

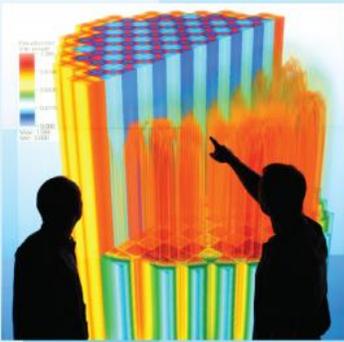


Power updates  
and plant life extension

CASL-U-2014-0014-002



Consortium for Advanced Simulation of LWRs



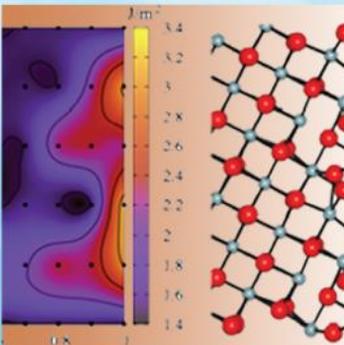
Engineering design  
and analysis

# VERA Common Input User Manual



Science-enabling  
high performance  
computing

Scott Palmtag  
Andrew Godfrey



Fundamental science

February 23, 2015



Plant operational data



U.S. DEPARTMENT OF  
**ENERGY**

**Nuclear Energy**



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# VERA Common Input

Consortium for Advanced Simulation of LWRs (CASL)

[www.casl.gov](http://www.casl.gov)

Technical Report  
CASL-U-2014-0014-002

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# List of Acronyms

**CASL** Consortium for Advanced Simulation of Light Water Reactors

**BOC** Beginning of Cycle

**BWR** Boiling Water Reactor

**CFD** Computational Fluid Dynamics

**CILC** Crud-Induced Localized Corrosion

**CIPS** Crud-Induced Power Shift (also called AOA)

**CTF** COBRA-TF (Subchannel Code)

**DNB** Departure from Nucleate Boiling

**EFPD** Effective Full Power Days

**EOC** End of Cycle

**GWd/MT** Gigawatt-Days per Metric Ton Heavy Metal

**HFP** Hot Full Power

**HZP** Hot Zero Power

**LWR** Light Water Reactor

**MOC** Middle of Cycle

**MWd/MT** Megawatt-Days per Metric Ton Heavy Metal

**PCI** Pellet-Cladding Interaction

**PCM** Percent Mille ( $10^{-5}$ )

**PPM** Parts per Million (usually boron)

**PSU** Pennsylvania State University

**PWR** Pressurized Water Reactor

**QA** Quality Assurance

**VERA** Virtual Environment for Reactor Applications

# Chapter 1

## Introduction

### 1.1 Introduction to CASL

The Consortium for Advanced Simulation of Light Water Reactors (CASL) is the first DOE Energy Innovation Hub, established in July 2010 for the purpose of providing advanced modeling and simulation (ModSim) solutions for commercial nuclear reactors.

CASL's vision is to predict, with confidence, the performance of nuclear reactors through comprehensive, science-based modeling and simulation technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability, and economics.

CASL's mission is to provide coupled, high-fidelity, usable modeling and simulation capabilities needed to address light water reactor operational and safety performance-defining phenomena.

CASL's foundational technology products include CASL solutions and CASL ModSim Technologies. CASL's ModSim technology, the Virtual Environment for Reactor Applications (VERA), provides higher-fidelity results than the current industry approach by incorporating coupled physics and science-based models, state-of-the-art numerical methods, modern computational science, integrated uncertainty quantification (UQ) and validation against data from operating pressurized water reactors (PWRs), single-effect experiments, and integral tests.

CASL will address, through new insights afforded by its ModSim technology, key nuclear energy industry challenges to furthering power uprates, higher fuel burnup, and lifetime extension while providing higher confidence in enhanced nuclear safety and this cleaner energy source.

The CASL Team is a consortium that consists of ten core partners and numerous contributing members. The CASL organization is led by Oak Ridge National Lab, and CASL's research

and development is executed in six technical teams called Focus Areas (FA) and one integrating technical area. This ground-breaking partnership provides unparalleled collective institutional knowledge, nuclear science and engineering talent, computational science leadership, and a record of LWR design and regulatory accomplishments!

More information on CASL can be found at the website [www.casl.gov](http://www.casl.gov).

## 1.2 VERA Core Simulator

One component of VERA is the VERA Core Simulator (VERA-CS). The core simulator is the specific collection of multi-physics computer codes used to model and deplete a LWR core over multiple cycles. Examples of the separate physics codes include cross sections, neutron transport, depletion, thermal-hydraulics, and fuel performance.

The purpose of the core simulator is to provide data and boundary conditions to model CASL Challenge Problems such as CIPS, CILC, DNB, and PCI analyses.

One important feature of the core simulator is that a single common input file is used to drive all of the different physics codes<sup>1</sup>. One benefit of using a single common input is that users only need to understand and be proficient with one input, instead of having to understand multiple inputs for multiple physics codes. Another benefit of using a single common input is that all codes work from a single geometry description, and this reduces errors due to inconsistent geometries in different codes.

The most up-to-date version of this document resides in the VERA Git repository file “VERAInExt/verain/docs/verain\_UM.pdf”. Please refer to this location for the latest version of the input manual.

## 1.3 Manual Organization

This manual is organized into two parts.

The first part, which includes Chapters 2 through 4, consists of a “User’s Manual”, which describes how a user would set up a typical input. This part of the manual gives the most common input cards that a user would need and describes how to use them. This part of the manual does not include a complete list of cards or show every available option.

---

<sup>1</sup>The only exception to this is for CFD codes, which generally require a detailed CAD file to support mesh generation and perform meaningful analysis.

The second part of the manual, Chapter 5, is a “Reference Manual” and includes a completing listing of every available input card.

The last chapter, Chapter 6, gives several example input decks. Additional input files can also be found in the code installation directory.

## Chapter 2

# User Manual

The VERA common input is an ASCII file. The VERA input is designed to be modular. The input is split into separate modules (or blocks) to describe the different geometric objects in the core and to define specific modeling options for each of the physics codes.

Geometric objects are defined as the physical “parts” of the reactor core, which includes fuel assemblies, control rod assemblies, removable burnable poison assemblies, and detectors. By defining each geometric object as a separate block, the objects can be described independently of each other and rely on very little global information. The independent descriptions make quality assurance (QA) easier and allows objects to be defined in one cycle and be re-used in subsequent cycles without worrying about input conflicts. Another advantage of the module approach is that it makes it easier to shuffle fuel assemblies, and insert and withdraw “inserts” (such as control rods, detectors, and removable burnable poison assemblies) into the fuel assemblies as the core configuration changes.

Additional modules/blocks are used to define modeling options and parameters for each of the physics codes. Separating the geometry description from the modeling options allows all of the physics codes to share the same geometry description and also allows the same input to be used with multiple physics codes.

The VERA input blocks are:

**CASEID** This block contains an input title card.

**CORE** This block describes the core layout including core map, assembly locations, control rod locations, and assembly insert locations. The CORE block contains data that does not change during a cycle depletion.

**STATE** These blocks describes reactor core operating parameters (statepoint values) at a par-

ticular point in time. Parameters include inlet temperature, pressure, power, and control rod positions. STATE values can (and usually do) change at each statepoint.

**ASSEMBLY** These blocks contains the geometry and physical description of the nuclear fuel assemblies. The assembly descriptions do not include control rods, detectors, or inserts.

**INSERT** These blocks contain the geometry and physical description of the assembly inserts. An insert is a generic term used to describe a removable burnable poison assembly or a thimble plug assembly.

**CONTROL** This block contains the geometry and physical description of a control rod assembly. A control rod assembly is similar to an assembly insert, except that it can move during operations.

**DETECTOR** This block contains the geometry and physical description of a detector string.

**EDITS** This block contains information on what edits the code should produce.

**COUPLING** This block contains parameters for coupling different physics codes together.

In addition to the blocks listed above, there are additional code-specific blocks that contain options specific to each physics code. Examples of code-specific blocks are **COBRATF**, **INSILICO**, and **MPACT**. Additional code-specific input blocks can be added as new physics codes are added to the core simulator.

The following sections in this chapter describe the most common concepts and features of each input block. This section does not provide a comprehensive list of each input card or option on each card. Refer to Chapter 5 for a detailed listing of all input and options.

## 2.1 Input Syntax

VERA input files are text files that contain standard printable ASCII characters. The data is organized in blocks with names and purpose as described in the introduction. The start of a block is denoted by the block name enclosed in square brackets, e.g. [STATE]. The file block structure is flat, so that there is no hierarchy in the block segments. A start of a new block also implies the end of the previous block. Currently, only the [STATE] block can have multiple instances to describe reactor operating conditions. Other blocks are unique, so that a new block with the same name of an existing block will overwrite the existing block data. There is no required order of the blocks in input file, except for the [STATE] blocks, in which each statepoint must be entered in the correct chronological order.

The blocks contain input cards that are generally organized as keyword-value pairs or keyword-tag-value triplets where tag denotes the keyword name tag that can be referenced in the other related commands. Keywords should not have blank spaces, as the spaces usually imply delimiters in the card data. A value can be a single or list entry. Input cards value entries can contain

different data types, depending on the card format. The data types are real numbers, integers, characters, and character strings. String entries that include spaces should be enclosed in single or double quote pairs.

The block, keyword and tag names are case sensitive. Therefore, it is recommended that users should not depend on the capitalization for differentiation between entries in the file.

The exclamation mark, `!`, is a special keyword that makes everything from it to the end of line ignored for processing and is used for adding comments in an input file.

The keyword *include* can be used to insert the contents of another file into the input file.

Short commands are expected to complete within a single line. Longer commands, like input maps, can be split across multiple lines.

An example input fragment showing blocks, comments, and cards, is shown below.

```
! comments start with an exclamation point

[STATE]           ! block names are enclosed in square brackets
  power  85.0     ! cards with parameters(s)
  flow   80.0     ! cards and parameters are separated by one or more spaces

  rodbank A 228   ! cards can span more than one line
           B 228
           C 228
           D 228

[CORE]           ! start of second block
  title  "Title must be enclosed in quotes if spaces are used"
```

Several legacy Fortran codes have special characters that allow you to skip or repeat input values. There are no such special characters used in the VERA input.

In this manual, the convention used is that all input examples are shown in **typewriter font**. When input cards are used in the text (not in the examples), they are listed in *italic font*. All block names are listed with square brackets around them.

## 2.2 Core Description

The [CORE] block describes the nuclear reactor core configuration. This block describes the core layout, including the placement of nuclear fuel assemblies, control rods, detectors, inserts, and other core parameters that do not change during a cycle depletion.

The geometric objects inside the core are defined in separate input blocks; the [CORE] block simply describes how all of these objects are placed together.

### 2.2.1 Core Geometry

The reactor core geometry must be defined first. The overall *size* of the core is given by the number of assemblies across one major axis of the core. The assembly pitch (*apitch*) defines the width of each assembly, including the assembly gap. The distance from the top of the lower core plate to the bottom of the upper core plate is given by the parameter *height*. The assembly layout is given by the *core\_shape* map. Note that the core shape map is the only “square” core map in the input, and it must be of *size* assemblies by *size*. Once the core shape is defined, subsequent core maps only include entries for actual fuel assembly locations.

```
size 15          ! number of assemblies across one axis
apitch 21.5      ! assembly pitch (cm)
height 406.337   ! distance from lower core plate to upper core plate (cm)
```

```
core_shape
0 0 0 0 1 1 1 1 1 1 1 0 0 0 0
0 0 1 1 1 1 1 1 1 1 1 1 1 0 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 0 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 0 0 0 0
```

The *core\_shape* map is unique because it is square in shape and composed of the integers 1 and 0. The 1 represents a location with a fuel assembly, and a 0 is an unoccupied location. The purpose

of this map is to define the shape for subsequent core maps.

Most physics codes support both calculations run in either full-core or quarter-core symmetry. If a calculation is run in quarter-core symmetry, the code must know if the symmetry is mirror symmetric or rotationally symmetric. The type of quarter-core symmetry is defined with the *bc\_sym* input card. The symmetry option is not used if the calculation is run in full-core.

```
bc_sym mir    ! define quarter-core symmetry as mirror
```

## 2.2.2 Core Maps

Core maps are used to define the location of geometry objects in the core. There are different core maps to define types and locations of assemblies, inserts, detectors, and control rods. The entries in the maps are composed of arbitrary length character strings. Even though the character strings can be any size, it is recommended to use compact names so the maps remain legible.

All of the maps require one entry for each assembly location defined in the *core\_shape* map. However, the input parser can be used to take advantage of core symmetry. If the core is symmetric, the user only needs to input the maps in quarter or octant symmetry, and the input parser will automatically unfold the map to full-symmetry. The symmetry used in the core maps is independent of the symmetry used to run the actual calculations. For example, the user can enter all of the core maps in octant symmetry and still run the calculations in quarter or full symmetry. The quadrant and octant that the parser is expecting is shown in Figure 2.1.

If there is an empty location in the map (e.g. if there is no detector or no control rod in an assembly), enter a dash “-” for that location. The dash is significant and signifies an empty location in the core map. (The dash represents something is missing, but it is still a valid assembly location. The “0” in the *core\_shape* represents an invalid assembly location.)

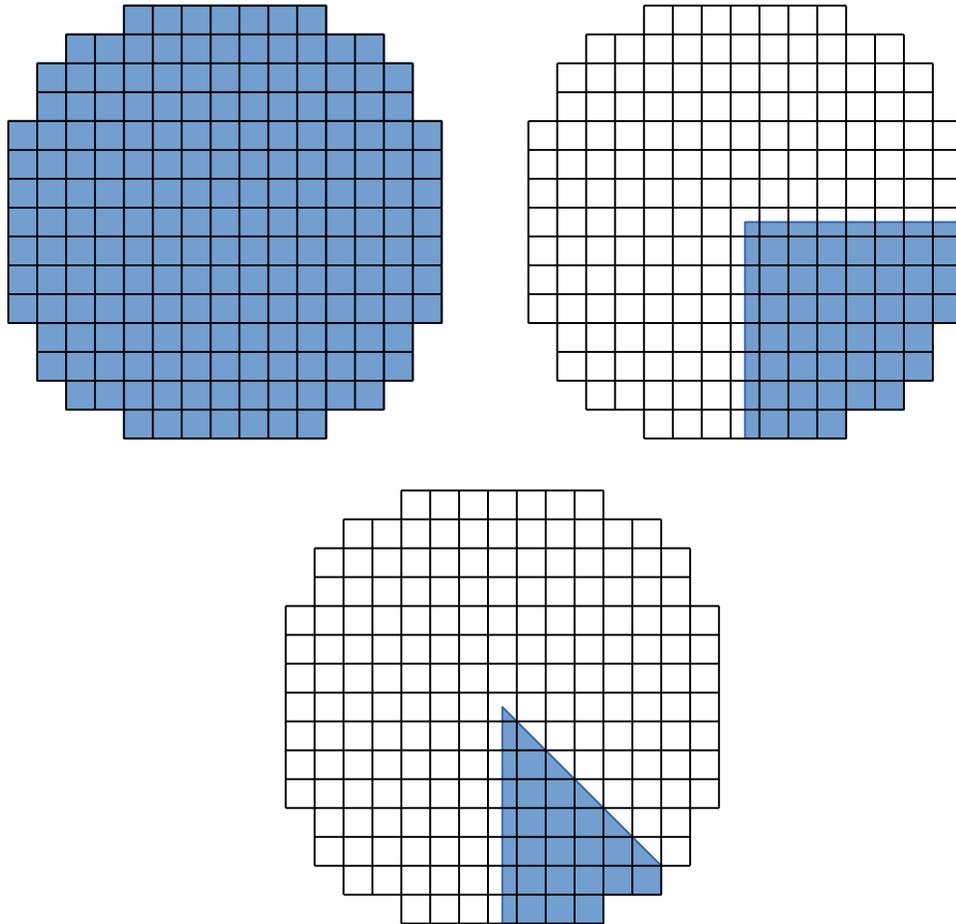


Figure 2.1: Full, quarter, and octant symmetry regions for a core map.

The *asm\_map* shows where the assembly types are located within the core. In the example below, there are three assembly types which will be defined in [ASSEMBLY] block(s).

```

asm_map
      A3 A3 A3 A3 A3 A3 A3
    A3 A3 A3 A1 A3 A1 A3 A1 A3 A3 A3
  A3 A3 A2 A1 A2 A1 A2 A1 A2 A1 A2 A3 A3
  A3 A2 A2 A2 A1 A2 A1 A2 A1 A2 A2 A2 A3
A3 A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3 A3
A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3
A3 A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3 A3
A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3
A3 A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3 A3
A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3
A3 A3 A1 A2 A1 A2 A1 A2 A1 A2 A1 A2 A1 A3 A3
  A3 A2 A2 A2 A1 A2 A1 A2 A1 A2 A2 A2 A3
  A3 A3 A2 A1 A2 A1 A2 A1 A2 A1 A2 A3 A3
    A3 A3 A3 A1 A3 A1 A3 A1 A3 A3 A3
      A3 A3 A3 A3 A3 A3 A3

```

The following map is equivalent to the previous map, but demonstrates the use of input with octant symmetry. Only values in the octant shown in Figure 2.1 are entered in the map and the parser automatically unfolds the map to full-symmetry.

```

asm_map
  A1
  A2 A1
  A1 A2 A1
  A2 A1 A2 A1
  A1 A2 A1 A2 A2
  A2 A1 A2 A1 A2 A3
  A1 A3 A1 A3 A3 A3
  A3 A3 A3 A3      ! assembly map with octant symmetry

```

The *insert\_map* is used to show where assembly inserts are located within the core. In the following qtr-symmetry example, the inserts are burnable poison assemblies with different numbers of pyrex rods. The *insert\_map* can also be used to place geometry objects such as thimble plugs. The geometry description of the inserts will be given in the [INSERT] block.

```

insert_map
-   BP20  -   BP20  -   BP20  -   BP12
BP20 -   BP24  -   BP20  -   BP24  -
-   BP24  -   BP20  -   BP16  -   BP8
BP20 -   BP20  -   BP20  -   BP16  -
-   BP20  -   BP20  -   BP24  -
BP20 -   BP16  -   BP24  BP12  -
-   BP24  -   BP16  -   -
BP12 -   BP8  -

```

The *insert\_map* is optional if no inserts are present in the core. A dash “-” is used to specify assembly locations without an insert.

The *det\_map* is used to show where detectors are located in the core. The geometry description of the corresponding detector strings is given in the [DETECTOR] block. In this example, there is only one detector type denoted with a “1”. Since the “1” occurs in a core map, it is treated as a character string. This example uses a full-symmetry map.

```

det_map
      - - 1 - - 1 -
      1 - - 1 - 1 - - - -
      - - - - - 1 - 1 - 1 - 1
      1 1 - - - 1 - - - - -
- - - - 1 - - - 1 - 1 - 1 - -
1 - 1 - - 1 - 1 - - - - 1 -
- - - 1 - - 1 - - 1 - - 1 - -
1 - 1 - 1 - 1 - - 1 - 1 1 1 -
- 1 - - - - - 1 - 1 - - - 1
- - - - 1 - 1 - - - - 1 - - -
1 - - - 1 - - 1 - - 1 - - - 1
      - - - - 1 - - 1 - - 1 - -
      - 1 - 1 - - 1 - - - - 1
      1 - - - 1 - - 1 - 1 -
      1 - - 1 - - -

```

The *det\_map* is optional if no detectors are present in the core. A dash “-” is used to specify assembly locations without a detector.

The control rod assemblies are described with two maps. The *crd\_map* defines the control rod types and locations in the core. The *crd\_bank* map assigns control rod locations to control rod banks. The control rod maps are optional if no control rods are present in the core. In the following example, there is only one control rod type with label “1”.

```

crd_map
      - - - - -
      - 1 - 1 - 1 - 1 - 1 -
      - - - 1 - 1 - 1 - 1 - - -
      1 - 1 - - - 1 - - - 1 - 1
      - - 1 - 1 - - - - - 1 - 1 - -
      - 1 - - - 1 - 1 - 1 - - - 1 -
      - - 1 - - - - - - - - 1 - -
      - 1 - 1 - 1 - 1 - 1 - 1 - 1 -
      - - 1 - - - - - - - - 1 - -
      - 1 - - - 1 - 1 - 1 - - - 1 -
      - - 1 - 1 - - - - - 1 - 1 - -
      1 - 1 - - - 1 - - - 1 - 1
      - - - 1 - 1 - 1 - 1 - - -
      - 1 - 1 - 1 - 1 - 1 -

```

```

crd_bank
      - - - - -
      - SA - B - C - B - SA -
      - - - SD - SB - SB - SC - - -
      SA - D - - - D - - - D - SA
      - - SC - A - - - - - A - SD - -
      - B - - - C - A - C - - - B -
      - - SB - - - - - - - - SB - -
      - C - D - A - D - A - D - C -
      - - SB - - - - - - - - SB - -
      - B - - - C - A - C - - - B -
      - - SD - A - - - - - A - SC - -
      SA - D - - - D - - - D - SA
      - - - SC - SB - SB - SD - - -
      - SA - B - C - B - SA -
      - - - - -

```

### 2.2.3 Core Baffle and Vessel

The core baffle (sometimes called the shroud) is a steel reflector that closely surrounds the fuel assemblies in the core. The barrel is a round steel structure that surrounds the baffle, and the vessel is the round outer pressure vessel. These structures are shown in Figure 2.2.

The *baffle* is defined with a single material, the size of the gap between the outer assembly and baffle, and the baffle thickness.

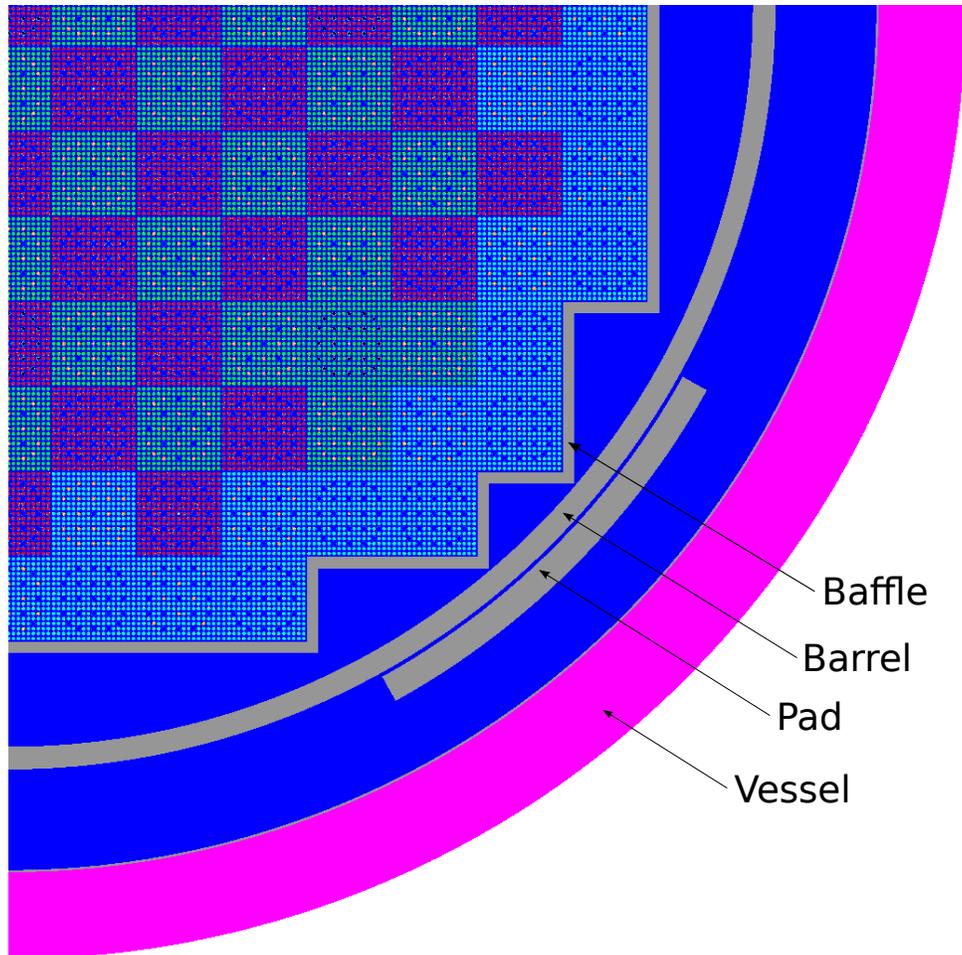


Figure 2.2: Core baffle and vessel (image courtesy of Andrew Godfrey).

```
baffle  SS304 0.19 1.26  ! material, gap (cm), and thickness (cm)
```

The barrel and vessel are defined with a *vessel* card. This card allows the user to enter any arbitrary number of rings surrounding a core by specifying the ring radii and the materials between the rings.

```
vessel  mod 166.7 SS304 169.2 mod 175.0 SS304 176.0  ! materials and radii (cm)
```

There is currently no input defined to specify the neutron pad.

## 2.2.4 Core Plates

The core plates are large steel plates at the top and bottom of the core that have various flow holes passing through them. All of the axial core heights are defined relative to the top of the bottom core plate and the total core *height* is defined as the distance between the top of the bottom core plate and the bottom of the top core plate.

The core plates are modeled in the neutronics codes as smeared materials. The upper and lower core plates are defined with a material composition, a thickness, and a volume fraction of the structural material. The remainder of the volume fraction is filled with coolant.

```
lower_plate SS304 5.0 0.5  ! material, thickness (cm), volume fraction
upper_plate SS304 7.6 0.5  ! material, thickness (cm), volume fraction
```

## 2.2.5 Small Core Geometries

Even though the VERA input is designed for “real” core geometries, it can accommodate smaller problems as well. For example, if the user only wants to run a single-assembly calculation, they would define the core size as one assembly by one assembly, and all of the core maps would contain a single assembly.

```
size 1  ! core composed of a single-assembly
core_shape
  1
```

If the user wants to model a single fuel rod, they would define a core with one assembly and an assembly with one rod in it.

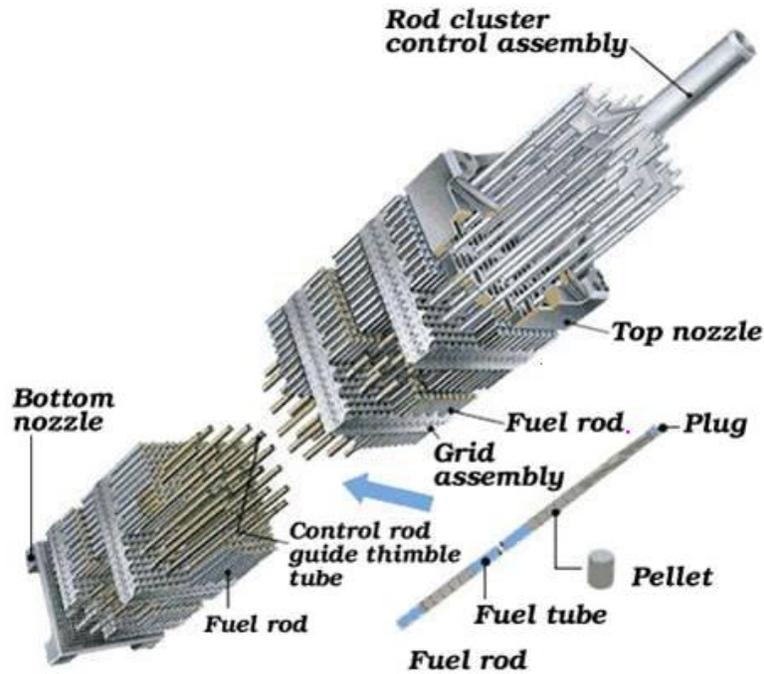


Figure 2.3: PWR Fuel Assembly (source: Public internet).

## 2.3 Assembly Description

The [ASSEMBLY] block contains the geometric description of a unique fuel assembly design (type). Multiple [ASSEMBLY] blocks are allowed to describe different assembly designs in the core.

If there are multiple assembly designs that are geometrically identical (i.e. everything is the same except the enrichments), then they can all be defined in a single [ASSEMBLY] block. Each assembly type will have a unique *axial* card with possibly unique axial levels and lattice types. Assemblies within a single reload typically have a design similar enough that they can share a single [ASSEMBLY] block.

If assembly designs are not geometrically identical (e.g. different vendors, different generations, etc.) they need to be defined in separate [ASSEMBLY] blocks. One advantage to having separate blocks for each assembly design is that each design can be modeled (and archived) independently without having to rely on global definitions.

A typical PWR assembly is shown in Figure 2.3. Refer to this figure in the following discussions.

A complete listing of all the input cards in the [ASSEMBLY] block is located in Section 5.4.

### 2.3.1 Initial Data

Each assembly block must contain a geometry description with the number of pins across the assembly and the pin pitch. An assembly block can also include an optional title card.

```

title "Westinghouse 17x17"      ! assembly title
npin 17                        ! number of pins across one side
ppitch 1.260                    ! pin pitch (cm)

```

The number of pins *npin* must be the same for every assembly in a core.

The inter-assembly gap on each side of the assembly is calculated as  $[apitch - npin * ppitch]/2$

The fuel and structural materials are defined with the following cards. See Chapter 3 for a complete description of the material inputs.

```

fuel U31 10.257 95.0 / 3.1      ! mat, density (g/cc), Theoretical density (%)
                                !      / U-235 enrichment (%)
mat inc 8.19                    ! mat, density (g/cc)
mat ss 8.0
mat zirc4 6.56

```

### 2.3.2 Cell Descriptions

Cell cards are used to describe “pincells”. A pincell is defined as a configuration of concentric cylinders (or rings) centered in a square region of coolant. Cell configurations can be used to model fuel rods or guide tubes, as shown in Figure 2.4.

The first parameter on the *cell* card is the cell ID. This is followed by a list of radii for each ring in the cell, followed by a slash. After the slash is a list of materials that compose each ring. The cell ID’s are used in the rod maps described in the next section.

```

cell 1      0.4096 0.418 0.475 / U31 he zirc4
cell GT          0.561 0.602 / mod  zirc4      ! guide tube
cell IT          0.561 0.602 / mod  zirc4      ! instrument tube
cell 7          0.418 0.475 / mod   mod        ! empty location
cell 8          0.418 0.475 /      he zirc4     ! plenum
cell 9          0.475 /            zirc4       ! pincap

```

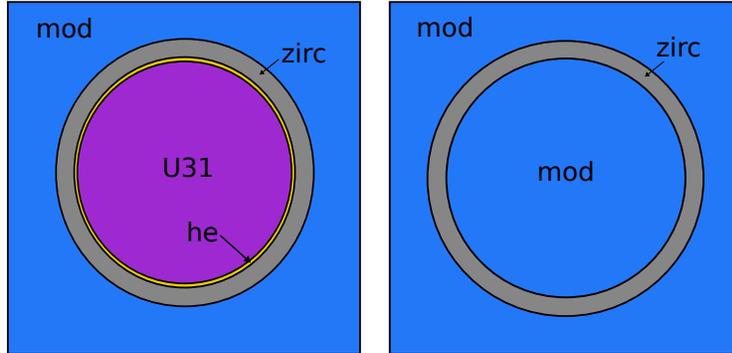


Figure 2.4: Pincell diagrams of a fuel rod and a guide tube.

In this example, in cell “1”, the material “U31” extends from radius 0 to 0.4096. The material “he” extends from a radius 0.4096 to 0.418. The materials “U31” and “he” are defined on *fuel* and *mat* cards, respectively. (Refer to Chapter 3 for a complete description on defining materials.)

The outside of each cell is automatically filled with the special material “mod”, which refers to the moderator (or coolant). The composition of “mod” is calculated by the codes using the local T/H conditions and the soluble boron concentration, and cannot be specified by a user on a *mat* card.

In the example above, the guide tube (GT) and instrument tube (IT) descriptions use the special moderator material “mod” to define the moderator material on both the inside and outside of the tubes.

Note that large water rods that span more than one lattice cell are not currently supported in the input (e.g. large CE water rods that span four lattice cells). In the future, an option will be added to the *cell* card to specify if a water rod spans more than one cell.

### 2.3.3 Lattice Descriptions

Once the cells are defined, they are placed into 2D “lattices” as shown below. Like the core maps, the lattice maps can be entered with either full-symmetry, qtr-symmetry, or octant-symmetry. The maps below are octant symmetric maps for 17x17 assembly designs.

```
rodmap FUEL1
IT
  1 1
  1 1 1
GT 1 1 GT
  1 1 1 1 1
  1 1 1 1 1 GT
GT 1 1 GT 1 1 1
  1 1 1 1 1 1 1 1
  1 1 1 1 1 1 1 1 1
```

```
rodmap LGAP1
IT
  7 7
  7 7 7
GT 7 7 GT
  7 7 7 7 7
  7 7 7 7 7 GT
GT 7 7 GT 7 7 7
  7 7 7 7 7 7 7 7
  7 7 7 7 7 7 7 7 7
```

```
rodmap PLEN1
IT
  8 8
  8 8 8
GT 8 8 GT
  8 8 8 8 8
  8 8 8 8 8 GT
GT 8 8 GT 8 8 8
  8 8 8 8 8 8 8 8
  8 8 8 8 8 8 8 8 8
```

```
rodmap PCAP1
IT
  9 9
  9 9 9
GT 9 9 GT
  9 9 9 9 9
  9 9 9 9 9 GT
GT 9 9 GT 9 9 9
  9 9 9 9 9 9 9 9
  9 9 9 9 9 9 9 9 9
```

Rod maps define each unique axial level in the assembly. The first parameter is the lattice name (e.g. FUEL1, PCAP1, etc.), followed by a map of the *cell* ID's.

Each entry in a rod map must be a valid cell ID.

### 2.3.4 Axial Descriptions

After rod maps are defined for each axial level, the lattices are “stacked” into an assembly using an *axial* card as shown below.

```
axial A1    6.050
  LGAP1  10.281
  PCAP1  11.951
  FUEL1 377.711
  PLEN1 393.711
  PCAP1 395.381
  LGAP1 397.501
```

The *axial* card tells the code how to place the lattices axially. The first parameter is the name of the assembly (A1), followed by a list of elevations and lattice types. For example, lattice “FUEL1” extends from 11.951 to 377.711 cm axially.

Multiple assembly types can be defined in a single [ASSEMBLY] block by using multiple *axial* cards, each with a unique assembly ID.

All axial elevations are defined relative to the top of the lower core plate.

### 2.3.5 Grid Spacer Descriptions

Grid cards are used to define unique grid spacer types. The following example defines two grid types, “END” and “MID”.

```
grid END inc 1017 3.866 ! grid spacer material, mass(g), height(cm)
grid MID zirc4 875 3.810
```

The grid types are placed axially with the *grid\_axial* card:

```
grid_axial
  END 13.884
  MID 75.2
  MID 127.4
  MID 179.6
  MID 231.8
  MID 284.0
  MID 336.2
  END 388.2
```

The elevations are the midpoints of the spacer grid and are relative to the top of the lower core plate.

### 2.3.6 Nozzle Descriptions

The assembly nozzles are modeled in the neutronics codes as smeared materials. This is a very good approximation since the nozzles are not in the active fuel region and are mostly composed of water, steel, and zirconium. The user only specifies a nozzle mass and a nozzle height. The total volume of the nozzle region is calculated from the assembly pitch and nozzle height. The volume of the nozzle is calculated from the nozzle mass and density. The volume of the coolant is then calculated as the total volume minus the volume of the nozzle. The coolant density is updated with the local T/H conditions.

```
lower_nozzle ss 6.05 6250.0 ! mat, height (cm), mass (g)
upper_nozzle ss 8.827 6250.0 ! mat, height (cm), mass (g)
```

Only a single material can be specified on a nozzle card. If the user wants to use more than one material to define a nozzle, they can define a custom material that is a mixture of the materials and then use the custom material in the nozzle card.

Note that the *lower\_nozzle* height should match the bottom elevation on the *axial* card. The *upper\_nozzle* height + the top elevation on the *axial* card must match the core *height* in the [CORE] block. The input parser does not currently perform a check to make sure the elevations are consistent. Therefore, this check should be performed in each of the individual physics codes.

## 2.4 Control Rod Assembly Description

The [CONTROL] block contains the geometric description of a control assembly.

A control rod assembly is defined in the same way that a fuel assembly is defined. The user specifies cells, lattices, and axial descriptions of the control rod assembly. The main difference between the control rod assembly and the fuel assembly is that the control rod assembly describes what is inside the guide tubes and the fuel assembly defines the guide tubes themselves.

Control rod positions change during operation, so the geometric description of a control rod should always be for a rod in the **fully inserted** position. In the example below, the bottom of the control rod in the fully inserted position is at an axial location of 15.46 cm.

```

title "B4C control rods with AIC tips"
npin 17

cell 1  0.382 0.386 0.484 / aic he ss      ! AIC cell
cell 2  0.373 0.386 0.484 / b4c he ss     ! B4C cell

rodmap  AIC
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - -
- - - - - - - -

rodmap  B4C
-
- -
- - -
2 - - 2
- - - - -
- - - - - 2
2 - - 2 - - -
- - - - - - -
- - - - - - - -

axial CR1 15.46 AIC  376.44 B4C  394.3

```

The name of the control rod “CR1” refers to the control rod type in the *crd\_map* in the [CORE] block.

Control rods positions are assigned to a control rod bank with the *crd\_bank* map in the [CORE] block, and then the banks are positioned with the *rodbank* card in the [STATE] block.

Note that the locations of the control rod fingers must match the guide tube locations in the corresponding [ASSEMBLY] block descriptions. Furthermore, the outer radii of the control rod fingers must be smaller than the inner radii of the guide tubes. The input parser does not currently perform a check to make sure the control rod finger descriptions are consistent with the guide tube descriptions. This check should be performed in each of the individual physics codes.

The user can define materials in the [CONTROL] block. These materials only have scope in this block and are not accessible by other blocks. See Chapter 3 for details.

A complete listing of all the input cards in the [CONTROL] block is located in Section 5.5.

### 2.4.1 Control Rod Stroke

The difference between control rod descriptions and assembly descriptions is that the control rods move during operation. This movement is defined with a *stroke* card.

The first value on the *stroke* card is the total length of the control rod travel (stroke) from fully inserted to fully withdrawn.

The second value on the *stroke* card is the number of steps in the fully withdrawn position. Step 0 is the fully inserted position. The number of steps in the fully withdrawn position is specified by the user, but 228 steps is often used for typical Westinghouse PWR's.

```
stroke 360.0 228      ! stroke (cm), number of steps fully withdrawn
```

To position the control rods in percent withdrawn (%), the number of steps should be set to 100 and each step will signify 1% withdrawn.

The geometry description in the input is for a control rod in the fully inserted position (step 0).

### 2.4.2 Control Rod Position Example

From the *axial* card shown above, the bottom of the AIC at the fully-inserted position is 15.46 cm. From the *stroke* card, the total stroke is 360.0 cm and the number of steps in the fully withdrawn position is 228 steps. Therefore, the bottom elevation of the AIC lattice at step N will be

$$E(N) = 15.46 + \frac{360.0 \cdot N}{228} \quad (2.4.1)$$

Using this formula, the bottom elevation of the AIC lattice at the following step positions is:

- step 228 (fully withdrawn) =  $15.46 + 360.0 * 228 / 228 = 375.46$  cm
- step 100 =  $15.46 + 360.0 * 100 / 228 = 173.35$  cm
- step 0 (fully inserted) =  $15.46 + 360.0 * 0 / 228 = 15.46$  cm

## 2.5 Insert Description

An assembly insert is defined in the same way as a fuel assembly or control rod assembly is defined. The user defines the insert using cells, lattices, and axial descriptions.

The fuel assembly description should contain the guide tube descriptions and the insert description defines what is inserted in the guide tubes. Assembly inserts can be inserted and withdrawn during a core shuffle (by specifying a *insert\_map* card in the [CORE] block), but cannot be moved during a cycle depletion.

The insert and control rod descriptions are very similar, with the only difference being that the insert cannot change position axially during a cycle depletion and a control rod moves axially during operations.

The following example shows a definition of a Pyrex insert.

```
[INSERT]
title "Pyrex"
npin 17
mat pyrx1 2.25 pyrex-vera
cell 1 0.214 0.231 0.241 0.427 0.437 0.484 / he ss he pyrx1 he ss
rodmap PY24
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - - -
- - - - - - - -

axial INS24 15.76 PY24 376.441
```

The name of the insert “INS24” refers to an insert type defined in the *insert\_map* in the [CORE] block.

The locations of the insert fingers must match the guide tube locations in the corresponding [ASSEMBLY] block descriptions. In addition, the outer radii of the insert fingers must be smaller than the inner radii of the guide tubes. The input parser does not currently perform a check to make sure the insert finger descriptions are consistent with the guide tube descriptions. This check should be performed in each of the individual physics codes.

As with [ASSEMBLY] blocks, multiple insert types can be defined in a single [INSERT] block by using multiple *axial* cards, each with a unique insert ID.

A complete listing of all the input cards in the [INSERT] block is located in Section 5.6.

## 2.6 Detector Description

A detector string is defined in the same way that a fuel assembly or insert assembly is defined. The user defines cells, lattices, and axial descriptions for the detector string.

The insert and detector descriptions are very similar, with the difference being that detectors have special properties used to calculate instrumentation signals.

```
[DETECTOR]
  title "Incore instrument thimble"
  npin 17

  mat he 0.0001786
  mat ss 8.0

  cell 1 0.258 0.382 / he ss

  rodmap LAT
    1
    - -
    - - -
    - - - -
    - - - - -
    - - - - - -
    - - - - - - -
    - - - - - - - -
    - - - - - - - - -

  axial D1 0.0 LAT 406.337
```

The name of the detector “D1” refers to a detector type defined in the *det.map* in the [CORE]

block.

A complete listing of all the input cards in the [DETECTOR] block is located in Section [5.7](#).

## 2.7 State Description

The [STATE] block defines the state of the core (power, flow, pressure, inlet temperature, rod positions, boron concentration, etc.) at a particular point in time. These values will typically change during a cycle depletion.

An example showing the most common input cards in the [STATE] block is shown below. A complete listing of all the input cards in the [STATE] block is located in Section 5.2.

```
[STATE]
power  98.0      ! % of rated power - rated values defined in [CORE] block
flow   100.0     ! % of rated flow
pressure 2250.0  ! psia
tinlet 557.33 F !
feedback on      ! turn on T/H feedback

boron   1285     ! initial boron ppmB
search boron     ! turn on boron search

sym qtr          ! run problem in qtr-symmetry

rodbank SA 228
        SB 228
        SC 228
        SD 228
        A  228
        B  228
        C  228
        D  167
```

The *sym* card tells the code to run the calculation in full-core or qtr-core symmetry. If the calculation is run in qtr-core symmetry, the symmetry is either set to qtr-core rotational or qtr-core mirror by the *bc\_sym* card in the [CORE] block.

The *rodbank* card is used to position the control rods. The *rodbank* input includes pairs of bank names and bank positions. The bank names correspond to the *crd\_map* in the [CORE] block. The positions indicate the position of the control rod bank in steps. Step 0 is fully inserted. The number of steps for a rod to be completely withdrawn is set by the *stroke* card in the [CONTROL] block (see Section 2.4.1). For Westinghouse PWR's, a typical value of fully-withdrawn is 228 steps.

## 2.8 Edits Description

The [EDITS] block is used to control the output edits.

One of the edits produced by the core simulator is the rod power. The user has the ability to specify the axial levels that the power is averaged over with the *axial\_edit\_bounds* card. The user may choose to average power over uniform axial intervals (like most nodal codes), or to specify the edit intervals manually.

(Note: the edit options are under development and more options will be added in the future.)

A complete listing of all the input cards in the [EDITS] block is located in Section 5.8.

### 2.8.1 COBRA-TF Nodalization

The *axial\_edit\_bounds* card is also used to set the axial nodalization when coupling the neutronics physics code to the COBRA-TF (CTF) subchannel code.

When running CTF, there is a restriction that the grid boundaries must be explicitly included in the *axial\_edit\_bounds*. This can get a little complicated for the user. In the VERA input, spacer grids are defined in the [ASSEMBLY] block by specifying the grid heights on the *grid* card and the elevations of the grid midpoints on the *grid\_axial* card. From the grid heights and midpoints, the elevations at the top and bottom of the spacer grid can be calculated, and then the top and bottom elevations must be included in the *axial\_edit\_bounds*.

For example, if a grid is defined with a centerline at 75.0 and a height of 2.5, then the *axial\_edit\_bounds* must include the points  $75.0 \pm 1.25 = 73.75$  and 76.25.

```
[ASSEMBLY]
grid GRID1 inc 1000 2.5      ! grid name, material, mass (g), and height (cm)
grid_axial                  ! locations of grid midpoints (cm)
  GRID1 75.0

[EDITS]
axial_edit_bounds
  ...
  73.75                      ! this array must include top and bottom grid boundaries
  76.25
  ...
```

The reason for this restriction is because the power is already calculated on the *axial\_edit\_bounds*,

so it is natural to use the same power distribution to couple to the CTF model as well. The grids must be explicitly included in the CTF boundaries so the loss coefficients are calculated correctly.

In the future, this restriction may be lifted and an additional edit bounds array may be added explicitly for CTF calculations.

## 2.9 Coupling Description

The [COUPLING] block defines the relaxation parameters and convergence criteria to be used when coupling different physics codes. These values are used to determine convergence *between* physics codes. Convergence criteria *within* a physics code is controlled by the code-specific block.

Refer to Section 5.12 for a complete listing of all the cards in the [COUPLING] block.

No code-specific information is included in the [COUPLING] block. All code-specific information is contained in the code-specific blocks. The [COUPLING] block is only used to define generic coupling parameters.

As an example, consider the following multi-physics code coupling:

1. Run T/H calculation
2. Run neutronics calculation
3. Check eigenvalue convergence
4. Check power convergence
5. Relax/dampen the power shape
6. If not converged, go to step 1.

The eigenvalue convergence in step 3 uses the card *epsk* to check the change in eigenvalue between coupled iterations. There are additional eigenvalue convergence criteria *within* the neutronics code, but the internal parameters are specified in the individual code blocks.

The power convergence in step 4 uses the card *epsp* to check the change in power between coupled iterations.

Additional convergence checks are made on the peak fuel temperature, maximum change in density, and change in boron concentration (if applicable).

The example shown above uses a Picard iteration to converge. Picard iterations usually need to apply a relaxation factor (also called a damping factor or under-relaxation factor) to one or

more of the calculated quantities to converge. The relaxation factors are applied in the following manner:

$$x = \omega x^{\text{new}} + (1 - \omega)x^{\text{old}} \quad (2.9.1)$$

where  $x$  is the calculated parameter and  $\omega$  is the relaxation factor. A relaxation factor of 1.0 signifies no relaxation is performed. A relaxation factor  $< 1.0$  signifies under-relaxation.

Relaxation factors can be specified for the point-wise power, point-wise temperature, and/or point-wise density. The relaxation is applied to the transferred quantities sent between physics codes. The state variables within each physics code are not changed.

An example [COUPLING] input block is shown below.

```
[COUPLING]
  epsk      5.0 ! eigenvalue convergence (pcm)
  eps_temp  1.0 ! temperature convergence (deg C)
  eps_boron 0.1 ! boron convergence (ppm)
  rlx_power 0.5 ! power relaxation factor
  rlx_tfuel 1.0 ! fuel temperature relaxation factor
  rlx_den   1.0 ! density relaxation factor
  maxiter   20 ! maximum number of coupled iterations
```

A complete listing of all the input cards in the [COUPLING] block is located in Section [5.12](#).

## Chapter 3

# Materials

This chapter contains a description of the material input. There are two types of materials in the input file – structural materials (input with a *mat* card) and fuel materials (input with a *fuel* card).

Structural materials can be defined in either the [CORE] block, or in the geometry object blocks [ASSEMBLY], [INSERT], [CONTROL], and [DETECTOR]. If the materials are defined in the [CORE] block, they have global scope. If the materials are defined in the geometry object blocks, they only have scope in the block they are defined. The reason for this is to maintain the modularity of the geometry objects.

Fuel materials can only be defined in [ASSEMBLY] blocks.

Materials are used in many different input cards. They are used to define cells, nozzles, core plates, baffles, grids, reflectors, etc. Every material that is used in the input must be defined with either a *mat* card or a *fuel* card.

### 3.1 Structural Materials

Structural materials are not fuel and do not deplete. Structural materials are defined with the following input card:

**mat** *user-mat density (library-name<sub>i</sub>, frac<sub>i</sub>, i=1, I)*

where:

- *user-mat* is a user-defined material name. It is case sensitive. *user-mat* is used to define material names in other input cards such as *cell*, *grid*, *nozzle*, etc. (No default)
- *density* is the material density in g/cc (No default)
- *library-name* is a corresponding material library name(s) for the user material. The library name must be defined in the material composition file. (Default = *user-mat*). Multiple library materials can be mixed to form a single user material.
- *frac* is the fraction of the library material in the user material. (Default=1.0 if there is only one library material in the user material).

There are two special user materials, “mod” and “vacuum”. The user can use these materials in cell definitions, but the code will automatically determine the composition of these materials based on T/H feedback and soluble boron concentrations. The user is not allowed to define a user material named “mod” or “vacuum” on a *mat* card.

The material libraries are code-specific libraries. Please refer to the specific physics codes to determine which library materials are available.

Some example material cards are shown below.

```
mat zirc4 6.56                ! library-name defaults to user-name
mat zirx  6.56 zirc4 1.0      ! user-name does not equal to library-name
mat B10   12.0 boron 1.0
mat XYZ   6.0  zirc4 0.8 ss 0.2 ! define new mixture of 80% zirc4 and 20% ss
mat ABCD  8.0  zirc4 0.8 ss 0.15 b4c 0.05
```

All of the material fractions must sum to either +1.0 or -1.0. If positive fractions are used, the fractions refer to weight fractions. If negative fractions are used, the fractions refer to atomic fractions.

### 3.1.1 Search Order

Structural materials can be defined in either the [CORE] block or one of the geometry object blocks. When a material is referred to in a block, it will look for the material definition in the following order:

1. The code will first look for the material name in the local block ([ASSEMBLY], [INSERT], [CONTROL], or [DETECTOR])
2. If the material is not found in the local block, it will look in the [CORE] block

If materials are defined in the [CORE] block, they have global scope over the entire input. If materials are defined in other blocks, they only have scope over the local block. This means that two geometry object blocks can use different material definitions with the same name. One example of this is that two assemblies can be defined with the material “zirc”, but the “zirc” can have different compositions in each of the assemblies.

## 3.2 Composition File

When using Insilico, all library materials must be included in a material composition file. The composition file is a code-specific file which contains a list of all of the available library materials.

The composition file is specified in the [INSILICO] block *mat.library* card, and is usually named “casl\_comp.sh5”.

Examples of typical library materials that are present on the composition file include:

- aic (silver-indium-cadmium)
- b4c (boron carbide)
- boron
- inc (Inconel)
- he (helium)
- ss (stainless steel)
- zirc4 (Zircaloy-4)

Refer to the code-specific composition file for a complete list of valid library materials.

## 3.3 Fuel Materials

Fuel materials are defined with *fuel* cards. Fuel materials are heavy metal oxides which are usually  $\text{UO}_2$  with different U-235 enrichments. Fuel materials may also include MOX fuel, which consists of mixtures of uranium, plutonium and other actinides. Fuel materials are different from structural materials in that they deplete and have additional properties as described below.

Fuel can only be defined in [ASSEMBLY] blocks, and fuel materials can only be referenced by *cell* cards in the [ASSEMBLY] block they are defined in.

Fuel materials are defined with the following input card:

```
fuel user-mat density thden / U-235-enrichment {HM-materiali=HM-enrichmenti, i=1, N}
{ / gad-material=gad-fraction }
```

Where:

- *user-mat* is a user-defined fuel name. It is case sensitive. (No default)
- *density* is the fuel material density in g/cc (No default). The density is used to calculate number densities.
- *thden* is the percent of theoretical density in the pellet (%) (No default). The theoretical density is only used to look up material properties in the fuel performance, it is not used to calculate number densities. There is no “double counting” between *density* and *thden*.
- *U-235-enrichment* is the U-235 enrichment in the fuel in weight % (No default).
  - If U-234 and U-236 are not specified, they will automatically be added to the fuel by a pre-determined function (see below)
  - If the sum of the heavy metal (HM) enrichments does not equal 100%, the remainder of the HM composition will be assigned to U-238.
- *HM-material*<sub>*i*</sub> is the material name for HM isotope *i* (Pu-239, Pu-241, etc.) (optional) The names of the HM materials must be valid library-names.
- *HM-enrichment*<sub>*i*</sub> is the enrichment of HM isotope *i* in weight % (optional)
- *gad-material* is the material name for the gadolium oxide (or other material) (optional). The gad material is usually a mixture defined on a separate *mat* card.
- *gad-fraction* is the weight percent of the gad material relative to the total fuel mass (optional)

Oxygen should not be included on the *fuel* card. The correct amount of oxygen will automatically be added to the HM to create an oxide (either UO<sub>2</sub> or (HM)O<sub>2</sub>).

The *density* is the “stack density” or “smeared density” and should include the volume of the pellet dishing and chamfers. It is calculated as the total mass of the fuel pellets divided by the total volume of the fuel

$$\text{stack density} = \frac{(\text{fuel mass})}{\pi(\text{pellet radius})^2 (\text{fuel height})} \quad (3.3.1)$$

The *thden* refers to the actual theoretical density of the pellet. This quantity is used in fuel performance codes to evaluate material properties.

If U-234 or U-236 enrichments are not included in the fuel definition, they are automatically added to the fuel with the following formulas:

$$W_{234} = 0.007731 \cdot W_{235}^{1.0837} \quad (3.3.2)$$

$$W_{236} = 0.0046 \cdot W_{235} \quad (3.3.3)$$

Where  $W_{23x}$  is the enrichment of each of the uranium isotopes in percent.

If a user specifically does NOT want U-234 or U-236, they should specify a U-234 and/or U-236 enrichment of zero.

Examples of typical *fuel* cards are shown below. The user only has to specify the U-235 enrichment and the code will automatically add U-234, U-236, U-238, and oxygen to the fuel.

```
fuel U21 10.4 95.2 / 2.1      ! 2.1% enriched UO2 fuel, no gad
fuel UO2-35 10.297 95.0 / 3.5 ! 3.5% enriched UO2 fuel, no gad
fuel U23 10.111 / 2.3        ! fuel with default thden
```

An example of a *fuel* card with gadolinia burnable poison is shown next. In this example, the gadolinia oxide is first defined with a *mat* card and is mixed with the fuel as 5% gad oxide and 95% UO<sub>2</sub> (weight percents).

```
mat gad5 7.407 gd2o3 1.0      ! define gad material separately
fuel U49 10.111 94.5 / 1.8 / gad5=0.05 ! 1.8% enriched fuel with 5% gad
```

Some examples of MOX fuel cards are shown next. In these cards, the user specifies the U-235 enrichment (the U-235 enrichment is usually small in MOX fuel) and the plutonium isotope enrichments. The code will automatically add U-234, U-236, U-238, and oxygen.

```
fuel PX1 10.111 94.5 / 0.711 Pu-239=23.4 Pu-241=1.9 ! Sample MOX fuel
fuel MOX1 10.111 94.5 / 1.0 Pu-238=1.0 Pu-239=26.0
Pu-240=12.0 Pu-241=8.0 Pu-242=3.0
```

Only oxide fuel can be defined on the *fuel* card. Metallic fuel is not supported.

# Chapter 4

## Depletion

This chapter describes depletion and working with restart files.

Depletion and restart files are only available with MPACT.

### 4.1 Depletion

Depletion refers to taking a step in time and calculating the change in number densities (isotopics) in the core.

A problem is depleted by including a *deplete* card in the [STATE] block, as in the following example:

```
[STATE]
  deplete EFPD 0.0 1.0 10.0 30.0
```

The first parameter on the card is the units used in the depletion and can be “EFPD” for Effective Full-Power Days, “GWDMT” for Giga-Watt-days per metric ton of initial heavy metal, or “hours”. Following the unit is a list of depletion steps to take. Each depletion step is referred to as a “statepoint” in the calculation.

Listing multiple statepoints on a single *deplete* card will deplete with all of the other values in the [STATE] block held constant. If the user wants to change a state parameter between depletion steps (power, flow, etc.), they can split the depletion over multiple [STATE] blocks. In the following example, the code depletes three statepoints at 50% power, changes the power to

100%, and depletes for four more statepoints. The statepoint at 10 EFPD is run at both 50% and 100% power.

```
[STATE]
  power 50.0
  deplete EFPD 0.0 1.0 10.0
[STATE]
  power 100.0
  deplete EFPD 10.0 30.0 60.0 90.0
```

## 4.2 Writing Restart Files

Often a user will want to run a depletion and save the isotopic data to a file that can be used to restart a calculation at a later time. This is useful if a calculation is long-running, and it needs to be split into multiple cases. Other times a user may want to save certain statepoints so they can go back and run perturbation, or flux map, calculations at the saved points.

The restart file includes all the isotopic data needed to restart a calculation. The restart file does not include the geometry description, so a regular input deck must also be used. A user should set up an input deck for a fresh core, and then use the restart file to overwrite the fresh isotopic concentrations with the isotopic concentrations on the restart file.

A restart file can be written at any statepoint by using a *restart\_write* card,

```
restart_write filename restart_label
```

Where “filename” is the name of the restart file, and “restart\_label” is an arbitrary user label used to differentiate multiple statepoints written to the same file. Examples of restart labels include “100EFPD”, “HZZ”, “22.56”, “100EFPD\_ARO”, etc. A restart file can include multiple statepoints as long as each one uses a different restart label.

If a *restart\_label* card is used with a *deplete* card, the restart file is written at the last exposure step of the depletion.

In the following example, a depletion is performed and restart files are written at multiple statepoints.

```
[STATE]
  deplete EFPD 0.0
  restart_write restart_cyc12.h5 "BOC"
[STATE]
```

```
deplete EFPD 20 40 80 100
! restart file is written at last exposure step on deplete card
restart_write restart_cyc12.h5 "100EFPD"
[STATE]
deplete EFPD 150 200
restart_write restart_cyc12.h5 "200EFPD"
[STATE]
deplete EFPD 250 300
restart_write restart_cyc12.h5 "300EFPD"
[STATE]
deplete EFPD 350 400
restart_write restart_cyc12.h5 "400EFPD"
[STATE]
op_date 1994/05/23      ! include shutdown date for EOC
power 80.0
deplete EFPD 423.4
restart_write restart_cyc12.h5 "EFPD423_EOC"
```

Another application of restart files is to write the final isotopic information at the end of cycle (EOC) so the data can be shuffled to a new cycle. (Core shuffles will be discussed in a later section.) If writing a restart file at the EOC, the shutdown date should be included using the *op\_date* card. The reason for including the shutdown date is so the code will be able to calculate the isotopic decay during the outage. An example of the *op\_date* card is shown in the last [STATE] block in the example above.

### 4.3 Reading Restart Files

A restart file can be read by including a *restart\_read* card in the [STATE] block.

```
restart_read filename restart_label
```

where “restart\_label” is the label that was used to write the restart file. The *restart\_read* card is used to restart an existing calculation, it is not used to do core shuffles.

In the following example, one of the restart files from the previous example is read and a new calculation is performed with a different power and boron concentration.

```
[STATE]
power 50.0
boron 800
restart_read restart_cyc12.h5 "200EFPD"
```

It is possible to write a statepoint in quarter-symmetry, then read the restart back in full-symmetry, or vice-versa.

There is currently a restriction that a user should not include a *deplete* card in any [STATE] block where a restart is read. Instead, the user should split the restart read and depletion into separate blocks, like the following example shows:

```
[STATE]
  restart_read restart_cycx.h5 "EFPD30" ! read restart at 30 EFPD
[STATE]
  deplete EFPD 60 90
```

## 4.4 Core Shuffling

A core shuffle occurs when the fuel assemblies are rearranged in a core, and/or new fuel is added to the core. Fuel assemblies can be brought in from the fuel pool that were discharged in previous cycles. Fuel can even be added that was discharged from other units (cross-unit shuffle).

When performing a core shuffle, the user needs to specify where existing fuel assemblies were moved from, and what the new fuel assemblies look like.

When fuel isotopics are written to a restart file, the assembly locations are saved based assembly based on the *xlabel* and *ylabel* labels. For example, with the following labels defined:

```
[CORE]
  xlabel  R P N M L K J H G F E D C B A
  ylabel  01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
```

The assembly locations are defined as:

```

          L-01 K-01 J-01 H-01 G-01 F-01 E-01
        N-02 M-02 L-02 K-02 J-02 H-02 G-02 F-02 E-02 D-02 C-02
      P-03 N-03 M-03 L-03 K-03 J-03 H-03 G-03 F-03 E-03 D-03 C-03 B-03
    P-04 N-04 M-04 L-04 K-04 J-04 H-04 G-04 F-04 E-04 D-04 C-04 B-04
R-05 P-05 N-05 M-05 L-05 K-05 J-05 H-05 G-05 F-05 E-05 D-05 C-05 B-05 A-05
R-06 P-06 N-06 M-06 L-06 K-06 J-06 H-06 G-06 F-06 E-06 D-06 C-06 B-06 A-06
R-07 P-07 N-07 M-07 L-07 K-07 J-07 H-07 G-07 F-07 E-07 D-07 C-07 B-07 A-07
R-08 P-08 N-08 M-08 L-08 K-08 J-08 H-08 G-08 F-08 E-08 D-08 C-08 B-08 A-08
R-09 P-09 N-09 M-09 L-09 K-09 J-09 H-09 G-09 F-09 E-09 D-09 C-09 B-09 A-09
R-10 P-10 N-10 M-10 L-10 K-10 J-10 H-10 G-10 F-10 E-10 D-10 C-10 B-10 A-10
R-11 P-11 N-11 M-11 L-11 K-11 J-11 H-11 G-11 F-11 E-11 D-11 C-11 B-11 A-11
```

```

P-12 N-12 M-12 L-12 K-12 J-12 H-12 G-12 F-12 E-12 D-12 C-12 B-12
P-13 N-13 M-13 L-13 K-13 J-13 H-13 G-13 F-13 E-13 D-13 C-13 B-13
  N-14 M-14 L-14 K-14 J-14 H-14 G-14 F-14 E-14 D-14 C-14
    L-15 K-15 J-15 H-15 G-15 F-15 E-15

```

The restart files also include the cycle number (which is stored as a label), so a cycle number and location can be used to define any assembly location in any cycle. For example “C3K-12” refers to location “K-12” of cycle “C3”. If no cycle number is specified, it defaults to the previous cycle number (i.e. cycle N-1).

New, fresh assemblies are defined by using a plus sign followed by the assembly type. For example “+ASMA” signifies a fresh fuel assembly of type “ASMA”.

Using these conventions, a new core loading pattern can be defined using a *shuffle\_label* map. The *shuffle\_label* map is a core map showing the the previous assembly locations and new assemblies fuel types.

The following example is the full-core loading pattern for cycle 2 of the BEAVRS benchmark. The cycle numbers are not used in the location labels because all of the assemblies were moved from the previous cycle (cycle 1), and the default behavior is to use the previous cycle number if no cycle is specified.

```

[CORE]
  cycle C2
  op_date 1996/03/02      ! cycle startup date
[STATE]
  shuffle_label
      L-10 +X34 +X32 +X34 +X32 +X34 E-10
      G-10 +X32 +X32 L-02 P-12 N-03 B-12 E-02 +X32 +X32 J-10
      F-09 +X34 N-02 N-10 +X32 D-11 R-10 M-11 +X32 C-10 C-02 +X34 K-09
      +X32 P-03 L-08 +X32 M-09 E-15 G-08 L-15 D-09 +X32 H-05 B-03 +X32
      F-05 +X32 F-03 +X32 M-04 +X32 M-03 A-10 D-03 +X32 D-04 +X32 K-03 +X32 K-05
      +X34 P-05 +X32 G-04 +X32 N-08 R-09 G-14 A-09 H-03 +X32 J-04 +X32 B-05 +X34
      +X32 D-02 E-12 A-11 N-04 G-01 B-09 H-15 J-14 J-01 C-04 R-11 L-12 M-02 +X32
      +X34 N-13 F-15 H-07 F-01 B-07 A-08 F-14 R-08 P-09 K-15 H-09 K-01 C-03 +X34
      +X32 D-14 E-04 A-05 N-12 G-15 G-02 H-01 P-07 J-15 C-12 R-05 L-04 M-14 +X32
      +X34 P-11 +X32 G-12 +X32 H-13 R-07 J-02 A-07 C-08 +X32 J-12 +X32 B-11 +X34
      F-11 +X32 F-13 +X32 M-12 +X32 M-13 R-06 D-13 +X32 D-12 +X32 K-13 +X32 K-11
      +X32 P-13 H-11 +X32 M-07 E-01 J-08 L-01 D-07 +X32 E-08 B-13 +X32
      F-07 +X34 N-14 N-06 +X32 D-05 A-06 M-05 +X32 C-06 C-14 +X34 K-07
      G-06 +X32 +X32 L-14 P-04 C-13 B-04 E-14 +X32 +X32 J-06
      L-06 +X34 +X32 +X34 +X32 +X34 E-06

```

The next example shows a quarter-core shuffle map. This map is not realistic, but it shows

how fresh assemblies are inserted along with assemblies from cycles 8, 19, 20, and 21. The fresh assemblies all have fuel type “A12”.

```
[CORE]
  cycle 22                ! new cycle number
  op_date 2012/10/02      ! cycle startup date
[STATE]
  shuffle_label
    8H-10 +A12 21E-03 +A12 21E-13 21G-02 21G-08 21N-04
    +A12 210-08 20C-04 19L-07 +A12 21E-06 +A12 21K-03
    21C-11 20D-03 21E-08 +A12 21M-04 +A12 21K-04 21A-07
    +A12 19G-10 +A12 21P-08 +A12 210-06 21B-06
    210-11 +A12 21D-11 +A12 21B-07 +A12 21G-11
    21B-09 21F-05 +A12 21F-13 +A12 21L-06
    21H-09 +A12 21D-09 21F-02 21M-07
    21D-04 21C-09 21G-01
```

At this time, there is a restriction where the user must also include an *assm\_map* card in the input to specify the fresh fuel assemblies. This restriction will be removed in the future so that the fresh assembly types specified on the *shuffle\_label* card will be used.

In addition to the loading patterns, a list of restart files must be included to define the restart search path. The order of the restart files is important and they must be in reverse chronological order.

```
restart_shuffle
  restart_file_12.h5 EOC12
  restart_file_11.h5 EOC11
  restart_file_10.h5 EOC10
  restart_file_5.h5  EOC5
```

The first restart file is used to define the “previous” cycle number. The cycle number from this file will be used as the default cycle number in the shuffle map. The code will search for the assembly on the first file. If the assembly is not found, the code will go to the second restart file, and so on.

The next section gives an example of a core shuffle.

#### 4.4.1 Core Shuffle Example

Consider an example where a core shuffle is occurring at the beginning of cycle 3. There are two EOC restart files that have already been written from cycles 1 and 2.

These examples are not complete, they only show the pertinent cards needed to perform the core shuffle.

The EOC 1 restart file was generated with the following input:

```
[CORE]
  cycle 1      ! could be any arbitrary string like CYC1, etc.
  xlabel  R P N M L K J H G F E D C B A
  ylabel  01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
[STATE]
  deplete EFPD ... 327.3    ! only last depletion date shown
  op_date "1993/03/01"      ! shutdown date
  restart_write restart_cyc1.h5 "EOC1"
[ASSEMBLY]
  ! this input includes a definition of assembly type ASMA
```

The EOC 2 restart file was generated with the following input:

```
[CORE]
  cycle 2
  xlabel  R P N M L K J H G F E D C B A
  ylabel  01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
[STATE]
  deplete EFPD ... 426.3
  op_date "1994/03/05"      ! shutdown date cycle 2
  restart_write restart_cyc2.h5 "EOC_with_coastdown"
[ASSEMBLY]
  ! this input includes a definition of assembly type ASMB
  ! but it must also include the description for ASMA from cycle 1
```

The following input is used to shuffle to Cycle 3:

```
[CORE]
  cycle 3
  op_date "1994/04/07"      ! start-up date of cycle
  xlabel  R P N M L K J H G F E D C B A
  ylabel  01 02 03 04 05 06 07 08 09 10 11 12 13 14 15

[STATE]
  shuffle_label
  1H-10 +ASMC E-03 +ASMC E-13 G-02 G-08 N-04
  +ASMC O-08 C-04 L-07 +ASMC E-06 +ASMC K-03
  C-11 D-03 E-08 +ASMC M-04 +ASMC K-04 A-07
```

```

+ASMC G-10 +ASMC P-08 +ASMC O-06 B-06
O-11 +ASMC D-11 +ASMC B-07 +ASMC G-11
B-09 F-05 +ASMC F-13 +ASMC L-06
H-09 +ASMC D-09 F-02 M-07
D-04 C-09 G-01

```

```

! One assembly was loaded from cycle 1 (in the center)
! This assembly had to have the cycle number prepended to it

```

```

! All of the other assemblies came from cycle 2. This is the default cycle,
! and the cycle number did not have to be prepended.

```

```

! restart using the EOC restart files from cycles 1 and 2

```

```

restart_shuffle
  restart_cyc2.h5 EOC_with_coastdown
  restart_cyc1.h5 EOC1

```

```

[ASSEMBLY]

```

```

! include descriptions for ASMA, ASMB, ASMC if they are
! all used in cycle 3

```

#### 4.4.2 Shutdown decay

When performing a core shuffle, a shutdown decay is performed on each assembly to account for the shutdown decay time. The shutdown decay calculation is important for calculating the decay and build-up of fission products, such as xenon and samarium.

The shutdown decay time is calculated using the shutdown date from when the assembly was discharged and the new cycle startup date. The discharge date is the *op\_date* on the restart file the assembly data was written. The cycle start-up date is the *op\_date* in the core shuffle deck.

#### 4.4.3 Cross Unit Shuffle

The shuffling methodology can support cross-unit shuffles.

To use cross-unit shuffling, the unit number must be specified in the [CORE] block.

```

unit 1    ! unit 1 of a 2 unit site

```

To read an assembly from a different unit, the unit label is prepended to the front of the location label in the *shuffle\_label* card using a colon. For example, “U2:C3G-04” is used to read the

assembly from Unit “U2”, cycle “C3” and location “G-04”.

Once the location labels have been defined, the user can mix and match restart files from different units in the *restart\_shuffle* card:

```
restart_shuffle
restart_file_U1_12.h5 EOC12
restart_file_U2_5.h5  EOC
restart_file_U1_11.h5 EOC11
restart_file_U2_4.h5  EOC
restart_file_U1_10.h5 EOC10
restart_file_U2_3.h5  EOC
restart_file_U1_5.h5  EOC5
```

The only “trick” is to get this list in the right chronological order because an assembly could theoretically go from U2:CYC3 to U1:CYC10 then back to U2:CYC6. Therefore, the restarts must be in the correct chronological order. Remember that the cycle numbers are arbitrary strings, so there really is no “order” to them. The order is defined by the order specified in the *restart\_shuffle* input.

The shutdown dates are written to each restart file so the shutdown decay will be correctly calculated for each assembly. It doesn’t matter what unit the assembly came from, the right shutdown dates will be used.

## Chapter 5

# Input Card Descriptions

This chapter contains a complete listing of the available input cards.

The input for each block is given in separate subsections.

In this chapter, input cards are given in **bold** text followed by the parameters on the card. Following each input card is a description of the parameters on that card.

An example of an input card is:

**card\_name** param1, param2

param1 The first parameter on card (units)

param2 The second parameter on card (units)

## 5.1 Block CASEID

[CASEID]

**title** case\_id

case\_id Problem name

## 5.2 Block STATE

[STATE]

**title** title

title Statepoint title

**op\_date** op\_date

op\_date Operating date of this statepoint. Used when writing restart files.  
(“MM/DD/YYYY” or “YYYY/MM/DD”)

**power** power

power Operating power (percent of rated power)

**flow** flow

flow Operating flow (percent of rated flow)

**bypass** bypass

bypass Bypass flow (percent of rated flow)

**tinlet** tinlet units

tinlet Inlet temperature

units (“F”, “K”, or “C”)

**tfuel** tfuel units

tfuel Fixed fuel temperatures - Only used if feedback is turned OFF

units (“F”, “K”, or “C”)

**modden** modden

modden Fixed moderator density (g/cc) - Only used if feedback is turned OFF

**xenon** xenopt

**xenopt** Xenon option (“zero”, “dep”, or “equil”)

**samar** samopt

samopt Samarium option (“zero”, “dep”, “equil”, or “peak”)

**boron** boron

boron Soluble boron concentration (ppm)

**b10** b10 b10\_depl

b10 Boron-10 fraction in coolant (atom percent) (default is 19.9 atom percent)

b10\_depl Flag to enable B-10 depletion in coolant (“on” or “off”, default is “off”)

**kcrit** kcrit

kcrit Critical eigenvalue used in boron search

**search** search

search Search option (“keff” or “boron”)

**pressure** pressure

pressure Core exit pressure (psia)

**deplete** deplete\_units deplete

deplete\_units Depletion units (“EFPD”, “GWDMT”, “hours”)

deplete List of depletion exposure steps - only used with depletion

**rodbank** bank\_pos bank\_labels

bank\_pos Steps withdrawn for each bank in list

bank\_labels List of control rod banks to position. Labels correspond to crd\_map in CORE block.

**feedback** feedback

feedback Flag to turn on and off T/H feedback (“on” or “off”). Currently not used, feedback is controlled by executable that is run.

**sym** sym

sym Core fraction to run problem in (“full” or “qtr”)

**restart\_shuffle** restart\_shuffle\_file restart\_shuffle\_label

restart\_shuffle\_file List of restart files to search during core shuffle

restart\_shuffle\_label List of user labels on restart files to search during core shuffle

**restart\_read** restart\_read\_file restart\_read\_label

restart\_read\_file Name of restart file to read  
 restart\_read\_label User label on restart file to read  
**restart\_write** restart\_write\_file restart\_write\_label  
 restart\_write\_file Name of restart file to write/create  
 restart\_write\_label User label to use when writing restart file  
**shuffle\_label** shuffle\_label  
 shuffle\_label Core map showing core shuffle instructions

### 5.3 Block CORE

#### [CORE]

**name** core\_name

core\_name Name of the reactor core

**cycle** cycle\_num

cycle\_num Cycle number (string)

**unit** unit

unit Reactor plant unit name. Only used for multi-unit sites with cross-unit shuffle. (string)

**op\_date** op\_date

op\_date Start-up date of core reload. Only used when performing core shuffle. (“MM/DD/YYYY” or “YYYY/MM/DD”)

**size** core\_size

core\_size Number of assemblies across one axis in full-core geometry (required)

**rated** rated\_power rated\_flow

rated\_power Rated thermal power at 100% power (MW)

rated\_flow Rated vessel flow at 100% flow (Mlbs/hr)

**rvc\_volume** rvc\_volume

rvc\_volume Volume of the Reactor Coolant System (cubic ft) (only used with B-10 depletion)

**apitch** apitch

apitch Assembly pitch (cm)

**baffle** baffle\_mat baffle\_gap baffle\_thick

baffle\_mat Baffle material

baffle\_gap Gap between outside assembly (including assembly gap) and baffle (cm)

baffle\_thick Thickness of baffle (cm)

**vessel** vessel\_mats vessel\_radii

vessel\_mats Vessel materials

vessel\_radii Vessel radii (cm)

**core\_shape** shape

shape Square map showing the fuel assembly locations. Enter 1 for fuel assembly locations and 0 for empty locations.

**rotate\_map** rotate\_map

rotate\_map Core map of assembly rotations (0-3)

**assm\_map** assm\_map

assm\_map Core map of the fuel assembly types. The assembly types correspond to assembly labels in the ASSEMBLY block. All fuel assemblies must have a type defined.

**insert\_map** insert\_map

insert\_map Core map of the fuel insert types and locations. The insert types correspond to insert labels in the INSERT block. Use a dash to specify assemblies with no inserts.

**det\_map** det\_map

det\_map Core map of the detector types and locations. The detector types correspond to detector labels in the DETECTOR block. Use a dash to specify assemblies with no detectors.

**crd\_map** crd\_map

crd\_map Core map of the control rod types and locations. The control rod types correspond to control rod labels in the CONTROL block. Use a dash to specify assemblies with no control rods.

**crd\_bank** crd\_bank

crd\_bank Core map of the control rod bank labels. These labels are used to position groups of control rods by bank label. Use a dash to specify assemblies with no control rods.

**lower\_plate** lower\_mat lower\_thick lower\_vfrac

lower\_mat Lower core plate material  
 lower\_thick Lower core plate thickness (cm)  
 lower\_vfrac Lower core plate material volume fraction. Remainder of volume fraction will be filled with coolant.

**upper\_plate** upper\_mat upper\_thick upper\_vfrac  
 upper\_mat Upper core plate material  
 upper\_thick Upper core plate thickness (cm)  
 upper\_vfrac Upper core plate material volume fraction. Remainder of volume fraction will be filled with coolant.

**bc\_sym** bc\_sym  
 bc\_sym Symmetry flag for the core when using qtr-symmetry. Flag is not used in full-symmetry. Valid options are “rot” and “mir”.

**bc\_bot** bc\_bot  
 bc\_bot Bottom neutron transport boundary condition, “vacuum” (default) or “reflecting”.

**bc\_top** bc\_top  
 bc\_top Top neutron transport boundary condition, “vacuum” (default) or “reflecting”.

**bc\_rad** bc\_rad  
 bc\_rad Radial neutron transport boundary condition, “vacuum” (default) or “reflecting”.

**xlabel** xlabel  
 xlabel List of 2-character assembly position labels in x-direction. These values are used in the edit maps.

**ylabel** ylabel  
 ylabel List of 2-character assembly position labels in y-direction. These values are used in the edit maps.

**height** height  
 height Total axial distance from bottom core plate to upper core plate (cm). Distance does not include core plate thicknesses.

**mat** mat  
 mat Refer to the detailed materials description given in the User’s Manual.

**lower\_ref** lower\_refl\_mats lower\_refl\_thicks lower\_refl\_vfracs

lower\_refl\_mats Lower reflector materials  
 lower\_refl\_thicks Lower reflector thicknesses (cm)  
 lower\_refl\_vfracs Lower reflector volume fractions

**upper\_ref** upper\_refl\_mats upper\_refl\_thicks upper\_refl\_vfracs

upper\_refl\_mats Upper reflector materials  
 upper\_refl\_thicks Upper reflector thicknesses (cm)  
 upper\_refl\_vfracs Upper reflector volume fractions

## 5.4 Block ASSEMBLY

[ASSEMBLY]

**title** title

title Long descriptive title for assembly.

**npin** num\_pins

num\_pins The number of rods along the edge of an assembly.

**ppitch** ppitch

ppitch Pincell pitch (cm)

**cell** cell

cell Refer to the cell description given in the User's Manual.

**rodmap** axial\_label cell\_map

axial\_label Label for this axial elevation description.

cell\_map Lattice map for this axial elevation. Use a dash for an empty location.

**axial** label axial\_labels axial\_elevations

label Label for this assembly. Label corresponds to assm\_map in CORE block.

axial\_labels List of axial labels for this assembly description. Correspond to labels in lattice maps.

axial\_elevations List of axial elevations for this assembly description (cm).

**dancoff** dancoff\_map

dancoff\_map Lattice map of Dancoff factors (not currently used).

**grid** label material mass height

label Grid label for a single grid type.

material Grid material for this grid type.

mass Grid mass for this grid type (g).

height Grid height for this grid type (cm).

**grid\_axial** grid\_map grid\_elev

grid\_map List of spacer grid labels for all grids in an assembly (labels correspond to grid card)

grid\_elev List of spacer grid elevations for all grids in an assembly (cm). Elevations refer to the grid midpoint.

**lower\_nozzle** lower\_nozzle\_comp lower\_nozzle\_height lower\_nozzle\_mass

lower\_nozzle\_comp Lower nozzle material.

lower\_nozzle\_height Lower nozzle height (cm)

lower\_nozzle\_mass Lower nozzle mass (g). Code will calculate the volume of the nozzle given the nozzle mass, and use coolant for remaining volume.

**upper\_nozzle** upper\_nozzle\_comp upper\_nozzle\_height upper\_nozzle\_mass

upper\_nozzle\_comp Upper nozzle material.

upper\_nozzle\_height Upper nozzle height (cm)

upper\_nozzle\_mass Upper nozzle mass (g). Code will calculate the volume of the nozzle given the nozzle mass, and use coolant for remaining volume.

**fuel** fuel

fuel Refer to the detailed materials description given in the User's Manual.

**mat** mat

mat Refer to the detailed materials description given in the User's Manual.

## 5.5 Block CONTROL

[CONTROL]

**title** title

title Long descriptive title for control rod description.

**npin** num\_pins

num\_pins The number of rods along the edge of an assembly.

**stroke** stroke maxstep

stroke Control rod stroke - distance between full-insertion and full-withdrawal (cm)

maxstep Total number of steps between full-insertion and full-withdrawal

**cell** Cell

Cell Refer to the cell description given in the User's Manual.

**rodmap** label cell\_map

label Label for this axial elevation description

cell\_map Lattice map for this axial elevation. Use a dash for no control rod.

**axial** control\_label axial\_labels axial\_elevations

control\_label Label for this control rod description. Label corresponds to crd\_map in CORE block.

axial\_labels List of axial labels for this control rod description. Correspond to labels in rod maps.

axial\_elevations List of axial elevations for this control rod description (cm).

**mat** mat

mat Refer to the detailed materials description given in the User's Manual.

## 5.6 Block INSERT

[INSERT]

**title** title

title Long descriptive title for assembly insert description.

**npin** num\_pins

num\_pins The number of rods along the edge of an assembly.

**cell** Cell

Cell Refer to the cell description given in the User's Manual.

**rodmap** label cell\_map

label Label for this axial elevation description

cell\_map Lattice map for this axial elevation. Use a dash for no insert rod.

**axial** insert\_label axial\_labels axial\_elevations

insert\_label Label for this assembly insert description. Label corresponds to insert\_map in CORE block.

axial\_labels List of axial labels for this assembly insert description. Correspond to labels in rod maps.

axial\_elevations List of axial elevations for this assembly insert description (cm).

**mat** mat

mat Refer to the detailed materials description given in the User's Manual.

## 5.7 Block DETECTOR

[DETECTOR]

**title** title

title Long descriptive title for detector description.

**npin** num\_pins

num\_pins The number of rods along the edge of an assembly.

**cell** Cell

Cell Refer to the cell description given in the User's Manual.

**rodmap** label cell\_map

label Label for this axial elevation description

cell\_map Lattice map for this axial elevation. Use a dash for no detector rod.

**axial** detector\_label axial\_labels axial\_elevations

detector\_label Label for this detector description. Label corresponds to det\_map in CORE block.

axial\_labels List of axial labels for this detector description. Correspond to labels in rod maps.

axial\_elevations List of axial elevations for this detector description (cm).

**mat** mat

mat Refer to the detailed materials description given in the User's Manual.

## 5.8 Block EDITS

### [EDITS]

**axial\_edit\_bounds** axial\_edit\_bounds

axial\_edit\_bounds The boundaries of the axial regions over which axial information should be printed.

**axial\_edit\_mesh\_delta** axial\_edit\_mesh\_delta

axial\_edit\_mesh\_delta Produces a uniform axial output grid (integrates pin powers over a uniform axial mesh).

## 5.9 Block COBRATF

### [COBRATF]

**nfuel** nfuel

nfuel Number of radial nodes in fuel pellet.

**nc** nc

nc Conduction option (see CTF Manual).

**debug** debug

debug Option to print additional debug information in xml2ctf processing (1=on)

**irfc** irfc

irfc Friction factor correlation number (see CTF Manual).

**dhfrac** dhfrac

dhfrac Fraction of power deposited directly in coolant.

**hgap** hgap

hgap Gap conductance ( $\text{W}/\text{m}^2 \text{K}$ )

**gridloss** gridlabel gridloss

gridlabel Spacer grid label (from ASSEMBLY block).

gridloss Spacer grid loss coefficient.

**epso** epso

epso Inactive option - ignored by code.

**oitmax** oitmax

oitmax Inactive option - ignored by code

**iitmax** iitmax

iitmax Inactive option - ignored by code

**dtmin** dtmin

dtmin Minimum time step (s).

**dtmax** dtmax

dtmax Maximum time step (s).

**tend** tend

tend End of time domain (s).

**rtwfp** rtwfp

rtwfp Ratio of time step sizes for conduction/fluid.

**maxits** maxits

maxits Maximum number of iterations.

**courant** courant

courant Courant limit

**maps\_filename** maps\_filename

maps\_filename Name of HDF5 and VTK files

**heated\_elements\_type** heated\_elements\_type

heated\_elements\_type 0=model nuclear fuel rods, 1=model electric heater tubes.

If you select electric heater tubes, all heater rods in the model will be electric heater tubes and you must input the inside diameter, outside diameter, and pitch of the tubes.

**heater\_tube\_id** heater\_tube\_id

heater\_tube\_id Heater tube inside diameter (cm)

**heater\_tube\_od** heater\_tube\_od

heater\_tube\_od Heater tube outside diameter (cm)

**heater\_tube\_pitch** heater\_tube\_pitch

heater\_tube\_pitch Heater tube pitch (cm)

**solver** solver

`solver` Pressure matrix solver (See ISOL in CTF Manual)

**parallel** `parallel`

`parallel` 0=serial execution, 1=parallel execution. Parallelization is on a per-assembly basis.

**global\_energy\_balance** `global_energy_balance`

`global_energy_balance` Steady-state convergence criteria for balance of energy in the model

**global\_mass\_balance** `global_mass_balance`

`global_mass_balance` Steady-state convergence criteria for balance of mass in the model

**fluid\_energy\_storage** `fluid_energy_storage`

`fluid_energy_storage` Steady-state convergence criteria for transient storage of energy in fluid

**solid\_energy\_storage** `solid_energy_storage`

`solid_energy_storage` Steady-state convergence criteria for transient storage of energy in solids

**mass\_storage** `mass_storage`

`mass_storage` Steady-state convergence criteria for transient storage of mass in fluid

**edit\_gaps** `edit_gaps`

`edit_gaps` Edit flag to turn on gap output file (1=generate file)

**edit\_channels** `edit_channels`

`edit_channels` Edit flag to turn on channel output file (1=generate file)

**edit\_rods** `edit_rods`

`edit_rods` Edit flag to turn on rod edits (temperatures) in deck.out file (1=generate file)

**edit\_dnb** `edit_dnb`

`edit_dnb` Edit flag to turn on DNB output file (1=generate file)

**edit\_convergence** `edit_convergence`

`edit_convergence` Edit flag to generate a file displaying convergence parameters each iteration

**edit\_hdf5** `edit_hdf5`

`edit_hdf5` Option to generate the HDF5 file (1=generate file)

**boil\_ht\_cor** boil\_ht\_cor

boil\_ht\_cor Boiling heat transfer correlation

**property\_evaluations** property\_evaluations

property\_evaluations Source for fluid property evaluations (“asme” for ASME-68, “iapws” for IAPWS-IF97)

**beta\_sp** beta\_sp

beta\_sp Turbulent mixing coefficient (used for both single-phase and two-phase mixing) (default=0.05)

**k\_void\_drift** k\_void\_drift

k\_void\_drift Equilibrium distribution weighting factor (void drift model coefficient) (default=1.4)

## 5.10 Block INSILICO

[INSILICO]

Please refer to the Insilico documentation for a listing of all the cards in the [INSILICO] block.

## 5.11 Block MPACT

[MPACT]

Please refer to the MPACT documentation for a listing of all the cards in the [MPACT] block.

## 5.12 Block COUPLING

[COUPLING]

**epsk** epsk

epsk Eigenvalue convergence criteria (pcm)

**epsp** epsp

epsp Power convergence criteria (L2 norm)

**eps\_temp** eps\_temp

eps\_temp Temperature convergence criteria (degrees F)

**eps\_boron** eps\_boron

eps\_boron Boron convergence criteria (ppm)

**rlx\_power** rlx\_power

rlx\_power Power relaxation factor. Recommend 0.5.

**rlx\_tfuel** rlx\_tfuel

rlx\_tfuel Fuel temperature relaxation factor. Recommend 1.0.

**rlx\_den** rlx\_den

rlx\_den Density relaxation factor. Recommend 1.0.

**maxiter** maxiter

maxiter Maximum number of coupled iterations.

**read\_restart** read\_restart

read\_restart Name of coupling restart file. Leave blank for no coupling restart.

**ctf\_iters\_max** ctf\_iters\_max

ctf\_iters\_max Maximum number of CTF time-steps per coupled iteration

**ctf\_iters\_growth** ctf\_iters\_growth

ctf\_iters\_growth Fractional change in ctf\_iters\_max by coupled iteration (1 is no change)

# Chapter 6

## Examples

This chapter includes several input examples. Additional examples can be found in the VERAIn Git repository.

### 6.1 Example 1 – Full-Core

The first example is a complete input for a full-core problem. This problem is Problem 7 of the CASL Progression Benchmark Problems and is based upon the publicly available description of the Watts Bar reactors.

More information on the CASL Progression Benchmark Problems can be found in the following CASL report:

- A. Godfrey, “VERA Core Physics Benchmark Progression Problem Specifications,” CASL Technical Report: [CASL-U-2012-0131-004](#), August 2014.

More details on Problem 7 can be found in:

- “Demonstration and Neutronics Coupled to Thermal-Hydraulics for a Full-Core Problem using VERA”, CASL Technical Report: [CASL-U-2013-0196-000](#), December 2013.

```

!
! Sample Test case for Problem 7 (Full-Core HFP)
!
[CASEID]
  title 'CASL Progression Problem 7 - Watts Bar Unit 1 Cycle 1 - Public'

[STATE]
  power 100.0          ! % of rated power
  flow 100.0           ! % of rated flow
  pressure 2250.0
  feedback on

  tinlet 565.0 K      !
  tfuel 900.0 K       ! (HFP value)
  boron 1285          ! ppmB
  modden 0.743        ! g/cc
  sym qtr

  rodbank SA 230
           SB 230
           SC 230
           SD 230
           A 230
           B 230
           C 230
           D 167

[CORE]
  size 15              ! assemblies across core
  rated 3411 131.68    ! MW, Mlbs/hr
  apitch 21.5
  height 406.337

  core_shape
    0 0 0 0 1 1 1 1 1 1 1 0 0 0 0
    0 0 1 1 1 1 1 1 1 1 1 1 1 0 0
    0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
    0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    0 1 1 1 1 1 1 1 1 1 1 1 1 1 0

```

```

0 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0
0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0
    
```

assm\_map

```

1
2 1
1 2 1
2 1 2 1
1 2 1 2 2
2 1 2 1 2 3
1 3 1 3 3 3
3 3 3 3
    
```

insert\_map

```

-
20 -
- 24 -
20 - 20 -
- 20 - 20 -
20 - 16 - 24 12
- 24 - 16 - -
12 - 8 -
    
```

crd\_map

```

1
- -
1 - 1
- - - 1
1 - - - 1
- 1 - 1 - -
1 - 1 - 1 -
- - - -
    
```

crd\_bank

```

D - A - D - C -
- - - - - SB - -
A - C - - - B -
- - - A - SC - -
D - - - D - SA
- SB - SD - - -
C - B - SA -
- - - -
    
```

det\_map

```

1 - - 1 - - -
    
```

```

      1 - - - 1 - - 1 - 1 -
    - 1 - 1 - - 1 - - - - 1
      - - - - 1 - - 1 - - 1 - -
    1 - - - 1 - - 1 - - 1 - - - 1
    - - - - 1 - 1 - - - - 1 - - -
    - 1 - - - - - 1 - 1 - - - 1
    1 - 1 - 1 - 1 - - 1 - 1 1 1 -
    - - - 1 - - 1 - - 1 - - 1 - -
    1 - 1 - - 1 - 1 - - - - 1 -
    - - - - 1 - - - 1 - 1 - 1 - -
      1 1 - - - - 1 - - - - -
    - - - - - 1 - 1 - 1 - 1
      1 - - 1 - 1 - - - - -
        - - 1 - - 1 -

```

```

baffle ss 0.19 2.85
vessel mod 219.71 cs 241.70

lower_plate ss 5.0 0.5 ! mat, thickness, vol frac
upper_plate ss 7.6 0.5 ! mat, thickness, vol frac

lower_ref mod 20.0 1.0 ! mat, thickness, vol frac
upper_ref mod 20.0 1.0 ! mat, thickness, vol frac

xlabel R P N M L K J H G F E D C B A
ylabel 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

mat he 0.0001786
mat inc 8.19
mat ss 8.0
mat zirc 6.56 zirc4

[ASSEMBLY]
title "Westinghouse 17x17 Assembly"
npin 17
ppitch 1.260

fuel U21 10.257 94.5 / 2.110
fuel U26 10.257 94.5 / 2.619
fuel U31 10.257 94.5 / 3.100

cell 1 0.4096 0.418 0.475 / U21 he zirc
cell 2 0.4096 0.418 0.475 / U26 he zirc
cell 3 0.4096 0.418 0.475 / U31 he zirc
cell 4 0.561 0.602 / mod zirc ! guide/instrument tube
cell 5 0.418 0.475 / he zirc ! plenum

```

```

rodmap LAT21
  4
  1 1
  1 1 1
  4 1 1 4
  1 1 1 1 1
  1 1 1 1 1 4
  4 1 1 4 1 1 1
  1 1 1 1 1 1 1 1
  1 1 1 1 1 1 1 1 1

```

```

rodmap LAT26
  4
  2 2
  2 2 2
  4 2 2 4
  2 2 2 2 2
  2 2 2 2 2 4
  4 2 2 4 2 2 2
  2 2 2 2 2 2 2
  2 2 2 2 2 2 2 2

```

```

rodmap LAT31
  4
  3 3
  3 3 3
  4 3 3 4
  3 3 3 3 3
  3 3 3 3 3 4
  4 3 3 4 3 3 3
  3 3 3 3 3 3 3
  3 3 3 3 3 3 3 3

```

```

rodmap PLEN
  4
  5 5
  5 5 5
  4 5 5 4
  5 5 5 5 5
  5 5 5 5 5 4
  4 5 5 4 5 5 5
  5 5 5 5 5 5 5
  5 5 5 5 5 5 5 5

```

```
axial 1 11.951 LAT21 377.711 PLEN 393.711
```

```
axial 2 11.951 LAT26 377.711 PLEN 393.711
axial 3 11.951 LAT31 377.711 PLEN 393.711
```

```
grid END inc 1017 3.866
grid MID zirc 875 3.810
```

```
grid_axial
  END 13.884
  MID 75.2
  MID 127.4
  MID 179.6
  MID 231.8
  MID 284.0
  MID 336.2
  END 388.2
```

```
lower_nozzle ss 6.053 6250.0 ! mat, height, mass (g)
upper_nozzle ss 8.827 6250.0 ! mat, height, mass (g)
```

[INSERT]

```
title "Pyrex"
npin 17
```

```
mat pyrx1 2.25 pyrex-vera
```

```
cell 1 0.214 0.231 0.241 0.427 0.437 0.484 / he ss he pyrx1 he ss
```

```
rodmap PY8
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
- - - - - - -
- - - - - - - -
- - - - - - - - -
```

```
rodmap PY12
-
- -
- - -
1 - - -
- - - - -
- - - - - -
- - - 1 - - -
```

```

- - - - -
- - - - -
rodmap PY16
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
- - - 1 - - -
- - - - - - -
- - - - - - -

```

```

rodmap PY20
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - -
- - - - - - -

```

```

rodmap PY24
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - -
- - - - - - -

```

```

axial 8 15.761 PY8 376.441
axial 12 15.761 PY12 376.441
axial 16 15.761 PY16 376.441
axial 20 15.761 PY20 376.441
axial 24 15.761 PY24 376.441

```

```

[CONTROL]
title "B4C with AIC tips"
npin 17
stroke 365.125 230 ! approx for 1.5875 step sizes and 230 max stroke

```

```

mat aic 10.2
mat b4c 1.76

cell 1  0.382 0.386 0.484 / aic he ss
cell 2  0.373 0.386 0.484 / b4c he ss

```

```

rodmap AIC
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - -
- - - - - - - -

```

```

rodmap B4C
-
- -
- - -
2 - - 2
- - - - -
- - - - - 2
2 - - 2 - - -
- - - - - - -
- - - - - - - -

```

```

axial 1  17.031
      AIC 118.631
      B4C 377.711

```

```

[DETECTOR]
title "Incore instrument thimble"
npin 17

```

```

mat he 0.0001786
mat ss 8.0

```

```

cell 1  0.258 0.382 / he ss

```

```

rodmap LAT
1
- -
- - -

```

```

- - - -
- - - - -
- - - - -
- - - - -
- - - - -
- - - - -

```

```
axial 1 0.0 LAT 406.337
```

## [EDITS]

```
axial_edit_bounds
  11.951  15.817  24.028  32.239  40.45
  48.662  56.873  65.084  73.295  77.105
  85.17   93.235 101.3   109.365 117.43
 125.495 129.305 137.37  145.435 153.5
 161.565 169.63  177.695 181.505 189.57
 197.635 205.7   213.765 221.83  229.895
 233.705 241.77  249.835 257.9   265.965
 274.03  282.095 285.905 293.97  302.035
 310.1   318.165 326.23  334.295 338.105
 346.0262 353.9474 361.8686 369.7898 377.711
```

## [COBRATF]

```

nfuel 10           ! number of fuel rings in conduction model
nc     1           ! conduction option - radial conduction
irfc   2           ! friction factor correlation default=2
dhfrac 0.02       ! fraction of power deposited directly into coolant
hgap   5678.3     ! gap conductance
gridloss END 0.9070 ! spacer grid loss coefficient
gridloss MID 0.9065 ! spacer grid loss coefficient
dtmin  0.000001
dtmax  0.1
tend   0.1
rtwfp  1000.0
maxits 10000
courant 0.8
```

## [COUPLING]

```

epsk   5.0 ! pcm
epsp   1.0e-4
rlx_power 0.6
rlx_tfuel 1.0
rlx_den 1.0
maxiter 100
```

## 6.2 Example 2 – Single-Assembly

The second example is a partial input for a single-assembly with T/H feedback. This problem is Problem 6 of the CASL Progression Benchmark Problems. See:

- A. Godfrey, “VERA Core Physics Benchmark Progression Problem Specifications,” CASL Technical Report: [CASL-U-2012-0131-004](#), August 2014.

A single-assembly is defined by creating a core with one assembly in it, as described in the small-core geometry discussion in Section [2.2.5](#).

This input is also used to demonstrate the modular structure of the input. The [ASSEMBLY], [EDITS], [INSILICO], [COBRATF], and [COUPLING] blocks are identical to Example Problem 1, and show how blocks can be re-used in different input decks. These blocks are not included here, but can be copied directly from the first example problem if the user wishes to run this problem.

```

[CASEID]
  title 'CASL Benchmark Progression Problem 6'
!=====
! Sample input for Problem 6 (Single-assembly with T/H feedback)
!=====

[STATE]
power 100.0      ! %
tinlet 559.0 F  !
boron 1300      ! ppmB
pressure 2250   ! psia

feedback on
sym full

[CORE]
size 1           ! 1x1 single-assembly

! The rated power and flow are scaled down for a single-assembly
! rated 17.67  0.6824 ! rated power and flow (MW, Mlbs/hr)

apitch 21.5     ! assembly pitch (cm)
height 406.328  ! core height (cm)

core_shape
  1             ! core map with a single assembly

assm_map
  A1           ! name of assembly

lower_plate ss 5.0 0.5 ! material, thickness (cm), vol frac
upper_plate ss 7.6 0.5 ! material, thickness (cm), vol frac
lower_ref  mod 26.0 1.0 ! material, thickness (cm), vol frac
upper_ref  mod 25.0 1.0 ! material, thickness (cm), vol frac

bc_rad reflecting    ! boundary condition

! Materials defined in the [CORE] block are global and can be accessed
! from any assembly, insert, etc.

mat he      0.000176 ! list of materials and densities
mat inc     8.19     ! The library-name defaults to user-name
mat ss      8.0
mat zirc    6.56 zirc4
mat aic     10.20
mat pyrex   2.23

```

```
mat b4c      6.56

include 'assembly.inc' ! Include [ASSEMBLY] block from Example 1
include 'edits.inc'    ! Include [EDITS]    block from Example 1
include 'insilico.inc' ! Include [INSILICO] block from Example 1
include 'cobratf.inc'  ! Include [COBRATF]  block from Example 1
include 'coupling.inc' ! Include [COUPLING] block from Example 1
```

### 6.3 Example 3 – 2D Lattice Geometry

The third example is a complete input for a 2D lattice. This problem is Problem 2A of the CASL Progression Benchmark Problems. See:

- A. Godfrey, “VERA Core Physics Benchmark Progression Problem Specifications,” CASL Technical Report: [CASL-U-2012-0131-004](#), August 2014.

A single-assembly is defined by creating a core with a one assembly in it, as described in the small-core geometry description in Section [2.2.5](#).

The 2D lattice is defined by specifying an *axial* card with one level and defining reflective boundary conditions on the top and bottom of the core with the *bc\_top* and *bc\_bot* input cards.

This example problem also shows how multiple assembly, insert, and control types can be defined by using multiple *axial* cards in a single input block.

```
[CASEID]
  title 'CASL AMA Benchmark Problem 2A - Fuel Lattice - Public'

[STATE]
  power 0.0                ! %
  tinlet 557.33 F          !
  tfuel 565 K              !
  modden 0.743             ! g/cc
  boron 1300               ! ppm
  rodbank A 1              ! rod fully withdrawn
  sym qtr

[CORE]
  size 1
  apitch 21.50
  height 1.0
  rated 0.01 0.01

  core_shape
    1

  assm_map
    ASSY

  insert_map
    -

  crd_map
    AIC

  crd_bank
    A

  bc_rad reflecting
  bc_top reflecting      ! specify top reflective boundary conditions
  bc_bot reflecting      ! specify bottom reflective boundary conditions

[ASSEMBLY]
  npin 17
  ppitch 1.26

! material definitions in an ASSEMBLY block only have scope in this block

  fuel U31 10.257 94.5 / 3.1
  mat he 0.000176
```

```

mat zirc 6.56 zirc4

cell 1 0.4096 0.418 0.475 / U31 he zirc
cell 2          0.561 0.602 / mod zirc

rodmap LAT
  2
  1 1
  1 1 1
  2 1 1 2
  1 1 1 1 1
  1 1 1 1 1 2
  2 1 1 2 1 1 1
  1 1 1 1 1 1 1 1
  1 1 1 1 1 1 1 1 1

axial ASSY 0.0 LAT 1.0

[INSERT]
title "Pyrex"
npin 17

! material definitions in an INSERT block only have scope in this block

mat he      0.0001786
mat pyrx1   2.25 pyrex-vera
mat ss      8.0

cell 1 0.214 0.231 0.241 0.427 0.437 0.484 / he ss he pyrx1 he ss

rodmap LAT8
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
- - - - - - -
- - - - - - -
- - - - - - - -

rodmap LAT12
-
- -
- - -
1 - - -

```

```

- - - - -
- - - - -
- - - 1 - - -
- - - - -
- - - - -

```

```

rodmap LAT16
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
- - - 1 - - -
- - - - -
- - - - -

```

```

rodmap LAT20
-
- -
- - -
1 - - -
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - -
- - - - -

```

```

rodmap LAT24
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - -
- - - - -

```

! multiple INSERT types can be defined by defining separate axial cards

```

axial PY8 0.0 LAT8 1.0
axial PY12 0.0 LAT12 1.0
axial PY16 0.0 LAT16 1.0
axial PY20 0.0 LAT20 1.0
axial PY24 0.0 LAT24 1.0

```

```

[CONTROL]
  title "B4C and AIC RCCAs"
  npin 17
  stroke 1.0 1          ! 1 step for in/out

! material definitions in a CONTROL block only have scope in this block

mat he      0.0001786
mat ss      8.0
mat aic     10.2
mat b4c     1.76

cell 1  0.382 0.386 0.484 / aic he ss
cell 2  0.373 0.386 0.484 / b4c he ss

rodmap LAT_AIC
-
- -
- - -
1 - - 1
- - - - -
- - - - - 1
1 - - 1 - - -
- - - - - - -
- - - - - - -

rodmap LAT_B4C
-
- -
- - -
2 - - 2
- - - - -
- - - - - 2
2 - - 2 - - -
- - - - - - -
- - - - - - -

axial AIC  0.0 LAT_AIC 1.0
axial B4C  0.0 LAT_B4C 1.0

[MPACT]

! include INSILICO and/or MPACT block here

```