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VISION User Guide VISION (Verifiable Fuel Cycle Simulation) Model

Jacob J. Jacobson
Robert F. Jeffers
Gretchen E. Matthern
Steven J. Piet
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August 2009

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Jacob J. Jacobson
Robert F. Jeffers
Gretchen E. Matthern
Steven J. Piet
Benjamin A. Baker[1]

[1]Idaho State University

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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VISION User Guide VISION (Verifiable Fuel Cycle Simulation) Model

Advanced Fuel Cycle Initiative

Prepared for
U.S. Department of Energy
Jacob J. Jacobson, INL
Robert F. Jeffers, INL
Gretchen E. Matthern, INL
Steven J. Piet, INL
Benjamin A. Baker, Idaho State
Idaho National Laboratory
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SUMMARY

The purpose of this document is to provide a guide for using the current version of the Verifiable Fuel Cycle Simulation (VISION) model. This is a complex model with many parameters; the user is strongly encouraged to read this user guide before attempting to run the model.

This model is an R&D work in progress and may contain errors and omissions. It is based upon numerous assumptions. This model is intended to assist in evaluating “what if” scenarios and in comparing fuel, reactor, and fuel processing alternatives at a systems level for U.S. nuclear power. The model is not intended as a tool for process flow and design modeling of specific facilities nor for tracking individual units of fuel or other material through the system. The model is intended to examine the interactions among the components of a fuel system as a function of time varying system parameters; this model represents a dynamic rather than steady-state approximation of the nuclear fuel system.

VISION models the nuclear cycle at the system level, not individual facilities, e.g., “reactor types” not individual reactors and “separation types” not individual separation plants. Natural uranium can be enriched, which produces enriched uranium, which goes into fuel fabrication, and depleted uranium (DU), which goes into storage. Fuel is transformed (transmuted) in reactors and then goes into a storage buffer. Used fuel can be pulled from storage into either separation of disposal. If sent to separations, fuel is transformed (partitioned) into fuel products, recovered uranium, and various categories of waste. Recycled material is stored until used by its assigned reactor type. Note that recovered uranium is itself often partitioned: some RU flows with recycled transuranic elements, some flows with wastes, and the rest is designated RU. RU comes out of storage if needed to correct the U/TRU ratio in new recycled fuel. Neither RU nor DU are designated as wastes.

VISION is comprised of several Microsoft Excel input files, a Powersim Studio core, and several Microsoft Excel output files. All must be co-located in the same folder on a PC to function. We use Microsoft Excel 2003 and have not tested VISION with Microsoft Excel 2007. The VISION team uses Powersim Studio 2008, the latest release. (In final testing, we discovered that it will run in Powersim Studio 2005, but the connections to the output file are gone.)

VISION 3.0 has more flexibility than previous versions, which were structured for only three reactor types - LWRs that can use only uranium oxide (UOX) fuel, LWRs that can use multiple fuel types (LWR MF), and fast reactors. One could not have, for example, two types of fast reactors concurrently. The new version allows 10 reactor types and any user-defined uranium-plutonium fuel is allowed. (Thorium-based fuels can be input but several features of the model would not work.) The user identifies (by year) the primary fuel to be used for each reactor type. The user can identify for each primary fuel a contingent fuel to use if the primary fuel cannot be made, e.g., a reactor designated as using mixed oxide fuel (MOX) would have UOX as the contingent fuel. Another example is that a fast reactor using recycled transuranic (TRU) material can be designated as either having or not having appropriately enriched uranium oxide as a contingent fuel.

Because of the need to study evolution in recycling and separation strategies, the user can now select the recycling strategy and separation technology, by year. Recycling strategy means how fuel is routed from used fuel storage into one or more separation facility types. As an example, a separation plant could be designated to use one source of UOX fuel for three decades and then shift to having a combination of UOX and MOX. Separation technology means how fuel is separated into products, which are routed into one of the 10 subsequent fuel types, or waste. So, for example, the user can designate a separation plant type to change efficiency (fraction of TRU into waste) or change from not recovering minor actinides (Np, Am, Cm, Bk, Cf) to later recovering them.

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ACRONYMS

AFCI	Advanced Fuel Cycle Initiative
Aq	Aqueous separation
BC	Base Case
BU	Burnup, sometimes incorrectly used as burned uranium
CANDU	CANada Deuterium Uranium reactor
CFR	Converter Fast Reactor
COEX	Co-Extraction producing RU and UPu as products and everything else as a waste
CR	Transuranic Conversion Ratio (TRU produced/TRU destroyed)
CY	Calendar Year
DU	Depleted uranium, the low U235 tailings from uranium enrichment
E-chem	Electrochemical separation, also known as pyroprocessing
EU	Enriched uranium, the high U235 produce from uranium enrichment
FBR	Fast Breeder or Burner Reactor
FPY	Full Power Year
FR	Fast Reactor
GNEP	Global Nuclear Energy Partnership
GWe	Gigawatt-electric
GWth	Gigawatt-thermal
HEU	Highly Enriched Uranium
HWR	Heavy water reactor
IMF	Inert Matrix Fuel (thermal reactor fuel without uranium)
INL	Idaho National Laboratory
Iso	Isotope
kt	Kilotonne
LSF	Legacy Spent Fuel, pre-2000 inventory of discharged LWR fuel
LTD	Long-Term Dose, a metric describing the hypothetical dose to the maximally exposed individual at a specific time after repository emplacement, scaled from 2004-vintage Yucca Mountain groundwater pathway calculations
LTH	Long-Term Heat, a metric describing the heat committed to waste disposal from time of repository closure to ~1500 years
LTR	Long-Term Radiotoxicity, a metric describing the radiotoxicity of isotopes at a specific time after repository emplacement
LWR	Light Water Reactor
LWR MF	Light Water Reactor Mixed Fuel, LWR that can use multiple fuels, e.g., MOX and/or IMF
LWR MOX	MOX fuel in Light Water Reactors
MF	Mixed Fuel in a thermal reactor, e.g., MOX or IMF
MOX	Mixed Oxide fuel, a mixture of uranium oxide and one or more transuranic element oxides, e.g. MOX-Pu or MOX-TRU
MRS	Managed Retrievable Storage
MT	Montana, sometimes used as metric ton (1000 kg), but the proper System Internationale unit would be Mg for megagram
PUREX	Plutonium-Uranium Extraction, producing RU and Pu as products and everything else as a waste stream
Rxtr	Reactor
RU	Recovered uranium from a separation process
SF	Spent Fuel, also called used fuel
SWU	Separative Work Unit

t	Tonne (metric ton)
TR	Thermal Reactor
TRU	Transuranics (Plutonium and higher on periodic table)
UOX	Uranium Oxide
UREX	Uranium Extraction
UREX+1	UREX producing U, and all-TRU as product streams and several sets of fission products as individual waste streams
UREX+2	UREX producing U and NpPu as product streams, and several sets of fission products as individual waste streams. AmCm goes into waste.
UREX+3	UREX producing U, NpPu, and AmCm as product streams and several sets of fission products as individual waste streams
UREX+4	UREX producing U, NpPu, Am, and Cm as product streams and several sets of fission products as individual waste streams
VHTR	Very High Temperature Reactor
VISION	Verifiable Fuel Cycle Simulation

TERMINOLOGY

Base case	A set of parameters in the main input file that defines a self-consistent scenario.
Decay products	Decay products of uranium, specifically Pb, Bi, Ra, Ac, Th, Pa
Fast burner or converter reactor	A fast reactor with transuranic conversion ratio < 1
Fast breeder reactor	A fast reactor with transuranic conversion ratio > 1
File	If extension xls - Excel2003 spreadsheet files, file names are in **bold** in this document. If extension sip - Powersim Studio files
Fuel recipe	Either the input or output composition of a reactor fuel, normalized so that the total recipe equals 1.00. Recipes are contained in the file **vision recipes ver5.xls**
Group 1A/2A	Alkali/Alkali earths, specifically Rb, Sr, Cs, Ba. For fuel cycle management, the most important radioactive Group 1A/2A are Sr90, Cs134, Cs135, Cs137.
Halogens	Group VII of the Periodic Table, specifically Br and I. For fuel cycle management, the most important radioactive halogen is I129.
Inert gases	Group O of the Periodic Table, specifically Kr and Xe. For fuel cycle management, the most important radioactive inert gases are Kr81 and Kr85.
Lanthanides	Elements La through Lu. For fuel cycle management, the most important isotopes are Ce144, Pm147, Sm146, Sm147, Sm151, Eu154, Eu155, Ho166m.
Legacy	Any reactor or used fuel that exists before the simulation begins, typically the year 2000.
Minor actinides	Transuranic isotopes other than plutonium, specifically Np, Am, Cm, Bk, Cf.
Prioritization - order	A facility capacity is used by a set of incoming flows such that source one is used first, then source two, etc. until the full capacity of the facility type is used.
Prioritization - percentage	A facility capacity is used by allocating a percentage of the capacity among a set of potential flows.
Powersim Studio	Commercial system dynamic software in which the core part of the VISION suite is written.
Routing - pull	A receiving facility attempts to pull material from a designated set of sending facilities. Thus, there must be a buffer inventory at each sending facility because the material may or may not be requested by one or more receiving facilities.
Routing - push	Material is sent by a facility independent of whether the receiving facility has sufficient capability for it. Thus, there must be a buffer inventory at the receiving facility.
Transition metals	In this report, literally elements not otherwise categorized, including Se, Mo, Ru, Pd, Pd, Cd, Sn, Sb, Te.
Transuranic	Isotopes above uranium in the Periodic Table, specifically Np, Pu, Am, Cm, Bk, Cf.
TRU Conversion Ratio (CR)	Ratio of transuranic material created during residence in a reactor divided by the transuranic material destroyed. This is related to but different from than fissile breeding ratio, which is the ratio of fissile material created/destroyed.
Separation efficiency matrix	Also can be described as separation technology matrix or separation partition matrix. User-defined matrices allocate percentages of each component of used fuel into fuel product streams, recovered uranium (RU), and/or waste streams.

VISION	The suite of Excel input files, Powersim core, and Excel output files that models the nuclear fuel cycle system.
Worksheet (or page)	Worksheets within a spreadsheet file, worksheet names are in **bold** in this document

VISION USER GUIDE

1. INTRODUCTION

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So, the user has three major year-by-year ways to control the fuel cycle: fuel recipes, recycling routing matrices that route used fuel to separation types, and separation efficiency matrices, which separate products from waste and also serve to route separation products back to fuel/reactor types.

This flexibility comes with two disadvantages. First, the magnitude of the required input has grown six-fold; the main input file (**base case settings ver6.xls**) has grown from 4.5 to 30 MB. So, we have started to create some Excel macro's to assist in data entry; please comment on their usefulness. Second, we cannot pre-define most of the output files a user might want, nor anticipate how a user would want them labeled. For example, fast reactors might be reactor type 3 or reactor 6 or not exist. So, we have added a page in the input file that asks users to supply their names for each run, each reactor type, each fuel type, and each separation type; these are used in the various output files. And, we have added Graph Viewer and Graph Builder macro's into relevant output files so the user can see pre-existing graphs as well as be guided into making new graphs. Pre-existing graphs will generally have to be modified before use, e.g., by deleting reactor, fuel, or separation types that are not used in a particular simulation.

1.1 Purpose

This model is an R&D work in progress and may contain errors and omissions. It is based upon numerous assumptions. This model is intended to assist in evaluating "what if" scenarios and in comparing fuel, reactor, and fuel processing alternatives at a systems level for U.S. nuclear power. The model is not intended as a tool for process flow and design modeling of specific facilities nor for tracking individual units of fuel or other material through the system. The model is intended to examine the interactions among the components of a fuel system as a function of time varying system parameters; this model represents a dynamic rather than steady-state approximation of the nuclear fuel system.

This is a model that is still being actively developed, and we invite feedback:

Jake Jacobson
208-526-3071
Jacob.jacobson@inl.gov

Gretchen Matthern
208-526-8747
Gretchen.matthern@inl.gov

As of this writing, there are a few features not yet working. These are noted in this guide as it is hoped they will be working soon.

1.2 Underlying Theory and Terminology of VISION

Even if you are very familiar with nuclear fuel cycles, we encourage you to read this subsection as it explains the underlying theory and terminology of VISION.

VISION models the nuclear cycle at the system level, not individual facilities, e.g., "reactor types" not individual reactors and "separation types" not individual separation plants. Nonetheless, to avoid repeating the word "types" countless times, this manual will often simply refer to "reactors" and "separations."

Figure 1-1 shows the basic VISION model of the nuclear fuel cycle. Natural uranium can be enriched, which produces enriched uranium, which goes into fuel fabrication, and depleted uranium (DU), which goes into storage. (DU) only comes out of storage if used in a reactor. Fuel is transformed (transmuted) in reactors and goes into a storage buffer. Used fuel can be pulled from storage into either separation of disposal. If sent to separations, fuel is transformed (partitioned) into fuel products, recovered uranium, and various categories of waste. Recycled material is stored until used by its assigned reactor type. Note that recovered uranium is itself often partitioned: some RU flows with recycled transuranic elements, some flows with wastes, and the rest is designated RU. RU comes out of storage if needed to correct the U/TRU ratio in new recycled fuel. Neither RU nor DU are designated as wastes.

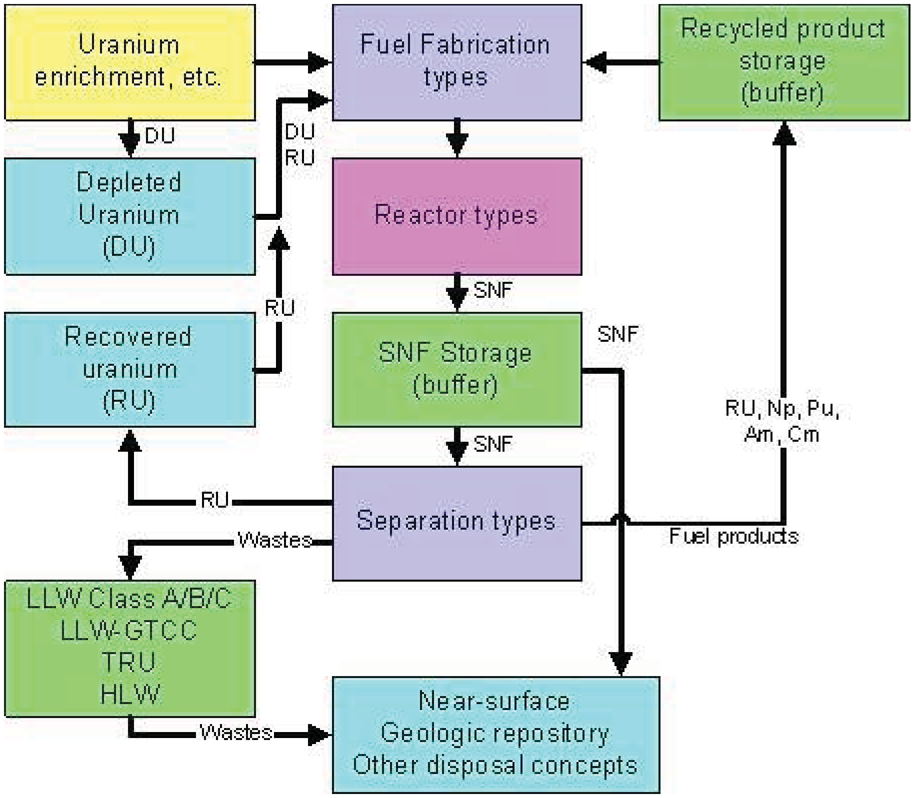


Figure 1-1. Basic VISION structure.

Thus, as fuel moves through the fuel cycle, there are two primary functions - transformation and routing. Transformation occurs at facilities and routing occurs between facilities. Routing does not change the material, it merely moves mass from one place to another. In the parlance of system dynamics, types of facilities are inventories or stocks; routing are flows. Facilities transform material in various ways, e.g.

- Transmutation at reactors,
- Separation (or partition) at separation plants,
- Fabrication at fabrication plants,
- Waste form creation and waste form packaging at waste processing plants, and
- Isotopic decay at waste storage and all of the above.[a]

Generally, the performance of each transformation operation is under the user's control. Transformation occurs by user-selected "recipes" that translate an input composition to an output composition. Separation occurs by user-selected "separation efficiency matrices" that partition incoming used fuel into fuel products, recovered uranium, and waste streams. At present, fabrication is not user controlled, material sent to a given fabrication plant always undergoes the type of fabrication appropriate for associated reactor type's fuel, which is itself specified by the fuel recipe selected for that reactor. That is, there is a 1:1 correspondence between fuel fabrication plant types and reactor types.

a. Exception - Isotopes are not decayed once put into a repository as our primary waste management concern is estimating the amount and character of waste forms at the time of emplacement.

Routing is also generally under the user's control. The primary exception is again fuel fabrication to reactor. There is no provision to route fuel from one fabrication plant type to a different reactor type.

In principle, routing can be specified either by "pushing" or "pulling."

- Push - Material is sent by a facility independent of whether the receiving facility has sufficient capability for it. Thus, there must be a buffer inventory at the receiving facility.
- Pull - A receiving facility attempts to pull material from a designated set of sending facilities. Thus, there must be a buffer inventory at each sending facility because the material may or may not be requested by one or more receiving facilities.

A real fuel cycle system could have both push and pull routing and thus buffers at both sending and receiving facilities. In VISION 3.0, we have chosen to primarily model routing from reactors to separation as "pull", hence buffers are closely associated with reactors, i.e., where used fuel is located such as wet and dry storage. That is, used fuel stays in used fuel storage unless or until pulled by separations or pulled by waste disposal. The routing of separation to fabrication/reactors is primarily modeled as "push", i.e., buffers are envisioned at receiving fuel fabrication plants. Whether push or pull, routing can theoretically be controlled either by priority order or percentage. Priority order means that some capacity is used by a set of incoming flows such that source one is used first, then source two, etc. until the full capacity of the facility type is used. VISION models reactor-to-separation as push/priority-list. Percentage means that material is received or sent to a set of places allocated by percentages. VISION models separation-to-fabrication/reactor by pull/percent.

Figure 1-2 shows the routing approach in VISION as well as two of the many alternatives to help differentiate among options. As noted above, VISION uses pull/priority routing from reactors to separation plants and push/percent from separation plants to fuel fabrication (hence reactors). The first alternative shown is pull/priority (reactor to separation) then pull/percent (separation to fuel fabrication). The second alternative is push/percent for both reactor-separation and separation-reactor. All options require at least one buffer between reactor and separation and one between separation and fuel fab; the diagram shows the buffer shifting position. (Here, "position" means in a logical sense, the physical location of buffers is not addressed.)

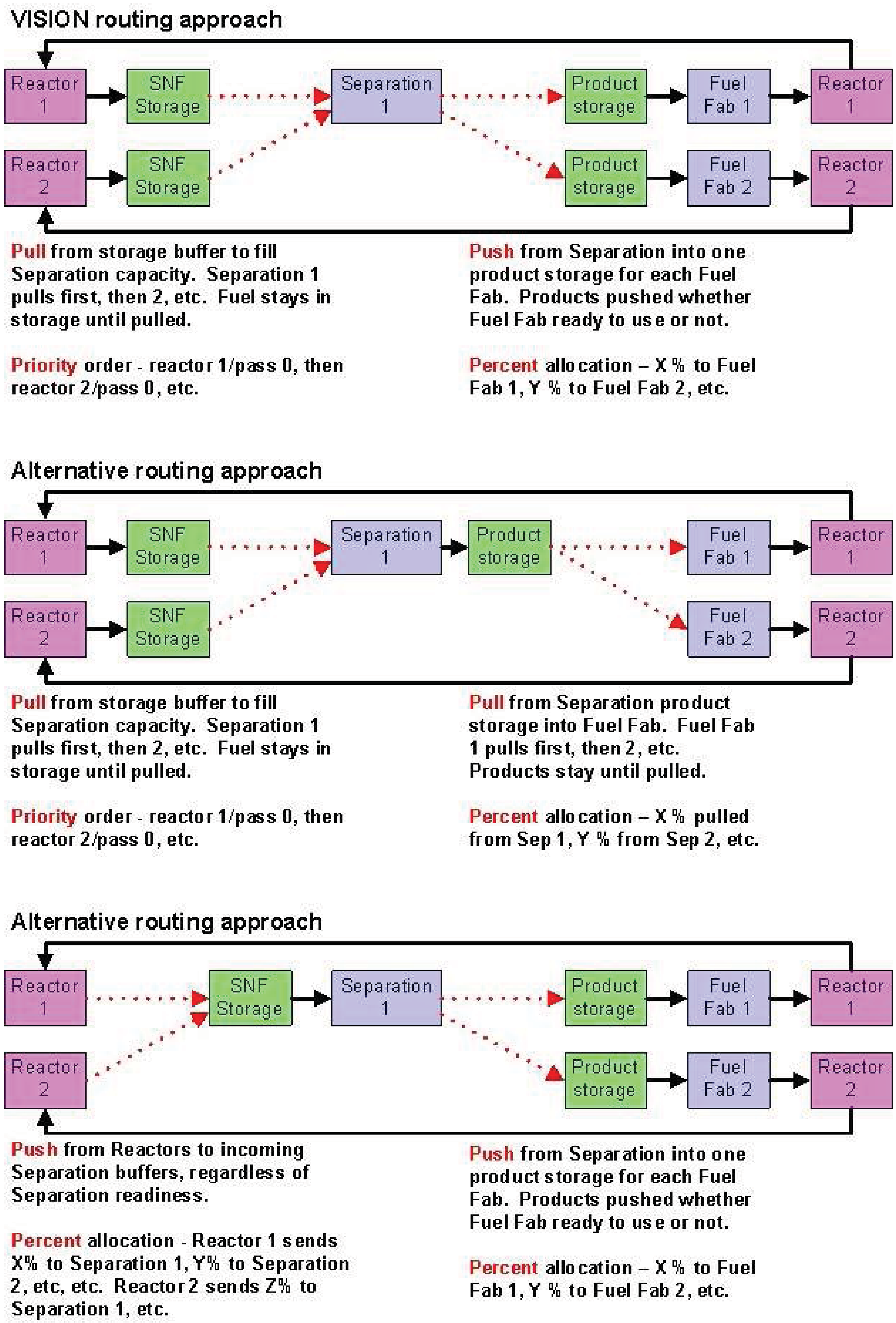


Figure 1-2. VISION Routing Approach.

1.3 Scope and Organization of VISION

VISION can be run two ways:

- Pre-defined base cases provide the simplest way to use VISION but the least flexibility. In this mode, the user selects a predefined base case, and the model automatically enters all of the parameters necessary by reading parameters from Microsoft Excel spreadsheets. Currently, when the user selects a predefined base case, they cannot change any of the parameters with the user interface.[b] Use of predefined base cases allows the user to select among several dozen different strategies, but the user cannot select any of the parameters for each case.
- User-defined base cases provide the most flexibility but require the user to identify each input parameter. For both predefined and user-defined base cases, VISION reads input parameters from Microsoft Excel spreadsheets prior to running the simulation. The user defined base cases allow the user to access the full flexibility of the model (available without making changes to the code itself) and to easily save those defined cases for repeated runs or varying specific parameters. Once all the parameters for a user defined case are defined in the Excel input files, the user defined cases can be run as simply as the predefined base cases. The user can copy parameters from one of the predefined base cases into the five slots for user-defined base cases in the Excel files and then modify them.

Previously, VISION could also be run via a user interface. The increased flexibility (and complexity) of the model now precludes this mode of operation.

We discourage users making changes directly in the model; if your needs suggest model changes, please contact us.

The typical user does not need to know the inner structure of the VISION model as long as they are familiar with the basics of the nuclear cycle and follow this user guide.[c] Nonetheless, it is instructive to consider the full scope of the model as shown in Figure 1-3. The color coding of the modules is the same as Figure 1-1 and designates the following:

- White - fundamental source material (uranium ore, high enriched uranium, Pu)
- Yellow - front end of the fuel cycle (uranium mining, enrichment, etc.)
- Blue - fuel recycling (separation and fabrication)
- Pink – reactors
- Green - in-process storage, packaging, etc.
- Bright blue - long-term storage and ultimate disposal

b. We have requested a change to the Powersim Studio software that would allow for users to make such changes.

c. There is also a methodology document, which is being updated.

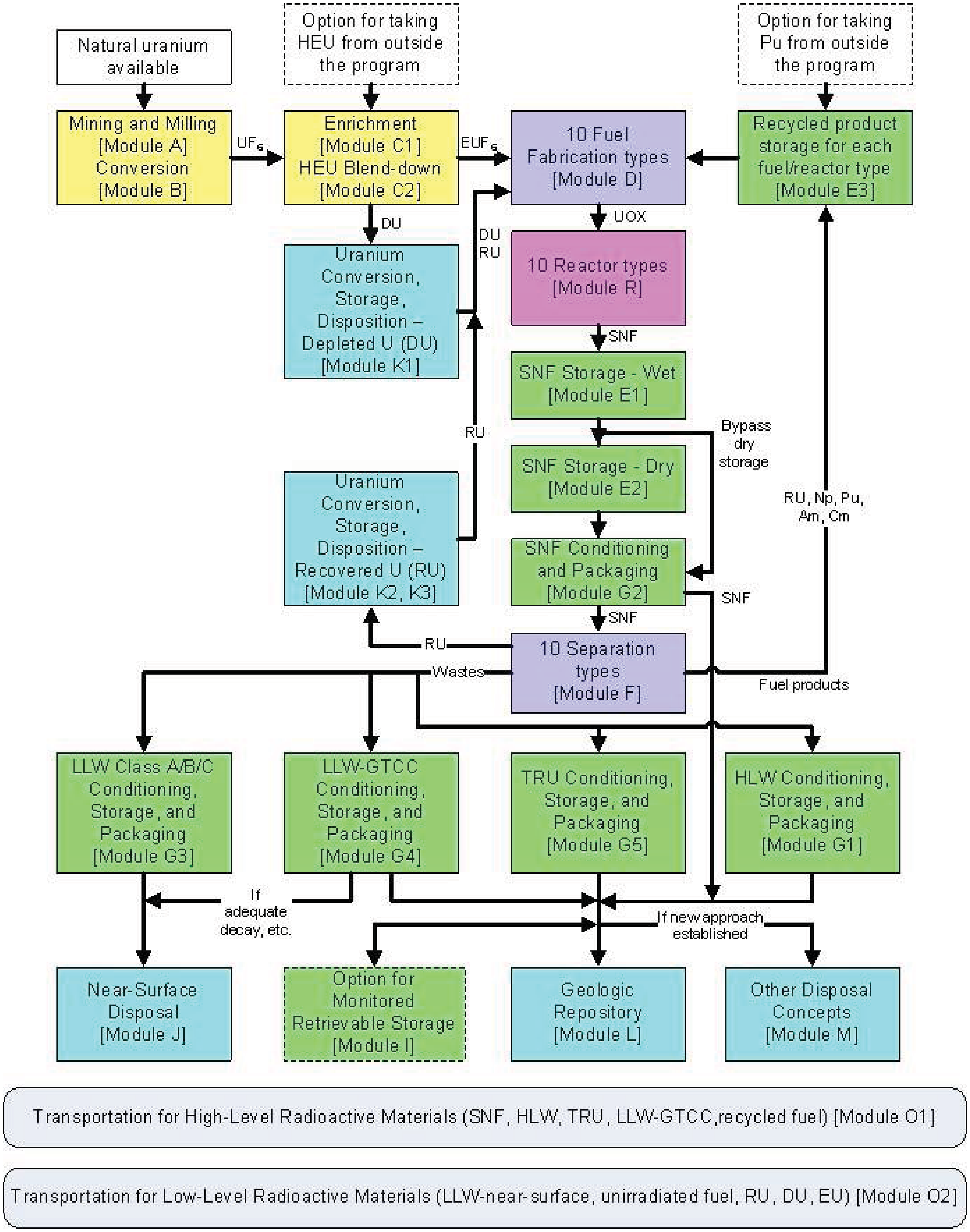


Figure 1-3. VISION Modules.

This color scheme is used where practical in this document and in the input and output Excel files.

As can be seen, the model addresses the entire fuel cycle from fundamental source material to ultimate disposal and the various steps and options in-between. After separations, all outputs are tracked. Based on the options selected by the user the model controls how much of each chemical element goes where.

1.4 Changes from Previous Versions

Table 1-1 summarizes the increase in flexibility (and complexity) between VISION 2.2 and 3.0. These have been motivated by the following:

- Requested benchmarks against other codes with scenarios lasting more than 100 years. The new model can run for 200 years.
- Interest in studying more reactor types than before, i.e., more than LWR-UOX, LWR-MF, and fast reactors. The new model can handle any uranium-plutonium fuel. It cannot yet reliably calculate the range of thorium fuel cycles.
- Interest in studying more reactor types concurrently.
- Interest in allowing yearly evolution of reactor type and separation type.

Table 1-1. Major Changes from Version 2.2

Number of …	VISION 2.2	VISION 3.0
… years of simulation	100	200
… reactor types	3 (hardwired)	10 (user-defined)
… isotopes tracked	60	81
… times reactor capacity can be changed	Yearly by 2 methods	Yearly by 3 methods
… user-defined fuel recipes that can be entered	2 thermal/run 2 fast/run	Hundreds
… times a reactor type's fuel recipe can be changed	2	Yearly
… times the routing from reactor to separation plant can be changed	Yearly (only by changing number of recycles)	Yearly (any reactor to any separation)
… separation types	3 (hardwired)	10 (user-defined)
… times a separation type's capacity can be changed	Yearly	Yearly
… user-defined separation fuel partition matrix that can be entered	15	40
… times a separation type's fuel partition matrix can be changed	Never	Yearly
… times the routing from separation to fabrication can be changed	Yearly (only by changing number of recycles)	Yearly (any separation to any fuel fab)
… times the routing from fabrication to reactor can be changed	Never	Never
… times the routing from separation to waste streams can be changed	Never	Yearly
waste management metrics	7	Most currently inactive
Size of base case setting file	4.5 MB	30 MB

2. KEY ASSUMPTIONS AND INITIAL PARAMETERS

2.1 Assumptions

2.1.1 Facility Behavior and Sizes

Each reactor, separation, and fuel fabrication type can represent one or more discrete facilities. All facilities of a given type have the same functional behavior and the same unit size, e.g., reactor capacity (GWe/reactor). They generally start and end at different times. If it is important to differentiate among behaviors of reactors or separation plants, the groups should be modeled as different types. For example, we typically model two “types” of LWRs - those that can only use UOX fuel and those with multiple fuel (MF) capability and thus can use either UOX or MOX (or IMF) fuel. Similarly, one might have a separation type for UREX+3, in which the products would be NpPu and AmCm, and another separation type for UREX+1, in which the product is all-TRU. All separation facilities of a given “type” do the same separation at each time step, so much to fuel products, so much to waste, etc. One can change the behavior over time, but that change applies to all facilities of the same type.

2.1.2 Combinations

Users of the model must ensure that the appropriate combinations of reactor, fuel, and operating conditions are selected when setting up a user defined base case or manual scenario. For example, fast reactors will not recycle fuel if no fuel is sent to fast reactors by routing LWR fuel to one or more separation types that then route fuel products to a separation-to-reactor buffer so that it can be used to make the appropriate type of fuel.

2.1.3 Priority among Reactors, Separations, and Fuel Fabrication Types

Generally, the priority among reactor types, among separation types, and among fuel fabrication types is controlled by the user through various input matrices. For example, by “pushing” fuel products from separation to fuel fabrication (by percent) and the 1:1 correspondence between fuel fabrication and reactor fuel type, there is no additional prioritization required at fuel fabrication. Recycled material has already been allocated by the separation efficiency matrices that push fuel products into each fuel fabrication.

There are two exceptions. First, recycling routing matrices define for each separation type the order in which that separation type pulls used fuel, e.g., pull from Fuel type 1, then Fuel type 3, then Fuel type 2. That separation type will pull fuel each time step until its separation capacity is used. If the user allows more than one separation type to pull the same fuel type, then the separation type with the lower number goes first - a hard-wired prioritization not under user control except by the order in which the user defined separation types.

> Example: Separation 2 and 3 are allowed to pull from Fuel type 2, whether or not they pull from other fuel types. So, Separation 2 is allowed to pull from any available Fuel type 2 to use its current separation capacity. After Separation 2 is completed, Separation 3 could use any remaining available fuel type 2. Separation 2 goes before Separation 3.

Second, legacy reactors retire in the order reactor-1 first, then reactor-2, and so forth.

2.1.4 Units

Unless otherwise stated, the model uses the following units:

- Reactor capacity in GWe, i.e., unit of power

- Energy and electricity generation in GWe-FPY (full power years), i.e., unit of energy
- Mass in kilotonnes (kt or ktonnes) - these are converted to t (tonnes) in output files
- Time in calendar years (CY) or full power years (FPY).
- Separation and fuel fabrication capacities are generally in units of kt/CY.

2.1.5 Reactor and Fuel Types

The assignments are made by the selection of fuel input and output recipes in the input Excel files. VISION does not perform reactor physics calculations. Instead, it uses input and output recipes that designate, by isotope, the composition of fuel entering and leaving a reactor.

A recipe represents core-averaged compositions.

VISION keeps track of the flow of material by recycle pass through 5 recycle passes. Recycle pass 0 is virgin material that has not been recycled. Since U235 is the only fissile isotope in nature, all pass 0 fuel is based on uranium. Pass 1 is the first recycle pass. Material that is recycled after the fifth recycle is re-allocated to recycle pass 5. Keeping track of recycle passes is critical to making VISION work as intended.

Material's recycle pass is remembered (conserved) in going from reactor to separation plant, in separation plants, and in fuel fabrication.

Material recycle pass is updated between separation and fuel fabrication.

- Material going from separation X to fuel fabrication X, is increased by 1, except that pass 5 goes to pass 5.
- Material going from separation X to some other fuel fabrication is reset to 1. So, material recovered from first-pass used MOX (pass 1) that goes to fuel fabrication for a fast reactor is reset to pass 1 and enters fast reactors as such. Material recovered from first-pass used MOX that stays as MOX gets updated to MOX pass 2.

Any type of uranium-plutonium fuel recipe can be used. *We have not tested the model with thorium recipes, partly because we are still assembling appropriate recipes. Off course there are as many thorium fuel cycle options as uranium-based options. The model already tracks relevant Th isotopes. The current model will not track use of thorium resources. Once-through thorium options (Th + U235 or Th + TRU) might work; the model would simply create Th to make the fresh fuel. Thorium options with recycled U233+TRU (or Pu) might work, provided uranium with appropriate U233 content was separated and sent to the appropriate fuel fabrication type. The "flow control" would be sent to the TRU (orPu). Thorium options in which the recycled U233 content should be the control on flow will not work.*

The sum of mass fractions in a fuel recipe must equal 1.0. Otherwise, mass will be created or destroyed each time fuel enters or leaves a reactor type.

All recipes for used fuel assume 0 years of cooling (time after exiting the reactor) have occurred. In the model, the used fuel can be decayed while in an interim or longer term storage facility.

Unless otherwise stated, Cm is meant to include Cm, Bk, and Cf isotopes. TRU means all elements above U, specifically Np, Pu, Am, Cm, Bk, Cf.

Figure 2-1 shows the Periodic Table from our perspective. The color coding (unavoidably different than the VISION module color coding) denotes groups of elements with similar behavior in chemical separations. Although the user is free to define chemical separation performance by isotope, the examples that come with VISION assume elements of the same color coding behave the same during chemical separation. For example, all of the lanthanides (plus yttrium) are assumed to be separated as a group. The only Group 1A/2A elements of significance as fission products are Rb, Sr, Cs, and Ba. The only halogens of significance are Br and I. The only inert gases of significance are Kr and Xe. H3 and C14 are considered separately because of their ubiquitous role in biological systems. More details can be found in Piet2009.

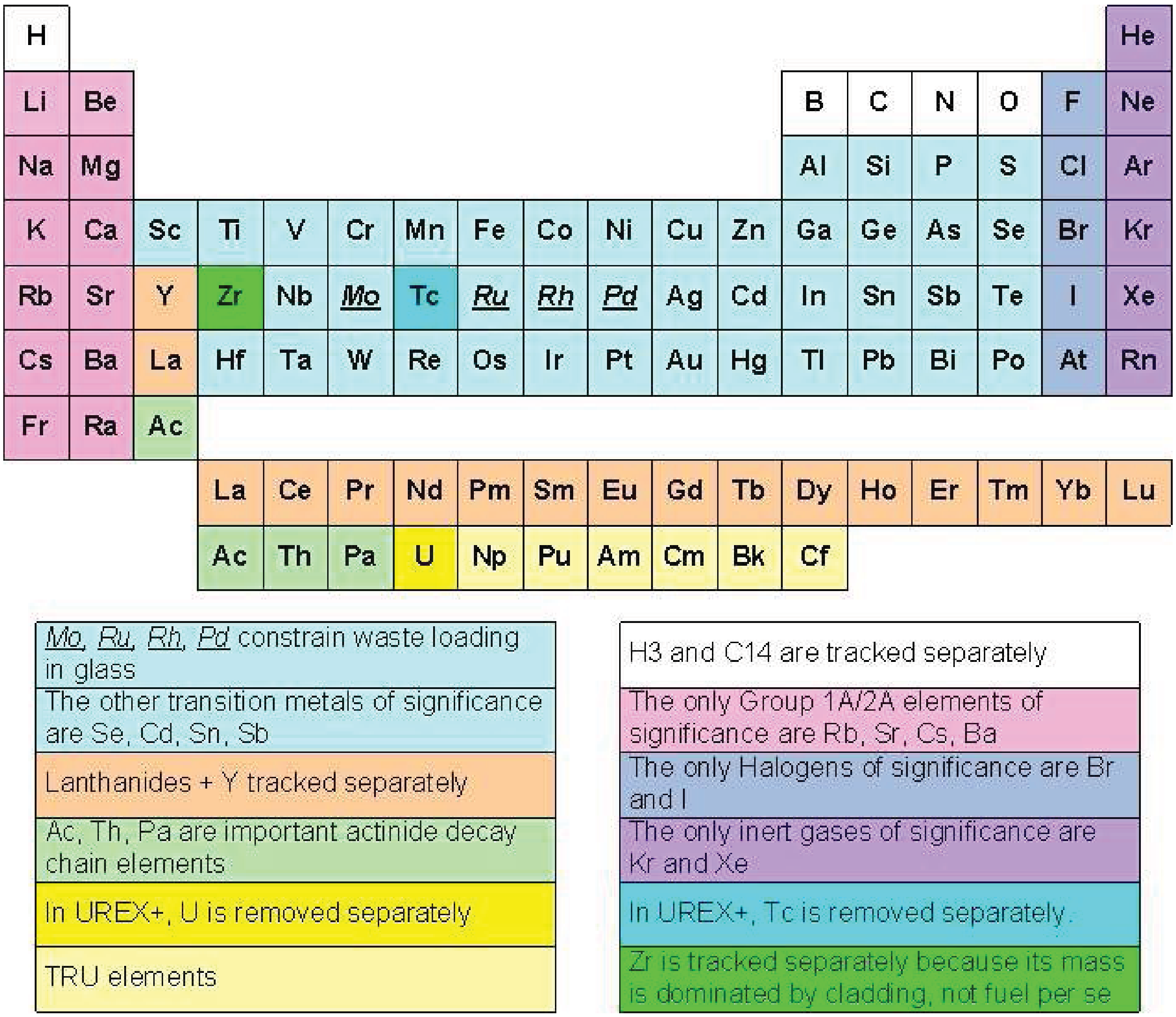


Figure 2-1. Periodic Table as seen from fuel cycle system analysis perspective.[Piet2009]

Table 2-1 lists the isotopes tracked in VISION. Only isotopes with halflives greater than 0.5 years are tracked. (Exception: Cm242 at 0.45 year.) The most important isotopes in each chemical group are included, as well as the residual mass (considered stable) in that group.

Table 2-1. Tracked Isotopes and Chemical Elements [Piet2009]

Actinides and Decay Chain		Fission Products	
He4 (stable)		H3	Other gases
Pb206	Transition metals	C14	
Pb207		C-other	
Pb208		Kr81	Inert gases (Group 0)
Pb210		Kr85	
Bi209		Inert gas other (Kr, Xe)	
Ra226	Group 2A	Rb	Group 1A/2A
Ra228		Sr90 w/Y90 decay	
Ac227	Actinides	Sr-other	
Th228		Zr93 w/Nb93m decay	Zirconium
Th229		Zr95 w/Nb95m decay	
Th230		Zr-other	
Th232		Tc99	Technetium
Pa231		Tc-other	
U232	Uranium	Ru106 w/Rh106 decay	Transition metals that constrain glass waste forms
U233		Pd107	
U234		Mo-Ru-Rh-Pd-other	
U235		Se79	Other transition metals
U236		Cd113m	
U238		Sn126 w/Sb126m/Sb126	
Np237	Neptunium	Sb125 w/Te125m decay	
Pu238	Plutonium	TM-other (Co-Se, Nb, Ag-Te)	
Pu239		I129	Halogens (Group 7)
Pu240		Halogen-other (Br, I)	
Pu241		Cs134	Group 1A/2A
Pu242		Cs135	
Pu244		Cs137 w/Ba137m decay	
Am241	Americium	Cs-other	
Am242m		Ba	
Am243		Ce144 w/Pr144m/Pr144 decay	Lanthanides (plus Y)
Cm242	Curium	Pm147	
Cm243		Sm146	
Cm244		Sm147	
Cm245		Sm151	
Cm246		Eu154	
Cm247		Eu155	
Cm248		Ho166m	
Cm250		LA-other plus Yttrium	
Bk249	Berkelium		
Cf249	Californium		
Cf250			
Cf251			
Cf252			

2.1.6 Fuel Flow Control

For each reactor type, the user can select among these approximations for how the model estimates how much fuel can be made from separated material available in the separated product storage.

0. Minimum of Pu239, Pu240, and Pu241, i.e., whichever isotope is most restrictive.
1. Pu239
2. Pu240
3. Pu241
4. TRU (sum of all TRU isotopes required in the fuel)
5. Pu (sum of all Pu isotopes required in the fuel)

For example, with “Pu” flow control (option 5), the model determines from the fresh fuel recipe the fraction of Pu in the fuel, say 10%. Then, based on the amount of Pu in separated product storage (downstream of the separation plant) the model determines the amount of fuel that can be made, regardless of the mix of individual Pu isotopes in separated material. The model then fabricates that fuel for use in the reactors. This has the effect of alchemy - the “wrong” mix of Pu isotopes is replaced with the “right” mix of Pu isotopes. The amount of isotope mismatch is tracked. *An improved approach whereby the recipe is adjusted to match the available mix of isotopes is in testing.* Meanwhile, the situation can be bracketed. Flow control “0” is the most restrictive and will see the least amount of recycled fuel produced. Flow control “4” (TRU is appropriate for fast reactors) or “5” (Pu is appropriate for thermal reactors) are the least restrictive and will see the most amount of recycle fuel produced.

The flow control options will have to be expanded in order for some thorium fuel options to work.

2.1.7 Isotope Decay

The model tracks and radioactively decays mass at an isotopic level. Isotope decay is currently applied to all locations in the model where mass remains in a facility for 1 or more years. This can be adjusted to no decay or decay only in wet storage when running user defined base cases or manual cases.

There is one exception. Once material has entered a repository, further isotopic decay is not performed as our primary waste management concern is estimating the amount and character of waste forms at the time of emplacement.

2.2 Initial Parameters

This section describes appropriate initial parameters when simulating the U.S. nuclear power plant fleet. All can be changed by the user to simulate the world or any other set of nuclear fuel cycle facilities.

2.2.1 Growth Rates

The amount of nuclear power capacity throughout the simulation depends on three types of user input, as follows:

- Total electrical growth rate (by year)
- Nuclear market share (by year)
- Nuclear generation in 2000, which was 86.002 GWe-FPY/CY but is nonetheless a user-controlled input.

The user is encouraged to set input parameters to replicate the following 2000 values:

- Total electrical generation of 433.7 GWe-FPY.
- Nuclear electrical generation of 86.002 GWe-FPY.
- Nuclear market share of 19.83%.

Table 2-2 provides a set of input parameters that closely replicates actual data from 2000 to 2006 even though VISION is constrained to a fixed reactor capacity factor and fixed average reactor capacity. Furthermore, VISION cannot decrease nuclear generation year by year except by retiring reactors. The actual ups and downs in nuclear generation from 2000 to 2006 arose from slight fluctuations in reactor capacity and increases in capacity (uprates), plus the addition of the 104th operational reactor. VISION was never designed to calculate precise yearly values; nonetheless, by starting the simulation with 2 reactors needing fuel and 3 more reactors starting construction, VISION will calculate nuclear generation similar to the actual data, as shown in Table 2-2.

Table 2-2. Nuclear Generation Data

	User Input		Actual Data [a,b,c]	Calculated by VISION
Year	Total Electricity Growth Rate	Nuclear Market Share	Nuclear Generation (GWe-FPY)	Nuclear Generation (GWe-FPY)
2000	1.2	19.83	86.00	86.00
2001	1.2	20.58	87.71	86.00
2002	1.2	20.22	88.99	86.83
2003	1.2	19.67	87.12	88.50
2004	1.2	19.86	89.95	89.34
2005	1.2	19.28	89.21	90.17
2006	1.2	19.42	89.80	90.17
2007	1.2	19.19	91.42	90.17

2000 nuclear power generation = 86.0019 GWe-FPY
Average LWR/LWRmf capacity = 0.928 GWe
Average LWR/LWRmf capacity factor = 0.90 FPY/CY
Reactors in 2000 = 103
Reactors under construction need fuel in 2000 = 2 (these become operational in 2002-2003, representing the effect of uprates)
Reactors under construction in 2000 = 3 (these become operational in 2003-2005, representing the effect of uprates and reactor104)

a. Conversion from thousand kW-hr generated each year (i.e., MWe-full power hr/CY) to GWe-FPY/CY by 0.001 GWe/MWe x 1 day/24 hour x 1 yr/365.25 days = 1.14e-7 GWe-FPY/CY.
b. DOE EIA2006a
c. DOE EIA2006b

2.2.2 Legacy Reactors

Nuclear reactors currently operating in the U.S. are designated as legacy reactors. The following four user-input parameters should be self-consistent:

- Nuclear capacity in 2000 (86.0 GWe-FPY/CY).
- Number of legacy reactors, i.e., in 2000 (103 reactors)
- Average capacity factor (0.90 FPY/CY)
- Average capacity per reactor (0.928 GWe/reactor)

The above four values are self-consistent. Indeed, the fourth parameter (0.928 GWe/reactor) was set to be consistent with the other three parameters.

103 reactors x 0.928 GWe/reactor x 0.90 FPY/CY = 86.0 GWe-FPY/CY

If the number of legacy reactors, average capacity factor, and average capacity is less than the user-input for 2000 nuclear generation, the model will start the simulation by ordering new reactors to catch-up with the desired nuclear generation.

If the number of legacy reactors, average capacity factor, and average capacity is greater than the user-input for 2000 nuclear generation, those reactors will continue to operate. No new reactors will be ordered until the nuclear demand (escalated from 2000 on the basis of nuclear market share and total electrical growth rate) exceeds the capacity from the legacy reactors.

As there are 103 reactors in 2000, if the case being studied involves MOX, then the allocation of legacy reactors should be 17 LWR-MF (16%) and 86 LWR (84%), see Table 2-3. If the case being studied is IMF, then the allocation should be 7 LWR-MFR (6%) and 96 LWR (94%), although this may be too conservative for the heterogeneous, blended IMF cases.

Table 2-3. Thermal Reactor Safety Constraints on MOX/IMF [adapted from M. Todosow]

	Single-Pass MOX			Single-Pass IMF		
	% of Reactors That Can Use	% of Core	% of All Fuel in Fleet (Reactors x Core)	% of Reactors That Can Use	% of Core	% of All Fuel in Fleet (reactors x core)
Current PWRs and BWRs	50%	33%	16%	25%	25%	6%
Future PWRs and BWRs	100%	100 %	100%	50%	100 %	50%

2.2.3 Legacy Fuel

All used fuel (also known as spent fuel) generated by these reactors, prior to 2000, is called legacy used fuel. Coupled with the LWR/LWR-MF split implied in Table 2-3, U.S. DOE EIA data [DOE EIA2002] have been used to generate Table 2-4. We model the legacy fuel such that all fuel at least 10 years old in 2000 is (or could have been) in dry storage; all fuel less then 10 years is assumed to be in wet storage.[d] To use these data, the user inputs the values of mass into the **Wet and Dry Storage** worksheet with fuel recipe numbers that correspond to the composition reflecting the average burnup.[e]

Table 2-4. U.S. Used Fuel, Prior to 2000

Suggested allocation in reactor/storage type in 2000	Mass (kilotones)	Average burnup (GWth-day/tonne)	Average age (years)	Years discharged
LWR-UOX (86 of 103 reactors) - wet storage	17.704	38.19	4.4	1991 to 2000
LWR-MOX (17 of 103 reactors) - wet storage	3.459			
LWR-UOX (86 of 103 reactors) - dry storage	17.946	26.89	16.6	1968 to 1990
LWR-MOX (17 of 103 reactors) - dry storage	3.507			
Total	42.616	32.50	10.6	

d. After initialization, used fuel generated during the simulation stays in wet or dry storage according to user inputs discussed later.

e. The current recipe file has recipes 106 for 38.19 burnup and 107 for 26.89 burnup; these recipes do not include the impact of aging, but they could be adjusted accordingly.

3. MECHANICS OF RUNNING VISION

The Powersim software functions on a presentation level or a modification level.

- In presentation level, the user sees only an unchangeable model interface.
- In modification level, the user can see the actual model (graph representation of the relationship among variables and all sorts of details) or the interface.

If you are using VISION via a free reader, you only have access to the presentation level. If you have a full version of Powersim, then you can access both levels. [Opening the model directly from the file name rather than opening the Powersim software and then opening the model file[f] will access only the presentation level.] This section supports both levels of operation.

3.1 Files Required to Run VISION

There are a set of files required to run the model. If the user has Powersim Studio 2005, we recommend that it be updated to service release 6. If the user does not have Powersim Studio software, she needs the free Powersim player, which can be downloaded at http://www.powersim.com/download/player.asp. The required files as follows:

- **VISION Release 3.0.sip** - this is the main model
- **vision base case settings ver6.xls** - input most of the specifications for pre-defined or user-defined simulations.
- **vision recipes ver5.xls** - contains the fuel recipes
- **vision half life ver4.xls** - contains the decay information for different isotopes
- **vision heatdosetox ver4.xls** - contains the isotope-specific dose conversion factors and other parameters used in calculations for dose, radiotoxicity, and heat
- **output data-1.xls** - collects the data produced by Powersim.

The system will store data for up to 5 runs in the input and output files.

The user will rarely, if ever, need to access or change the **heatdosetox** and **half life** files, which contain isotope-specific data used by VISION.

The file **vision base case settings ver6.xls** reads the list of available recipes from **vision recipes ver5.xls**. Powersim will work fine if the link between these two files isn't updated, but the list of available recipes in **vision base case settings ver6.xls** will not be up to date.

Cautions:

1. *The only one of these files that can be renamed is **VISION Release 3.0.sip**. All others are called by the main model, which will fail if files with those names do not exist.*

f. The Powersim VISION model file has an extension of sip. If opened by clicking on the filename, you can only access the presentation level. If you open the file by first launching Powersim and then having it open the file, you can access the modification level.

2. *All Excel files must remain in Office2003 format (extension xls); they cannot be Office2007 format (extension xlsx).*
3. *The Excel files must be in the same folder as the sip file.*
4. *Do not change the format of any of the above files, e.g., add or delete columns or rows. Do not re-order the sequence of rows or columns. Do not rename the worksheets within a file. One can re-order the sequence of worksheets within a given file, except for **output data-2.xls** in which even the sequence of worksheets is fixed.*
5. *Several of these Excel files contain macros, when you open the file, Excel will ask you whether you want to enable the macros, click "Enable Macros."*

The following files are not required to run the model, but they are very valuable and are described in section 6:

output data-2.xls - reformats the data in output data-1

output checks.xls - assists the user in checking the validity of the simulations just run

output fuel masses by class.xls - graphs fuel masses by class, e.g., mass of TRU

output fuel masses.xls - graphs fuel masses (summed over all classes)

output reactors.xls - graphs reactor information

output separations.xls - graphs separation information

output waste.xls - graphs waste management information (not currently available)

Cautions:

6. ***output data-1.xls** will have a varying number of columns of data because the number of reactors, separations, or fuels can vary from 1 to 10. Before using any of the graphing files, use **output data-2.xls**, which copies data from **output data-1** and puts into a standard 10-reactor, 10-fuel, 10-separation format. All the graphing files read from **output data-2.xls** via links. Therefore, the graphing files will not show the results of new Powersim runs until both **output data-2.xls's** data loading macro is run and the link between **output data-2** and the graphing file is updated.*
7. *After completing a run, the following files should be saved - **base case settings ver6.xls**, **output data2.xls**, and any relevant graphing files.*

Users experienced in using Excel may find it convenient to develop their own output files that extract only data relevant from their studies from **output data-2.xls**. For example, it is possible to copy the existing graphical output files and then modify them.

3.2 Getting to the Main Page

Whether you open VISION by clicking on the model icon or by starting Powersim and then opening the main model file, VISION will first open Excel files - **vision base case settings ver6.xls** and **output data-1.xls.** It will ask you whether you wish to update vision base case settings ver6.xls, it is easiest to say "no". (The update is simply to check the link to the recipe file for the most recent list of available fuel recipes.) If you say "yes", VISION will want then ask whether you wish to save the changes. If you then try to save it as its original name, VISION and Excel get into an infinite loop mating dance.

Cautions:

8. *Do not close these files until you are finished running VISION.*

VISION then opens in the presentation level with a title page that indicates the version and date of the model you have opened.

If you will be using the presentation level, follow these steps:

1. Pressing **"enter"** brings you to the disclaimer page
2. Once you read this, press "**I agree**" to continue

If you would like to use the modification level, press the icon, shaped like a projection screen ( ), in the toolbar at the top (remember to +first open Powersim and then open the model if you want to access the modification level). It will open in one of the pages of the model, depending on what was open when the model was last saved. To get to the Main Page, go to the "interface" page, which is third from the left. The left-most page is "Program Directory," which has links to the interface page as well as the others. You may wish to resize the image so that the entire main page fits on your screen.

Either way, you should see the Main Page (figure 3-1).

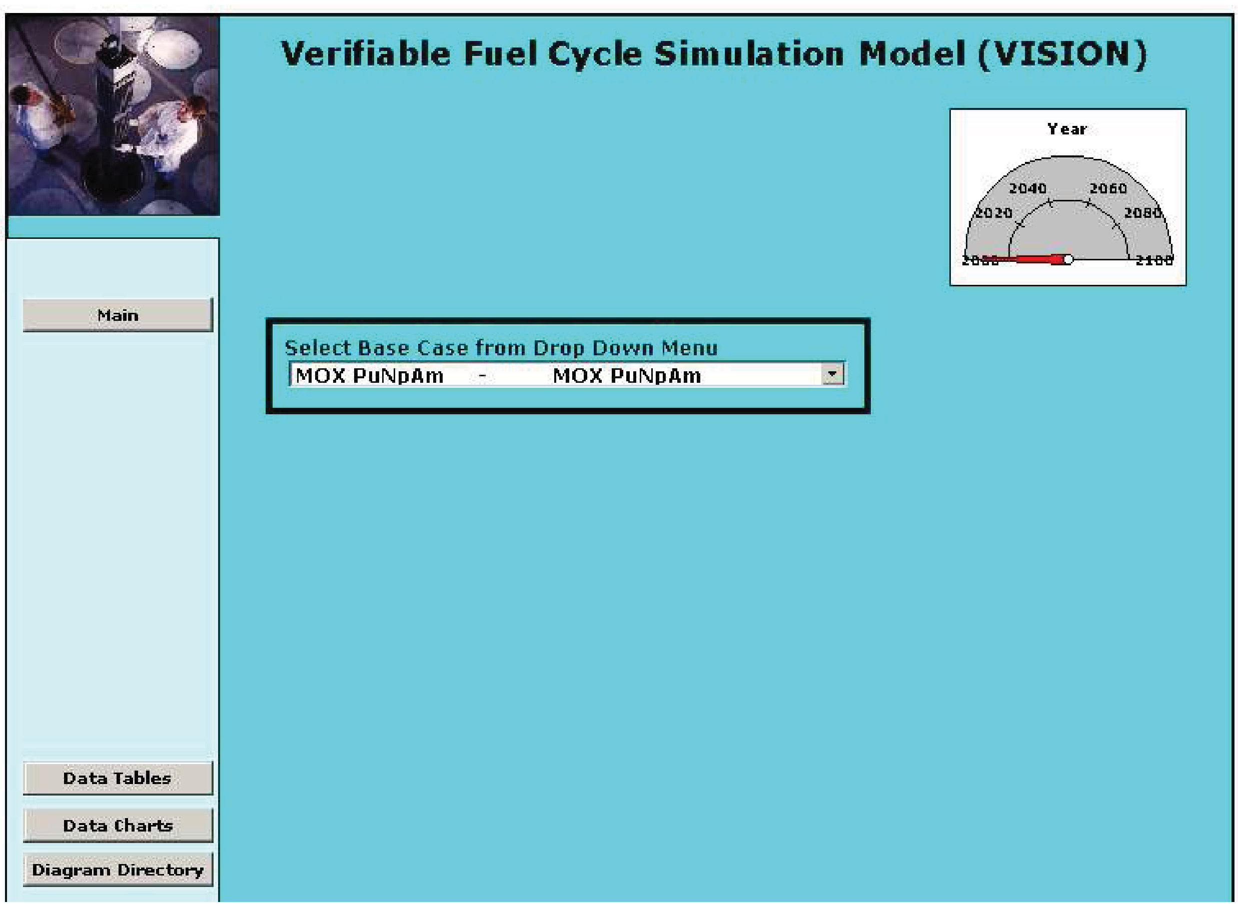


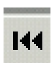
Figure 3-1. VISION main screen in Powersim Studio.

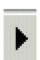
3.3 Running VISION

There is one pull-down menu and three key Powersim buttons needed to run the model:

The pull-down menu selects the case to run, each case corresponds to a set of parameters in a column in **base case settings ver6.xls**, either a pre-defined case or the last five options, which are allocated for user defined cases.

Within the box, is listed the entire selection of base cases from which the user may choose. At the end of the list are "User Defined" base cases that can be set by the user. To run one of the base cases, click the base case you want to run and then hit the play button on the tool bar. All of the pre-defined cases are constructed with two phases that often have a technology change between the two phases. The example above shows MOX transitioning to a burner fast reactor.

 Reset (control-R) resets all the settings to their defaults and erases any data generated during the execution. The model will return to "run 1." Data already saved in **output data-1.xls** will not be immediately erased, but will be written over as soon as additional runs are executed.

 Play/Stop (control space) toggles between playing (running) the model and stop.

 Advance simulation one step (control shift space) advances a stopped simulation one time step (a quarter year). After completing a run, use this button to advance to the next run, to a maximum of "run 5."

Cautions:

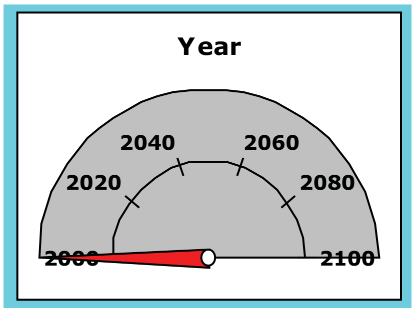
9. *Do not attempt to go to the next "run" without clicking on the "advance simulation"*  *button.*
10. *When you advance to a new run, the settings in the interface return to their defaults.*
11. *After the 5th run, clicking on the "advanced simulation" button will return the model to the 1st run. If you proceed to additional runs without copying and saving output files, VISION will write over your previously performed run 1 data in* ***output data-1****.*
12. *The model is currently set to use a 0.25 year time step and we recommend not changing this.*[g]

g. The time step can be adjusted by going to '"Simulation" on the tool bar and then going to "simulation settings" at the bottom of the pull down menu. However, we have not tested the model at alternative time steps. At higher time steps, it is likely that use of input parameter smaller than the time step, e.g., 0.25 years for enrichment time, would not work.

Depending on whether you opened presentation level or modification level, you will also see various Powersim software buttons above this VISION page and a Powersim list of models and variables to the left of this VISION page.

The left-hand buttons in the left-hand column allow you to navigate among the various pages of the control panel, while the rest of this page provides access to data output and different sections of the model. In later sections of this document we will discuss how to load input values using Excel files and we will also present how to set-up VISION to run several scenarios.

The **"Year"** gauge in the top right corner indicates the progress of the model while running a scenario.



3.3.1.1 Data Tables

The tables within Powersim provide limited output values from latest run of the VISION model. A more extensive set of output values is available via the Excel output tables. The data tables only show one run of the VISION model. Use the Excel outputs to save data from the run; these tables are intended only to help observe what is happening during a simulation.

3.3.1.2 Data Charts

The user can scroll down and see a number of charts that provide output values from the VISION model, although this is limited. A more extensive set of output values is available via the Excel output tables. The data charts will show only the latest run of the VISION model. Use the Excel outputs to save data from the run; these charts are intended only to help observe what is happening during a simulation.

3.3.1.3 Diagram Directory

Clicking on any of the buttons in the diagram directory will take the user to that portion of the model specified. The model will show all the dynamic logic within the VISION model. In order to get back to the main interface from this screen, use the arrows in the bottom left corner to scroll to the farthest right and then click on the "Interface" tab from the bottom set of tabs.

3.4 Suggestions for Inputting Data

If you have used VISION in the past, be aware that much of the information formally input on the **Reals 1** worksheet page are now in reactor, separation, or fuel fabrication worksheets. This actually makes input easier as data are grouped more logically.

It helps if you go methodologically through the worksheets in sequence (same sequence whether you use the navigation buttons or the tabs at the bottom). Previous versions of the model did not have worksheets in the same sequence as mass actually flows.

While doing so, it is very helpful to color code the cells in the Excel input files appropriate to your cases and to how you conceptualize the problem. The **vision base case settings ver6.xls** file has many examples.

It helps to print out the three **base case settings** worksheets that merely list the **available recipes**, **separation efficiency matrices**, and **recycle routing strategy matrices**.

We suggest you keep consistency by "numbers" among reactors, separation, and fuel fabrication such that (1) = LWR/UOX/UOX separation, (2) = LWR MF/MOX/MOX separation, (3) = FR/FR/FR separation, etc even if one doesn't have MOX in a particular simulation so that S2 = 0.

4. VISION INPUT VIA BASE CASE SETTINGS FILE

This is the master input file. The Excel file **vision base case settings ver6.xls** contains multiple worksheets. If the file does not open at the **NAVIGATION** worksheet, click on that tab, it is the most left of the tabs and is colored red.

From the **NAVIGATION** worksheet, one goes to the other worksheets to input the required data. One can, of course, manually go to different worksheets by clicking on the tabs at the bottom of the page. Other than the basic information worksheets, which have red-colored tabs and just provide information, each worksheet follows the same general arrangement.

Explanations of the variables in that worksheet appear on the left most and right most columns. These denote the variable names (as they are called in Powersim), units, and ranges of appropriate variables. In between are the various base cases, pre-defined on the left and user-defined on the right, typically columns CU to CY. There are five columns set aside for user-defined cases. The buttons on the **NAVIGATION** worksheet page will take you to the user-defined columns.

The first three rows of most worksheets contain column labels, data must be entered starting in row 4.

Cautions:

13. *If VISION is not open when you change an input file, save the file before opening VISION to ensure VISION reads your updated information. If VISION is open when you change an input file, VISION will not see the change until you save the file and advance to the next run in VISION.*

The rest of this section explain what information appears in each worksheet, listed in order they appear in the **base case settings ver6.xls** file.

4.1 Basic Information (RED) Worksheets

These worksheets do not accept information from the user; they provide navigation and lists of options currently entered into appropriate locations. The four worksheet tabs are colored red, they are as follows:

- **NAVIGATION**
- **List_of_reactor_types_&_recipes**
- **List_of_separation_types**
- **List_of_routing_strategies**

4.1.1 Basic (RED) - NAVIGATION

The **NAVIGATION** page (figure 4-1) has a link for each one of the pages within the **vision base case settings ver2.xls** file. There are links on each of the pages within the file that return to the **NAVIGATION** page for convenience. Some pages have cross-linked buttons, e.g., the worksheet **List of separation types** has a button to the separation matrices on **Separation Stream Splits**, which is where new separation matrices are entered. It has a button back to **List of separation types** for the user to verify that the new matrix name was registered.

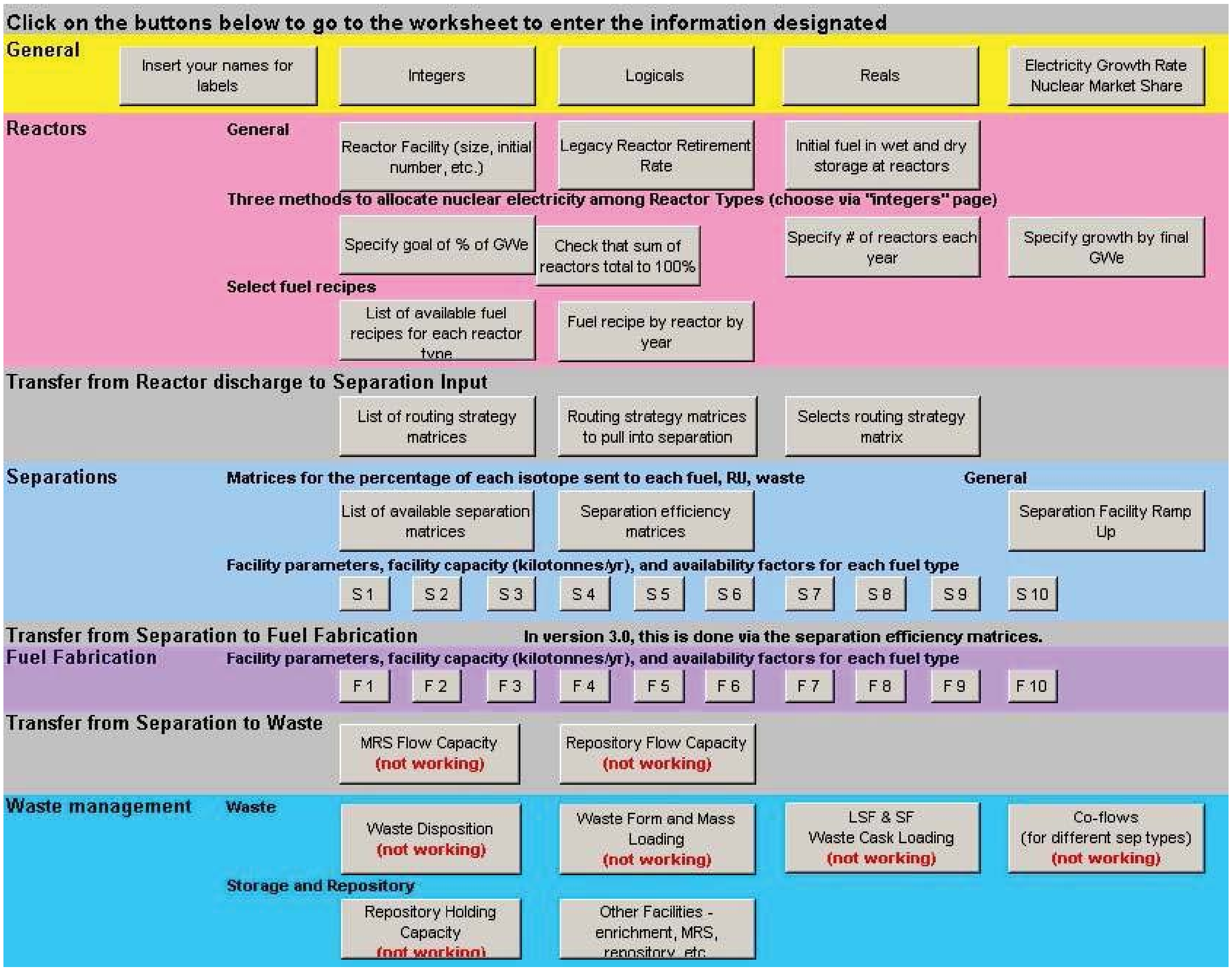


Figure 4-1. NAVIGATION worksheet page.

4.1.2 Basic (RED) - List of reactor types and recipes

This worksheet lists the available recipes by reading what information has been entered into **vision recipes ver5.xls**. If you wish to use a recipe that is not listed on this worksheet, go to vision **vision recipes ver5.xls** (section 5) and enter it. It should then appear on this worksheet.

There are also three special options that are available to the user.

- A correlation for LWR UOX fuel as function of burnup between 33 and 100 GWth-day/tonne-iHM.
- A correlation for fast reactor metal fuel as a function of TRU CR between 0.00 and 1.00.
- *A correlation for fast reactor oxide fuel as a function of TRU CR between 0.00 and 1.00.*

Table 4-1 explains how to select fuel recipes. The user can add recipes to the blank columns in the 100, 200, 300, 400, 500, 600, or 700 pages, sequentially from the left. Changing any of the pre-defined recipes would invalidate base cases that use them.

Table 4-1. Fuel Recipe Numbering Scheme

Transformation Performance
Transmutation - change from input composition to output composition is determined by which reactor fuel recipe is used. Fuel recipes are found in the fuel recipe file, numbered from -2 to at high as 799. At present, only a limited number of columns are used and linked back to the **List of reactor types & recipes**, but in principle the user could add columns up to x99 for each recipe type. *-2 to 0 - Correlation for fast reactor oxide fuels* 0 to 2 - Correlation for fast reactor metal fuels 2 to 100 - Correlation for LWR burnup 101 to 199 - LWR uranium fuels 201 to 299 - Uranium fuels for other reactors 301 to 399 - LWR MOX 401 to 499 - LWR IMF 501 to 599 - Fuels to recycle in other reactors 601 to 699 - Fuels for metal-fueled fast reactors 701 to 799 - Fuels for other fast reactors Fuel recipes are later user selected for each reactor type for each year.

4.1.3 Basic (RED) - List of separation types

This worksheet lists the separation types from 01 to 40 by reading what information has been entered into the **Separation Stream Splits** worksheet. If you wish to user a matrix that is not listed on this worksheet, go to **Separation Stream Splits** and enter it. Table 4-2 shows the numbering scheme. The user is encouraged to add separation matrix values to any of the blank matrices. Changing any of the pre-defined matrices would invalidate pre-defined base cases that use them.

Table 4-2. List of Separation Efficiency Matrices

Transformation Performance
Partition - how the contents of used fuel are allocated among fuel product streams, 3 grades of recovered uranium (RU), and several waste form options. Separation efficiency matrices are numbered from 1 to 40. 1 to 20 - aqueous 21 to 30 - electrochemical 31 to 39 - other 40 - once through About half are blank and available for user definition.

4.1.4 Basic (RED) - List of routing strategies

Recall that the recycle routing matrices send fuels from used fuel storage to separation types. This worksheet lists the recycling routing options from 01 to 15 by reading what information has been entered into the **Recycle Strategy Matrix** worksheet. If you wish to user a matrix that is not listed on this worksheet, go to **Recycle Strategy Matrix** and enter it. The current matrices are listed in Table 4-3. Changing any of the pre-defined matrices would invalidate pre-defined base cases that use them.

Table 4-3. List of Recycling Routing Matrices

1	Reserved for development testing
2	Reserved for development testing - 3 region base case (see Appendix A)

3	Reserved for development testing - 10 reactor case (see Appendix A)
4	Blank
5	Blank
6	1-tier recycling UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 FR fuel (assumed to be pass1 thru pass5 of fuel-3) is routed to separation-3
7	2-tier recycling UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
8	One thermal recycle, then dispose UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX ((or IMF) assumed to be pass1 of fuel-2) is routed to disposal
9	Multiple thermal recycle UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX ((or IMF) assumed to be pass1 thru pass5 of fuel-2) is routed to separation-2
10	Blank
11	Blank
12	Stop fast recycling, send everything to thermal reactors. This is actually the same routing as 2-tier assuming that FR fuel is separated and then the products are sent to thermal reactors. So, the routing used fuel-to-separation is the same as 2-tier, but the routing from separation-to-fuel is different. The latter is set by separation efficiency matrices. UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
13	Stop thermal recycling, send everything to fast reactors. This is actually the same routing as 2-tier assuming that MOX fuel is separated and then the products are sent to fast reactors. So, the routing used fuel-to-separation is the same as 2-tier, but the routing from separation-to-fuel is different. The latter is set by separation efficiency matrices. UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
14	Stop recycling, send everything to disposal Passes 0 through 5 of fuels 1, 2, and 3 are routed to disposal.
15	Once through Pass 0 of fuels 1, 2, and 3 are routed to disposal. In once through, no fuel every gets past pass0, therefore no routing is required for passes 1 to 5.

4.2 General (YELLOW) Worksheets

The general worksheets require the user to provide general information about cases. Compared to previous versions of VISION, relatively little information remains in these worksheets. Virtually all data on reactors, separation, and fuel fabrication are now on worksheets dedicated to each of those functions. The six general worksheet tabs are colored yellow, they are as follows:

- **Run Informatio**n
- **Integer 1**
- **Logical 1**
- **Reals 1**

- **Growth Rate**
- **User help on growth rates**

4.2.1 General (YELLOW) - Run Information

This worksheet requests the user to provide labels for

- Your name for each simulation run
- Names for fuel types
- Names for reactor types
- Names for separation types

The user does not need to enter anything into rows 5-7, but should ensure that the numbers calculated there are correct. The spreadsheet looks at the number of names entered for each case and thus determines (via the number of blanks) how many fuel, reactor, and separation types there are. Then, cells I5, I6, and I7 denote the maximum number of those types among the five runs.

Cautions:

14. *These data are for five runs, which may or may not be user-defined cases 1-5.*
15. *The cells I5, I6, and I7 tell **output data-2.xls** how many fuel types, reactor types, and separation types have data in **output data-1.xls**. If these parameters are incorrect, then the translation from **output data-1** to **output data-2.xls** will be incorrect.*

4.2.2 General (YELLOW) - Integer 1

This worksheet page allows the user to set basic parameters that control all reactors, all fuel types, all separations for the entire simulation. Table 4-4 lists the parameters and recommended values for this worksheet.

Table 4-4. Integer Worksheet Parameters

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case 1&2 Selection	Positive Integer between 1 and 102	This is a sequential number starting from the left.	Do not change, for information only
Base case uranium resource to use switch	1 = Known 2 = Known and Unknown 3 = Known + Unknown + Imagined	The corresponding values are input on the Reals 1 Worksheet. The model keeps track of how uranium resource is depleted.	Select "3"
Base case used fuel decay switch	0 = Decay All 1 = Decay Wet Storage Only 2 = Decay None	Which inventories calculate isotope decay?	Select "0"
Base case repository open date	Date between 2000 and 2100	Overridden by Repository Capacity Worksheet. Zero flow means repository is closed.	2017 or thereafter
Base case TR Pu control switch	*Moved to Reactor Facility worksheet, to be deleted here*		
Base Case FR Pu control switch	*Moved to Reactor Facility worksheet, to be deleted here*		

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case start legacy reactor retirement date	Date between 2000 and 2100	This determines when legacy reactors start the retirement process and move into the condition of readying to retire, which means the model can order replacement reactors and then stops ordering fuel for them. Reactors actually go off line about six years (legacy reactors retirement delay + legacy reactors shut down delay) years later.	2020
Base case date to switch to ramp 2	*To be deleted, no longer used*		
Base case separation capacity basis	*To be deleted, no longer used*		
Separations combination switch	*To be deleted, function replaced with reactor-to-separation recycle routing strategy matrices*		
Manually set FBR switch	*To be deleted, no longer used, no longer needed*		
Base case reactor order case	*0 - let system optimize reactor mix using the percent goals set on **Reactor %s** worksheet times the nuclear power growth specified on **Growth Rate**. Not working reliably yet for FR.* 1 - force VISION to use the number of reactors input by the user on the **Reactor #'s** worksheet. 2 - force VISION to build reactors to match the user specified growth for each reactor type via the end-simulation value on **Reactor Facility** worksheet times the year by year fraction of that value on **Reactor Growth % of Final** worksheet.		Select "0" *for cases without FR*
Base case fuel fab order case	0 - let system optimize fuel fabrication capacity growth 1 - force VISION to build fuel fabrication capacity set on **Fuel Fab 1 through 10** worksheets		Select "0"
Base case separations order case	0 - let system optimize separation capacity growth 1 - force VISION to build separation capacity on **Separation 1 through 10** worksheets		Select "0"

4.2.3 General (YELLOW) - Logical 1

It is particularly important that the user correctly set all these switches appropriate for their scenario. Do not depend on one switch overriding another. Table 4-5 lists the parameters for this worksheet.

Table 4-5. Logical 1 Worksheet Parameters

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case send SF to repository	TRUE means used fuel is allowed to go to repository, other settings determine which parts of the repository are used (permanent or retrievable or both), the size of the repository, and the receipt rate at the repository. FALSE means used fuel can never go to a repository even if other switch settings imply the existence of a repository. HLW and other wastes are sent to the repository either way.		Generally TRUE
Base case retrieve SF from repository switch	TRUE creates a retrievable repository for used fuel. FALSE means that used fuel in the repository cannot be retrieved. If material is sent to the repository and is not allowed to be retrieved from the repository, the system will act as though a permanent repository with a capacity limit equal to the repository holding capacity exists HLW and other wastes are not retrieved from the repository either way.		Depends on your scenario
Base case unlimited repository flow capacity switch	If TRUE, set repository flow receipt limit on **Reals** worksheet as a generic high upper limit. If FALSE, set repository flow receipt on **Repository Flow Capacity** worksheet Either value applies to used fuel receipt at a permanent and/or retrievable repository. Receipt of HLW and other wastes are never limited.		Usually set to FALSE
Base case unlimited repository holding capacity switch	If TRUE, then the retrievable repository capacity is unlimited, i.e., the year-by-year settings in **Repository Holding Capacity** worksheet are overridden. The permanent repository limit set on **Reals 1** worksheet remains in effect. If FALSE, set repository holding capacity on the **Repository Holding Capacity** Worksheet. Since the permanent repository capacity limit is set on **Reals 1**, the retrievable repository capacity limit is the difference between the repository holding capacity (**Repository Holding Capacity Worksheet**) and the permanent repository capacity limit (**Reals 1**). Capacity for HLW and other wastes is not limited.		Usually set to FALSE
Base case SF permanent repository switch	TRUE creates a permanent repository for used fuel, the size of the permanent repository(ies) is set on the **Reals 1** page. The size of the permanent repository should always be less than or equal to the size of the repository holding capacity set on the **Repository Holding Capacity** worksheet. FALSE means that there is no permanent repository. (This is overridden if "retrieve from repository" is FALSE, i.e., the repository acts as if it is permanent.) HLW and other wastes can go to a repository and are not retrieved from the repository either way.		Depends on your scenario
Base case BU is waste	*To be deleted, function now handled by fuel recipes*		
Base case use burned U phase 1	*To be deleted, function now handled by fuel recipes*		
Base case unlimited MRS capacity switch	TRUE means the MRS capacity is unlimited. FALSE means the MRS capacity is limited.		*Not yet working, MRS holding capacity always unlimited.*

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case unlimited product storage capacity switch	TRUE means Storage Facilities have unlimited product storage. FALSE means Storage Facilities have limited capacity.		*Not yet working, always unlimited.*
Base case use youngest least cycled fuel first	*To be deleted, function handled by separation-to-reactor recycle routing strategy matrices*		
Base case use MRS switch	TRUE / FALSE	TRUE creates an MRS (managed retrievable storage) or centralized storage facility. FALSE turns off the option of an MRS/ centralized flow facility	Depends on scenario

4.2.4 General (YELLOW) - Reals 1

These are often the most important parameters of the entire simulation, see Table 4-6.

Table 4-6. Reals Worksheet Parameters

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case known uranium resources	Kilotonnes of U	Gives the model the values for these three benchmarks	3,100 kt-U
Base case estimated conventional uranium resources (includes known uranium resources)			16,000 kt-U
Base case estimated unconventional uranium resources			4,200,000 kt-U
Base case natural enrichment	Units or allowed variables	Impact	0.711
Base case tail enrichment			0.25
Base case USA year-2000 demand level	>0 GWe-FPY/year (not zero)	Initial nuclear power generation rate[h]	86.00193 GWe-FPY to match 2000 U.S. data
Base case Initial Nuclear Power Percent	>0 to 100 (do not use % symbol)	VISION calculates the initial total electricity demand in 2000 from the nuclear electricity / nuclear market share, = 433.7 GWe-FPY for U.S.	19.83 to match 2000 U.S. data
Base case unlimited repository flow capacity	≥0 kilotonne/yr	This specifies the flow rate of material to the repository when the unlimited repository flow capacity switch in **Logical 1** worksheet is set to TRUE. The repository flow capability only applies to unprocessed used fuel; the receipt rate for HLW and TRU waste is unlimited.	50 kt/year

[h] Average LWR/LWRmf capacity x average LWR/LWRmf capacity factor x number of legacy reactors should equal to the nuclear power generation in 2000.

Parameter	Units or Allowed Variables	Impact	Recommended Values
Base case unlimited repository holding capacity	≥0 kilotonne	This specifies the overall repository holding capacity (permanent repository capacity + retrievable repository capacity), when the unlimited repository holding capacity is set to TRUE on **Logical 1** worksheet . The capacity limit only applies to unprocessed used fuel, the repository has unlimited capacity for HLW and TRU waste.	7000 kilotonne
Base case permanent repository limit	≥0 kilotonne	This specifies the permanent repository capacity; it should be less than the repository holding capacity, which is set with the **Repository Holding Capacity** worksheet or the above value. The capacity only applies to unprocessed used fuel, the repository has unlimited capacity for HLW and TRU waste.	63 kilotonne
Delete last row			

4.2.5 General (YELLOW) - Growth Rate Worksheet and User Help on Growth Rates Worksheet

The growth rate of nuclear power demand is set by a combination of the total electricity growth rate and the market share of nuclear power. In the upper table on **Growth Rate**, the annual percent growth rate of electricity is specified, year by year. In the lower table on **Growth Rate**, the annual market share of nuclear reactors as a percent of electricity is specified.

This worksheet is used if "Base case reactor order case" on the **Integer 1** worksheet is set to 0, in which case nuclear power demand is set on **Growth Rate** for the entire reactor fleet. If "Base case reactor order case" is set to 1, then growth is not determined by **Growth Rate**, but instead is determined by the precise number of reactors specified on **Reactor #'s**. If "Base case reactor order case" is set to 2, then growth is not determined by **Growth Rate**, but instead is determined by each reactor type separately using a combination of the end-simulation capacity set on **Reactor Facility** and the year by year values set on **Reactor Growth % of Final**.

A second worksheet, **User Help on Growth Rates**, is provided to help the user calculate the appropriate nuclear market share when a electricity grow rate and nuclear growth rate are known, or when specific nuclear market penetrations at specific times are known.

4.3 Reactor (PINK) Worksheets

The set of reactor worksheets provide input for the reactor fleet. The worksheets **Reactor Facility**, **Legacy Reactor Retirement Rate**, **Wet and Dry Storage**, and **Reactor Fuel Types** are used in all simulations. In a given simulation, only one of the worksheets **Reactor %s**, **Reactor #'s**, or **Reactor Growth % of Final** are used, depending on which reactor order case on Integer 1 was selected. When **Reactor %s** is used, then **Reactor %s Total** provides the user with the total of the percentages he specified on **Reactor %s**; that total should be 100. Table 4-7 summarizes how these worksheets work together.

Table 4-7. Reactor Capacities and Transformation Performance in VISION

Capacity	Transformation Performance
Reactor Order Case switch in "**Integer 1**" among 0. Let system optimize reactor mix by giving VISION a goal of the percent allocation among the reactor types (by year). VISION uses **Reactor %s** time **Growth Rate**. 1. Force VISION to use specific number of reactors each year. VISION uses **Reactor #'s.** 2. Force VISION to build reactors according to the product of (a) end-simulation GWe-year goal times (b) the percent of that goal to be achieved each year. VISION uses **Reactor Facility** and **Reactor Growth % of Final**. Reactors that are operational when the simulation starts are retired according to the **Legacy Reactor Retirement Rate** data. All other reactors retire when their lifetime (set on **Reactor Facility**) is met.	Transmutation - change from input composition to output composition determined by which reactor fuel recipe is selected by year on **Reactor Fuel Types**. Fuel recipes are found in the **vision recipe ver5.xls** file, numbered from -2 to 799. -2 to 0 - Correlation for fast reactor oxide fuels 0 to 2 - Correlation for fast reactor metal fuels 2 to 100 - Correlation for LWR burnup 101-199 - LWR uranium fuels 201-299 - Uranium fuels for other reactors 301-399 - LWR MOX 401-499 - LWR IMF 501-599 - Fuels to recycle in other reactors 601-699 - Fuels for metal-fueled fast reactors 701-799 - Fuels for other fast reactors Fuel recipes are set for each reactor type for each year. The user can add recipes to the blank columns in the 100, 200, 300, 400, 500, 600, or 700 pages, sequentially from the left. Changing any of the pre-defined recipes would invalidate base cases that use them.

4.3.1 Reactor (PINK) - Reactor Facility

Table 4-8 lists the parameters entered on this worksheet. Note that fuel residence time, fuel burnup, and capacity factor are not entered here, but instead are entered with fuel composition data in **vision recipe ver5.xls**.

Table 4-8. Reactor Capacities and Transformation Performance in VISION

Parameter	Units or Allowable Values	Impact	Recommended Value for LWRs	Recommended Value for Fast Reactors
Licensing Time	≥0.25 years (≥ time step)	Sets duration of licensing, between when reactors are ordered and when they start construction.	2	2
Construction Time	≥0.25 years (≥ time step)	Sets duration of construction between when they are licensed and when they are ready for fuel. Reactors don't actually start operation unless fuel is available.	4	4
Lifetime	≥0.25 years (≥ time step)	How long reactors operate.	60	60
Reactor power	GWe/reactor	Converts #s of reactors into power. If reactor order case = 0 or 2, it only determines the number of reactors	0.928 GWe per reactor[i]	Depends on your scenario

i. 103 reactors x 0.928 GWe/reactor reactor size x 0.90 FPY/CY capacity factor = 86.0 GWe-FPY/CY in 2000.

		but the mass flows are really controlled by energy demand and fuel burnup. If reactor order case = 1, this parameter times **Reactor #'s** divided by fuel burnup determines mass flows.		
Fuel Flow Control switch	0, 1, 2, 3, 4, 5	Controls the limiting isotope(s) which will determine the amount of new fuel that can be produced given the minimum amount of that specific isotope in a given fuel recipe. 0 = min(Pu239, Pu240, Pu241) 1 = Pu239 2 = Pu240 3 = Pu241 4 = TRU 5 = Pu	5 (total Pu)	4 (total TRU)
Thermal Efficiency	0.01 to 1.00		0.34	0.38
Legacy Reactors	Integer	Number of reactors operational when simulation starts	86 LWR-UOX 17 LWR-MOX	0
Fresh Reactors	Integer	Number of reactors just beginning service when simulation starts	0	0
Reactors near retirement	Integer	Number of reactors starting the retirement process when simulation starts	0	0
Reactors under construction	Integer	Number of reactors starting construction when simulation starts	3 (See Table 2-2)	0
Reactors under construction need fuel	Integer		0	0
Reactors being licensed	Integer	Number of reactors starting licensing when simulation starts	2 (See Table 2-2)	0
Final GWe for % Growth	GWe-year	Used when reactor order case on **Integer 1** = 2.	0	0

4.3.2 Reactor (PINK) - Legacy Reactor Retirement Rate

As of 2000, there were 103 operating reactors in the U.S. In this model, these reactors are called legacy reactors, reactors present before the simulation starts. Many, if not most, of these reactors have or will obtain license extensions to operate beyond their original lifespan. To specify the retirement of these legacy reactors, the user must specify the number of reactors remaining during a 30-year period in the **Legacy Reactor Retirement Rate** worksheet and specify the Base Case Start Legacy Reactor Retirement Date on the **Integer 1** worksheet. A retirement rate that considers both the start date and the expected lifetime of these reactors has been calculated and is used for all of the base case options.

4.3.3 Reactor (PINK) - Wet and Dry Storage

When fuel is discharged from a reactor, it goes into "wet" storage, where "wet" is meant to imply that cooling of the fuel is required. For UOX or MOX or IMF, this is the traditional water pool. Regardless of its destination, fuel must stay in wet storage for a minimum time set by the user for each reactor type. That is, the model never allows fuel to move from wet storage until the minimum time set by the user is achieved.

When fuel is moved from "wet" storage, it goes to "dry" storage. It can move into repository or separation capacity to the extent that either has sufficient capacity to process that fuel; in such cases the model ignores the time period for "dry" storage. Otherwise, used fuel accumulates in dry storage until moved to a centralized monitored retrievable storage at the end of the time period specified by the user, provided that the MRS is turned on. If the MRS is not turned on, the used fuel stays in dry storage until there is capacity to move it to separations or repository.

All used fuel (also known as spent fuel) generated by these reactors, prior to 2000, is called legacy used fuel. Coupled with the LWR/LWR-MF split implied in Table 2-3, U.S. DOE EIA data [DOE EIA2002] have been used to generate Table 2-4, repeated below. To use these data, the user inputs the values of mass into the **Wet and Dry Storage** worksheet with fuel recipe numbers that correspond to the composition reflecting the average burnup.[j] We make the simplifying assumption that legacy fuel prior to 2000 is modeled as being in wet storage if younger than 10 years and being in dry storage if older than 10 years. The 10-year threshold is set to be consistent with the 10-year minimum time in wet storage we use in LWR simulations.

Table 2-4. U.S. Used Fuel, Prior to 2000 (replicated here)

Suggested allocation in reactor/storage type in 2000	Mass (kilotones)	Average burnup (GWth-day/tonne)	Average age (years)	Years discharged
LWR-UOX (86 of 103 reactors) - wet storage	17.704	38.19	4.4	1991 to 2000
LWR-MOX (17 of 103 reactors) - wet storage	3.459			
LWR-UOX (86 of 103 reactors) - dry storage	17.946	26.89	16.6	1968 to 1990
LWR-MOX (17 of 103 reactors) - dry storage	3.507			
Total	42.616	32.50	10.6	

4.3.4 Reactor (PINK) - Reactor %s and Reactor %s Total

This worksheet is used when reactor order case on **Integer 1** is set to 0. It allows the user to set the percent of each type of reactor to be requested for new reactors being ordered. The user sets the percent for each type of reactor as a function of time. The sum must equal 100 and can be quickly checked by looking on the **Reactor% Total** worksheet.

4.3.5 Reactor (PINK) - Reactor #'s

This worksheet is used when reactor order case on **Integer 1** is set to 1. This option should be used with caution by the user, since specifying the number of reactors will override the specifications for reactor power generation and possibly order fast reactors for which there is no fuel. When using this option, the number of reactors must be specified for the full 100 years or 200 years of the simulation and for each type of reactor.

4.3.6 Reactor (PINK) - Reactor Growth % of Final

This worksheet is used when reactor order case on **Integer 1** is set to 2. This option should be used with caution by the user, since specifying the end-simulation growth value input on Reactor Facility times these values will override the specifications for reactor power generation and possibly order fast reactors for which there is no fuel.

j. The current recipe file has recipes 106 for 38.19 burnup and 107 for 26.89 burnup; these recipes do not include the impact of aging, which would transform some Pu241 into Am241, but they could be adjusted accordingly.

4.3.7 Reactor (PINK) - Reactor Fuel Types

The worksheet specifies the reactor fuel recipe for each reactor type for each year, see Table 4-9. It is recommended that the user not attempt to use a “reactor type” beyond the range of fuel types that an actual reactor technology could reasonably be expected to accommodate, e.g., burn fast reactor fuels in a LWR or use fast breeder reactor fuel compositions in a reactor initially using fast burner reactor fuel compositions.[k]

Recall that selecting a fuel recipe number invokes several parameters from **vision recipes ver5.xls**, as described further in section 5. These factors are interconnected and therefore they reside together in the recipe file. They are follows:

- Fuel burnup (GWth-day/tonne-iHM)
- Capacity factor
- Fuel residence time (calendar years)
- The input and output compositions for this primary fuel.
- The number of a contingent fuel (if any) that VISION will use in this reactor if the primary fuel cannot be made. The contingent fuel should be a uranium-based fuel.
- Uranium priority 1 to 6 - what type of uranium supply (EU, NU, DU, RU) should be used to make up the correct amount of uranium in the fuel once the uranium in the incoming separation-to-fuel buffer is accounted for.

k. Breeders typically require blankets surrounding the core; burners do not. So, a reactor initially built only for burner fuels would not be capable of later using breeder fuel compositions without substantial modification.

Table 4-9. Fuel Types

Reactor technology	Appropriate reactor fuel numbers in **vision recipe ver5.xls**
LWR	33 to 100 - LWR burnup correlation 101 to 110 - recipes in **100_UOX_Once_Thru** worksheet
LWR MF (multiple fuel)	33 to 100 - LWR burnup correlation (Values from 2 to 100 are allowed by VISION but values from 2 to 32 produce unreliable results in the current burnup correlation.) 101 to 110 - recipes in **100_UOX_Once_Thru** worksheet 301 to 315 - recipes in **300_LWR_MOX** worksheet 401 to 415 - recipes in **400_LWR_IMF** worksheet
HWR or VHTR	Appropriate recipes among 201 to 210 - recipes in **200_Other_Once_Thru** worksheet
HWR or VHTR possibly using recycled material	Appropriate recipes among 201 to 210 - recipes in **200_Other_Once_Thru** worksheet 501 to 510 - recipes in **500_Other_Thermal_Recycle** worksheet Currently all the 500 recipe slots are blank.
Fast burner reactor, sodium cooled	-1.00 to 0.00 - fast reactor oxide TRU CR correlation 0.00 to 1.00 - fast reactor metal TRU CR correlation (Values from -2.00 to 0.00 and 0.00 to 2.00 are allowed by VISION but values below -1 and above +1 produce unreliable results in the current TRU CR correlations.) Appropriate recipes among 601 to 630 - recipes in **600_Metal_Cooled_FR** worksheet
Fast breeder reactor, sodium cooled	Appropriate recipes among 601 to 630 - recipes in **600_Metal_Cooled_FR** worksheet
Fast reactors with other coolants	701 to 710 - recipes in **700_Other_Cooled_FR** worksheet Currently all the 700 recipe slots are blank.

If for example you want to vary the capacity factor of a reactor type, create duplicate recipes that vary only by the capacity factor and select among them.[1]

The appropriate primary fuel in a LWR capable of using multiple fuels (LWR-MF) is one of the MOX (fuel numbers 2xx) or IMF (fuel numbers 3xx) recipes. If the contingent fuel is a UOX recipe (typically fuel number 103, for 51 GWth-day/tonne burnup UOX), then that UOX is used when the supply of MOX or IMF is inadequate. That UOX is considered by VISION to be MOX recycle pass0 and is distinct from UOX that may be used as the primary fuel in UOX-only LWRs.

Recipes 101, 601, and 602 are special cases as they evoke the LWR burnup correlation (recipe 101) or fast reactor TRU CR correlations (recipes 601, 602). In these cases, the user must specify the burnup in the appropriate places in **vision recipes ver5.xls**, which is used whenever such recipes are selected. If you want to use the LWR burnup or TRU CR correlations by year, use 33 to 100 (LWR burnup correlation), 0 to +2 (fast reactor metal TRU CR), or *-2 to 0 (fast reactor oxide TR CR)*.

4.4 Reactor to Separation Routing (GREY) Worksheets

These two worksheet control the routing of used fuel from reactor wet/dry storage into separation types.

1. Strictly speaking, one should also modify the recipe slightly to account for differences as the capacity factor during irradiation is varied.

4.4.1 Reactor to Separation Routing (GREY) - Recycle Strategy Option

The user specifies on this page which of the recycle routing strategy matrices defined on the **Recycle Strategy Matrix** worksheet is used for each year. Since each recycle routing strategy matrix addresses all recycle passes, all reactor/fuel types, and all separation types, only one matrix is selected for each year.

Changing recycle routing strategy matrix from one year to the next means that the fleet's recycling strategy has fundamentally changed.

4.4.2 Reactor to Separation Routing (GREY) - Recycle Strategy Matrix

These matrices provide the priority for separations and disposal. Within a fuel type, the prioritization by pass and reactor source must also be specified for each separation facility type. This is accomplished through the matrices in this page. Each separation facility type is assumed to accept one type of fuel. In cases where more than one type of fuel is sent to a single type of separations facility, all of the fuel entering that separations facility will be considered the nominal fuel type for that facility when it exits. At any given point in time, material coming from a given Reactor, Pass can only be specified as a single Fuel Type, Pass. At any given point in time, material coming from a given Reactor, Pass can only be specified as going all to separations or all to disposal. The matrices must be filled out using a 3 numeral code. The first e numerals indicate the reactor type and the fourth numeral indicates the pass.

Fuel types correspond to codes 10 to 19.

Recycle passes correspond to code 0 to 5.

Each matrix defines the priority order for fuel to enter a given separation type.

Recall that the same fuel recipe can be used in multiple places. For example, in a MOX capable reactor, the primary fuel is one of the MOX recipes (fuel number 2xx) and the contingent fuel is a UOX recipe (typically fuel number 103). Thus, a strategy of one recycle pass in a MOX-capable reactor means that there are both pass0 and pass1 fuel in that fuel slot. Consider an example where MOX is fuel-2, hence code "11x". So, the recycling routing matrix must account for both 110 (MOX, pass 0 = UOX) and 111 (MOX, pass 1). The user can then decide which of two approaches to use, as follows:

- Pull 110 (MOX, pass 0 = UOX) to the same separation plant as 100 (UOX, pass 0) and 111 (MOX, pass 1 = MOX) to a separate separation plant designed for MOX. This implicitly assumes there is a mechanism to physically separate MOX from UOX in the LWR-MOX reactors, as is appropriate if the fuels are different assemblies.
- Pull 110 and 111 to the same separation plant, designed for a UOX-MOX fuel mix. This would be appropriate if the fuels are co-mingled within fuel assemblies.

Said another way, the underlying cause for the complexity and the different ways of modeling a scenario correspond to actual variations in how a scenario would work in reality. The complexity isn't the model, the model is reflecting the complexity of the real world.

The user determines the priority order in which each separation plant capacity is used, e.g., specifying if fast reactor fuel is fuel type-3 (hence code 12x), then two strategies can be created:

- Pull 125, 124, 123, 122, 121 into the separation type means that the most recycled fuel goes first.
- Pull 121, 122, 123, 124, 125 into the separation type means the least recycled fuel goes first.

In this example, if the user has defined a contingent (uranium) fuel for the fast reactor, that fuel (code 120) would need to be added to the list.

Cautions:

16. *The recycle routing strategy matrix must account for all fuels and recycle passes that may exist during a simulation.*

Table 4-3. List of Recycling Routing Matrices (repeated from earlier subsection)

1	Reserved for development testing
2	Reserved for development testing
3	Reserved for development testing
4	Blank
5	Blank
6	1-tier recycling UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 FR fuel (assumed to be pass1 thru pass5 of fuel-3) is routed to separation-3
7	2-tier recycling UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
8	One thermal recycle, then dispose UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX ((or IMF) assumed to be pass1 of fuel-2) is routed to disposal
9	Multiple thermal recycle UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX ((or IMF) assumed to be pass1 thru pass5 of fuel-2) is routed to separation-2
10	Blank
11	Blank
12	Stop fast recycling, send everything to thermal reactors. This is actually the same routing as 2-tier assuming that FR fuel is separated and then the products are sent to thermal reactors. So, the routing used fuel-to-separation is the same as 2-tier, but the routing from separation-to-fuel is different. The latter is set by separation efficiency matrices. UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
13	Stop thermal recycling, send everything to fast reactors. This is actually the same routing as 2-tier assuming that MOX fuel is separated and then the products are sent to fast reactors. So, the routing used fuel-to-separation is the same as 2-tier, but the routing from separation-to-fuel is different. The latter is set by separation efficiency matrices. UOX (assumed to be pass0 of fuel-1 and fuel-2) is routed to separation-1 MOX (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-2 FR fuel (assumed to be pass1 up to pass5 of fuel-2) is routed to separation-3
14	Stop recycling, send everything to disposal Passes 0 through 5 of fuels 1, 2, and 3 are routed to disposal.
15	Once through Pass 0 of fuels 1, 2, and 3 are routed to disposal. In once through, no fuel every gets past pass0, therefore no routing is required for passes 1 to 5.

4.5 Separation (BLUE) Worksheets

There are three types of separation worksheets, as follows:

- **Facility Ramp Up** - defines for each separation type what fraction of the facility's rated capacity is operational during the first several years of operation.
- **Separation 1 through 10** - defines several parameters for that separation type, including capacity and which separation efficiency matrix is to be used, by year.
- **Separation Stream Splits** - defines the performance of a separation type.

Table 4-10 summarizes how these worksheets work together.

Table 4-10. Separation Facility Capacities and Transformation Performance in VISION

Capacity	Transformation Performance
Separations Order switch in **Integer 1** among 0. Let VISION optimize separation capacity. VISION builds separation capacity subject to the Separations Data, which is set on the **Separations** worksheets. 1. Force VISION to build specific separation capacity each year, the capacity is also set on the **Separation**s worksheets. Note: The Separations Date switch in **Separation X** worksheets overrides capacity specifications; capacity is built but not used. Capacity specified above is then reduced by the defined facility rampup specified on the **Facility Ramp Up** worksheet.	Partition - how the contents of used fuel are allocated among fuel product streams, 3 grades of recovered uranium (RU), and several waste form options. This is determined by the separation efficiency matrices defined on the **Separation Stream Splits** worksheet. Separation efficiency matrices are numbered from 1 to 40. 1 to 20 - aqueous 21 to 30 - electrochemical 31 to 39 - other 40 - once through About half are blank and available for the user to define. The user is encouraged to add separation matrix values to any of the blank matrices. Changing any of the pre-defined matrices would invalidate base cases that use them. The list of recipes (including any the user has added) is given on page "**List_of_separation_types**"

4.5.1 Separation (BLUE) - Facility Ramp Up

This page allows the user to specify the speed with which a Separation Facility comes on line. The first column specifies the year number (1-20). The second column represents the percentage of the facility completed with one representing 100% or the facility is complete. This column is cumulative. Years (1-20) must total 100%. Each reactor has a rate 1 and rate 2. The second rate is more efficient than the first.

4.5.2 Separation (BLUE) - Separation 1 through Separation 10

Table 4-11 lists the parameters set on these worksheets, one for each separation type. Most of the parameters are straightforward, with exception of specification of separation efficiency matrix by recycle pass. Except in rare circumstances, the array of selection of separation efficiency matrices for the six recycle passes (0 through 5) will be identical. The only known exception is recycling 2 or more times in one type of reactor, e.g., LWR-MOX, and then sending fuel to another type of reactor, e.g., fast reactor. Otherwise, all recycle passes in a given separation facility should have the same separation efficiency matrix.

Table 4-11. Parameters set on the Separation Worksheets

Parameter	Units or Allowed Variables	Impact	Recommended Values
Construction Time	≥0.25 years (≥ time step)	Sets delay for construction of separation facilities.	5
Lifetime	≥0.25 years (≥ time step)	How long separation plants operate.	60
Separation duration	≥0.25 years (≥ time step)	How long material resides in the separation plant	1
Unlimited separation capacity	TRUE = VISION does not limit separation by capacity FALSE = VISION does limit separation by capacity TRUE is unrealistic but a helpful option for debugging a case if one suspects that mass flow is choked at separations.		FALSE
Separation facility size	> 0 kilotonnes/ calendar year (not zero)	Determines the unit size of these facilities. Only integer number of these facilities can be built. If allowed by user input settings, VISION will calculate the number of required facilities and round up.	Depends on your scenario
Initial Pu239 stockpile	≥0 kilotonnes-Pu239	This allows the user to specify the amount of Pu239, available from sources external to the fuel cycle.	Depends on your scenario
Separations date	Date between 2000 and 2100, inclusive	This date overrides the separation capacity specified elsewhere. This means that separation capacity can exist before the specified start date but that separations will not start before that date.	2020
Number of recycle passes (200 rows)	*To be deleted, function handled by recycle routing and separation efficiency matrices*		
Capacity for that separation facility type by year (200 rows)	0 to 1000 Kilotonnes/ calendar year	Determines the capacity each year if Separations Order switch in **Integer 1** = 1, otherwise no impact.	
Separation efficiency matrix numbers by year (200 rows) for recycle pass 0, then pass 1, 2, 3, 4, and 5.	1 to 40	This decides which of the separation efficiency matrices is used for each recycle pass for each year.	
Separations capacity availability factor	0.00 to 1.00 FPY/calendar year	Determines the fraction of time during a year that separation facilities generate 100% of their rated capacity	1.0

Some examples:

Matrix 1 - simulates UREX+1 or electrochemical separation, sends TRU to fuel-2, with waste segregated into several types, appropriate to use for separation-1 (all recycle passes) if these are operating on UOX or MOX and all TRU is to be recovered and sent to fuel-2.

Matrix 2 - same as matrix 1 except sends TRU to fuel-3, appropriate to use for separation-2 (all recycle passes) if these are operating on UOX or MOX and all TRU is to be recovered and sent to fuel-3. So, material separated from used MOX (if a 1-pass MOX strategy) is sent elsewhere. TRU gets into MOX not from separation-2 but from separation-1. TRU sent from UOX pass 0 goes to fresh MOX pass 1.

Matrix 6 - simulates UREX+2 so that NpPu is recovered and sent to fuel-2, AmCm goes into waste.

Matrix 13 - simulates UREX+4 so that NpPuAm is recovered and set to fuel-2, Cm goes into waste.

Matrix 16 - simulates COEX so that U and Pu is recovered and sent to fuel-2, NpAmCm goes into waste.

4.5.3 Separation (BLUE) - Separation Stream Splits (Separation Efficiency Matrices)

This worksheet specifies the isotopic composition (on a mass percent basis for each isotope) for each stream exiting a given separations option. There are 40 separations options available, including various versions of UREX+, COEX, Electrochemical (Table 4-12). One separation strategy can be defined for each fuel type for each year.

The separation efficiency matrices perform several functions, as follows:

- Identify which TRU elements are recovered and how they are grouped, see examples in Table 4-12.
- Identify what fraction of fission product become impurities in fuel material.
- Identify where fuel products go, i.e., new fuel fabrication 1 through 10. This separation-to-fuel-fab routing could instead by done by a different set of routing matrices of fuel products into fuel fabrication. That alternative modeling approach would be appropriate if we wanted to specify fuel fabrication by *pulling* feedstock from multiple separation facilities, instead of the current approach of *pushing* fuel products from separation into fuel fabrication buffers.
- *NOTE: The RU buffers are not yet working. Instead, send RU to the appropriate fuel product buffers. Unused RU will accumulate there and not be counted as waste.*

  FUTURE: Identify which of three recovered uranium storage buffers to send uranium that is recovered separately from one or more TRU products. It is anticipated that some scenarios will involve multiple reactor types in which case the stockpile of RU would need to be kept separate, e.g., relatively high enriched used uranium from VHTR would be put into RU-H and moderately enriched uranium from LWR would be RU-M, and low enriched uranium from used HWR fuel would be RU-L.
- Define how many and which waste streams are produced.
- Identify which chemical elements go into which waste stream.
- Identify how much uranium and TRU does into each waste stream.

Table 4-12. Definition of Separation Efficiency Matrices

	Technology	Fuel goes to fuel fabrication number	Waste strategy
1	UREX+1 (all TRU recovered)	2	Segregated waste streams
2	UREX+1 (all TRU recovered)	3	Segregated waste streams
3	UREX+1 (all TRU recovered)	2	All to HLW

4	UREX+1 (all TRU recovered)	3	All to HLW
5	Blank		
6	UREX+2 (NpPu recovered, AmCm to waste)	2	Segregated waste streams
7	UREX+2 (NpPu recovered, AmCm to waste)	3	Segregated waste streams
8	UREX+2 (NpPu recovered, AmCm to waste)	2	All to HLW
9	UREX+2 (NpPu recovered, AmCm to waste)	3	All to HLW
10	Blank		
11	UREX+3 (NpPu and AmCm recovered)	NpPu to 2 AmCm to 3	Segregated waste streams
12	UREX+3 (NpPu and AmCm recovered)	NpPu to 2 AmCm to 3	All to HLW
13	UREX+4 (NpPu, Am, and Cm recovered)	NpPuAm to 2 Cm to waste	Segregated waste streams
14	Blank		
15	Blank		
16	COEX	2	All to HLW
17	COEX	3	All to HLW
18	Blank		
19	Blank		
20	Blank		
21	Electrochemical (all TRU recovered)	3	Segregated waste streams
22	Electrochemical (all TRU recovered)	3	All to HLW
23	Electrochemical (all TRU recovered)	4	Segregated waste streams
24	Electrochemical (all TRU recovered)	5	Segregated waste streams
25	Blank		
26	Blank		
27	Blank		
28	Blank		
29	Blank		
30	Blank		
31	Dry (only volatile fission products are removed, everything else becomes quite impure new fuel)	2	All to HLW
32	Dry (only volatile fission products are removed, everything else becomes quite impure new fuel)	3	All to HLW
33	Dry (only volatile fission products are removed, everything else becomes quite impure new fuel)	7	All to HLW
34	Blank		
35	Blank		
36	Blank		
37	Blank		
38	Blank		
39	Blank		
40	Once through (everything to HLW)	NA	All to HLW

The samples in **base case settings ver6.xls** denote two bounding waste management strategies. Of course, the user can define whatever strategy she wants.

- Segregated waste streams - waste is segregated into several streams with the intention that many would not be classified as HLW. See Table 4-13, 4-14, and 4-15.
- All to HLW - other than volatile species, all waste goes into a single waste form that would be HLW.

Table 4-13. Illustrative UREX+1 Separation Efficiency Matrix

	Pu Np Am Cm Recycle Stream	RU Stream	I Stream	Gas Stream	Tc Stream	Cs Sr Stream	LnFP Stream	Discard Stream	UDS Stream	Zr SS Stream
Ra to Pa							100	Not used,	Not used, 25% of the Tc goes with this stream, but is included with the Tc waste for ultimate disposal anyway	Not used, such mass accounted for via co-flows
U		99.9					0.1			
Np	99.9						0.1			
Pu	99.9						0.1			
Am	99.9						0.1			
Cm-Cf	99.9						0.1			
H3				99.9			0.1			
C14							100			
Kr				99.9			0.1			
Sr, Cs						99.9	0.1			
Tc					99.9		0.1			
I			99.9				0.1			
FP otherr							100			

RU = recovered uranium, FP = fission product, Ln = lanthanides, UDS = undissolved solids.
Sum of numbers in each row must equal to 100.
The separation efficiency matrix does not address cladding isotopes, e.g., steel

Table 4-14. Illustrative Separation Efficiency for U+UPu+NpPuAm+CsSr+I+Tc Separation of UOX

	RU Pu Np Am Cm Recycle Stream	Pu Np Am Cm Recycle Stream	RU Stream	I Stream	gas Stream	Tc Stream	Cs Sr Stream	Lnfp Stream	Discard Stream	UDS Stream	Zr SS Stream
Ra to Pa								100	Not used,	Not used, 25% of the Tc goes with this stream, but is included with the Tc waste for ultimate disposal anyway	Not used, such mass accounted for via co-flows
U	1.3		98.6					0.1			
Np		99.9						0.1			
Pu	99.9							0.1			
Am		99.9						0.1			
Cm-Cf		99.9						0.1			
H3					99.9			0.1			
C14								100			
Kr					99.9			0.1			
Sr, Cs							99.9	0.1			
Tc						99.9		0.1			
I				99.9				0.1			
FP otherr								100			

RU = recovered uranium, FP = fission product, Ln = lanthanides, UDS = undissolved solids.
Sum of numbers in each row must equal to 100.
The 1.3% U mixed with Pu produces a 50:50 UPu product
The separation efficiency matrix does not address cladding isotopes, e.g., steel

Table 4-15. Illustrative Electrochemical Separation Efficiency of FR Metal Fuel

	RU Pu Np Am Cm Recycle Stream	RU Stream	I Stream	gas Stream	Tc Stream	Cs Sr Stream	LnFP Stream	discard Stream	UDS Stream	Zr SS Stream (Metal Waste Stream)
Ra to Pa			No iodine stream, included with CsSr stream		No Tc stream, included with metal waste stream			Not used Process salt accounted for as the waste form material for the FP stream	Not used, such mass included in FP stream	100
U	3.4	93.3								3.3
Np	99.9									0.1
Pu	99.9									0.1
Am	99.9									0.1
Cm-Cf	99.9									0.1
H3				99.9						0.1
C14										100
Kr				99.9						0.1
Sr, Cs						99.9				0.1
Tc										100
I						99.9				0.1
FP other							50			50

RU = recovered uranium, FP = fission product, Ln = lanthanides, UDS = undissolved solids.
Sum of numbers in each row must equal to 100.
The separation efficiency matrix does not address cladding isotopes, e.g., steel and Zr.

4.6 Fuel Fabrication (PURPLE) Worksheets

The set of fuel fabrication worksheets is simpler than reactors or separations, primarily because of the 1:1: correspondence between fuel fabrication and fuel type, i.e., there is one fuel fabrication type dedicated to each fuel type. There are other simplifying factors. There is no fuel fab facility rampup specification. The routing coming into fuel fabrication is a “push” time from separations, whereas the routing from reactors into separations is a “pull” type. And, the transformation in fuel fabrication facilities is effectively to blend recycled TRU (if any) with a uranium stream. Because of the 1:1 correspondence, those composition requirements are set via fuel recipes, not on fuel fab worksheets.

Thus, there is a single type of fuel fabrication worksheet, **Fuel Fab 1 through 10**, which defines several parameters for that separation type, including capacity and which separation efficiency matrix is to be used, by year. Table 4-16 shows how fuel fabrication capacities and transformation performance are set.

Table 4-16. Fabrication Facility Capacities and Transformation Performance in VISION

Capacity	Transformation Performance
Fuel Fab Order switch in **Integer 1** among 0. Let VISION optimize fuel fab capacity. 1. Force VISION to build specific fuel fab capacity each year, the capacity is set on the **Fuel Fab** worksheets.	Blending - Fuel is made according to the compositions according to the selection of fuel recipes available in **vision recipes ver5.xls** by fuel number in the **Reactor Fuel Types** worksheet. Each fuel fab type has two types of source material, recycled and uranium. The only available recycled material is what is in the separation-to-fuel-fab buffer, which is controlled by **Separation Stream Splits**. Uranium is used according to uranium priority set with the fuel recipes, e.g., whether to use enriched uranium (EU) or recovered uranium (RU).

4.6.1 Fuel Fabrication (PURPLE) - Fuel Fab 1 through Fuel Fab 10

Table 4-17 lists the parameters set on the **Fuel Fab** worksheets, one for each separation type. Most of the parameters are straightforward and generally similar to analogous settings in the **Separations** worksheets.

Table 4-17. Parameters Set on Fuel Fab Worksheets

Parameter	Units or Allowed Variables	Impact	Recommended Values
Fuel Fab construction time	≥0.25 years (≥ time step)	Sets delay for construction of fabrication facilities , does not impact fuel flows.	2 years
Fuel Fab lifetime	≥0.25 years (≥ time step)	Determines lifetime of fuel fab facilities, does not impact fuel flows.	60 years
Fuel Fab license time	≥0.25 years (≥ time step)	Sets delay for facility licensing	1 year
Enrichment time	≥0.25 years (≥ time step)	Determines the delay for the enrichment process. Individual enrichment plant types are not tracked.	1 year
Used fuel wet storage time	1 to 10 years (integer values only) (≥ time step)	Determines the minimum time used fuel must stay at the reactor before going anywhere else.	Before on-site separation - 1 year Before off-site separation - 10 year
Used fuel dry storage time	1 to 5 years (integer values only) (≥ time step)	Has no effect on when fuel can move to repository or separation facilities, which are controlled by their processing rates. Determines how long fuel must wait in dry storage before going to an MRS (if there is one).	1 year
Unlimited fuel fabrication capacity for LWR	>0 kilotonne/yr (not zero)	This allows the user to set a number such that the Fuel Fab Facilities will be able to produce as much fuel as is necessary. The associated "logical" switch must be set to use unlimited fuel fabrication.	1000 kt/year
Base case fuel fabrication facility size	> 0 kilotonnes/year (not zero)	Determines the unit size of these facilities. Only integer number of these facilities can be built. If allowed by user input settings, VISION will calculate the number of required facilities and round up.	Depends on your scenario
Capacity for that fuel fabrication facility type by year (200 rows)	0 to 1000 Kilotonnes/ calendar year	Determines the capacity each year if Fuel Fab Order switch in **Integer 1** = 1, otherwise no impact.	
Base case fuel fabrication capacity factor (200 rows)	0.00 to 1.00 FPY/calendar year	Determines the fraction of time during a year that fuel fabrication facilities generate 100% of their rated capacity	1.0 FPY/CY

4.7 Waste Management (BRIGHT BLUE) Worksheets

The final set of worksheets primarily address waste management. This includes Other Facilities. The mass of waste is defined by the flow through separations and the separation efficiency matrices selected on the **Separation** worksheets and defined on the **Separation Stream Splits** worksheets. Waste (kilotonnes) times the waste loading provides the mass of waste forms (kilotones). The waste form mass times the waste form density provides the waste form volume. The waste loadings (kilotonne-waste/kilotone-wasteform) and waste form density (kilotone-wasteform/m3-wasteform) are input on the **Waste Form and Mass Loading** worksheet. Unprocessed used fuel mass is converted to wasteform volume by the parameters on the **LSF & SF Waste** worksheet. The **Waste Disposition** worksheet provides the parameters that determine the type of disposition facility that each waste stream goes to - (1) decay storage, (2) LLW ABC Class waste, (3) LLW GTCC waste, (4) HLW, (5) HLW, and (6) not waste. The **Repository Holding Capacity** and **Repository Flow Capacity** worksheets provide the allowable inventory and receipt rate of repositories.

4.7.1 Waste Management (BRIGHT BLUE) - Other Facilities

This worksheet accepts input for facilities not defined elsewhere, see Table 4-18.

Table 4-18. Parameters Set on Other Facilities Worksheet

Parameter	Units or Allowed Variables	Impact	Recommended Values
Enrichment duration	*To be deleted, parameter on Fuel Fabrication worksheets*		
Wet storage duration	*To be deleted, parameter on Fuel Fabrication worksheets*		
Dry storage duration	*To be deleted, parameter on Fuel Fabrication worksheets*		
MRS duration	Integer values only		Depends on your scenario
MRS construction time	≥0.25 years (≥ time step)	Has no effect on mass flows	Depends on your scenario
MRS lifetime	≥0.25 years (≥ time step)		Depends on your scenario
Repository Construction Time	≥0.25 years (≥ time step)		Depends on your scenario
Repository Lifetime	Integer values only		Depends on your scenario

4.7.2 Waste Management (BRIGHT BLUE) - Coflows (*Inactive for VISION 3.0*)

This page allows the definition of 6 co-flow streams for each of the 15 separation strategies. The first five materials, ZR, SS, process discard, salts and metals 3, require the user to specify the number of kilograms of material per kilogram of fuel. The sixth material, Rags and Bags, requires the user to specify the volume (in cubic meters) per kilogram of fuel. These materials are part of the fuel cycle, but are not active parts of the fuel. They are important however for waste, storage, and economic purposes. The numbers are currently approximations and need further refining.

4.7.3 Waste Management (BRIGHT BLUE) - Waste Disposition (*Inactive for VISION 3.0*)

The "Waste Disposition" page is split up into three parts, one for each fuel type. This page specifies the waste classification for each stream from separations. The type of separations process (aqueous or electrochemical) is set elsewhere in the base case settings file, but the user needs to have decided what separation strategy will be used for each fuel type in order to properly specify the waste classification for each stream from separations. The rows beneath each fuel type list the possible separation streams; different separation strategies and fuels will use different subsets of the streams. There are six categories listed at the bottom of the page which are as follows: 1-Decay Storage, 2-LLW ABC, 3-GTCC, 4-HLW, 5-TRUW, 6-Not Waste. Next to each option listed beneath the "Separation Stream" the user can enter numbers (1-6) corresponding to the numbers listed above. Numbers (1-5) deal with different levels of storage and disposal. Number (6) allows the user to specify what elements go through recycling.

4.7.4 Waste Management (BRIGHT BLUE) - Waste Form and Mass Loading (*Inactive for VISION 3.0*)

This page allows the user to specify mass and volume of the wasteform for each separation stream in a given fuel type. The values for wasteform loading are in the form of a mass fraction defined as mass of contaminant stream/mass of wasteform. The user is encouraged to specify a low, mid, and high waste loading (and accompanying waste density). The values for wasteform density are in the form of tonne of wasteform per cubic meter of wasteform. The color coding allows the user to see where the information was obtained from. To the far right of the users screen is a list showing the same colors and the sources associated with those colors. From the different documents, there may be ranges given with respect to the different amounts of mass contributed and so forth. The low end of the range corresponds to the "low" in the Excel file. The same goes for the "Med" and "High".

4.7.5 Waste Management (BRIGHT BLUE) - Worksheet for LSF & SF Waste (*Inactive for VISION 3.0*)

This page allows the user to set the cask mass loading (kilotonnes of casked fuel per kilotonne of fuel) and cask (with fuel) density (kilotonnes of casked fuel per cubic meter) for legacy spent fuel and spent fuel. The numbers currently in the worksheet are preliminary and should be used with caution.

4.7.6 Waste Management (BRIGHT BLUE) - MRS Flow Capacity (*Inactive for VISION 3.0*)

The user can include a monitored retrievable storage (MRS) facility in the analysis. The parameters that can be specified are

- Whether MRS is present or not.
- Dry storage time before material can be moved to the monitored retrievable storage.
- MRS capacity.

4.7.7 Waste Management (BRIGHT BLUE) - Repository Holding Capacity

The user can include a retrievable repository facility in the analysis. The retrievable repository capacity is not limited in total mass, but the rate that material can be sent to the repository is limited. The oldest (longest time out of the reactor) and then most cycled fuel has priority for entering the repository.

The user can include a permanent repository facility. The user can specify a limit on the permanent repository in terms of either legacy used fuel (pre-2000), used fuel, or both. The user specified repository receipt rate for the retrievable repository also applies to the permanent repository.

This page allows the user to specify the total repository holding capacity (permanent and retrievable) as a function of time. This page is used when Base Case Unlimited Repository Holding Capacity Switch (on the **Logical 1** worksheet) is set to FALSE.

4.7.8 Waste Management (BRIGHT BLUE) - Repository Flow Capacity

This page allows the user to specify the total repository flow capacity as a function of time. This page is used when Base Case Unlimited Repository Flow Capacity Switch (on the **Logical 1** worksheet) is set to FALSE.

5. VISION INPUT VIA RECIPES VER1.XLS file

This file contains the following types of input information:

- Fuel recipes described below
- Fuel interpolation correlations described below
- *Worksheets for a future 1-group perturbation approach (not currently used)*

Each recipe data column contains the following information:

- Fuel burnup (GWth-day/tonne-iHM)
- Capacity factor (FPY/calendar years)
- Fuel residence time (calendar years)
- The input and output compositions for this primary fuel.
- Uranium priority 1 to 6 - what type of uranium supply (EU, NU, DU, RU) should be used to make up the the correct amount of uranium in the fuel once the uranium in the incoming separation-to-fuel buffer is accounted for.
- The number of a contingent fuel (if any) that VISION will use in this reactor if the primary fuel cannot be made. The contingent fuel should be a uranium-based fuel.
- The mass fractions for the input fuel composition. These must sum to 1.0
- The mass fractions for the output fuel composition. These must sum to 1.0.
- *1-Group cross sections for (n,fission) - not yet used*
- *1-Group cross sections for (n,gamma) - not yet used*
- *1-Group cross sections for (n,2n) - not yet used*

Table 4-10 (replicated here) lists the available fuel recipes, which are found on seven worksheets in this file.

Table 4-10. Fuel Types (replicated here)

Reactor technology	Appropriate reactor fuel numbers in **vision recipe ver5.xls**
LWR	33 to 100 - LWR burnup correlation 101 to 110 - recipes in **100_UOX_Once_Thru** worksheet
LWR MF (multiple fuel)	33 to 100 - LWR burnup correlation (Values from 2 to 100 are allowed by VISION but values from 2 to 32 produce unreliable results in the current burnup correlation.) 101 to 110 - recipes in **100_UOX_Once_Thru** worksheet 301 to 315 - recipes in **300_LWR_MOX** worksheet 401 to 415 - recipes in **400_LWR_IMF** worksheet
HWR or VHTR	Appropriate recipes among 201 to 210 - recipes in **200_Other_Once_Thru** worksheet
HWR or VHTR possibly using recycled material	Appropriate recipes among 201 to 210 - recipes in **200_Other_Once_Thru** worksheet 501 to 510 - recipes in **500_Other_Thermal_Recycle** worksheet Currently all the 500 recipe slots are blank.
Fast burner reactor, sodium cooled	-1.00 to 0.00 - fast reactor oxide TRU CR correlation 0.00 to 1.00 - fast reactor metal TRU CR correlation (Values from -2.00 to 0.00 and 0.00 to 2.00 are allowed by VISION but values below -1 and above +1 produce unreliable results in the current TRU CR correlations.) Appropriate recipes among 601 to 630 - recipes in **600_Metal_Cooled_FR** worksheet
Fast breeder reactor, sodium cooled	Appropriate recipes among 601 to 630 - recipes in **600_Metal_Cooled_FR** worksheet
Fast reactors with other coolants	701 to 710 - recipes in **700_Other_Cooled_FR** worksheet Currently all the 700 recipe slots are blank.

Cautions:

17. *Do not reorder or change the list of isotopes on each worksheet; all must be the same.*

18. *Changing any of the pre-defined recipes will invalidate case cases that use them.*

5.1 List of Recipes Worksheet

This worksheet page simply lists the recipes that have been entered on the seven pages of recipes. **Base case settings ver6.xls** reads this page.

5.2 User Help Worksheet

This worksheet page is not used by any other file or worksheet. It is simply an aid to the user. Recall that the recipe pages require the following data:

- Fuel burnup (GWth-day/tonne-iHM)
- Capacity factor (FPY/calendar years)
- Fuel residence time (calendar years)

And, the base case settings ver6.xls file will have a thermal efficiency (GWe/GWth). The user may not have these parameters and may instead have fueling rate or electricity generation rate or # of refueling batches. This page guides the user to calculate the required values from other combinations of parameters.

5.3 100 - LWR Once Through Recipes

This page contains the UOX fuel recipes. Recall that as an alternative to selecting one of there recipes, the user can input a value from 33 to 100, which VISION will interpret as a value for LWR UOX burnup and use the LWR burnup correlation (**Interpolation LWR BU** worksheet) instead of one of these recipes.

Recipe 101 is a special case as it uses the LWR burnup correlation (recipe 101) in a different way. In these cases, the user must specify the burnup in cell N5. If you want to use the LWR burnup or TRU CR correlations by year, use 33 to 100 (LWR burnup correlation). Recipe 101 can be used, for example, to create a series of user defined recipes for particular purposes. For example, recipes 106 and 107 were created from recipe 101 by inputting the appropriate pre-2000 burnup value for legacy fuel, then copying and pasting into those columns. Thus, recipes 106 and 107 approximate the average composition of fuel 0-10 and 11-40 years old in 2000. Having these recipes allows the user to then define in the **Wet and Dry Storage** worksheet the appropriate composition.

Similarly, one would want to create a new 100-series recipe if you wanted a contingent fuel to be 45 GWth-day/tonne burnup instead of 51, which is recipe 103.

Recipes for 33 and 51 GWth-day/tonne-iHM UOX come from [Stillman2004]. The LWR burnup correlation comes from [Yacout2008], so that the recipes for wet and dry storage are derived from that correlation.

The “Depleted U Composition” column is used to calculate the depleted U and should not be changed.

5.4 200 - Other Once Thru Recipes

This worksheet contains recipes for other thermal reactors using once-through or all-uranium fuel.

5.5 300 - MOX Recipes

This worksheet page contains the MOX recipes. VISION is structured to allow up to 5 recycle passes. Therefore, all recycle fuels (300s, 400s, 500s, 600s, 700s) are structured to have 5 columns of data. If one has data for only a single recycle pass, those data must be in the column for pass 1, the other four columns left blank.

It is important to remember that VISION tracks core-averaged compositions. So, a strategy in which a mixture of MOX pins and UOX pins are used requires a single recipe that averages over the sets of pins.

Similarly, a complex blending of multiple fuel sources is invisible to VISION, the core-averaged recipe must be input. This is the strategy used in the multi-recycle recipes on this worksheet.[Youinou2009]

5.6 400 - IMF Recipes

This worksheet page contains the IMF recipes. VISION is structured to allow up to 5 recycle passes. Therefore, all recycle fuels (300s, 400s, 500s, 600s, 700s) are structured to have 5 columns of data. If one has data for only a single recycle pass, those data must be in the column for pass 1, the other four columns left blank.

It is important to remember that VISION tracks core-averaged compositions. So, a strategy in which a mixture of IMF pins and UOX pins are used requires a single recipe that averages over the sets of pins. This is what is used in the multi-recycle recipes on this worksheet.[Pope2009]

5.7 500 - Other Thermal Recycle Recipes

This worksheet page is reserved for recycle fuels other than MOX or IMF. There is one draft recipe for the DUPIC fuel composition (direct use of uranium and plutonium in CANDUs).

5.8 600 - Metal-Cooled Fast Reactor Recipes

This page contains the fast reactor fuel recipes. Recall that as an alternative to selecting one of there recipes, the user can input a value from 0.00 to 1.00, which VISION will interpret as a value of fast reactor TRU conversion ratio. If positive, metal-fueled metal-cooled. If negative, oxide-fueled, metal-cooled. The FR TRU CR correlations are on **Interpolation FR-metal CR** and **Interpolation FR-oxide** CR worksheets. The burner fast reactor data come from [Hoffman2006, Hoffman2007]. The correlation approach is described in [Yacout2008].

VISION is structured to allow up to 5 recycle passes. Therefore, all recycle fuels (300s, 400s, 500s, 600s, 700s) are structured to have 5 columns of data. If one has data for only a single recycle pass, those data must be in the column for pass 1, the other four columns left blank. Currently in the AFCI program, we have only recipes for the first (startup) and equilibrium recycle pass, in which case the startup composition is entered into recycle pass 1 and the equilibrium composition is entered into recycle pass 5.

Recipes 601 and 602 are special cases as they use the FR TRU CR correlations. In these cases, the user must specify the burnup in cell E2 (metal) or K2 (oxide).

5.9 700 - Other-Cooled Fast Reactor Recipes

This worksheet page is reserved for fast reactor recipes other than metal-cooled. It is currently blank but you can input recipes if you wish.

5.10 Other Worksheets

The other worksheets in this file should not be changed by the user.

5.10.1 Interpolation Burnup Worksheet

This worksheet shows how a burnup of 51 can then be changed to anything else specified by the user and have the correct recipes produced for the different burnups.[Yacout2008]

Caution: Nothing on this page should be changed by the user.

5.10.2 Interpolation FR-metal CR Worksheet

This worksheet contains correlations for modifying recipes as a function of TRU conversion ratio. The methodology is described in [Yacout2008] but those correlations have been updated by extracting more details from [Hoffman2007] for isotopes that are tracked by VISION 3.0 that were not tracked by VISION 2.2.

Caution: Nothing on this page should be changed by the user.

5.10.3 Interpolation FR-oxide CR Worksheet

This worksheet contains correlations for modifying recipes as a function of TRU conversion ratio. The methodology is described in [Yacout2008] but those correlations have been updated by extracting more details from [Hoffman2007] for isotopes that are tracked by VISION 3.0 that were not tracked by VISION 2.2.

Caution: Nothing on this page should be changed by the user.

5.10.4 Worksheets Named Yellow, Blue, Green, Nu, VISION k-infinity

These worksheets are for a new submodel in VISION, which is not yet operational.

6. VISION OUTPUTS

There are two types of output files, those that contain data dumps directly from the VISION Powersim model and those intended to organize and graph those data for user analysis.

The Powersim portion of VISION will store data for up to five runs in the Excel file **output data-1.xls**, which is typically at least 5 MB. The user can directly access and analyze those data. However, **output data-1.xls** will have a varying number of columns of data as the number of reactor types, fuel types, and separation types varies. And, if you leave your data in **output data-1.xls**, the next time you run VISION, Powersim will overwrite whatever is in **output data-1.xls**.

Instead, we recommend a two-step process that will provide the user with various graphs and a macro to help you produce other graphs of the data. The first step uses **output data-2.xls**, which copies data from **output data-1.xls** and puts it into a standard format of 10 reactors types, 10 separation types, and 10 fuel types - many of which will be blank. This allows other graphing files to reliably link to **output data-2**; several such files are described in following subsections.

output checks.xls - helps the user perform some checks of the output data

output reactors.xls - graphs reactor and electricity generated information

output fuel masses by class.xls - graphs fuel masses by class, e.g., mass of TRU or U

output fuel masses.xls - graphs fuel masses (summed over all classes)

output separations.xls - graphs separation information

output waste.xls - not included with VISION 3.0

Cautions:

19. *The **output data-2.xls** expects **output data-1.xls** to be in the same folder. If it is not, the macro in **output data-2.xls** that copies data from **output data-1.xls** will not function.*
20. *Data are not transferred automatically from **output data-1.xls** to **output data-2.xls**, you must either run the macro in output data-2.xls or copy data manually.*
21. *The other output files expect **output data-2.xls** and **base case settings ver6.xls** to be in the same folder. If not, you will have to update the "link" from those file to the output file in question. And, the Graph Builder macro in the other output files will not function.*
22. *The macros in the output files will work faster if the files are not "minimized" in Windows.*
23. *Data are generally automatically transferred from output data-2 to other output files. Due to quirks in Excel, sometimes you have to manually update links. Go to "Edit" then "Links" and manually update the links.*
24. *After running up to five cases, the user should make a copy of **base case settings ver6.xls**, **output data-2**, and other output file of interest.*
25. *Until you have saved the files and broken links, all Excel files must remain in Office2003 format (extension xls); they cannot be Office2007 format (extension xlsx).*

6.1 Output Data-1.xls

The vision model dumps directly to this file for up to five runs which corresponds to the tabs. The tabs will be numbered according to which runs they correspond with. This information will be used in the savable output files.

This file is not intended for direct user use, nonetheless, the user may find need to go to the raw data and hence this guide will provide an overview of the file and how it is organized.

The worksheets all have names of the form XXXX-n, where n is the number of the run from 1 to 5. All "1" worksheets appear before all "2" worksheets, etc. The order of the set of "n" worksheets is kept the same. The top two or three rows of each worksheet may have labels indicating the variable name in VISION and the unit. All other rows proceed from 1/1/2000 to 1/1/2100, showing yearly data.

Note that some cells do not contain data, only #Num!, which means that the Powersim model is not currently dumping appropriate data to those cells. This generally denotes an obsolete part of validationdata, which are no longer used but not removed because it would change the order of columns.

Each worksheet in **output data-1.xls** corresponds to a particular page in the Powersim model to make it easier to trace backward. The worksheets in **output data-1.xls** are as follows:

- **US Reactor Park**- contains the number (not capacity and not electricity generated) of reactors that are legacy reactors, legacy reactors near retirement, legacy reactor near shutdown, retired legacy reactors, reactors during licensing license, reactors during construction, reactors during contruction needing fuel, ready reactors, fresh reactors, reactors near retirement, reactors near shutdown, retired reactors, and operating reactors. Each of those parameters is divided by reactor type. It also contains the total number of operating reactors, summed over all reactor types, the capacity (by reactor type), and the total capacity.

- **Fuel Cycle** - contains several mass flow parameters, notably the mined ore, accumulated depleted uranium, and how much fuel is in enrichment, fuel fabrication, ready fuel, reactors, wet storage, dry storage, MRS.

- **Separations Facilities** - contains the number of separation facilities at the stages of design and license, construction, ready to operate, working (operating), new retirement, or retirement. Each stage has as many columns as there are separation facility types.

- **Fuel fabrication Facilities** - contains the number of fuel fabrication facilities at the stages of design and license, construction, ready to operate, working (operating), new retirement, or retirement. Each stage has as many columns as there are fuel fabrication facility types.

- **Mass Calcs** - contains the mass of fuel by chemical element by stage of the fuel cycle (fuel fabrication, ready fuel, fuel in reactors, wet storage, dry storage, MRS, retrievable repository, permanent repository). Each has as many columns as there are fuel types.

- **U ore inventory** - contains (by fuel type) the consumed U ore and consumed U.

- **Enrichment Capacit**y - contains the cumulative SWUs (by fuel type) and total SWUs.

- **Repository** - contains the mass of fuel (by fuel type) in permanent and retrievable repository.

- **Fuel Makeup from Separations** - contains information on the mass of material in the buffers between separations and fuel fabrication.

- **Future Demand** - contains information on total and nuclear electricity predictions.

6.2 Output Data-2.xls

Start on the **START HERE** worksheet, which will guide you through use of this spreadsheet file. This spreadsheet translates the raw VISION output file (**output data-1.xls**) into a common format with 10 reactor types, 10 separation types, and 10 fuel types. It reads and copies from **output data-1.xls** and pastes information into itself. Therefore **output data-2.xls** does not have an automatic link back to **output data-1.xls**.

First, open the input (**base case settings ver6.xls**) and output (**output data-1.xls**) files, or whatever you may have renamed them. The macros in **output data-2.xls** will not work unless those two files are open.

Second, if appropriate, clear the data in **output data-2.xls**. There are buttons to clear a specific run or clear all runs. Remember, data cleared are data gone! You do not have to clear previous data to bring in replacement data from **output data-1.xls**; however, we recommend doing so because your new data may have fewer numbers of reactors, fuels, and separation types. Note that the "clear run" feature allows you to run various simulations and decide to keep only some of the runs, clearing the other ones.

Third, set the input and output file names for the macros to use. The files must be in the same folder as **output data-2.xls** and must include the extension .xls. The defaults names are **base case settings ver6.xls** and **output data-1.xls**.

Fourth, load data from the input and output files. There are buttons to load a specific run or all the runs. Note that the "load run" feature allows you to replace just one of the runs you've previously calculated with a new data set. It is not possible to load new run X, however, into anything other than run X.

Fifth, open the graphic output files of interest.

Cautions:

26. *Do not alter the worksheets in any way - names, order, format, etc.*

6.3 Output Files with Graphs

Other than **output data-1.xls** and **output data-2.xls**, all output files have the same format and same macros.

All require **output data-2.xls** and **base case settings ver6.xls** to be properly populated. You can have the output files read some a file with a name different that **output data-2.xls** but its format must be the same. If you chose to read from a differently named file you have to correct the connections from output data-2.xls to that output file, which means editing the links from **output data-2.xls** and **base case settings ver6.xls** by going to "Edit" on the Excel menu, then "Links".

All output files have multiple worksheets.

- **START HERE** - guides you through that output file.
- **By run** - a worksheet that sums all of the parameters in question over reactor types, fuel types, separation types, whatever is appropriate
- **Parameter Run1 through Run5** - worksheets with more detail, one for each simulation run.
- Other worksheets going into yet more detail if appropriate.

Each output file has several pre-defined graphs. For each type of graph, there is one pre-set for a 100-year simulation and one pre-set for a 200-year simulation.

There are two macros in each output file, accessible via buttons or by "control" shortcuts.

- Graph Viewer (control-shift-E) - allows you to view thumbnails of all graphs in that currently active worksheet, in sets of 9. Click of a thumbnail to go directly to it. Once there you can view it or alter it as with any Excel graph.
- Graph Builder (control U) - guides you through the process of making a new graph from data in output data-2.xls. You can, of course, make graphs manually if you are adequately familiar with Excel graphs and linking data between Excel files.

6.3.1 Output_Checks

If the file does not open in the **START HERE** worksheet, please go to it. "**START HERE**" is the left most worksheet. This file helps the answer the following questions:

- Are the names you gave to each run what you intended?
- Are the runs that actually ran what you intended?
- Is the Reactor Order Case what you intended?
- Is the Separation Order Case what you intended?
- Does the sum of disposition paths for each isotope in each of the Separation Efficiency Matrices = 100%?
- Did you tell VISION to create enough legacy reactors to generate the nuclear electricity you wanted at the start of the simulation?
- Did you tell VISION to retire all the legacy reactors you created?
- Is the nuclear electricity that VISION calculated sufficiently close to what you intended?
- Is the number of "ready reactors" acceptable throughout the simulation?

6.3.2 Output_Reactors

If the file does not open in the **START HERE** worksheet, please go to it. "**START HERE**" is the left most worksheet. Verify the labels for reactor types. The spreadsheet is designed so that reactor types with a non-blank name will show data.

The worksheets in this file graph electricity generated per year (GWe-FPY/CY), operating capacity (GWe), capacity added each year (GWe/calendar year), capacity retired each year (GWe/calendar year). The first data worksheet has these data for all reactors for each run. The next five worksheets have these data by reactor type for each run.

There is also a ungraphed set of calculations that perform a "balance" check on the reactor capacity of each reactor type for each run. After the first year, the delta in capacity (new year - last year) should equal the capacity addition minus the capacity retired.

6.3.3 Output_Separations

If the file does not open in the **START HERE** worksheet, please go to it. "**START HERE**" is the left most worksheet.

This file pulls the data for the following parameters:

Separation capacity (tonnes/CY) requested by the user

Separation capacity (tonnes/CY) actually built

Separation flow (tonnes/CY) into separations from used fuel

Separation flow (tonnes/CY) from separations into buffer boxes

6.3.4 Output_Fuel_Masses

If the file does not open in the **START HERE** worksheet, please go to it. "**START HERE**" is the left most worksheet.

This worksheet examines the mass and flow of fuel throughout the system. This worksheet does not differentiate by chemical element or isotope.

There are three sets of worksheets.

- By run (all fuels) - total mass of fuel (all locations) for each run.
- By fuel (all loc) runs 1 through 5 - mass of fuel (all locations) by fuel type for each run.
- By loc by fuel runs 1 through 5 - mass of fuel, by location, by fuel type, for each run.

Even the last five worksheets group certain locations together to enable the graphs to be readable. The grouping is as follows:

- Uranium location = uranium conversion + uranium enrichment
- Fab location = fuel fabrication + ready fuel
- Reactor location = fuel in reactors
- Storage location = wet storage + dry storage + MRS
- Separations = separations processes + buffer between separations and fuel fabrication
- Repository = retrievable repository + permanent repository

The more detailed location breakdown can be found directly in **output data-1.xls** or **output data-2.xls**.

The last five worksheets also provide (ungraphed) the rate of reactor fuel input and reactor fuel output, by fuel type (not by reactor type).

6.3.5 Output_Fuel_Masses_By_Class

If the file does not open in the **START HERE** worksheet, please go to it. "**START HERE**" is the left most worksheet. The worksheet is similar to "Fuel Masses" with two key differences. It provides more detailed information in that the total mass is divided into uranium, individual TRU elements, and sum of fission products.

Similar to **Fuel Masses**, there are three sets of worksheets.

- By run (all fuels) - total mass of fuel (all locations) for each run.
- By fuel (all loc) runs 1 through 5 - mass of fuel (all locations) by fuel type for each run.
- By loc by fuel runs 1 through 5 - mass of fuel, by location, by fuel type, for each run.

Even the last five worksheets group certain locations together to enable the graphs to be readable. The grouping is as follows:

- Depleted uranium
- Uranium location = uranium conversion + uranium enrichment
- Fab location = fuel fabrication + ready fuel
- Reactor location = fuel in reactors
- Storage location = wet storage + dry storage + MRS
- Separations = separations processes + buffer between separations and fuel fabrication
- Repository = retrievable repository + permanent repository

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Appendix A

Pre-Defined Base Cases

This appendix describes the pre-defined base cases, which have three purposes. First, we originally developed most of these cases for the Scenario Definition, Evaluation, and Trade-offs (SETS) study.[Piet2006] They therefore provide some of the benchmarking used upon subsequent model upgrades. Section A-3.7 describes newer benchmark cases. Second, user study of the base cases can help understand how to use VISION to model various types of situations. Third, running the pre-defined base cases can help the user understand fuel cycle system dynamics in general and VISION in particular.

A-1. Phases

In previous versions of VISION and its predecessor model, DYMOND, there were three phrases associated with reactor technology development and deployment. All of the SETS base cases have that structure. Separation and waste management technology is held constant but reactor technology can change twice: phase 0 is the initial condition and lasts until the beginning of phase 1, and phases 1 and 2 are the second and third time periods.

Phase 0 is the initial time period; this phase starts in 2000 and always uses light water reactors without recycle, reflecting the current U.S. reactor fleet. The end of this phase is set by the start time for Phase 1. Under default conditions, the initial U.S. fleet in 2000 is assumed to have 103 light water reactors, of these, 86 reactors are assumed to be capable of only utilizing UOX fuel and are designated as LWRs in the model, while the remaining 17 reactors are assumed to be capable of utilizing UOX or MF fuel and are designated as LWR-MF.

Phase 1 is the second time period; this phase starts between 2000 and 2100 as defined in the different base cases. The value in the SETS base cases was either 2020 or 2025. Phase 1 continues until the start of Phase 2 (the start of Phase 2 is defined by the user in manual mode by the slider bar). Phase 1 is and should be earlier than Phase 2.

Phase 2 is the last time period; this phase starts between 2000 and 2100, it was 2040 in the SETS base cases. The end of Phase 1 is specified by the start time for Phase 2. Phase 1 always precedes Phase 2.

A-2. Fuel and Reactor Types

This subsection describes the different reactor and fuel types in the SETS base cases.

Many of the fuels which are listed below have specific transuranics listed such as Pu, Np, Am, or Cm. When these are included with the fuel type, only the transuranics specified are used within that fuel recipe. Each fuel recipe is very specific. This allows the user to track the use of the different transuranic elements.

A-2.1 Once Thru – No Recycle

This is uranium oxide (UOX) fuel that can be utilized in an LWR or LWR-MF reactors; there is no recycle material included. Selecting this option continues the fuel type from Phase 0. This fuel requires thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR-MF reactors used can be varied. UOX is the only fuel that can be used by the LWRs.

A-2.2 MOX-NpPu

Note: originally we referred to this option as MOX-PuNp but later changed terminology so that the list of transuranic elements is always in Periodic Table order. This fuel is mixed oxide (MOX) fuel made with Np, Pu, and recovered U (uranium that has been through a reactor as fuel) that can be utilized by LWR-MF reactors; recycling of fuel must be present for MOX to be produced. The MOX-NpPu recipe is a full core MOX or homogenous fuel assembly; it is intended to fill the entire core. The program is set-up to make as much MOX fuel as is requested and available; fuel requested but not available is made up by UOX fuel. This fuel requires LWR MF thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR MF reactors used can be varied. This base case uses the older MOX-NpPu recipe, which was for a single recycle. The **vision recipe ver5.xls file** now also contains a multi-recycle MOX-NpPu option.[Youinou2009]

A-2.3 MOX-NpPuAm

Note: originally we referred to this option as MOX-PuNpAm but later changed terminology so that the list of transuranic elements is always in Periodic Table order. This is mixed oxide (MOX) fuel made with Pu, Np, Am, and burned U (uranium that has been through a reactor as fuel) that can be utilized by LWR MF reactors; recycling of fuel (set later) must be present for MOX to be produced. The MOX PuNpAm recipe is a full core MOX; it is intended to fill the entire core. The program is set-up to make as much MOX fuel as is requested and available (this program carries an isotopic mass balance and uses the sum of elemental Pu as the determiner for the availability of MOX); fuel requested but not available is made up by UOX fuel. This fuel requires LWR-MF thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR-MF reactors used can be varied. MOX-NpPuAm fuel is user specified to have 1 – 5 passes (recycles). The original base case used older multi-recycle data for MOX-NpPuAm, which has been upgraded to higher quality data.[Youinou2009]

A-2.4 IMF NpPu

This is inert matrix fuel (IMF) made with Np and Pu and can be utilized by LWR MF reactors; recycling of fuel must be present for IMF to be produced. The IMF-NpPu recipe is a full core IMF; it is intended to fill the entire core. The program is set-up to make as much IMF fuel as is requested and available (this program carries an isotopic mass balance and uses the sum of elemental Pu as the determiner for the availability of IMF); fuel requested but not available is made up by UOX fuel. This fuel requires LWR MF thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR MF reactors used can be varied. This base case uses the older IMF-NpPu recipe, which was for a single recycle. The **vision recipe ver5.xls file** now also contains a multi-recycle IMF-NpPu option.[Pope2009]

A-2.5 IMF-NpPuAm

This is inert matrix fuel (IMF) made with Np, Pu,, Am, and depleted uranium (DU) and can be utilized by LWR MF reactors. Recycling of fuel must be present for IMF to be produced. The IMF-NpPuAm recipe is a blended core IMF, this means that in a single fuel assembly some of the pins will contain IMF and some will contain UOX made with DU. The program is set-up to make as much IMF fuel as is requested and available (this program carries an isotopic mass balance and uses the sum of elemental Pu as the determiner for the availability of IMF); fuel requested but not available is made up by UOX fuel. This fuel requires LWR MF thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR MF reactors used can be varied. IMF PuNpAm is user specified to have 1 – 5 passes (recycles). The original base case used older multi-recycle data for IMF-NpPuAm, which has been upgraded to higher quality data.[Pope2009]

A-2.6 IMF-PuNpAmCm

This is inert matrix fuel (IMF) made with Np, Pu, Am, and Cm can be utilized by LWR MF reactors. Recycling of fuel must be present for IMF to be produced. The IMF-NpPuAmCm recipe is a full core IMF; it is intended to fill the entire core. The program is set-up to make as much IMF fuel as is requested and available (this program carries an isotopic mass balance and uses the sum of elemental Pu as the determiner for the availability of IMF); fuel requested but not available is made up by UOX fuel. This fuel requires LWR MF thermal reactors for utilization; later in the set-up the relative proportion of LWR to LWR MF reactors used can be varied. This base case uses the older IMF-NpPuAmCm recipe, which was for a single recycle and stopped at Cm246. The **vision recipe ver5.xls file** now also contains a multi-recycle IMF-TRU option, which covers the entire range of TRU elements Np, Pu, Am, Cm, Bk Cf.[Pope2009]

A-2.7 FR-Burner

This selects **burner fast reactors**, designated as FBR (the "B" stands for either breeder or burner) in the model. Recycling of fuel must be present for fast reactors to operate. Burner fast reactors are net consumers of transuranics. Later in the set-up the relative proportion of LWR, LWR MF, and FBR reactors used can be varied. New fast reactors are not brought online unless there is sufficient fast reactor fuel available (based on Pu). Thermal reactors, LWR MF, are brought online to replace the capacity of fast reactors that cannot be brought online due to insufficient fuel. The LWRmf reactors use MOX or IMF fuel if that is part of the scenario; otherwise they use UOX if no thermal recycling is included in the scenario. The fast reactor is user specified to have 1- 5 passes (recycles). The original base case used older multi-recycle data for CR=0.25 metal fuel fast reactors, whereas these data have been retained for this base case, higher quality data for a range of CR is now available.[Hoffman2006, Hoffman2007]

A-2.8 FR-Breeder

This selects **breeder fast reactors**, designated as FBR (the "B" stands for either breeder or burner) in the model. Recycling of fuel must be present for fast reactors to operate. Breeder fast reactors are net producers of transuranics. Later in the set-up the relative proportion of LWR, LWR MF, and FBR reactors used can be varied. New fast reactors are not brought online unless there is sufficient fast reactor fuel available (based on Pu). Thermal reactors, LWR MF, are brought online to replace the capacity of fast reactors that cannot be brought online due to insufficient fuel. The LWR MF reactors use MOX or IMF fuel if that is part of the scenario; otherwise they use UOX if no thermal recycling is included in the scenario. The fast reactor is user specified to have 1- 5 passes (recycles). The original base case used older multi-recycle data for CR=1.07 metal fuel fast reactors, whereas these data have been retained for this base case, higher quality data for a range of CR is now available.[Hoffman, in publication]

A-3. Phase 1 - Phase 2 Box

Within the "phase 1 phase 2" box, is listed the entire selection of base cases from which the user may choose. At the end of the list are "User Defined" base cases which can be set by the user. In order to run one of the base cases, click the base case you want to run and hit the play button on the tool bar. All of the base cases listed before the "1-tier" cases start phase 1 in 2025 and phase 2 in 2040.

These descriptions are grouped according to what fuel/reactor is chosen for phase 1 among the base cases. This extensive set of base cases were developed to survey the fuel cycle options in 2005-2007 studies as well as test the behavior of the model under diverse conditions. There are six groupings from the SETS report [Piet2006] discussed in sections 3.1 through 3.6, as follows:

Phase 1 = once-through, i.e., recycling is delayed to phase 2.

Phase 1 = IMF-NpPuAm, i.e., multiple passes of blended, heterogeneous core IMF is used in Phase 1

Phase 1 = MOX-NpPu, i.e., a single pass of MOX-NpPu is used in Phase 1

Phase 1 = MOX-NpPuAm, i.e., multiple passes of blended MOX is used in Phase 1

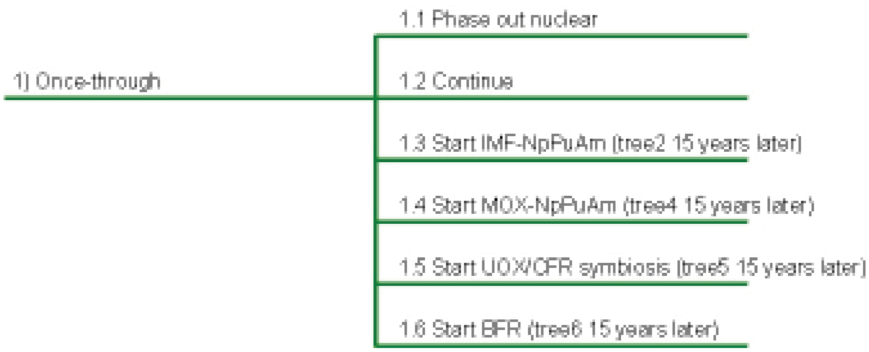
Phase 1 = FR burner with TRU conversion ratio of 0.25

Phase 1 = FR breeder with TRU conversion ratio of 1.07

The six groups include an explanation of why such a base case exists as well as the reasons for the differing phase 2 options given the same phase 1 option. Not all of the fuel types with all the different transuranic combinations are listed below.

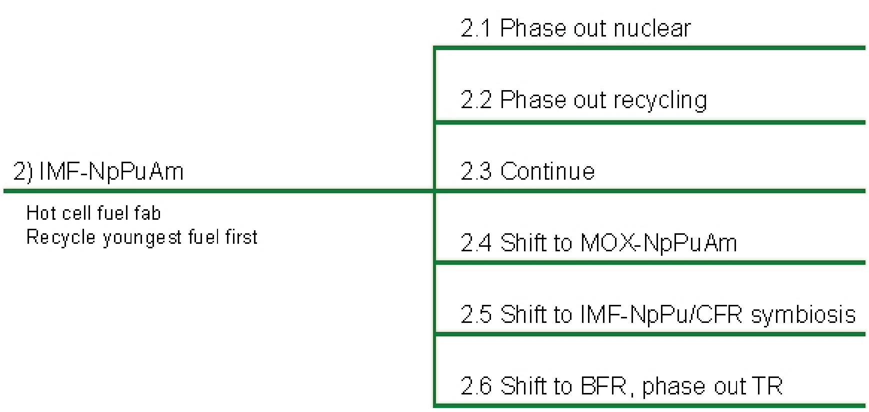
A-3.1 Once-Through

The purpose of using UOX fuel in phase 1 is to see the affects of delaying recycling until 2040. In 2040 phase 2 begins and there are six options listed. The six options listed for phase 2 allow for further exploration within the nuclear fuel cycle.



A-3.2 IMF-NpPuAm

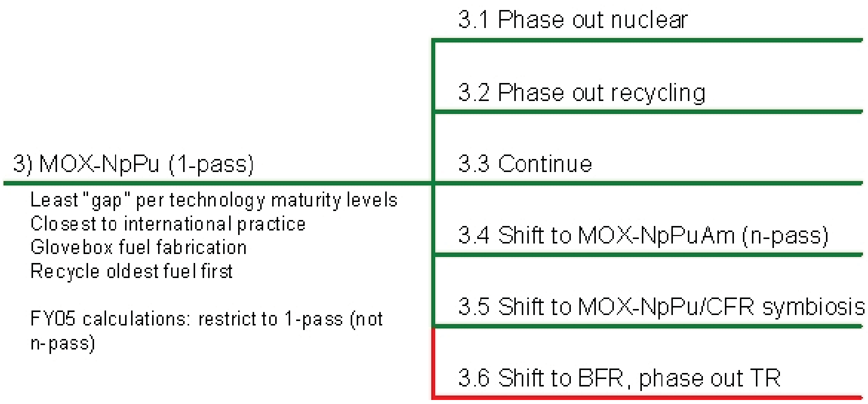
The purpose of using IMF-NpPuAm (which uses blended IMF/UOX cores) in phase 1 is to attempt the fastest possible reduction in LTH, LTD, and LTR using thermal reactors and UREX+ separation technology. Assumes n-pass IMF fuels and their separation are practical. This IMF approach uses blended fuel assemblies, with ¾ UOX and ¼ IMF, with the TRU in used fuel UOX and IMF in one generation making the IMF in the next generation. Other n-pass IMF approaches require analysis, including increasing the IMF/UOX ratio to further accelerate benefits or require fewer reactors to use the blend. 3 kt/yr separation plant starts in 2025. All fuel that can be made from that separation plant is assumed to be used in the growing TR fleet. The six options listed for phase 2 allow for further exploration within the nuclear fuel cycle.



A-3.3 MOX-NpPu

The purpose of using MOX-NpPu in phase 1 is the fact that this option most accurately resembles the current international practice and current technology, while avoiding separation of Pu. It is restricted to 1-

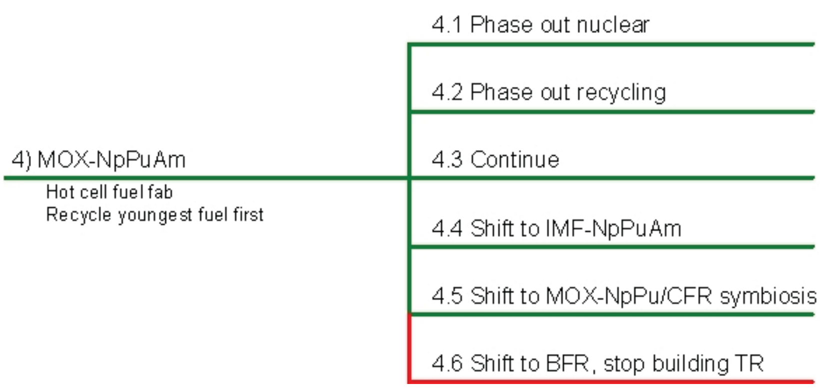
recycling pass in current analyses. The six options listed for phase 2 allow for further exploration within the nuclear fuel cycle.



A-3.4 MOX-NpPuAm

The purpose of using MOX-NpPuAm in phase 1 is to attempt modest repository benefits using thermal reactors, UREX+ technology, and fuels relatively similar to current UOX and MOX-Pu.

Assumes RU is the uranium component in MOX; the Pu/U ratio increases each cycle to keep the cores critical. Other n-pass MOX approaches require analysis, including keeping the core critical by increasing the uranium enrichment instead of the Pu/U ratio. The six options listed for phase 2 allow for further exploration within the nuclear fuel cycle.



A-3.5 FR Burner

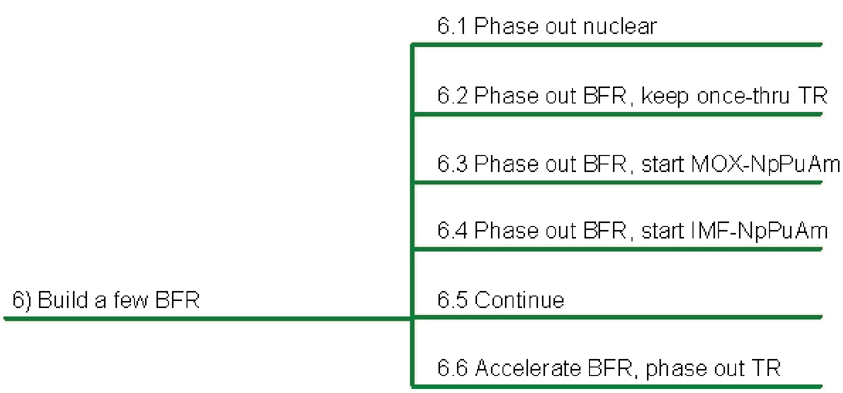
The purpose of using FR burner fuel in phase 1 allows for the exploration of the different pros and cons of FR burner reactors. The early FR experience would set the stage for BFR when uranium resources warrant. Balancing all the components of this type of system is not straightforward. FR deployment is limited by the amount of Pu available for FR fuel, existing FR's have 1st priority on fuel over new FR's, if insufficient fuel is available for FR's to start, the missing capacity is met by starting thermal reactors. The six options listed for phase 2 allow for further exploration within the nuclear fuel cycle.

In DYMOND and versions of VISION prior to 2.2, it was possible to start fast reactors and then phase out fast reactors with fuel in the fast reactor loop (separation, fuel fab, reactor) moving back to LWRs. Version 2.2 did not have this capability so that options 5.2, 5.3, and 5.4 could not be simulated. Version 3.0 now allows these options and we are rebuilding those base cases.

A-3.6 FR Breeder

Start breeder FR in 2025 and moves into FR, skipping recycling in TR. It aims to accommodate a hypothetical combination of limited uranium resources and high nuclear growth. It is unique among the options in that BFR uses depleted uranium.

In DYMOND and versions of VISION prior to 2.2, it was possible to start fast reactors and then phase out fast reactors with fuel in the fast reactor loop (separation, fuel fab, reactor) moving back to LWRs. Version 2.2 did not have this capability so that options 6.2, 6.3, 6.4 could not be simulated. Version 3.0 now allows these options and we are rebuilding those base cases.



A-3.7 Recent Pre-Defined Base Cases

The VISION benchmark and verification plan [Smith2007] identified 5 cases to use when testing new major releases of the model, see Table A-1. Three of those cases are among the SETS pre-defined base cases noted above. The last two use CR=0.50 fast reactors with and without a single recycle of MOX between UOX and fast reactors. We have defined five additional cases to exercise new capabilities in VISION 3.0, also in Table A-1.

Table A-1. Benchmark Cases

Case (Reactor Specifications)	Source of Data	Why Include	Comments
1=UOX at 50 burnup	SETS report [Piet2006 VISION benchmark [Smith2008]	VISION B&V plan [Smith2007]	Tests front-end capabilities
1=UOX-51 2=Single-mass MOX-NpPu			Tests thermal recycle
1=UOX-51 2=Multipass IMF-NpPuAm			Tests use of EU for the blended heterogeneous IMF Tests multipass recycling in thermal reactors
1= UOX-50 3= CR=0.50 fast reactor	VISION benchmark [Smith2008]		Exercise 1-tier capabilities Exercise external Pu supply
1= UOX-50 2= MOX 3= CR=0.50 fast reactor			Tests multi-tier dynamic transition case to demonstrate most complex situation
1 LWR per reactor slot	Self-generated	Tests 10 reactor slots Tests LWR BU correlation Tests legacy reactor retirement with 10 reactor slots	
1=LWR 2=HWR	Modification of INPRO GAINS benchmark (LWR and HWR business as usual)	Tests HWR capability Tests third method of growth specification	
1=LWR-UOX 2=LWR-MF 3=FR 4=LWR-UOX 5=HWR 6=LWR-UOX 7=HWR	Modification of INPRO GAINS benchmark (3 non-geographical regions)	Test partial multi-region capability Test having 4 reactor technologies	
Use all 10 slots 1 = LWR-UOX 2 = LWR MF 3 = FR-burner-metal 4 = FR-burner oxide 5 = FR-breeder metal 6 = HWR-UOX (no sep) 7 = HWR-DUPIC (new recipe) 8 = VHTR 9 = LWR-UOX region2 (no sep) 10 = blank (multiregion sep)	Self-generated	Tests 10 slots for reactor, separation, fuels. Tests wide range of reactor and fuel types concurrently. Tests fully automatic ordering of reactors, fuels, and separation capacity Tests draft ORNL HWR-DUPIC recipe	
1=LWR UOX 2=LWR MOX 3=FR Separation/fuel/reactor changes	Self-generated	Tests change of separation strategy Tests 4 phases Tests concurrent separation/fuel changes Tests phase out of thermal recycling	

A-3.7.1 One LWR per Reactor Type

This is a new case, designed to test 10 reactor slots, each has a single LWR in 2000. One LWR retires every 2 years starting in 2020, so that reactor-1 should retire first, then reactor-2, etc.

The fuels, however, differ among the 10 reactor slots, allowing test of the LWR burnup correlation feature, see Table A-2.

Table A-2. Reactor, Fuel, and Separation Specifications for One LWR per Reactor Type

#	Reactor	Fuel	Fuel #	Separations	Separation #
1	LWR	UOX 51 burnup	103	None	None
2	LWR	UOX 51 burnup	51	None	None
3	LWR	UOX 50 burnup	50	None	None
4	LWR	UOX 33 burnup	102	None	None
5	LWR	UOX 33 burnup	33	None	None
6	LWR	UOX 51 burnup	103	None	None
7	LWR	UOX 51 burnup	51	None	None
8	LWR	UOX 50 burnup	50	None	None
9	LWR	UOX 33 burnup	102	None	None
10	LWR	UOX 33 burnup	33	None	None

A-3.7.2 UOX-51 to CR=0.50 Fast Reactor

The 2007/2008 benchmark had the following basic parameters.

Table A-3. Reactor, Fuel, and Separation Specifications for Early 1-Tier Benchmark

#	Reactor	Fuel	Fuel #	Separations	Separation #
1	LWR	UOX	103	UREX+1	2
2					
3	FR	Metal CR=0.50	605	Electrochemical	21

A-3.7.3 UOX-51 to 1-pass MOX-Pu to CR=0.50 Fast Reactor

The 2007/2008 benchmark had the following basic parameters.

Table A-4. Reactor, Fuel, and Separation Specifications for early 2-Tier Benchmark

#	Reactor	Fuel	Fuel #	Separations	Separation #
1	LWR	UOX	103	UREX+3	11
2	LWR MF	MOX-NpPu	308	UREX+1	2
3	FR	Metal CR=0.50	605	Electrochemical	21

A-3.7.4 LWR and HWR Once Through

A new test case was developed from an INPRO GAINS benchmark described elsewhere.[Dixon2009] Key points of the scenario are as follows:

- Two types of reactors (LWRs and HWRs) in a once-through fuel cycle. Each 1 GWe capacity/reactor, 80% capacity factor, 33% thermal efficiency, and 40-year lifetime.
- 5000 GWe-year in 2100, 4700 for LWRs, 300 for HWRs
- Uses historic reactor capacities through 2008, then 6% HWRs thereafter
- Growth is based on fixed output at 2030, 2050, 2100 with linear growth between points. No additional growth after 2100.
- No growth after 2100.

The scenario is modeled using the third method of growth specification, namely set the target electricity production in 2100 and the percent of that target yearly from 2000 to 2100. Key specifications are in Table A-5.

Table A-5. Reactor, Fuel, and Separation Specifications for LWR and HWR Once-Through

#	Reactor	Fuel	Fuel #	Separations	Separation #
1	LWR	UOX (45 burnup)	108	None	None
2	HWR	Oxide (7 burnup)	203	None	None

A-3.7.5 Approximation of Three Regions

A new test case was developed from an INPRO GAINS benchmark described elsewhere.[Dixon2009] Key points of the scenario as they specified it are as follows:

- Region 1 = mature infrastructure, including recycling with fast burner reactors after 2040; 45% of historic growth, high future growth.
- Region 2 = mature infrastructure with both LWRs and HWRs, once-through fuel cycle with indefinite dry storage; 30% of historic growth moderate future growth.
- Region 3 = limited infrastructure with both LWRs and HWRs; 25% of historic growth, very high future growth.
    - Independent case - once-fuel fuel cycle, dry storage
    - Synergistic case - gets fresh LWR fuel from other regions (2/3^rd from Region 1, 1/3^rd from Region 2), returns SNF -No conversion or enrichment capabilities

VISION 3.0 was not designed for full multi-region capability. However, it can model many dynamics of multiple regions, including the mix of reactor and fuel types and most routing among reactor fleets. There are four ways in which it cannot directly model the above specification.

First, it cannot model enrichment or uranium mining segregated by region or reactor type or fuel type. In the real world, uranium enrichment and uranium mining are international commodities and VISION merely calculates the required flows for each of the 10 reactor fleets. A user trying to directly model the above specification would have to manually add the specified mining, conversion, enrichment, and UOX fuel fabrication flows from region 3 to region 1 and region 2.

Second, it cannot directly model the above growth specification. Recall that users can specify reactor growth in three ways:

- Specify growth for the combined nuclear reactor fleets on **Growth Rate** worksheet, specify the percent of that total allocated (by year) for each of the reactor types on the **Reactor %s** worksheet.
- Specify the precise number of reactors for each reactor types, by year, on the **Reactor #'s** worksheet.
- Specify the year-2100 electricity generated for each reactor type on the **Reactor Facility** worksheet, then specify (by reactor type), the percent of the year-2100 value for each reactor type by year on the **Reactor Growth %** of Final worksheet.

The first method treats the entire simulation as a single "region" in the sense that there is a single nuclear energy growth specification; the third method treats each reactor type as its own "region" in the sense that it has its own energy growth specification independent of other reactor types (other regions). The INPRO GAINS specification lies between these, with reactors 1-3, 4-5, 6-7 having 3 growth specifications. This would be modeled by VISION by any of the three methods if external calculations were done to translate the specifications. This of course loses some hypothetical dynamics of multi-region scenarios in that VISION would not have reactors 1-2-3, 4-5, 6-7 interacting with regard to growth among themselves. For example, if region 1 was as specified and region 2 had LWR and FR (instead of LWR and HWR once through), then a true multi-region scenario would require algorithms for deciding FR/LWR interaction in regions 1 and 2 either independent or dependent on each other. Alternatively, if region 2 had LWR and HWR but the HWR used the DUPIC fuel option (using used LWR fuel), then there would be an intra-region interaction between HWR and LWR. In the current specification; however, there is no intra-region interaction between 4-5 and between 6-7.

Third, VISION cannot directly model the fuel routing from region 3 back to regions 1 and 2. The INPRO GAINS specification is that 2/3 goes to region 1 and 1/3 goes to region 2. This is a "push/percent" routing approach, whereas VISION uses a "pull/priority" routing from reactor to separations. For VISION 3.0 testing, we merely want to test having mass flows among reactor and separation types. Region 2 (reactors 4-5) do not make or receive fuel from region 3. Region 3 (reactors 6-7) do.

Fourth and final, VISION does not have the ability to specify legacy reactor retirement by reactor type; instead it retires reactor-1 first, then reactor-2, etc. A more exact simulation of the INPRO GAINS case would be simulated by starting before 2000 so that there were no legacy reactors.

The total fleet is assumed to start at 100 GWe-FPY/calendar year, which is assumed to be 15% of total electricity. With all initial reactors assumed to be 1 GWe capacity operating at 90% capacity factor, there must be 111 reactors in 2000, allocated as in Table A-6.

Table A-6. Reactor, Fuel, and Separation Specifications for LWR and HWR Once-Through

#	Reactor	Assumed % in 2000	Fuel	Fuel #	Separations	Separation #
1	LWR	0.5 x 45% x 111 → 25	UOX (45 burnup)	108	UREX+3	11
2	LWR MF	0.5 x 45% x 111 → 25	MOX-NpPu	308	UREX+1	2
3	FR	Zero	Metal CR=0.50	605	Electrochemical	21
4	LWR	0.5 x 30% x 111 → 17	UOX (45 burnup)	108	None	None
5	HWR	0.5 x 30% x 111 → 17	Oxide (7 burnup)	203	None	None
6	LWR	0.5 x 25% x 111 → 14	UOX (45 burnup)	108	Back to sep-1	
7	HWR	0.5 x 25% x 111 → 14	Oxide (7 burnup)	203	Back to sep-1	

A-3.7.6 10 Reactor and Fuel Types

We created this test case to exercise all 10 reactor-separation-fuel-fab trains with a wide range of reactor types concurrently. It also gave us a chance to test a new (draft) fuel recipe supplied by ORNL for the DUPIC fuel cycle.

Table A-7. Reactor, Fuel, and Separation Specifications for LWR and HWR Once-Through

#	Reactor	Fuel	Fuel #	Separations	Separation #
1	LWR	UOX	103	UREX+3	11
2	LWR MF	MOX-Pu	301	UREX+1	2
3	FR	Metal CR=0.50	605	Electrochemical	21
4	FR	Oxide CR=0.50	610	Electrochemical	23 (mod of 21 but send to fuel-4 instead of 3)
5	FR	Metal CR=1.07	614	Electrochemical	24 (mod of 21 but send to fuel-5 instead of 3)
6	HWR	Oxide	203	None	None
7	HWR	DUPIC	204	None	None
8	VHTR	Oxide	201	None	None
9	LWR	UOX	103	None	None
10	None	None	None	Into DUPIC fuel	33 (modification of 32 but send fuel to 7 instead of 3)

A-3.7.7 Separation Technology Change

We created this scenario to test multiple concurrent reactor/fuel/separation technology changes. There are effectively four phases:

a - once through

b - recycle used UOX via COEX, make MOX-Pu, start fast reactors

c - recycle used UOX via UREX+4, make MOX-NpPuAm, continue fast reactors

d - recycle used UOX via UREX+1, phase out thermal reactor recycling

The transition from 1 to 2 tests the change in separation technology from not recovering the so-called minor actinides (Np, Am, Cm, Bk, Cf) to recovering them. We modeled this by changing from COEX (separation matrix 16) to UREX+4 (separation matrix 11) for the separation-1 type. Note that the specifications for reactor-2/fuel-2 do change (deliberately) in this example from early/middle from MOX-Pu (fed by COEX) to MOX-NpPuAm (fed by UREX+4).

The third phase tests phase out of thermal reactor use of recycled material. This means that separation-1 changes (from UREX+4 to UREX+1) and fuel-2 changes (from MOX-NpPuAm back to UOX).

This scenario tests the model (and user's) ability to coordinate changes as follows:

- **Reactor Fuel Type** worksheet
- **Recycle Strategy Option** worksheet from once-through (matrix 15) to 2-tier recycling (matrix 7) for both "b" and "c" phases to phase out thermal recycling (matrix 13).
- **Separation** worksheets

Table A-8. Reactor, Fuel, and Separation Specifications for LWR and HWR Once-Through

#	Reactor	Fuel	Fuel #	Separations	Separation #
1-a	LWR	UOX	103	None	None
1-b	LWR	UOX	103	COEX	16
1-c	LWR	UOX	103	UREX+4	11
1-d	LWR	UOX	103	UREX+1	2
2-a	LWR MF	UOX	103	None	None
2-b	LWR MF	MOX-Pu	301	UREX+1	2
2-c	LWR MF	MOX-NpPuAm	306	UREX+1	2
2-d	LWR MF	UOX	103	UREX+1	2
3	FR	Metal CR=0.50	605	Electrochemical	21