral E of location 9
  hole 97001 origin x=-1.87070999 y=13.77696000 z=9.84250000 rotate a1=-90
'    boral E of location 1
  hole 97001 origin x=-1.87070999 y=69.67855000 z=9.84250000 rotate a1=-90
'    cell spacer #2 (right and left)
  cuboid  203      0.79375      0.0
                  79.5401       0.0
                 424.815        0.0        origin x=29.41955
  media       1     1   203  -101  -102  -103  -104
'    boral E of location 5
  hole 97001 origin x=30.21330001 y=41.32580000 z=9.84250000 rotate a1=-90
'    boral W of location 11
  hole 97001 origin x=29.41954999 y=18.30705000 z=9.84250000 rotate a1=90
  cuboid  204      0.0         -0.79375
                  79.5401       0.0
                 424.815        0.0        origin x=-29.41955
  media       1     1   204  -101  -102  -103  -104
'    boral W of location 4
  hole 97001 origin x=-30.21330001 y=41.32580000 z=9.84250000 rotate a1=90
'    boral E of location 8
  hole 97001 origin x=-29.41954999 y=18.30705000 z=9.84250000 rotate a1=-90
'    cell spacer #3 (right and left)
  cuboid  205      0.79375      0.0
                  58.42         0.0
                 414.655        0.0        origin x=57.7723
  media       1     1   205  -101  -102  -103  -104
'    boral W of location 12
  hole 97001 origin x=57.77229999 y=13.77696000 z=9.84250000 rotate a1=90
'    boral E of location 6
```

```
  hole 97001 origin x=58.56605001 y=45.96130000 z=9.84250000 rotate a1=-90
  cuboid  206      0.0         -0.79375
                 58.42         0.0
                414.655        0.0        origin x=-57.7723
  media       1     1   206  -101  -102  -103  -104
'    boral E of location 7
  hole 97001 origin x=-57.77229999 y=13.77696000 z=9.84250000 rotate a1=-90
'    boral W of location 3
  hole 97001 origin x=-58.56605001 y=45.96130000 z=9.84250000 rotate a1=90
'          clip outer walls for locations 3,6
  cuboid  207      0.79375      0.0
                 30.2133       0.0
                424.815      414.655      origin x=57.7723
  media       1     1   207
  cuboid  208      0.0         -0.79375
                 30.2133       0.0
                424.815      414.655      origin x=-57.7723
  media       1     1   208
'    boral inside locations
'    horizontal ([1], pag 162)
'    ===========================================================================
'    boral N of cell 10
  hole 97001 origin x=13.77696000  y=25.68321001 z=9.84250000
'    boral N of cell 12
  hole 97002 origin x=69.67855000  y=25.68321001 z=9.84250000
'    boral N of cell 9
  hole 97001 origin x=-13.77696000 y=25.68321001 z=9.84250000
'    boral N of cell 7
  hole 97002 origin x=-69.67855000 y=25.68321001 z=9.84250000
'    ===========================================================================
'    boral S of cell 11
  hole 97001 origin x=41.32580000  y=6.40079999 z=9.84250000 rotate a1=180
'    boral S of cell 8
  hole 97001 origin x=-41.32580000 y=6.40079999 z=9.84250000 rotate a1=180
'    ===========================================================================
'    boral N of cell 5
  hole 97001 origin x=18.30705000  y=53.23205001 z=9.84250000
'    boral N of cell 4
  hole 97001 origin x=-18.30705000 y=53.23205001 z=9.84250000
'    ===========================================================================
'    boral S of cell 6
  hole 97001 origin x=45.96130000  y=33.35654999 z=9.84250000 rotate a1=180
'    boral S of cell 3
  hole 97001 origin x=-45.96130000 y=33.35654999 z=9.84250000 rotate a1=180
'    ===========================================================================
'    boral N of cell 2
  hole 97002 origin x=13.77696000  y=81.58480001 z=9.84250000
'    boral N of cell 1
  hole 97002 origin x=-13.77696000 y=81.58480001 z=9.84250000
'    vertical ([1], pag 162)
'    ===========================================================================
'    boral E of cell 10
  hole 97001 origin x=25.68321001  y=13.77696000 z=9.84250000 rotate a1=-90
'    boral E of cell 2
  hole 97002 origin x=25.68321001  y=69.67855000 z=9.84250000 rotate a1=-90
'    ===========================================================================
'    boral W of cell 9
  hole 97001 origin x=-25.68321001 y=13.77696000 z=9.84250000 rotate a1=90
'    boral W of cell 1
  hole 97002 origin x=-25.68321001 y=69.67855000 z=9.84250000 rotate a1=90
'    ===========================================================================
'    boral W of cell 5
  hole 97001 origin x=6.40079999   y=41.32580000 z=9.84250000 rotate a1=90
```

```
'    ============================================================================
'    boral E of cell 4
  hole 97001 origin x=-6.40079999  y=41.32580000 z=9.84250000 rotate a1=-90
'    ============================================================================
'    boral E of cell 11
  hole 97001 origin x=53.23205001  y=18.30705000 z=9.84250000 rotate a1=-90
'    ============================================================================
'    boral W of cell 8
  hole 97001 origin x=-53.23205001 y=18.30705000 z=9.84250000 rotate a1=90
'    ============================================================================
'    boral W of cell 6
  hole 97001 origin x=33.35654999  y=45.96130000 z=9.84250000 rotate a1=90
'    ============================================================================
'    boral E of cell 3
  hole 97001 origin x=-33.35654999 y=45.96130000 z=9.84250000 rotate a1=-90
'    ============================================================================
'    boral E of cell 12
  hole 97002 origin x=81.58480001  y=13.77696000 z=9.84250000 rotate a1=-90
'    ============================================================================
'    boral W of cell 7
  hole 97002 origin x=-81.58480001 y=13.77696000 z=9.84250000 rotate a1=90
'    ============================================================================
'    ============================================================================
'    fuel
  hole 97124 origin x=-13.77696000 y=69.67855000 z=0.00000002 rotate a1=90
  hole 97123 origin x=13.77696000  y=69.67855000 z=0.00000002
  hole 97122 origin x=-45.96130000 y=45.96130000 z=0.00000002 rotate a1=-90
  hole 97121 origin x=-18.30705000 y=41.32580000 z=0.00000002
  hole 97120 origin x=18.30705000  y=41.32580000 z=0.00000002 rotate a1=90
  hole 97119 origin x=45.96130000  y=45.96130000 z=0.00000002 rotate a1=180
  hole 97118 origin x=-69.67855000 y=13.77696000 z=0.00000002 rotate a1=90
  hole 97117 origin x=-41.32580000 y=18.30705000 z=0.00000002 rotate a1=180
  hole 97116 origin x=-13.77696000 y=13.77696000 z=0.00000002 rotate a1=90
  hole 97115 origin x=13.77696000  y=13.77696000 z=0.00000002
  hole 97114 origin x=41.32580000  y=18.30705000 z=0.00000002 rotate a1=-90
  hole 97113 origin x=69.67855000  y=13.77696000 z=0.00000002
  boundary    1

 unit 97999
  com='basket, [1] pag 162'
  cylinder  1     85.72499999    430.02199999      0.00000001
  hole 97400
  hole 97800 rotate a1=180
  media       2     1     1
  boundary    1
 unit 98999
  com='canister, [1] pag 154'
  cylinder  1     86.995      460.502        0.0
  cylinder  2     86.995      460.502      436.372
  cylinder  3     85.725      460.502        6.35
  cylinder  4     85.725      436.37201      6.35
  hole 97999  origin z=6.35
  media       1     1     2
  media       1     1     1    -2    -3
  media       2     1     4    -2
  boundary    1
 global unit 99999
  com='outer world with canister surrounded by 50 cm of water'
  cylinder  1    136.99501    510.50201    -50.00001
  cylinder  2    136.995      510.502      -50.0
  hole 98999
  media       0     1     1    -2
  media       2     1     2
```

```
  boundary    1
end geom

read bounds
 all=vacuum
end bounds

' Assembly Type: Westinghouse 17x17 OFA/V5
read array

#import arrays.tmpl using <assemblies>

end array

' ------------------------------------------------------------------
' Plot
' ------------------------------------------------------------------
read plot
ttl='Cask Cross Section at half height'
  TYP=XY
  XUL=-100.0 YUL=100.0  ZUL=230.
  XLR=100.0  YLR=-100.0 ZLR=230.
  NAX=2500 end
ttl='Vertical Cask Cross Section at y=10cm'
  TYP=XZ
  XUL=-140.0 YUL=10.0  ZUL=525.
  XLR=140.0  YLR=10.0  ZLR=-55.
  NAX=2500 end
end plot

end data

end
```

E.2 JSON for the Cask Model


```
{
    'axial_node_count' : 2
    ,"assembly_count" : 24
    ,"fuel_pin.stack_length" : 365.76
    ,'assemblies' : [
        {
          'assembly' : 1
          ,'assembly.type' : 'w1717wl'
          ,"fuel_pin.pitch" : 1.25980
          ,"fuel_pin.pellet_outer_radius" : 0.39220
          ,"fuel_pin.clad_outer_radius" : 0.45720
          ,"fuel_pin.clad_inner_radius" :  0.40010
          ,"fuel_pin.stack_length" : 365.76
          ,"assembly.pitch" : 21.4166
        }
        ,{
          'assembly' : 2
          ,'assembly.type' : 'w1717wl'
          ,"fuel_pin.pitch" : 1.25980
          ,"fuel_pin.pellet_outer_radius" : 0.39220
          ,"fuel_pin.clad_outer_radius" : 0.45720
          ,"fuel_pin.clad_inner_radius" :  0.40010
          ,"fuel_pin.stack_length" : 365.76
          ,"assembly.pitch" : 21.4166
        }
        ,{
```

```
    'assembly' : 3
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 4
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 5
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 6
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 7
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 8
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 9
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
```

```
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 10
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 11
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 12
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 13
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 14
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 15
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
```

```
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 16
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 17
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 18
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 19
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
  ,{
    'assembly' : 20
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.23980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 19.8368
  }
  ,{
    'assembly' : 21
    ,'assembly.type' : 'w1717wl'
    ,"fuel_pin.pitch" : 1.25980
    ,"fuel_pin.pellet_outer_radius" : 0.39220
    ,"fuel_pin.clad_outer_radius" : 0.45720
    ,"fuel_pin.clad_inner_radius" :  0.40010
    ,"fuel_pin.stack_length" : 365.76
    ,"assembly.pitch" : 21.4166
  }
```

```
        ,{
          'assembly' : 22
          ,'assembly.type' : 'w1717wl'
          ,"fuel_pin.pitch" : 1.25980
          ,"fuel_pin.pellet_outer_radius" : 0.39220
          ,"fuel_pin.clad_outer_radius" : 0.45720
          ,"fuel_pin.clad_inner_radius" :  0.40010
          ,"fuel_pin.stack_length" : 365.76
          ,"assembly.pitch" : 21.4166
        }
        ,{
          'assembly' : 23
          ,'assembly.type' : 'w1717wl'
          ,"fuel_pin.pitch" : 1.25980
          ,"fuel_pin.pellet_outer_radius" : 0.39220
          ,"fuel_pin.clad_outer_radius" : 0.45720
          ,"fuel_pin.clad_inner_radius" :  0.40010
          ,"fuel_pin.stack_length" : 365.76
          ,"assembly.pitch" : 21.4166
        }
        ,{
          'assembly' : 24
          ,'assembly.type' : 'w1717wl'
          ,"fuel_pin.pitch" : 1.25980
          ,"fuel_pin.pellet_outer_radius" : 0.39220
          ,"fuel_pin.clad_outer_radius" : 0.45720
          ,"fuel_pin.clad_inner_radius" :  0.40010
          ,"fuel_pin.stack_length" : 365.76
          ,"assembly.pitch" : 21.4166
        }
    ]
}
```


E.3 Cask Model Sub-templates

E.3.1 assembly_materials.tmpl

```
#repeat assembly_materials[<assembly:fmt=%.0f>].tmpl using node=1,<axial_node_count>
```

E.3.2 assembly_geometry.tmpl

```
#import <assembly.type>.geometry.tmpl
```

E.3.3 W1717WL.geometry.tmpl

```
' The guide tube unit is #eval fmt=%.0f (100+assembly) as guide_tube_unit#
#import <assembly.type>.guide_tube.tmpl
#repeat pin_unit.tmpl using node=1,<axial_node_count>

' Nodes (pins bundled in nodes)
'
#repeat <assembly.type>.node_unit.tmpl using node=1,<axial_node_count>

' Assemblies (nodes in assembly)
'
#import assembly_unit.tmpl
```

E.3.4 W1717WL.guide_tube.tmpl

```
unit 101
```

```
  com='guide tube'
  cuboid   1 0.6299 -0.6299 0.6299 -0.6299  #eval fmt=%.2f
(<fuel_pin.stack_length>/<axial_node_count>)# 0.
  cylinder 2 0.5613                          #eval fmt=%.2f
(<fuel_pin.stack_length>/<axial_node_count>)# 0.
  cylinder 3 0.602                           #eval fmt=%.2f
(<fuel_pin.stack_length>/<axial_node_count>)# 0.
  media       5     1     2
  media       6     1     3    -2
  media       5     1     1    -3
  boundary    1
```

E.3.5 pin_unit.tmpl

```
unit #eval fmt=%.0f (10000+100*<assembly>+<node>) as unit#
  com='fuel pin  in assembly #eval fmt=%.0f (assembly)# node #eval fmt=%.0f (node)#'
  cuboid   1 4p#eval fmt=%.4f (<fuel_pin.pitch>/2)# #eval fmt=%.2f
(<fuel_pin.stack_length>/<axial_node_count>) as ztop#  0.
  cylinder 2 <fuel_pin.pellet_outer_radius>   <ztop>  0.
  cylinder 3 <fuel_pin.clad_inner_radius>   <ztop>  0.
  cylinder 4 <fuel_pin.clad_outer_radius>   <ztop>  0.
  media    #eval fmt=%.0f (1000+(assembly-1)*axial_node_count+node)#     1     2
  media      14     1     3    -2
  media      12     1     4    -3
  media      13     1     1    -4
  boundary    1
```

E.3.6 node_unit.tmpl

```
unit #eval fmt=%.0f (20000+100*<assembly>+<node>) as unit#
  com='assembly  #eval fmt=%.0f (assembly)# node #eval fmt=%.0f (node)#'
  cuboid   1   4p10.70829   <pin_stack_length>    0.00000
  array #eval fmt=%.0f (unit)# 1  place <place_x>     <place_y>     1 0.0 0.0 0.0
  boundary    1
```

E.3.7 assembly_unit.tmpl

```
unit #eval fmt=%.0f (30000+assembly) as unit#
  com='assembly #eval fmt=%.0f (assembly)#'
  cuboid   1   4p#eval fmt=%.6f (17.0*fuel_pin.pitch/2.0-0.02)#   #eval fmt=%.2f
(<fuel_pin.stack_length>)#    0.00000
  array #eval fmt=%.0f (unit)# 1  place 1 1 1 0.0 0.0 0.0
  boundary    1
```

E.3.8 arrays.tmpl

```
#repeat  <assembly.type>.pin_array.tmpl using node=1,<axial_node_count>
#import node_array.tmpl
```

E.3.9 W1717WL.pin_array.tmpl

```
' The guide tube unit is #eval fmt=%.0f (100+assembly) as guide_tube_unit#
  ara= #eval fmt=%.0f (20000+100*<assembly>+<node>)# nux= 17 nuy= 17 nuz= 1
    fill
     #eval fmt=%.0f (10000+100*<assembly>+<node>) as funit# #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
```

```
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
<guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit>
#eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
<guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
<guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
<guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
```

```
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
<guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit>
#eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)#
#eval fmt=%.0f (funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)#   <guide_tube_unit> #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
     #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval
fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f
(funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)# #eval fmt=%.0f (funit)#
    end fill
```

E.3.10 node_array.tmpl

```
  ara=  #eval fmt=%.0f (30000+assembly)# nux= 1 nuy= 1 nuz=#eval fmt=%.0f
(axial_node_count)#
    fill
    #func(node=1,<axial_node_count>) 20000+100*assembly+node#
    end fill
```