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Revision 1

Software Requirements Specification

Verifiable Fuel Cycle Simulation (VISION) Model

AFCI Economic Benefits and Systems Analysis Teams

November 2005

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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AFCI Economic Benefits and Systems Analysis Team

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Idaho Falls, Idaho 83415

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Acronyms

AFC	Advanced Fuel Cycle
AFCI	Advanced Fuel Cycle Initiative
ANL	Argonne National Laboratory
BCC	Base Construction Cost
CH	Contact Handled
COA	Code of Accounts
D&D	Decontamination and Decommissioning
DDS	Design description for software
DOE	U.S. Department of Energy
EMWG	Economic Modeling Working Group
FICA	Federal Insurance Contribution Act
FOAK	First-of-a-Kind
HLW	High-level Waste
IAEA	International Atomic Energy Agency
IDC	Interest During Construction
IMF	Inert Matrix Fuel
INL	Idaho National Laboratory
ISU	Idaho State University
LANL	Los Almos National Laboratory
LFR	Lead-Cooled Fast Reactor
LLW	Low-level Waste
LUEC	Levelized Unit of Electricity Cost
LWR	Light Water Reactor
MOX	Mixed Oxide Fuel
MRS	Monitored Retrievable Storage
MSR	Molten Salt Reactor
NOAK	Nth-Of-A-Kind
NRC	Nuclear Regulatory Commission
O & M	Operations and Maintenance
OCRWM	Office of Civilian Radioactive Waste Management
ORNL	Oak Ridge National Laboratory
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RH	Remote Handled
RTM	Requirements traceability matrix
SCMP	Software configuration management plan
SCWR	Supercritical-Water-Cooled Reactor
SFR	Sodium-Cooled-Fast Reactor
SMP	Software management plan
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratory
SQAP	Software quality assurance plan
SRS	Software Requirements Specification
STP	Software test plan
SWU	Separative Work Unit
TCIC	Total Capital Investment Cost
TOC	Total Overnight Cost
TRU	Transuranic
TSLCC	Total System Life Cycle Cost
UREX	Uranium Extraction Process
V&V	Verification and Validation
VHTR	Very-High Temperature Reactor
VISION	Verifiable Fuel Cycle Simulation Model
WBS	Work Breakdown Structure

WIT	What-It-Takes
WSRC	Westinghouse Savannah River Company
WU	Weapons Useable
YMP	Yucca Mountain Project

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Introduction

The purpose of this Software Requirements Specification (SRS) is to define the top-level requirements for a Verifiable Fuel Cycle Simulation Model (VISION) of an Advanced Fuel Cycle (AFC). This simulation application is intended to serve as a broad systems analysis and study tool applicable to work conducted as part of the AFCI (including cost estimates) and Generation IV reactor development studies. This is a "living document" that will be modified over the course of the execution of this work element, but with configuration control of the INL work package manager for AFCI Integrated Model Development, in consultation with the INL work package manager for AFCI Economic Benefits.

Need, Scope, and Purpose For VISION

There is a lack of validated and verified estimating models to support fuel cycle cost analysis. Previous cost studies have failed to provide a complete economic accounting of all the relevant fuel cycle costs (e.g., omission of D&D costs, refurbishment, or waste forms) that comprise the overall life cycle costs of a facility. Such "partial" studies can result in misleading conclusions. The goal of the VISION model is to establish a credible systems basis for an AFC and to create a reference source for fuel cycle unit costs.

Scope of VISION

VISION will dynamically simulate an AFC from cradle to grave, including mining of raw material to disposition of waste after electricity generation. It models the nuclear fuel cycle and accounts for, or accommodates changes in process capability, including transition from "design and construct to startup to equilibrium to final D&D" states as well as material, capital, and operating costs. To accomplish this cradle to grave analysis, VISION should simulate distinct fuel cycle activities, called modules, which represent the various front-end fuel cycle, back-end fuel cycle, waste disposition, and transportation functions.

Purpose of VISION

VISION is intended to be the AFCI system analysis simulation tool of the entire fuel cycle (including cost estimates) to assist in evaluating and improving major fuel cycle options against all four AFCI programmatic objectives – waste management, proliferation resistance, energy recovery, and systematic fuel management (economics, safety, at-reactor storage).

VISION is NOT intended to actually manage the fuel cycle. For example, there is no intent to track each fuel assembly from each reactor, as might be required for actual fuel management.

VISION will build upon the functionality contained in the Dynamic Model of Nuclear Development (DYMOND) originally developed for the Generation IV Fuel Cycle Cross Cut group. The VISION model will incorporate the DYMOND model and add (1) isotopic flow control and decay, (2) additional recipes from transmutation analyses such as VHTR with recycling, (3) simplified models for fuel separation and fabrication, (4) cost calculations, (5) uranium resources model, and (6) increased flexibility in transitions and combinations of individual fuel cycle technologies.

The VISION model will be used to:

- Quickly assess and evaluate, with reasonable accuracy, relative economic differences in fuel cycle strategies and timing.
- Understand issues and opportunities for keeping nuclear power an economically competitive option;
- Create an in-depth basis for understanding fuel cycle costs, their sensitivities and uncertainty; and
- Develop economic tools to evaluate creative solutions to make the nuclear fuel cycle cost competitive.
- Estimate a levelized cost of electricity.
- Compare strategies – once-thru, single-pass, multi-pass thermal, thermal/fast symbiotic, breeder.
- Compare technologies – IMF vs. MOX, separation processing, reactor type.
- Improve, but not optimize, scenarios.
- Simulate feedback looks, e.g., the conversion of a UOX-capable to MOX-capable reactor could be controlled by an algorithm involving the accumulation of available MOX, the cost of the conversion, the downtime for the conversion, cost of new reactors, etc.
- Explore new ideas vs. established lines of thinking.
- Conduct qualitative and quantitative comparisons of alternative fuel cycles with respect to:
    - resource requirements,
    - reactor types and mix,
    - sequencing and timing,
    - interim waste storage,
    - energy recovery,
    - proliferation resistance,
    - safety
    - waste streams, and
    - repository capacity and performance requirements.

Typical, but by no means all, of the questions that may be answered with VISION include:

- What does it take to defer or reduce number of repositories? When? Cost?
- How to reduce Pu inventory?
- How to reduce transportation costs and numbers?
- Should the US offer more fuel services?
- How much Pu may be made or destroyed from a scenario? When? How much in storage?

Users of VISION

There are two major groups of users anticipated for the VISION model. The user group will have a direct bearing on the implementation of some of the requirements described in the requirements section of this document.

Group 1: Composed of analysts, scientists, System Engineers, and model developers internal to the AFCI project within the Department of Energy (DOE) and affiliated National Laboratories or AFCI contractors. These users will be responsible for developing the model, conducting theoretical "what-if" scenarios to test assumptions and further refine alternatives, assessing the reliability and robustness of model results, and making suggested changes to the model based on their studies. In general this class of users will have access to internal versions of the model for testing, analysis and experimentation.

Group 2: Composed of analysts, scientists, System Engineers, and Department of Energy employees external to the AFCI project. These users will use a compiled or "locked" version of the model to conduct analysis and "what-if" scenarios within the published functionality of the model. These users will have access to approved and published versions of the software that have been through an established quality assurance process that verifies and validates the model.

VISION is not intended for use by people unfamiliar with advanced fuel cycles, the issues, terminology, and basic interrelationships.

High-Level Functionality

VISION will dynamically model an AFC from cradle to grave, including mining of raw material to disposition of waste after electricity generation. To accomplish this cradle to grave analysis, VISION should simulate distinct fuel cycle activities, called modules, which represent the various front-end fuel cycle, back-end fuel cycle, waste disposition, and transportation functions.

Each type of fuel cycle facility or activity is referred to as a module (see Figure 1). A module represents a specific fuel cycle function that is separate but dependent on other fuel cycle activities (e.g., the enrichment module is influenced by the enrichment required by the fuel manufactured in the fuel fabrication module). The modules are assembled in various ways to create different fuel cycle scenarios. The set of mass flow and economic assessment modules must be divided into the following types:

- Front-end
- Reactor
- SNF storage
- Recycling (separation, fabrication of recycled fuel, etc.)
- Back-end modules
- Transportation

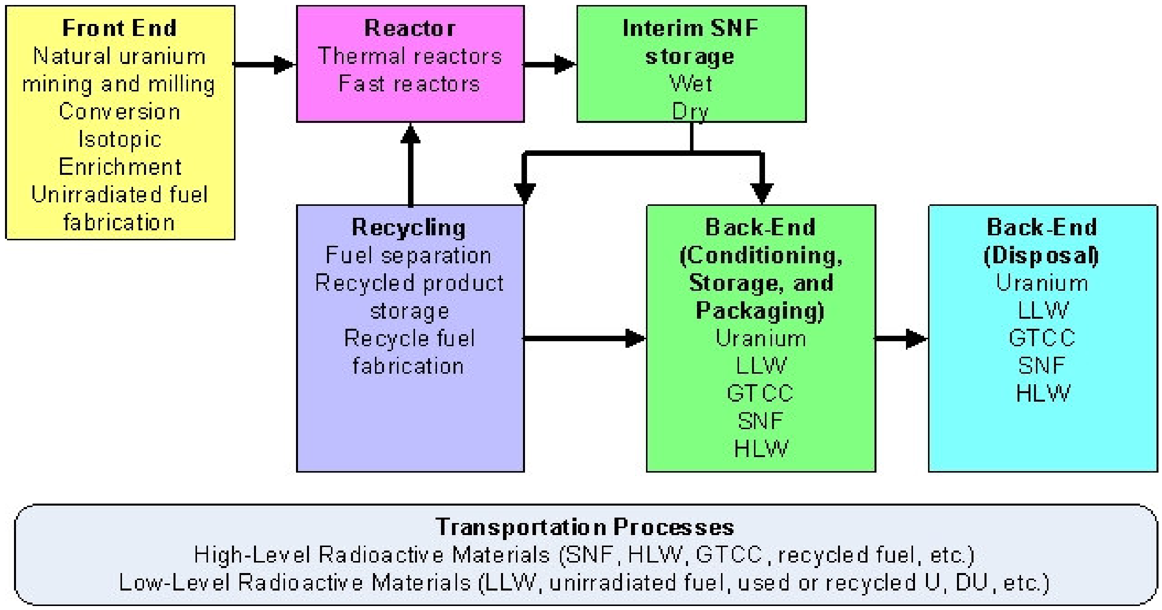

Figure 1. AFC Classes of Modules

Front-end Modules

The functionality of the front-end modules must include, but is not necessarily limited to, the modules sketched in Figure 2. The associated functionality does not necessarily have to be ultimately organized in this fashion (modules A, B, C1/C2, D1).

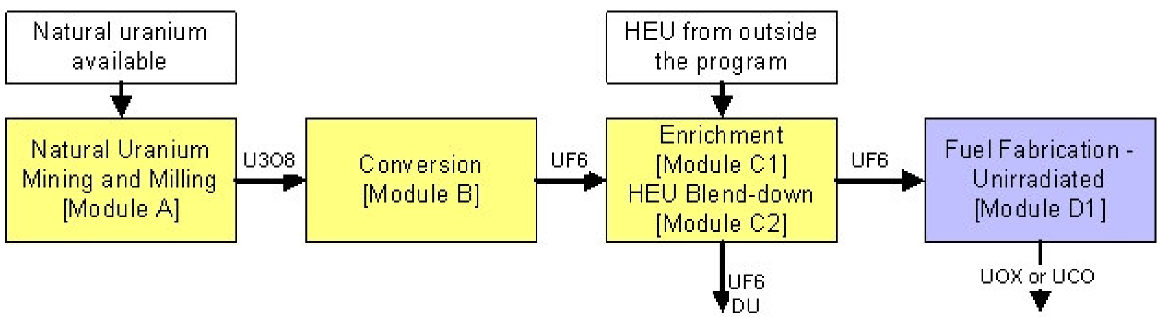

Figure 2. Front-end Module Functionality

The front-end fuel cycle modules are generally related to commodity types of services provided by commercial sources, hence "unlimited capacity" throughput.

Module	Module Name	Allow limited capacity?	General Description (NOTE, in VISION, these modules have both non-economic and economic versions, thus the descriptions are broader than only "cost")
A	Natural Uranium Mining and Milling	No	Includes the factors involving extraction of uranium from the earth through production of uranium concentrate in the form of U_3O_8 commonly known as "yellowcake." Module A needs to start with an initial stock of conventional-pessimistic resources, conventional-optimistic resources, or unconventional resources. The values are user defined, the default values shall be large (approximately infinity) so that generally the model is unconstrained when it runs.
B	Conversion	No	Takes the mined U_3O_8 concentrate and further purifies and converted to a UF_6 solid in cylinders for feed to a uranium enrichment plant.
C1	Enrichment (Isotopic Separation)	No	Uses the UF_6 solid in cylinders to enrich the % of U-235 from 0.711% to the 3–5% typical of the enrichment used for LWR fuel fabrication, or higher for typical VHTR fuels. Module C1 can supply LEU to either unirradiated fuel (module D1) or recycled fuel (module D2).
C2	HEU Blend-down	No	U.S. and Russian government-owned highly enriched uranium (HEU) blended down as a secondary supply to meet demand for low enriched uranium (LEU). Module C2 can supply LEU to either unirradiated fuel (module D1) or recycled fuel (module D2). Module C2 needs to start with an initial stock (outside AFCI, user defined, default=0) of existing HEU potentially available for blend-down.
D1 (and 8 submodules)	Fuel Fabrication – Unirradiated (contact handled)	Yes	Uses chemical, ceramic/metallurgical, and mechanical steps to take enriched UF_6 and convert it to finished fuel assemblies.

Reactor Modules

The functionality of the reactor modules must include, but is not necessarily limited to, the modules sketched in Figure 3. The associated functionality does not necessarily have to be ultimately organized in this fashion (modules R1, R2), but must be able to differentiate between thermal and fast reactors.

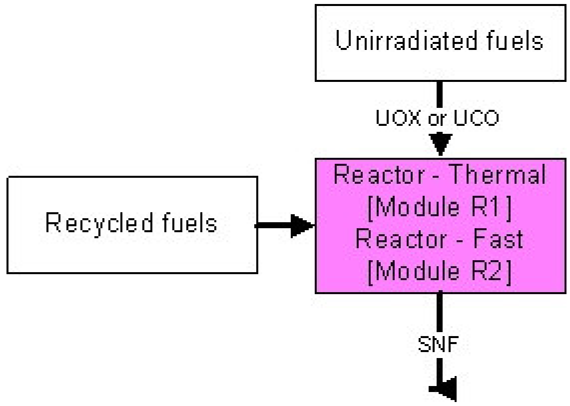

Figure 3. Reactor Modules

Reactors are integral to the fuel cycle. Reactor/transmutation baseline cost data are provided in Appendix C of the *2005 Advanced Fuel Cycle Cost Basis*. The SNF storage (Module E) and SNF packaging for transport and disposal (module H) are generally located at reactor sites.

The reactor modules are always handled in the "limited capacity" fashion.

Module	Module Name	Allow limited capacity?	General Description (NOTE, in VISION, these modules have both non-economic and economic versions, thus the descriptions are broader than only "cost")
R	Reactor (Thermal/Fast)	Always	Baseline data for future thermal and fast reactors are based on Generation IV Roadmap activity.

SNF Interim Storage Modules

When discharged from reactors, all fuels generate so much heat that they must be actively cooled, hence "wet" interim storage. As fuels cool, they can be transferred to either passively cooled ("dry") storage or packaged for shipment elsewhere (Figure 4). (The packaging module is covered elsewhere.) It is to be understood that "wet" does not necessarily mean water. For example, sodium-reactor metal fuel is actively cooled by placement in sodium, not water.

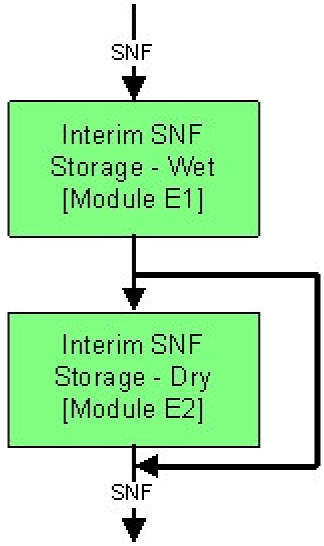

Figure 4. Spent Nuclear Fuel Interim Storage Modules

Module	Module Name	Allow limited capacity?	General Description
E1	Interim SNF storage – reactor wet	Eventually	Pool storage (at reactor) of SNF from existing commercial reactor operations. When fuel is sufficiently aged that active cooling is no longer required, it can be transferred to dry storage (module E2) or SNF packaging (module G2) for shipment elsewhere.
E2	Interim SNF storage – reactor dry	Eventually	Dry storage (at reactor) of SNF coming from reactor wet storage and includes handling costs involved with transfer from wet to dry storage. When it is moved, it goes to SNF packaging (module G2) for shipment elsewhere.

Recycling Modules

The functionality of the recycling modules must include, but is not necessarily limited to, the modules sketched in Figure 5. The associated functionality does not necessarily have to be ultimately organized in this fashion (modules G2, F1/F2, E3, D2), but must be able to differentiate between aqueous and pyrolytic separation. The recycle-fuel module (D2) must be able to accommodate many types of input (enriched uranium, DU, BU, NpPu, Am, Cm) and produce multiple types of recycle fuel. Unless the separation plant is co-located with reactors, SNF must be packaged (module G2) before it can be shipped to separation (or disposal).

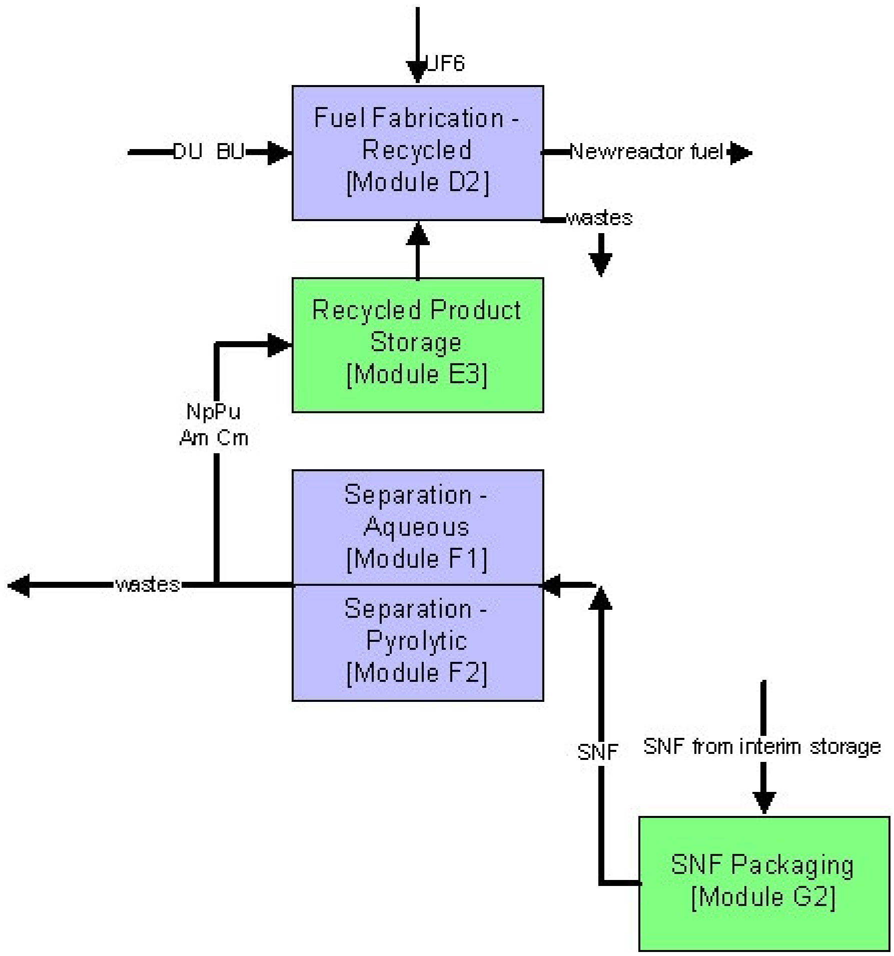

Figure 5. Recycle Modules

The recycle modules (D2, E3, F1 & F2, and G) are associated with reprocessing of the fuel and may be provided by some combination of government and private sources.

Module	Module Name	Allow limited capacity?	General Description (NOTE, in VISION, these modules have both non-economic and economic versions, thus the descriptions are broader than only "cost")
D2	Fuel Fabrication – recycled	Yes	Uses chemical, ceramic/metallurgical, and mechanical steps to take fissile material from the back-end fuel cycle to convert to finished fuel assemblies. In some cases, all stages of fabrication require remote fabrication, e.g., MOX-NpPuAm. In other cases, all stages require glovebox but not full remote handling, e.g., single-pass MOX-NpPu. In other cases, some steps are contact, some are glovebox, and some are fully remote, e.g., assemblies that blend UOX, IMF-NpPu, and Am targets.

Module	Module Name	Allow limited capacity?	General Description (NOTE, in VISION, these modules have both non-economic and economic versions, thus the descriptions are broader than only "cost")
E3	Recycled products storage	Eventually	Storage of the actinide by-products produced from the reprocessing of thermal reactor and fast reactor fuels. Would typically be required to support blending needs. Module E3 should start with an initial stock (outside AFCI, user defined, default=0) of potentially available weapons-grade Pu that could be added to the fuel cycle system. Blending WG-Pu into new fuel would be accounted for in module D2.
F1	Separation – Aqueous (Elemental Separation)	Yes	Separation of SNF elemental components using aqueous process to support recycling of fissile materials. Includes receipt of SNF through end-product production.
F2	Separation – Pyrolytic (Elemental Separation)	Yes	Separation of SNF elemental components using a pyrolytic process to support recycling of fissile materials. Includes receipt of SNF through end-product production.
G1	HLW Conditioning, Storage, and Packaging	Eventually	Conditions the waste, provides interim storage of the treated waste, and packages the HLW in preparation for transport to a repository. Module G1 is downstream of separation and fuel fabrication.
G2	SNF Conditioning, Storage, and Packaging	Eventually	Same as G2, but for unprocessed SNF instead of HLW. Module G2 is downstream of wet storage (module E2) and dry storage (module E1).

Back-end Modules

Some of the back-end fuel cycle modules (I, L and M) are the responsibility of the government as provided by the Nuclear Waste Policy (NWPA)[1]. Only a limited number of these types of facilities would be built (Figure 6).

[1] Information on the NWPA can be found at http://www.ocrwm.doe.gov/ymp/about/nwpa.shtml.

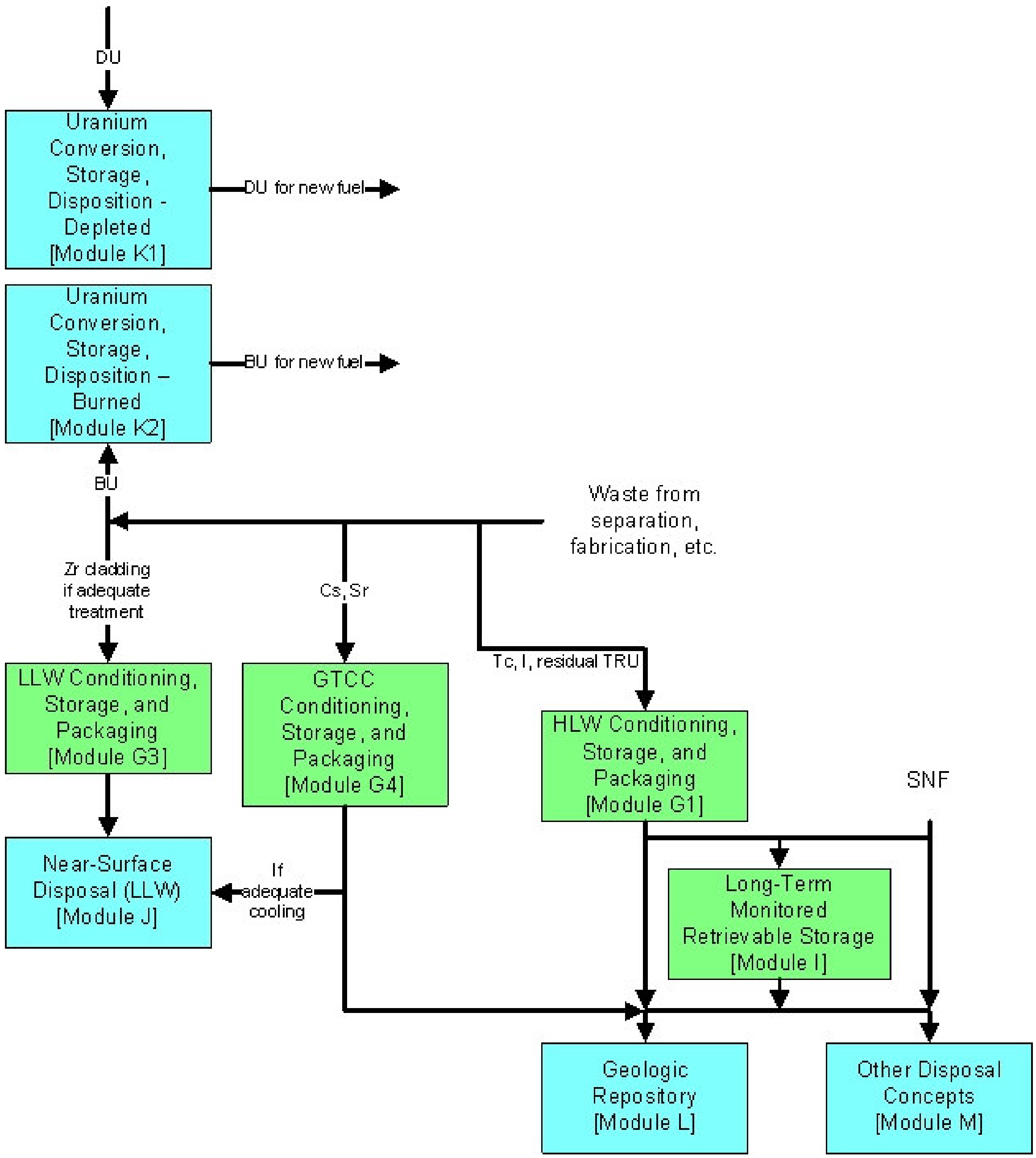

Figure 6. Back-end Modules

Module	Module Name	Allow limited capacity?	General Description
G1	HLW Conditioning, Storage, and Packaging	Eventually	Conditions the waste, provides interim storage of the treated waste, and packages the HLW in preparation for transport to a repository. Module G1 is downstream of separation and fuel fabrication.
G3	LLW Conditioning, Storage, and Packaging	Eventually	Mass flow e.g. for LWR with Zr clad fuels are to be disposed as LLW instead of GTCC or HLW.

Module	Module Name	Allow limited capacity?	General Description
G4	GTCC Conditioning, Storage, and Packaging	Eventually	This is analogous to G1, G2, and G3 but for waste that is GTCC at time of separation, e.g, Cs and Sr. Cs and Sr must either (a) be stored ~300 years to qualify for near-surface disposal (module J) or (b) be disposed as GTCC. Under current NRC rules, the only disposition path for GTCC is geologic repository (module L)
I	Long-Term Monitored Retrievable Storage	Yes	Long-term storage of SNF/HLW until shipped to a geologic repository.
J	Near Surface Disposal (LLW)	Eventually	Engineered or trench disposal of LLW including waste and fill placement, and monitoring.
K1	Uranium Conversion, Storage, and Disposition - Depleted	Low priority	Conversion, storage, and disposal of depleted UF_6. In some scenarios, this material is later withdrawn to use in breeder fast reactors.
K2	Uranium Condition, Storage, and Disposition - Burned	Low priority	Conversion, storage, and disposal of burned uranium. In some scenarios, this is only a brief holding pad for BU from separation (module F) to fuel fabrication (module D2). In other scenarios, this can be "permanent" disposal (as can be DU in module K1) with withdrawal decades later, if at all. Because of the high cost of TRU storage in module E3, we do not store burned uranium there; hence the need for a new BU module.
L	Geologic Repository	Yes	Includes inception through closure for repository operations. VISION will keep the following streams separate – SNF (which may be withdrawn later), HLW, and GTCC.
M	Other Disposal Concepts	Yes	Speculative SNF/HLW disposal alternatives to a deep geologic repository, such as deep bore hole, and others.

Transportation Modules

The functionality of the transportation modules must include, but is not necessarily limited to, the modules sketched in Figure 7. The associated functionality does not necessarily have to be ultimately organized in this fashion (modules O and P), but must be able to differentiate between low-level and high-level radioactive materials.

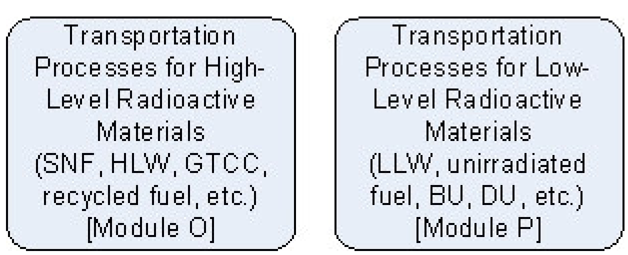

Figure 7. Transportation Modules

The transportation modules (O and P) support the transport of new fuel, recycled fuel, and shipment of SNF, HLW and low-level waste (LLW). Transportation of raw fuel to the reactor is provided by the reactor owner/utility. SNF transportation from the reactor to interim storage and the repository is the responsibility of the government. High-level waste and LLW transportation resulting from recycling could be provided by some combination of government and private sources.

Module	Module Name	Allow limited capacity?	General Description
O	Transportation for High-Level Radioactive Materials	Not applicable	Transportation of recycled irradiated fuel and SNF/HLW per relative unit, includes handling not already included in interim storage. Includes required operations to condition and package the SNF for shipment to the repository, interim storage, or to a reprocessing facility. NOTE: the non-economic version of this module, without economics, will assemble an estimate of all flows of classes of materials, e.g., GTCC, HLW, SNF, recycled fuel.
P	Transportation for Low-Level Radioactive Materials	Not applicable	Transportation for new fuel, unirradiated materials, and LLW per relative unit, includes handling not already included in interim storage. NOTE: the non-economic version of this module will assemble an estimate of all flows of classes of materials, e.g., unirradiated fuels, BU, DU, EU, and LLW.

Assumptions

The following assumptions are made regarding the development and use of VISION:

- Existing models that satisfy all or part of the expectations and requirements described in this document will be located and be used if possible.
- Some new development or modification of existing models will be needed to satisfy all the requirements.
- The model needs to be developed or modified in time to help provide cost comparisons for decisions anticipated in 2007.
- The model will be distributed and used beyond the INL.
- The model will be of sufficient quality to pass independent external (external to the INL) review for compliance with requirements and for technical soundness.

Requirements

The following section describes the team's/customer's requirements for VISION. These requirements are divided into six major subject areas. Priority for each requirement is indicated by a 1, 2, or 3 designations.

Flow Model Variables

No.	Name	Description:	Priority	Acceptance Criteria:
1.1	Track Mass Inventories	Track the total mass (Kilogram, Kg) flows and inventories of Fresh Fuel, SNF, Recycled material, HLW, TRU through each phase of the nuclear fuel cycle (fuel development, reactors, recycling, storage).	1	Verify output against base cases run from DYMOND-US. 10-09-05 Ver1. Verify SNF Produced, Total Recycled Material and HLW Produced. (All Modules)
1.2	Track Isotopes Mass Inventories	Track the total mass (Kilogram, Kg) and process losses of the isotopes of interest through each phase of the nuclear fuel cycle (fuel development, reactors, recycling, storage).	1	Verify output against base cases run from DYMOND-US. 10-09-05 Ver1. Verify SNF Produced, Total Recycled Material and HLW Produced.
1.3	SNF composition	For each Fuel Recipe fed into a reactor estimate the mass of SNF (Kilograms, Kg) that exits the reactor at the end of its reactor fuel cycle. This should be done for each isotope of interest in the fuel.	1	Verify output of several selected fuel recipes against Argonne spreadsheet estimates.
1.4	U Needed	For each scenario, estimate the mass (Kilogram, Kg) of U, U233 and U235 and U233 needed for the fuel supply used in the reactors.	1	Verify base cases against spreadsheet calculations.
~~1.5~~[2]	~~Material Availability~~	~~Estimate material availability, timing and volume, of recycle materials.~~	~~1~~	~~Verify(1) that the model is correctly estimating the quantity of available material for each time period. The available material includes fuel components such as Np, Am and Cs. User selectable table(s)/chart(s) that track estimated raw material available. (Modules affected: A, B, C, D1, K)~~
1.6	Transportation Volume	Track the kg-miles transported per year between scenario locations (see requirement 4.13) for: 1. Uranium concentrates, 2. Fabricated fuel, 3. SNF, 4. Recycled fuel, 5. Waste	2	Verify(1) that the model is correctly estimating transportation volume at each time period for each of the identified submodels. The model interface will supply a user selectable table(s)/chart(s) that tracks transported material.

[2] Requirements shown with strikethrough text were included in Rev. 0 of this document, but have been dropped as a requirement in this revision.

No.	Name	Description:	Priority	Acceptance Criteria:
1.7	Number Of Shipments	Estimate the number of shipments, based on the transportation type(s) selected to a repository for: 1. SNF, 2. HLW 3. Recycled fuel	2	Verify against spreadsheet calculations based on use cases.
1.8	Energy Efficiency Factor	Calculate changes in energy efficiency factor.	1	Verify against spreadsheet calculations based on use cases.
1.9	Radiotoxicity Indices Of SNF/HLW	Calculate the long-term heat generation in a repository (LTH), long-term groundwater hypothetical dose from the repository (LTD), long-term radiotoxicity (LTR), weapons-usable inventory (WU)	1	Verify against spreadsheet calculations based on use cases.
1.10	Radioactive Decay	Estimate mass (Kilogram, Kg) lost through radioactive decay for each isotope of interest for any stocks with a holding time greater than one - year for each: 1. Model module 2. Inventory at each generation of recycle 3. Location scenario selected by the user.	2	Verify against spreadsheet calculations based on use cases.
1.11	Heat Load	Estimate the heat load from material placed in the geological repository.	1	Verify against spreadsheet calculations based on use cases.

Economic Analysis Functionality

No.	Name	Description:	Priority	Acceptance Criteria:
2.1	Facility Ownership Cost	Estimate cost for recycle facility ownership options including: 1. government, 2. private, 3. hybrid (government and private). Recognize that different facilities have different "owner" ship.	2	Verify against spreadsheet calculations based on use cases.
2.2	AFCI Cost Modules	Incorporate cost module variables that are consistent with the AFCI Cost Basis report. Ability to use mass flows, volumes, waste form, reactors data, and specified modeling inputs to calculate representative fuel cycle costs for each module.	1	Verify modules against current Functional & Operational Requirements and interface relationships defined in AFCI Cost Basis.
2.3	Total Costs	Estimate total fuel cycle and system costs including the LUEC, that includes fuel cycle and reactors cost a per kWh basis.	1	Verify against cost data from accepted reports or from EMWG spreadsheet calculations. ($/kWh)
2.4	Separation Cost	Estimate the separation cost as a function of different separation product combinations.	3	Verify against cost data from accepted reports or from spreadsheet calculations.
2.5	Fuel Fabrication Cost	Estimate recycle fuel fabrication cost ($/kg) as a function of key processing parameters that can drive costs (e.g., fuel type, gamma field, neutron emission rate, heat rate and facility size).	3	Verify against cost data from accepted reports or from spreadsheet calculations.
2.6	Front-end Fuel Cycle supply and demand	Incorporate Uranium front-end supply/demand variables and relationships to enable pricing fuel costs based on selected market conditions.	3	Compare results to separate spreadsheet or calculations performed through separate Uranium model.
2.7	Back-end Fuel Cycle	Incorporate variables and algorithms to mimic simplified functionality of the RW-Total System Model (TSM).	3	Compare modeling results for packaging, transportation, and disposal against RW- cases run with the TSM.
2.8	Facility Conversion Costs	Estimate the total cost ($) to change the capabilities of a facility, e.g., change UOX-capable reactor to a MOX and UOX capable reactor.	3	To be determined
2.9	Manual Cost Overrides	Allow the user to override module costs including setting reactor costs to zero to obtain fuel cycle cost estimates only.	2	Verify that the interface allows the user to override preset module cost algorithms.
2.10	Cost Uncertainty	Provide functionality to perform (DPL like) cost uncertainty analysis and provide Tornado and Rainbow diagrams of cost variables that have significant impacts on the costs.	2	Verify that model provides uncertainty analysis consistent with independent DPL calculations.

No.	Name	Description:	Priority	Acceptance Criteria:
2.11	Case Cost Comparability	Provide functionality to compare individual modules, total modules, and LUEC costs between multiple cases and provide means to identify differences in case assumptions.	1	Evaluate separate cases individually.
2.12	Fuel Cycle Economic Analysis	Provide capability to perform the waste flow analysis independent from the economic analysis, with the ability to turn economic capability on/off without influencing the balance of the model.	1	Verify functionality to turn off the economics.

Analysis of Estimates or Measures

No.	Name	Description:	Priority	Acceptance Criteria:
3.1	Alternative Comparison	Display alternative strategy/scenario in a simple to compare format such as chart and/or table with differences calculated for all model variables.	1	Confirm that the model interface includes the functionality to run comparative scenarios and has the ability to display charts and tables that list the results to allow easy comparison of scenario outcomes. (User interface)
3.2	Sensitivity	Perform sensitivity analysis of outcome values based on selected/key input parameters. Display the results in a chart and/or table.	3	Confirm that the model interface includes the functionality to run sensitivity analysis.
3.3	Optimize a Scenario	Optimize selected output variables based on a set of selected input parameters that use a user supplied objective function(s).	3	Confirm that the model interface includes the functionality to run optimizations with user defined objective functions.
3.4	Reactor Construction	Estimate when reactors are constructed (fleet size) based on unsatisfied electricity/H2/other demand, retirement age of existing reactors, first available date for new design, and mix for U and TRU management,	1	Reactor fleet size determined dynamically based on above criteria. Verify output against base cases run from DYMOND-US. 10-09-05 Ver1.
3.5	Reactor Number And Mix	Estimate the reactor number and mix based on total unsatisfied electric and/or H2/other demand, retirement age of existing reactors, first available date for new design, mix for U and TRU management,	1	Verify reactor number and mix determined dynamically based on electric demand against spreadsheet calculations.
3.6	Separation and Fuel Fabrication Capacity	The model must be able to be run with either unlimited separation and fuel fabrication capacity - or - with user-defined capacity increments.	1	Verify reprocessing capacity is determined dynamically based on need, unit size and time to construct against spreadsheet calculations.
3.7	Data Confidence Intervals	Provide confidence intervals for selected output variables.	2	Verify modeling software has capability to calculate confidence intervals.
3.8	Reactor Construction based on Burn up	Reactor fleet size determined dynamically. Based on economics. (such as mill/kW-hr if a function of burnup, amount to be sent to repository, CO2 credits, government economic factors, anywhere in the system, etc.) consider both H2 and electricity OR - link with other models e.g. NERAC	1	Reactor fleet size determined dynamically based on above criteria. Verify output against base cases run from DYMOND-US. 10-09-05 Version 1.
3.9	Reactor Number And Mix based on Burn up	Reactor number and mix determined dynamically based on electric demand. Based on economics.. ((such as mill/kW-hr if a function of burnup, amount to be sent to repository, CO2 credits, government economic factors, anywhere in the system, etc.) consider both H2 and electricity OR - link with other models e.g. NERAC	1	Verify reactor number and mix determined dynamically based on electric demand against spreadsheet calculations.

No.	Name	Description:	Priority	Acceptance Criteria:
3.10	Dynamically Create Reprocessing Capacity	The model should dynamically create reprocessing capacity based on need, unit size, time to construct (forward projection) and allow user defined reprocessing capacity.	2	Verify reprocessing capacity is determined dynamically based on need, unit size and time to construct against spreadsheet calculations. Verify user defined reprocessing capacity is available.

General Model Architecture Elements

No.	Name	Description:	Priority	Acceptance Criteria:
4.1	Graphical User Interface	Develop a Graphical User Interface (GUI) for selection of values of input variables and user selected options.	3	Confirm that the model has a user interface available that allows the user to specify input parameters and run scenarios.
4.2	Default Values	Provide default values for all input variables.	1	Confirm that initially that model interface input parameters are initialized with default values.
4.3	Multi-dimensional Arrays	Provide the capability to work with up to a six-dimensional array, with a minimum of three dimensions.	1	Verify that the interface has acceptable default values at startup time.
4.4	Input interface	Model could be run: (a) through GUI, (b) input deck, (c) at the programming/modeling level	1	Verify that the GUI has a selectable interface based on technical expertise or password profile
4.5	Select Inappropriate Input Warnings	Allow user to select the level of warning for inappropriate input. Model can be run with (a) prevent inappropriate input values, (b) allow but warn, (c) warning turned off. If running in GUI mode, automatically prevent inappropriate input values. If running in "input deck" or "programming/modeling" level, then prevent, warn, no-warn are all options.	2	Verify that the model has selectable warning flags on input parameters.
4.6	Reactor Mixes	Allow the user to define the mix of reactors and adjust the mix through time.	1	Verify that the interface allows the user to specify the reactor mix.
~~4.7~~	~~Reactor Cost~~	~~Allow the user to input reactor cost or set the cost to zero for fuel cost estimates only.~~	~~2~~	~~Verify that the interface allows the user to specify reactor cost~~
4.8	Fuel "Types" and burn-up	Allow the user to define fuel "types" in terms of reactor type, achievable burn up, etc.	1	Verify that the interface allows the user to specify fuel types in terms of reactor type, achievable burn up.
4.9	Burn Up Rates	Allow the user to select among discrete values associated with input/discharge data composition sets, each labeled as to its burn up.	2	Confirm that the interface allows the user to select discrete burn up rates based on reactor/fuel types.

No.	Name	Description:	Priority	Acceptance Criteria:
4.10	Reprocessing Throughput	Allow users to adjust input to reprocessing facility as function of fuel age (minimum). Allow as strategies (a) oldest fuel first. In either case, also allow user to determine/input minimum fuel age at time of reprocessing. (default value is 5 years)	1	Verify that the interface allows the user to adjust reprocessing throughput as a function of fuel age.
4.11	The Size/Throughput Rates	Allow the user to adjust the size/throughput rates of specific classes of facilities (modules).	2	Verify that the interface allows the user to adjust the size/throughput rates.
4.12	Modes of Operation	Allow three modes of model operation: (a) User input controls discrete processing plant capacity growth + discrete repository capacity growth. Then interim storage is the free variable and both processing plant and repository unit sizes must be input/default. (b) User input controls discrete processing plant and interim storage capacity limit. Then repository inventory is the free variable. (c) User input controls interim storage and discrete repository. Then processing plant required is the free variable.	1	Verify that the interface allows the user to run the model via the 3 modes of operation.
4.13	Location Scenarios	Allow the user to select different location scenarios (e.g. on-site processing, regional, national, global, or fixed (e.g. 1500 miles)).	2	Verify that the interface that allows the user to select different location scenarios (national, regional or fixed).
4.14	Modes Of Transportation	Allow the user to select different modes of transportation for each material stream and the volume per load for a specific transportation mode (i.e. road, rail).	2	Verify that the interface allows the user to select different transportation modes and volumes for material streams.
4.15	Energy Outlook	Allow user to either: (a) define growth rate, (b) use default projection such as EIA, (c) input data from other models, (d) dynamic link with other models	1	Verify that the interface allows the user to specify the energy demand from either a defined growth rate from a variety of internal and external sources (e.g. NEMS).
4.16	Timing And Sequencing	Allow the user to define certain timing and sequencing parameters, such as, interim storage time, reprocessing time, etc.	1	Verify that the interface allows the user to adjust the timing and sequencing for system parameters.
4.17	Select Input Materials Streams	Allow the user to select for different input materials streams (e.g. fuel).	1	Verify that the interface that allows the user to specify different input material streams.

No.	Name	Description:	Priority	Acceptance Criteria:
4.18	Select For Recycled Streams	Allow the user to select for different recycled product streams coming out of recycling (MOX/IMF/FR).	1	Verify that the interface allows the user to specify different recycled product streams coming out of recycling.
4.19	Loading And Fuel Management Scheme	Allow the user to input the loading and fuel management scheme (how much of each fuel type to start up, how much core/target/blanket replaced each refueling, etc.) for each reactor type.	1	Verify that the interface allows the user to input loading and fuel management schemes (how much of each fuel type to start up, how much core/target/blanket replaced each refueling, etc) for each reactor type.
~~4.20~~	~~Escalation Schemes~~	~~Allow the user to input different escalation schemes (e.g. Use U.S. Department of Labor statistics for escalation of operations costs.).~~	~~2~~	~~Verify that the interface allows the user to specify which escalation scheme to use (e.g. US Department of Labor statistics for escalation of operations costs).~~
4.21	Interest Rate	Allow the user to input different interest rates (e.g. Use U.S. Department of Treasury statistics for interest rates). Selectable as different for different capital projects (at the module level) in fuel cycle, esp. if owner varies.	2	Verify that the interface allows the user to specify which escalation scheme to use (e.g. US Department of Labor statistics for escalation of operations costs).
4.22	Objective Function	Allow the user to define an objective function that will optimize a specific set of outcome parameters based on selected model parameters. (see optimization requirement 3.3).	2	Verify that the software allows the user to define and run an objective function for optimization.
4.23	Save and retrieve Input Files	Allow the user to save and retrieve input files to a file name and location of their choice and to reuse the saved file for later runs. Or create input files from other sources outside of this model.	1	Verify that the interface allows the user to save/retrieve input files.
4.24	Graphical Output	Have the ability to produce graphical output of all model variables, or reports/variables from an available list (see requirement 4.25) as they change through time.	1	Verify that the interface has the functionality to produce charts/tables of all model variables selected by the user.
4.25	Select Outputs	Allow the user to select the number and type of output display or charts from an available list.	1	Verify that the interface allows the user to specify the type of output (charts/tables) for each system variable.
4.26	Flag Extreme Conditions	Flag output variables that exceed reasonable conditions.	3	Verify that extreme condition warning messages flag when the model has exceeded reasonable conditions.
4.27	Drill Down Capability	Provide high-level visual displays of the model output that users can "drill down" through to increasing levels of detail for causal tracing.	2	Verify that the interface allows layered summary reports that allow progressively more detailed sub reports.
4.28	Time Step Capability	Provide the user the capability to adjust the time limits and time increments so that users can step through time to interpret system behavior.	2	Verify that the interface that allows the user to adjust time parameters and step through time and view the selected outputs.

No.	Name	Description:	Priority	Acceptance Criteria:
4.29	Save Output Files	Allow the user to save output files to a file name and location of their choice.	2	Verify that the interface allows the user to select and store scenario output data.
4.30	Internal Consistency Checks	Provide model internal consistency checks to prevent running simulation cases that are not physically realizable.	2	Verify that the model has built-in consistency checks to prevent unrealistic conditions.
~~4.31~~	~~Non-Linear Changes In Cost Variable~~	~~Provide for non-linear changes in cost variable such as materials supply.~~	~~2~~	~~Verify that the model has the functionality to use non-linear functions in cost variables.~~
4.32	Fuel Blending	Provide for ability to accommodate fuel blending requirements relative to supply and product constraint assumptions including related inventory requirements.	3	Verify that the model has the functionality to blend fuel based on supply and product constraints.
4.33	Interface with DPL software	Provide an output file at the end of a simulation from a user specified time step that can be used by a DPL software program.	1	Verify that the model produces an output file and that the output file can be read by a DPL software package.
4.34	Number of isotopes	Model must be able to track up to 100 isotopes. In each case, the chemical element and the atomic number (and meta-stable state if relevant) must be differentiated. The model must also incorporate the half-life of each isotope to facilitate shifting between mass units and activity units.	1	Verify the model can handle multi-dimensional arrays with up to 100 elements in a dimension
4.35	On/Off	Provide the user the option to turn on/off the economics calculations for a simulation.	1	Verify that the interface allows the user to turn the economic analysis on and off for a simulation.
4.36	Missing economic data alert	Alert users when economic or cost data is not available due to the simulation configuration specified by the user.	2	Verify that the interface alerts the user when economic data is not available for a simulation configuration.
4.37	Model Configuration	Provide high-level visual displays of the model structure (module links and flow sequences) that users can "drill down" through to increasing levels of detail.	2	Verify that the model has the functionality to display various layers of detail or portions of the model.
4.38	Minimum isotopes	Model must be able to handle, at minimum, the following isotopes: U235, U238, Np237, Pu238, Pu239, Pu 240, Pu241, Am241.	1	Verify that the model includes the following isotopes: U235, U238, Np237, Pu238, Pu239, Pu 240, Pu241, Am241.

No.	Name	Description:	Priority	Acceptance Criteria:
4.39	Reprocessing Throughput	Allow users to adjust input to reprocessing facility as function of fuel age (minimum). Allow as strategies (a) youngest fuel first. In either case, also allow user to determine/input minimum fuel age at time of reprocessing. (default value is 5 years)	2	Verify that the interface allows the user to adjust reprocessing throughput as a function of fuel age.
4.40	Fuel Recipes	The following fuel types must be included in the model: o UOX (33, 51, and 100 burnup) o MOX-NpPu, one-pass o MOX-NpPuAm, multi-pass o MOX-NpPuAmCm o IMF-NpAm, one-pass o IMF-NpPuAm, multi-pass o IMF-NpPu-Am targets, multi-pass o UOX to Converter Fast Reactor o MOX-NpAm, one-pass to Converter Fast Reactor o IMF-NpAm, one-pass to Converter Fast Reactor o UOX to Breeder Fast Reactor o MOX-NpAm, one-pass to Breeder Fast Reactor o IMF-NpAm, one-pass to Breeder Fast Reactor	1	Verify that the specified fuel types are included in the model.
4.41	Reactor types	The following reactor types must be included in the model: o Thermal Reactor -light water o Fast Reactor – converter and breeder o Thermal Reactor – very high temperature	1	Verify that the specified reactor types are included in the model.
4.42	Defined Energy Outlooks	The following energy demand scenarios for the U.S. shall be included: - 0% annual growth rate in nuclear energy demand - 1.8% annual growth rate in nuclear energy demand - 3.2% annual growth rate in nuclear energy demand	1	Verify that the defined energy outlooks are available for the user to select.

No.	Name	Description:	Priority	Acceptance Criteria:
4.43	Unlimited Capacity	Except for the reactor modules, all modules must be able to run with "unlimited capacity" throughput, that is, subject only to the demand from the number of reactors, all other parts of the system are unconstrained. Sufficient uranium is mined, sufficient fuel is recycled, sufficient fuel is fabricated, etc. to keep the specified number of reactors operating. "Unlimited" flow can imply commodity costing, i.e., an implicit assumption that whatever is needed will be able to be purchased.	1	Verify modules in model can be run in an unconstrained (subject only to the demand from the number of reactors, i.e. sufficient uranium is mined, sufficient fuel is recycled, sufficient fuel is fabricated, etc.) throughput mode.
4.44	Limited Capacity	Must also be possible to run many of the modules with “limited capacity” throughput, that is, the throughput is controlled by the existence (or lack thereof) of a discrete number of facilities providing a given function. “Limited capacity” flow will generally imply costing on the basis of discrete plants. Reactor modules are always run in “limited capacity” mode. At minimum, fuel fabrication and fuel separation must be able to be run in “limited capacity” mode; others will be defined later. The limited capacity for a given module can be specified in one of two ways – user or automated or a mixture thereof. • User-defined limited capacity means the user must define the number of plants with specified capacity, facility lifetime, and facility capacity factor. • Automated limited capacity means that the model will define the relevant parameters.	1	Verify modules in model can be run in a constrained (subject to defined capacity of discrete facilities such as reprocessing or mining) throughput mode. Verify the constraints can be user defined or set by model default settings.

Hardware/Software

No.	Name	Description:	Priority	Acceptance Criteria:
5.1	Computer	The model should run on a standalone desktop PC or laptop computer using current technology and running the MS Windows XP operating system.	1	Verify that the model runs on desktop systems/laptops using Windows operating systems.
5.2	Software	The model should be developed using off-the shelf commercial software.	1	Verify that the software used to build the model is commercially available.
5.3	Transparent Architecture	The model should be in open source so that analysts, Systems Engineers and project modelers can modify the structure and calculations within the model. This feature is available for only members of the AFCI program.	1	Verify that the model can be provided to other users in two modes: one where the model equations are accessible and a second where the model equations can be viewed but not edited.
5.4	Non-Proprietary	The model should be non-proprietary.	1	Verify that the software has no proprietary requirements.
5.5	Distribution	The model should be distributed at a minimal charge to users.	3	Verify that the software has a minimal or no charge for distribution.
~~5.6~~	~~Number of characters~~	~~No limit on number of characters in equation editor.~~	~~1~~	~~Verify the model has no limit on number of characters in equation editor.~~
5.7	Number of array elements	Provide capability for up to 500,000 elements in an array with at least 3 dimensions in an array.	1	Verify the model has capability for up to 500,000 elements in an array with at least 4 dimensions in an array
5.8	Number of model elements	Able to accommodate up to 64,000 elements in the model.	1	Verify the model is based on a 64 bit or larger platform
5.9	Locked version	Provide a locked (executable only) version of the model for any individuals outside User Group 1.	1	Verify that a locked version of the model can be distributed and that a user can not unlock the model or access the source code.
5.10	Configuration Control	Develop and implement a Software Management Plan that includes a configuration control process for official model releases.	1	Prepare a Software Management Plan and a Configuration Control Plan before modeling work begins.

Constraints

No.	Name	Description:	Priority	Acceptance Criteria:
6.1	Constraints from *Advanced Fuel Cycle Cost Basis*	The model's default and uncertainty ranges will be consistent with the current assumptions and formulas (e.g., unit consistency, code of accounts, U.S. Dollar as the monetary standard, base year for all calculations, etc.) as defined in the current AFC Cost Basis. Model constraints will be updated as the Advanced Fuel Cycle Cost Basis is updated.	1	Verify that defaults for inputs and uncertainty ranges are based on good assumptions, formulas and reference data.
~~6.2~~	~~Cost Data~~	~~Use selected cost data (e.g. the sunk, operations and buildup costs of repository) developed by RW.~~	~~2~~	~~Confirm that the model has the capability to select RW's Cost data.~~
~~6.3~~	~~YMP Consistency~~	~~Present output units consistent with the YMP economic analysis so the numbers can be compared.~~	~~2~~	~~Confirm that the output units are consistent with YMP economic analysis so that cross comparisons can be made easily.~~
6.4	Time Step	Have a minimum time unit of one month and a maximum time unit of one year.	1	Confirm that the model runs with a time step of a minimum of one month and a maximum of one year.
6.5	Stochastic	Provide for stochastic inputs for selected variables.	2	Confirm that the model interface has the functionality to allow the model to use stochastic inputs for selected variables.
6.6	Units	All units report by the model at the end of a simulation will be in Kilograms (Kg).	1	Verify the model will provide mass output in Kilograms (Kg).

Software Quality

The model identified in this SRS has been evaluated in accordance with the Software Management procedures of the INL (MCP-550). Based on that evaluation the VISION is classified as a "Level D" or "Deferrable" software application. The application does not meet the criteria specified for a higher classification level. Data in the deferrable class, if lost, can affect individual performance, but would not affect INL mission success. Applications in this class have no requirement to be back on-line within a specified period of time.

Quality Documentation

Software classified at a level D requires a minimal Software Management Plan (SMP) be completed. The following documents will be prepared for this model:

A. Software Management Plan (SMP), which will include:
   - Software Quality Assurance Plan (SQAP)
   - Software Configuration Management Plan (SCMP)

B. Software Requirements Specification (SRS)
C. Software Platform Evaluation
D. Planning and Design Basis (sometimes called a Design description for software or DDS)
E. User documentation

Optional software application documentation that may include a requirements traceability matrix (RTM).

Performance Testing

Performance testing will be in accordance with the software quality assurance plan and the software test plan. Presentations and publications for external communication using data or results from VISION will require peer review before submittal.

Verification and Validation

Verification and validation refers to the process of determining whether the requirements for a system or component are complete and correct, the products of each development phase fulfill the requirements or conditions imposed by the previous phase, and the final system or component complies with specified requirements. Verification evaluates the system or component to determine if it satisfies specified requirements. Validation evaluates the system or component for proof of correctness.

Reference Documents

Shropshire, D.E., K.A. Williams, W.B. Boore, J.D. Smith, B.W. Dixon, M. Dunzik-Gougar, R.D. Adams. 2005. 2005 Advanced Fuel Cycle Cost Basis. Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho 83415. INEEL/EXT-04-02282 Draft Rev A.