2006-1235: USING NONPROLIFERATION ASSESSMENT TOOL (NAT) SOFTWARE FOR TEACHING PROLIFERATION CONCEPTS ASSOCIATED WITH THE NUCLEAR FUEL CYCLE

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Using Nonproliferation Assessment Tool Software (NAT) for Teaching Proliferation Concepts Regarding the Nuclear Fuel Cycle

Introduction

The University of Texas at Austin has developed a software package, the Nonproliferation Assessment Tool (NAT), supported by a contract with the Oak Ridge National Laboratory, Nuclear Science and Technology Division, International Safeguards Group. The NAT software package is an advancement in the field of nuclear nonproliferation because of its ability to collect, manipulate, analyze, and store large amounts of Nuclear Fuel Cycle (NFC) facility data in order to produce a comparative Proliferation Resistance (PR) value as well as a Nuclear Security (NS) measure for NFC facilities and facility chains, respectively. With non-proliferation and nuclear fuel cycle courses now becoming more popular with both graduate and undergraduate nuclear engineering courses, it is worthwhile to develop an interactive software program that can readily explain the major concepts in these areas. These capabilities can be utilized to teach students about the facilities that comprise the NFC as well as how different parameters affect the PR or NS value of a facility or chain of facilities, respectively.

Which Students Can Best Benefit from the NAT

It is recommended to incorporate NAT into nuclear engineering courses focusing on fuel cycles or nonproliferation in the junior year and above. Graduate students interested in proliferation resistance quantification methodologies can also benefit from the NAT software. Students who can name the basic facilities used in the nuclear fuel cycle and understand their purpose will reap the greatest benefits from the incorporation of the NAT software into their coursework.

Using NAT to Teach Students about NFC Facilities

When using the NAT software package, the user is first required to enter pertinent data on the NFC facilities of interest. The following facility types are included in the software:

1. Mine/Mill
2. Conversion
3. Enrichment
4. Fuel Fabrication
5. Reactor
6. Reprocessing
7. Permanent Storage

All facilities require descriptive information such as the facility name, country, location, latitude, longitude, etc. The quantitative data required for each facility type differs somewhat due to the nature of each, but many fields are synonymous for all facilities. Table 1 lists all the required fields for each facility type. There is a Help function that, when activated, describes each input variable. Finding and entering NFC facility data helps students to learn more about the different facilities and to become more familiar with their unique processes. See Figure 1 for an example of a completed Facility Data Input screen for a reactor. When all required data have been entered, the user can have NAT calculate the PR value for that facility.

Saved facilities can be viewed, sorted, edited, and archived using the Facilities screen (Figure 2).

There are three reports associated with facility data input and calculations: Facility Input Values, Facility Utility Functions, and Facility Report.[1] The Facility Input Values report is a list of all the parameters and their values entered for a particular facility. The Facility Utility Functions report lists the calculated values for the utility functions discussed later on in this paper. The Facility Report includes the information in both reports above as well as the resulting PR value for the facility. These reports allow students to check their work and see how the software is determining the facility PR value.

Table 1. Quantitative Data Required for Each NFC Facility Type[1]

Field	Facility Type						
	Mining & Milling	Conversion	Enrichment	Fuel Fabrication	Reactor	Reprocessing	Permanent Storage
Bulk Throughput (MT/yr)	✓	✓	✓	✓		✓	✓
Measurement Uncertainty (%)	✓	✓	✓	✓	✓	✓	✓
Frequency of Measurement	Never	✓	✓	✓	✓	✓	✓
Process Duration (days)	✓	✓	✓	✓		✓	✓
Percent of Steps Using Item Accounting (%)	✓	✓	✓	50	100	16	100
Physical Barriers	Remote	✓	✓	Secure	Inaccessibl e	✓	Vault
Number of Steps that Change Material	1	✓	✓	1	✓	6	✓
Probability of Unidentified Movement (%)	✓	✓	✓	✓	✓	✓	✓
Separability	Mining & milling product	✓	✓	Solid fuel with structural materials	Solid fuel with structural materials	Separated Pu solution	Solid fuel with structural materials
Facility outputs material in containers that weigh less than 200 lbs and are smaller than 2 cubic feet	✓	✓	✓	✓	✓	✓	✓
Inventory Np^{237} (kg)				✓	✓	✓	✓
Inventory Pu (kg)				✓	✓	✓	✓
Inventory Am (kg)				✓	✓	✓	✓
Inventory U^{233} (kg)				✓	✓	✓	✓
Inventory U^{235} < 20% enriched (kg)		✓	✓	✓	✓	✓	✓
Inventory $U^{235} \geq$ 20% enriched (kg)				✓	✓	✓	✓
Inventory $U^{235} \geq$ 50% enriched (kg)				✓	✓	✓	✓
Inventory Th (kg)				✓	✓	✓	✓
Conversion Type		✓					
U^{235} Enrichment		0.72	✓	✓	✓		
Reprocessing Type						UREX	
Fractional Recovery of Uranium						✓	
Reactor Type					PWR		
Average Reactor Thermal Power (MWt)					✓		
Fuel Type					U^{235} enriched UO_2		
Number of Cycles					✓		
Cycle Length (years)					✓		
Refueling Downtime (days)					✓		
Storage Time (years)					✓		
Core Loading (MT)					✓		
Facility type from which the fuel comes							Reactor
Does fuel originate from a Reactor or Reprocessing facility?							✓

Figure 1. Example of a Completed Facility Data Input Screen for a Reactor

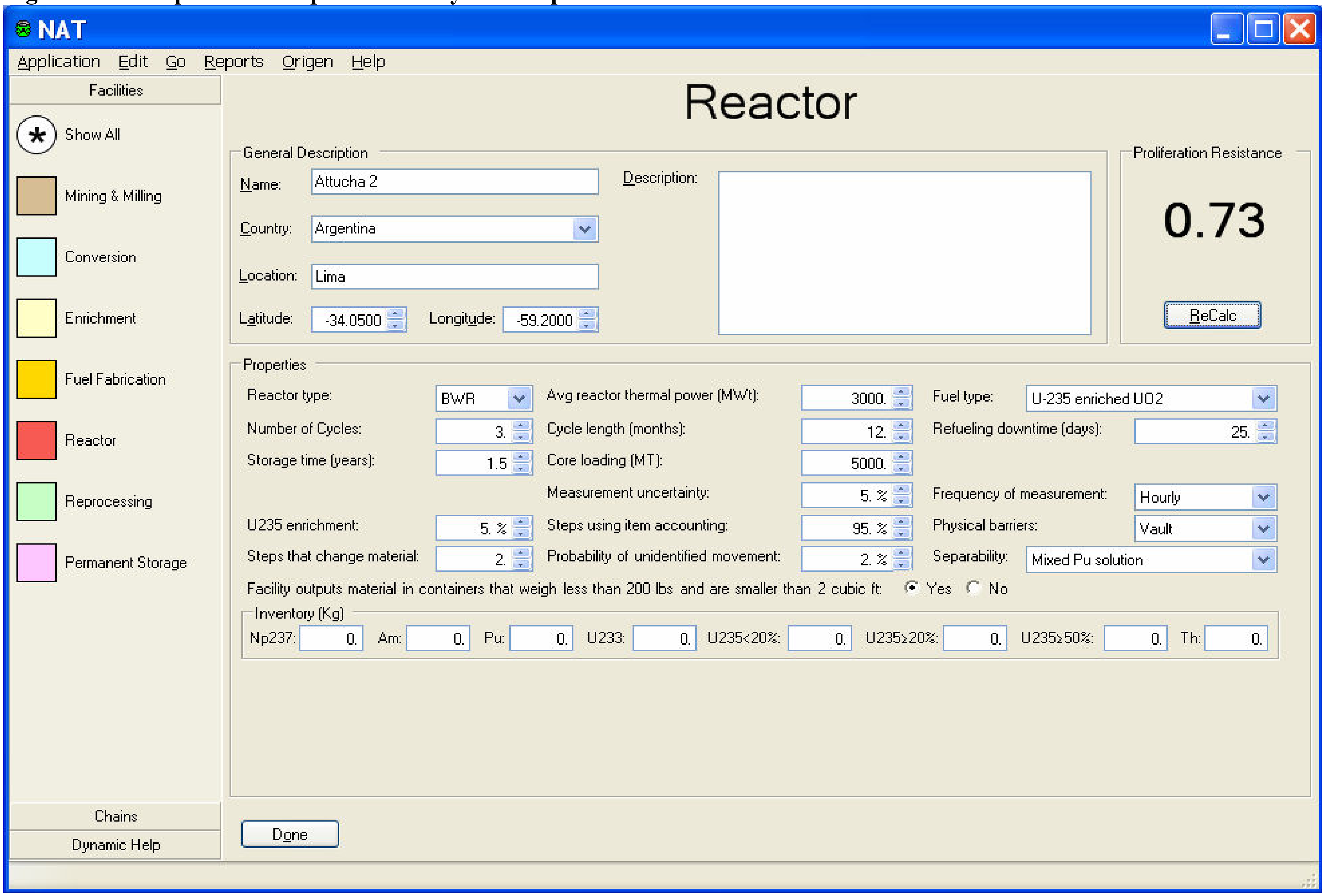
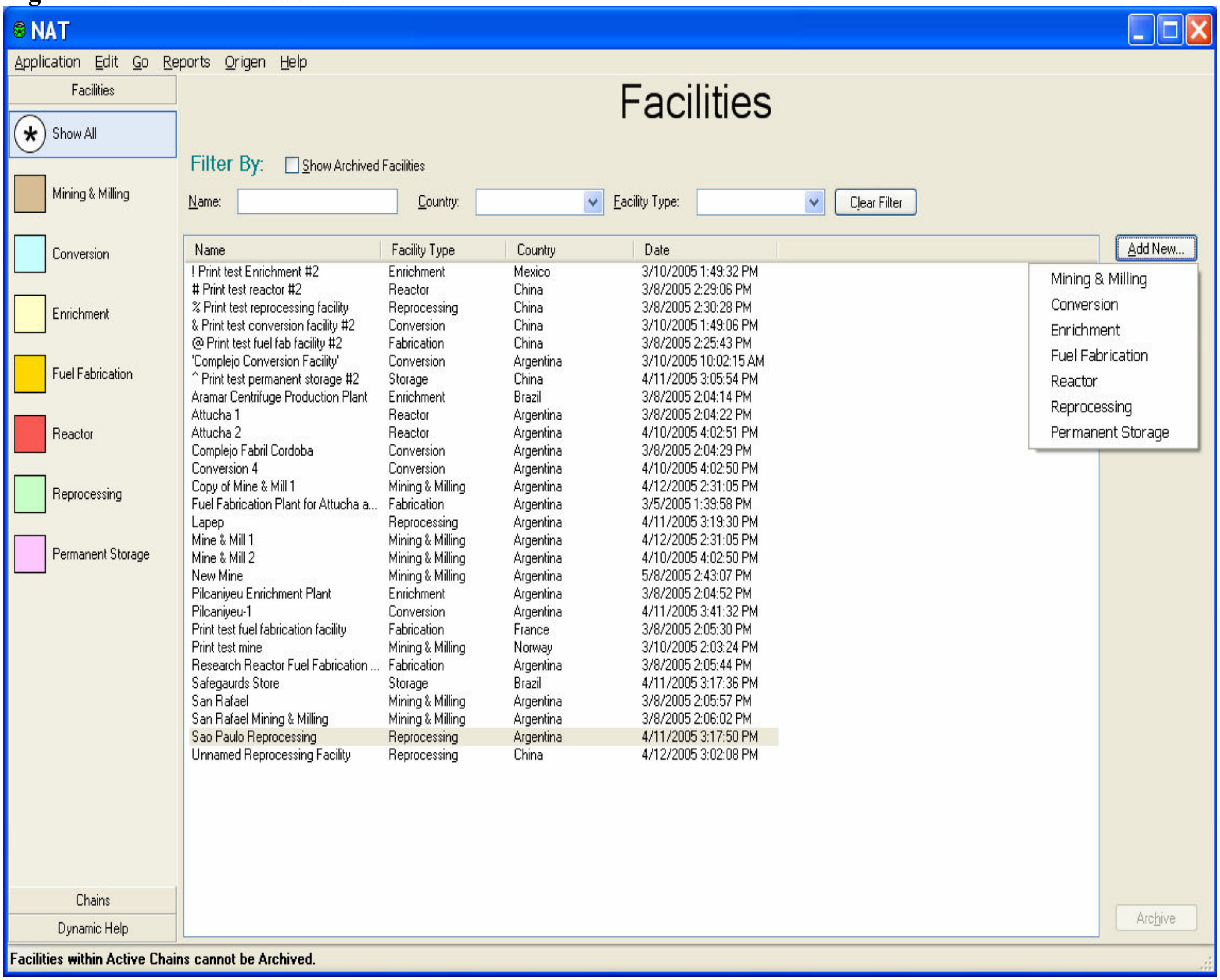


Figure 2. NAT Facilities Screen



Using NAT to Teach Students about NFC Facility Chains

After entering data for the NFC facilities of interest, the student may then form a chain of facilities that represents the material mass flow through the NFC. The NAT software package has been programmed with certain logic for combining facilities into a chain. (See Figure 3.) The NAT software provides visualizations of the NFC chain in all the Facility Data Input screens within a NFC chain (Figure 4) as well as in two of the six available report types: the Executive Summary Report and the Process Flow Report.[1] Saved NFC chains can be viewed, sorted, edited, and archived using the Chains screen in the exact same manner as the Facilities screen mentioned previously and depicted in Figure 2.

Figure 3. Facility Flow Logic for NFC Facility Chains[2]

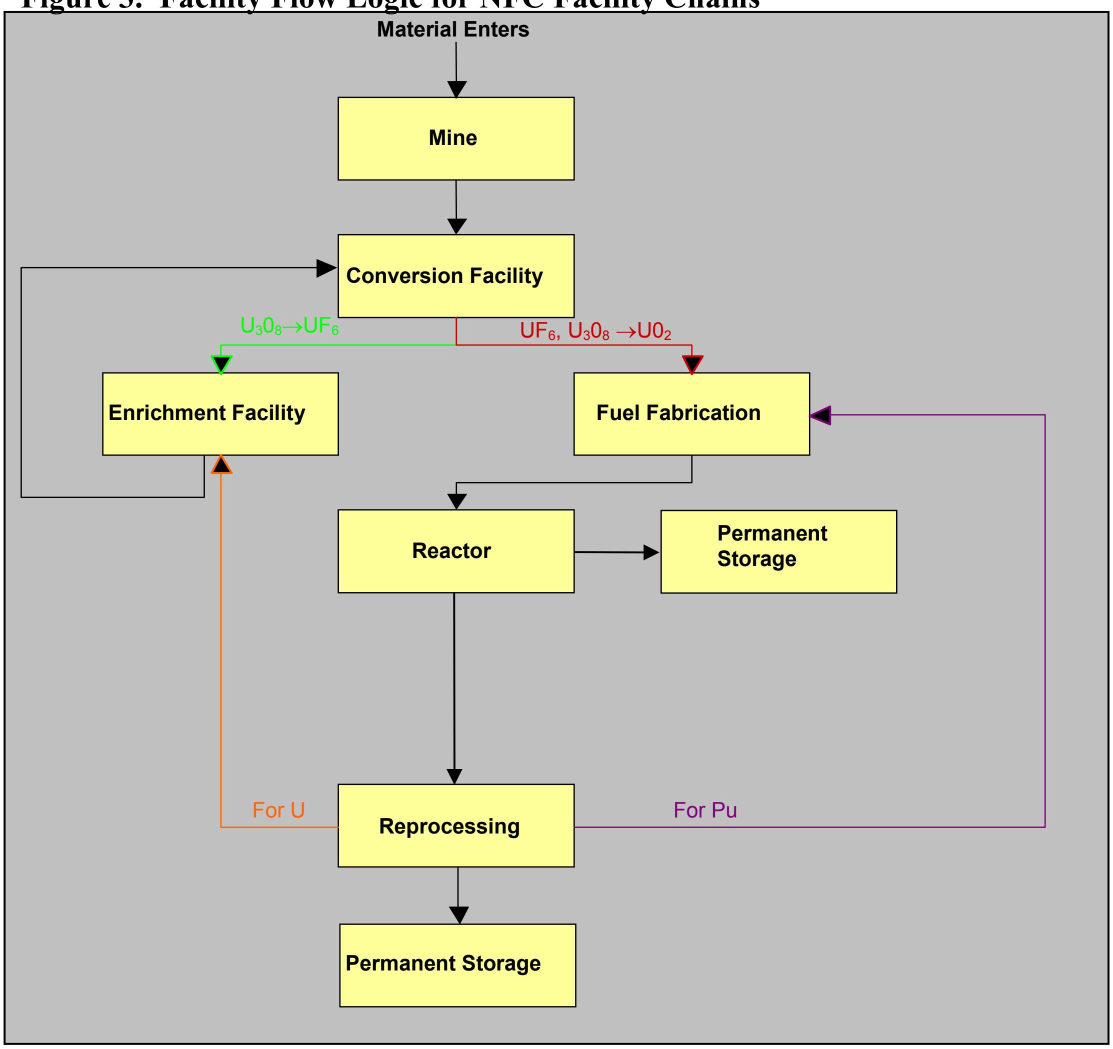
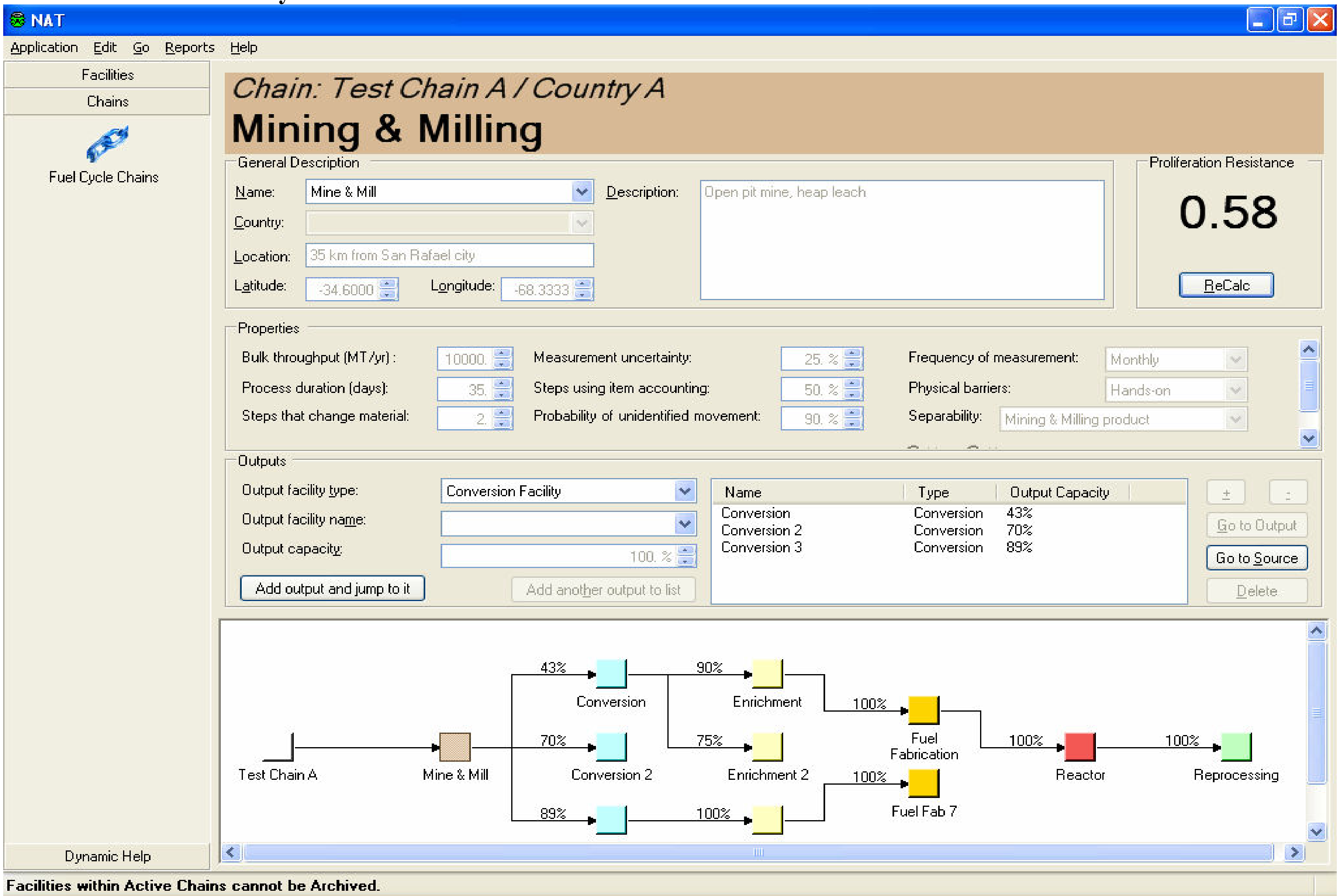


Figure 4. Visualization of a NFC Facility Chain Provided by the NAT Software Package in a Mining & Milling Facility Screen Accessed within a Fuel Cycle Chain



By having students enter data on NFC facilities, linking them into chains, and visualizing the chains using the NAT GUI, they have the opportunity to learn many things. They learn about the kinds of facilities in a NFC chain, and the processes that go on there. The students also learn the correct order of the facilities within the NFC chain. They learn what the data input fields represent and where to find the data required - an essential skill for any researcher or scientist.

Using NAT to Teach Students about Proliferation Resistance

The NAT software package introduces students to two topics within the nonproliferation field. The first concept is the introduction to the various isotopes of interest with regards to proliferation resistance and the respective facilities that may produce or have on site these isotopes. In contrast, a more universal concept of applied quantitative methodologies, specifically the Multi-Attribute Utility Analysis (MAUA), is introduced. This introduction can lead to discussions on other methodologies used for quantifying PR, for example,

1. Expert Group Delphi,
2. Comparative Value Measure,
3. Probabilistic Risk Analysis, and
4. Risk/Consequence Analysis.[3,4]

During this discussion, qualitative methodologies for improving PR can also be mentioned, such as improvements in facility designs and fuel compositions.

The NAT software package uses the Multi-Attribute Utility Analysis (MAUA) algorithm developed by Charlton, Gariazzo, and Ford[5]. The MAUA algorithm creates a PR value by evaluating and normalizing 15 different attributes related to PR using utility functions, u_j. Results from each of the 15 different utility functions are then multiplied by weighting factors, w_j, and summed to create a single PR value, ranging from 0 to 1- a value of one indicating the highest level of PR. The PR value for each facility is displayed in the respective facility data input screen. The equation used to determine PR is shown below.

$$PR_i = \sum_{j=1}^{15} w_j u_j (x_{ij})$$

The 15 different attributes and their respective weights are listed in Table 2. The weights were determined by expert group polling.

Using the NAT software package, the PR value can be plotted over time (Figure 5). Calculations for all the utility functions, PR values, as well as the original data input values for all facilities in a chain are listed in the NAT Process Flow Report.

Table 2. The 15 Attributes Used in the NAT MAUA Application to PR Quantification[6]

Measure	(i)	Attribute	Weights
Attractiveness Level	1	DOE Attractiveness Level (IB through IVE)	0.10
	2	Heating rate from Pu in material [Watts]	0.05
	3	Weight fraction of even Pu isotopes	0.06
Concentration	4	Concentration [SQs/MT]	0.10
Handling Requirements	5	Radiation dose rates [rem/hr at distance of 1 meter]	0.08
	6	Size/weight (>200 lbs or >2ft^3)	0.06
Type of Accounting System	7	Probability of unidentified movement of material (surveillance)	0.06
	8	Frequency of measurement	0.08
	9	Measurement uncertainty [SQs per year]	0.09
	10	Separability	0.03
	11	Number of processing steps that change material form	0.04
	12	% of processing steps that use item accounting	0.05
Accessibility	13	Physical barriers	0.10
	14	Inventory [SQs]	0.04
	15	Fuel load type (Batch or Continuous reload)	0.06

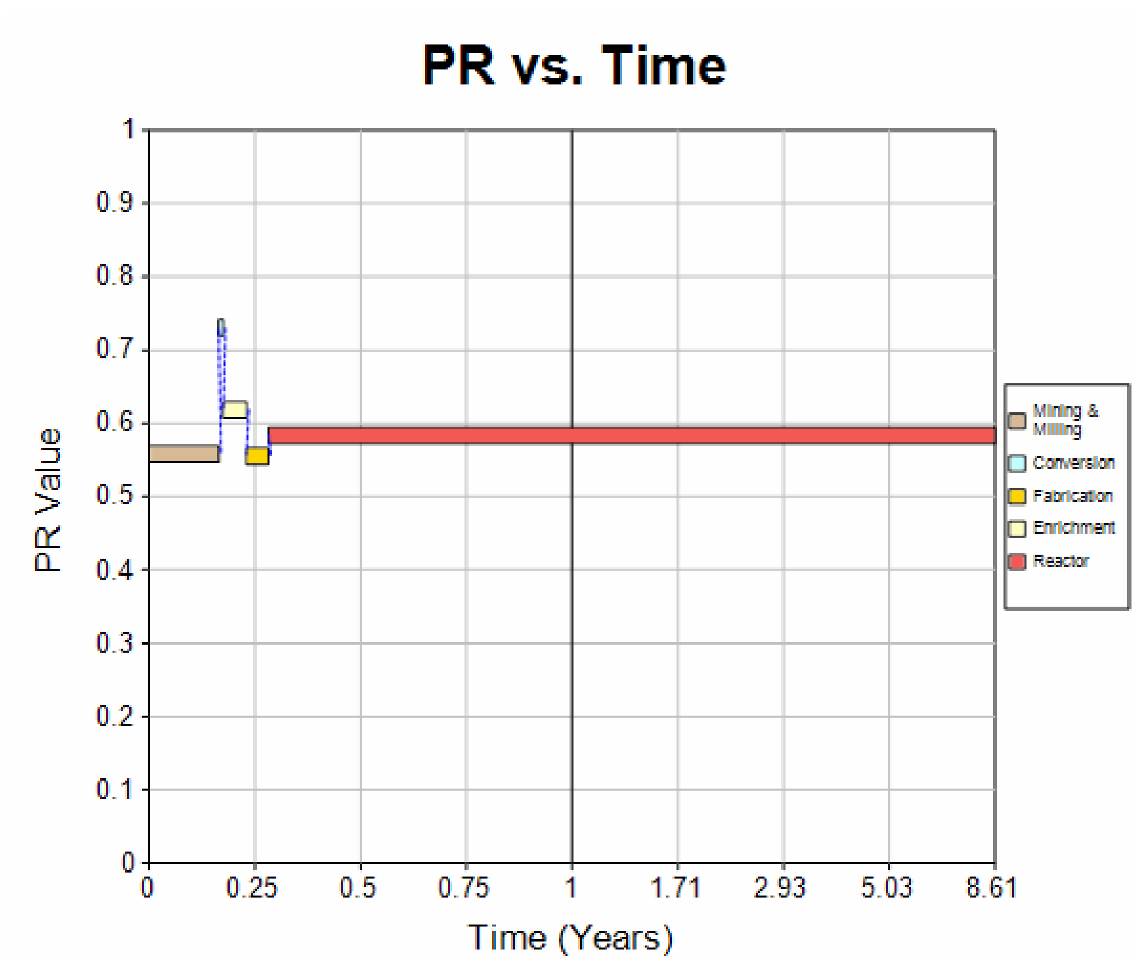


Figure 5. A NAT-Generated PR vs. Time Graph for a NFC Chain

In addition, the NAT software package can calculate a weighted average of the PR values of an entire chain of NFC facilities, i.e., the Nuclear Security (NS) measure. The NS value is calculated according to the equation below,

$$NS = \frac{\sum_k PR_k \cdot \Delta t_k}{\sum_k \Delta t_k},$$

where k is the number of facilities in the chain, PR_k is the PR value of facility k, and Δt_k is the amount of time nuclear materials are processed or stored at the facility.

By having students calculate and plot PR values for NFC facilities, they can see that the PR is a dynamic variable. The instructor can have students analyze the points in the NFC chain that have the lowest PR values. Discussions may then ensue on which facilities are most vulnerable and why, as well as what steps can be taken to increase the PR of certain facilities and processes. Students can experiment by changing the values of different data input fields and observing the effects on the calculated PR and NS values. Outputs may be viewed onscreen or printed via the reports mentioned earlier and summarized below in Table 3. In addition, students can discuss the advantages and disadvantages of using quantitative methodologies, such as MAUA, in comparison to other quantitative methodologies or qualitative methodologies in decision-making circumstances.

Table 3. Contents of NAT Reports

	Report Type					
	NFC Facility Reports			NFC Chain Reports		
	Report Names					
Information Included in Reports	Facility Input Values	Facility Utility Functions	Facility Report	PR vs. Time Graph	Process Flow Report	Summary Report
Input Data	✓		✓		✓	
Utility Function Results		✓	✓		✓	
PR Values		✓	✓		✓	
Weights		✓	✓		✓	
Chain Diagram					✓	✓
Summary Table						✓
Facility Reports					✓	
PR vs. Time Graph				✓	✓	✓
NS Value						✓

Using NAT to Teach Students about ORIGEN2.2

In order to assess the nuclear material characteristics after irradiation and decay required by the NAT MAUA algorithm, additional logic development was created for the interface of the NAT software package with ORIGEN2.2. ORIGEN 2.2 is required to calculate the PR values for the reactor, reprocessing, and permanent storage facilities. It is possible to view the ORIGEN 2.2 batch file, input deck, and resulting output deck via the *Origen* top menu. As shown below, this menu is visible only when you are viewing the data input screen of a reactor, reprocessing, or permanent storage facility (Figure 6).

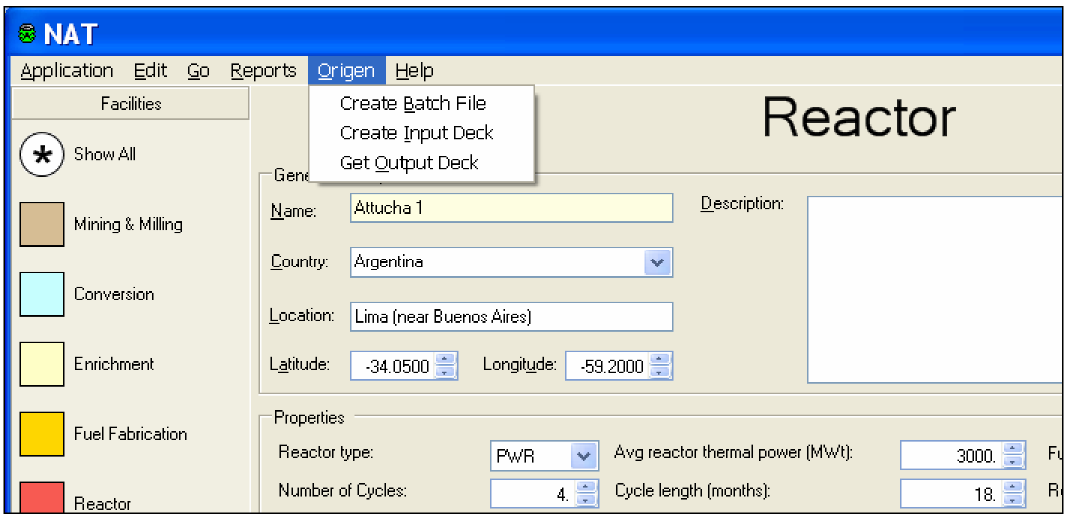


Figure 6. A Portion of the Reactor Data Input Screen Highlighting the NAT *Origen* Top Menu

Instructors can use this feature of the NAT GUI to familiarize students with the capabilities of ORIGEN2.2, the structure of the batch file, input decks, and output reports. This type of instruction will be more receptive if the students are already familiar with the processes of irradiation and decay. However, this can be used as a springboard for discussion on these processes for students not familiar with irradiation and decay.

NAT Software Package Documentation

As part of the NAT software package, there is an associated User's Guide[1] as well as a Final Report[7]. Students may use the User's Guide to help them learn about all the capabilities of the NAT software. If the instructor would like to spend more time on details of the MAUA algorithm and interfacing with ORIGEN 2.2, the Final Report is an excellent reference for both the instructor and the student alike because it contains all the technical details of the science behind the software.

Conclusion

The NAT software package has been developed by UT-Austin under a contract with the Oak Ridge National Laboratory, Nuclear Science and Technology Division, International

Safeguards Group. Instructors or mentors can use the NAT to teach students the following concepts:

- What facilities comprise the NFC?
- What is the purpose of each NFC facility?
- In what order do materials flow through the NFC?
- What are some quantitative and qualitative methodologies for assessing PR?
- What parameters are important for determining the PR of a NFC facility?
- Where can one find the pertinent data for determining the PR of a NFC facility?
- Is the PR value a static or dynamic variable?
- What can be done to increase or decrease the PR of a NFC facility?
- Which parameters most heavily affect the PR value?
- What is ORIGEN? What are its capabilities?
- What is the structure of an ORIGEN2.2 input deck? Batch file? Output report?

There are several report types as well as other visualization tools that allow users to see the input data and results. The NAT software uses ORIGEN2.2 to calculate PR values for NFC facilities that process irradiated and/or decaying nuclear materials, i.e., reactors, reprocessing and storage facilities.

The capabilities of the NAT GUI can also be used as a springboard for discussions on nuclear fuel irradiation and decay as well as on quantitative and qualitative methods of assessing PR. The documentation that comes with the software[1,7] can be used to support in-depth discussions of the aforementioned concepts.

The software uses Microsoft Access 2003, object -oriented programming techniques, and is written in Visual Basic.NET (VB.NET) version 2003. ORIGEN 2.2 is not included in the NAT software package, but must be installed on the same computer for NAT to operate properly. ORIGEN 2.2 may be obtained by request from ORNL's Radiation Safety Information Computational Center at http://www-rsicc.ornl.gov/.

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