

## **INTEGRATED LOGISTICS SIMULATION AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE (RFETS)**

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### **ABSTRACT**

The Kaiser-Hill Team is using a discrete-event simulation model to analyze material movement logistics plans that are a part of the integrated planning for closure for the Rocky Flats Environmental Technology Site (RFETS). By simulating the on-site movement and shipment of all material streams (including special nuclear material, waste, and excess equipment), it is possible to analyze the feasibility of baseline schedules, identify constraints, quantify the impact of proposed solutions, and assess alternative scenarios for activities that will take place between 1999 and 2010.

The model steps through closure activities, while always creating and maintaining an integrated picture of inventories and of the demand on the modeled resources. New or expanded facilities can be brought on line in the model, and decommissioned facilities can be taken out. Material flow can be re-routed. Simulation is an especially powerful tool for analyzing 1) the integration and interaction of multiple material streams, 2) the impact on shipping schedules of waste treatment, waste characterization, and limited throughput, often in complex combinations, and 3) workload leveling strategies.

### **INTRODUCTION**

The Rocky Flats Environmental Technology Site (RFETS) occupies an area of approximately 6,200 acres in northern Jefferson County, Colorado, approximately 15 miles northwest of Denver. From its original construction in the early 1950s to manufacture parts for nuclear weapons from nuclear and non-nuclear materials and to recover plutonium, the Site has developed into an industrial complex consisting of more than 700 facilities and structures.

Following the cessation of production activities, the Site has been faced with the challenging task of risk reduction and cleanup. The Site is aggressively pursuing a goal of closure by the end of 2006 provided certain assumptions are met. This goal may be attained through a concerted effort of DOE, HQ and the Site to focus on eliminating identified barriers to off-site shipments and disposition of wastes and SNM.

The purpose of this paper is to describe the development process of the integrated material logistics model for RFETS. First is a discussion of the planning challenges currently faced and why computer modeling was chosen to help meet these challenges. The Getting Started section describes the initial steps in characterizing the material movements at the site. The next section provides a brief description of the Micro Saint Simulation Software that is being used for this project. It provides a description of the modeling environment without going into details of the syntax used for expressions within a model. The next two sections describe the development of a prototype model and the subsequent integration of multiple material streams. The Current Model section provides a brief description of the current state of the integrated model. Model Verification and Validation describes the methods used to determine the accuracy of model predictions. The section on using the model gives examples of analysis techniques. Finally, some conclusions and lessons learned are presented along with a discussion of future work on the model.

### **THE NEED FOR MODELING**

Prior to the start of the Integrated Logistics Simulation project, Kaiser-Hill had developed several planning components that included top-level strategies and plans, agreements with regulatory agencies, a work breakdown structure, and a multi-year logic network of more than 20,000 activities. The scope and

complexity of the closure project raises questions about whether it is possible to move and ship all the excess equipment, nuclear material, waste, and decommissioning debris on schedule. Kaiser-Hill needed a way to show that the project goals were attainable. The focus of this effort has been to analyze the movement of material both on and off the plant across the entire proposed closure schedule. The objectives of the effort are:

1. To analyze the logistic feasibility of closure plans,
2. To identify and analyze constraints on material movement, and
3. To analyze alternate solutions and scenarios.

Kaiser-Hill determined that a computer simulation of the material movement would provide the best insights into the dynamics of the closure process. Simulation can provide answers to questions such as:

- Will there be enough capacity at each process?
- What happens when multiple material streams compete for the same resources?
- What happens when the level of activity in decommissioning and equipment/waste/debris handling reaches a level several times what has been experienced to date?
- Is there enough dock capacity to handle peak work levels?
- How would capacity needs be shifted when the schedule is compressed?
- Can the material be shipped off site on schedule?

## GETTING STARTED

The first step was to develop a map of material movement at Rocky Flats. An example of this is shown in Figure 1.

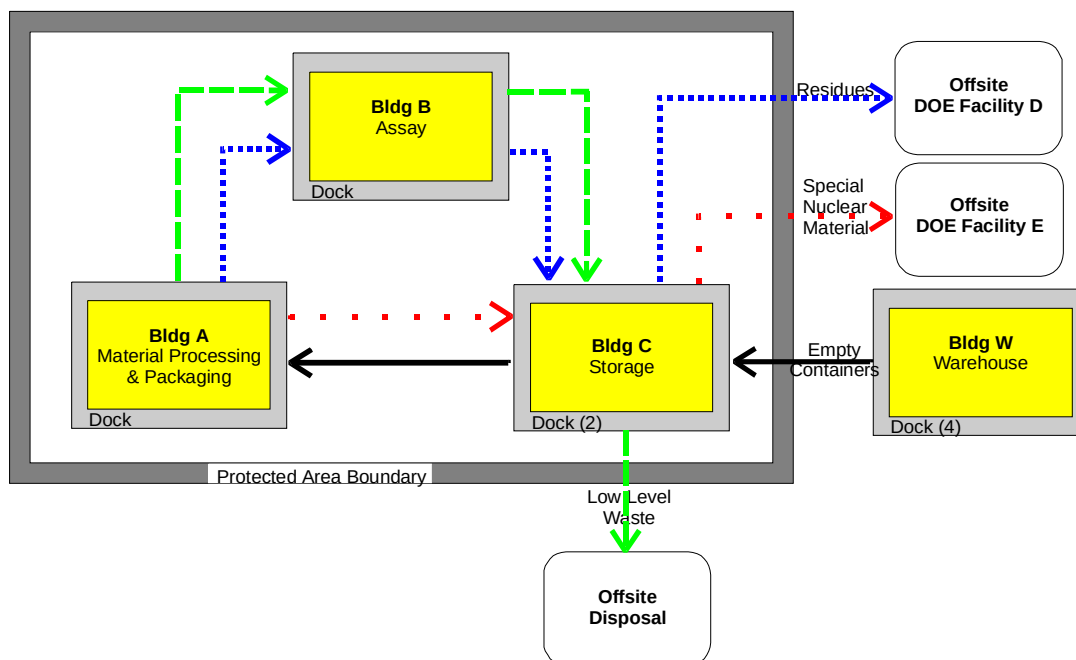


**Figure 1. Material Movement Map Concept**

In the diagram, The gray rectangle represents an area within the RFETS facility of higher security called the Protected Area (PA). Vehicles moving across this boundary must pass through security portals. The smaller rectangles represent buildings at the facility both inside and outside the PA. Each of these rectangles has a border which represents a dock at that building. In order for material to move in or out,

it must pass through the dock. The ovals represent off-site facilities and the arrows represent different material streams. For example, the Low Level Waste (LLW) stream, represented by the gray line with long dashes, begins in Building A where it is processed and packaged. The packaged waste is then transported to Building B for assay, Building C for storage, and finally shipped for off-site disposal.

The purpose of the Material Movement Map was to bound the scope of the modeling, including the desired level of detail. It was determined that on-site and off-site processes would be modeled as “black boxes” characterized only by the capacity and the throughput rate for each. In addition, the common denominator for material movement would be the truckload rather than the individual container.

### MICRO SAINT SIMULATION SOFTWARE

The simulation tool used for this effort is called Micro Saint. Figure 2 is an example of a Micro Saint network diagram showing part of the material stream from Figure 1. The ovals represent tasks or steps in the process and are connected by arrows that represent the sequence of events. Each task is assigned parameters based on the process requirements. These include a mean and standard deviation for the task execution time, expressions that represent the use of resources, and rules that represent material movement throughout the network. In this example, node 1 represents LL Waste in Building A. When the model is run, a simulated truck load of material moves from one task to the next. The mean time and standard deviation for the loading task is used to determine its simulated execution. This is true for each node in the example network. The packaged material is then moved to Building B to be assayed. The rectangle in front of node 4 represents a queue. The assay equipment and facility are resources. If they are being used when the material from Building A arrives then the material will wait in the queue until the resources are available. Once the assay is complete, the material is then moved to storage in Building C to await transportation to disposal facility.

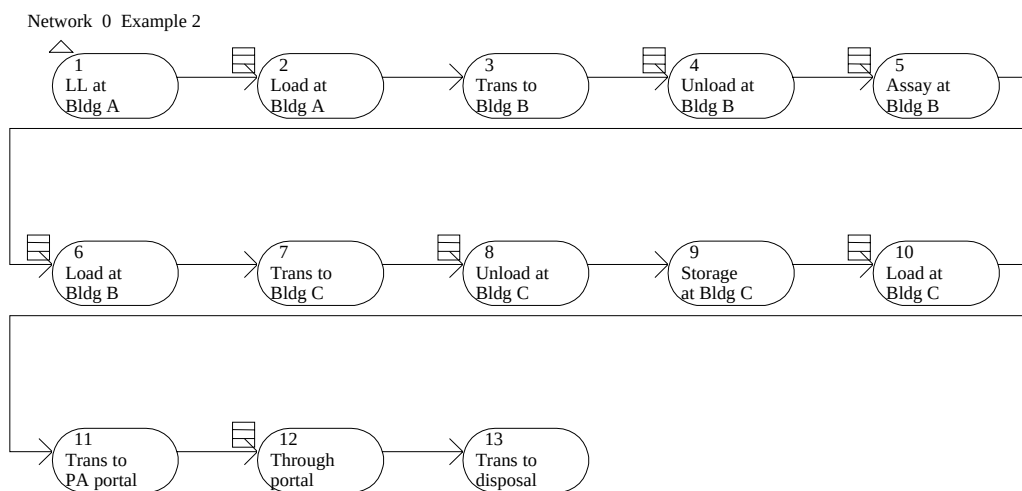


**Figure 2. Network Diagram – Low Level (LL) Waste**

### DEVELOPMENT OF A PROOF-OF-CONCEPT PROTOTYPE MODEL

Model development was performed in two phases. The first phase involved the development of a prototype model of a single material stream. The purpose of the prototype was to determine how best to characterize an individual stream and develop a model structure that would allow for other material streams to be progressively integrated. This section describes a basic example of how a single material stream was modeled.

A single material stream is characterized in two parts. The first part is the amount of material to be transported from a specific building and a schedule for that movement. In the case of LLW, the amount of material was estimated in cubic meters. For the material movement schedule, start and end dates for all the material from a specific building were provided. In order to model this, a calendar was included in the model that simulates the passage of time in days and keeps track of the date based on a simulation start date input by the model user. The amount of material to be moved from a building is distributed between the start and end dates, and transfers by truck are scheduled using the model calendar.

The second part of stream characterization is the shipment transportation path across the site. Figure 2 shows the basic network diagram for LLW from the flow diagram in Figure 1.

This flow includes:

- loading and unloading of material at buildings A, B, and C
- transportation between buildings
- assay at Bldg B
- storage at Bldg C
- transportation through the PA portal and to disposal.

The characterization of each of these tasks includes a mean and standard deviation for the execution time for each task. The model uses this information to simulate time while the model is running. The network diagram in Figure 2 includes queues at tasks 2, 4, 5, 6, 8, 10, and 12. These represent tasks which require the use of limited resources. The loading and unloading tasks at each building require the use of the dock. If the dock is being used then the truck must wait in the queue until the dock is available. The diagram in Figure 1 shows that Building C has two docks. In this case, the model allows two trucks to be loaded and or unloaded at the same time. Likewise, if the assay facility in Building B is being used, then the material must wait until the facility is available. The same is true for transportation through the portal. If a vehicle is already transiting the portal then others must wait.

When the model of this single stream is executed, individual transfers are initiated in the network diagram based on the schedule and model calendar. As they pass through the tasks, they use and release the relevant resources and the simulation calendar advances based on the time taken for individual tasks to execute. In this way, the model can predict how long the complete process will take. The model can also predict potential bottlenecks in the process by keeping track of the number of loads building up at a queue. In addition, the model keeps track of the amount of material that has been sent to disposal and can produce a report of shipments over time.

Out of the pilot demonstration came several conclusions and additional concepts to be followed in an expanded simulation. First was that Micro Saint had the flexibility to handle everything from shipment of individual items on a prescribed schedule to on-site movement of bulk material. Various truck fleets and capacities could be incorporated. Logic driven by dates, throughput rates, shipping schedules or facility decommissioning schedules, storage facility capacity limits, and starting or ending operational dates could all be handled. Data could be gathered on any parameter for which a logic could be specified. In addition, it was determined that the iteration cycle within the simulation would be one hour and that the model would be constructed to incorporate the most significant material streams at a high level, with detail to be added later, as necessary.

## **DEVELOPMENT OF AN INTEGRATED MODEL**

The integrated model was developed by adding material streams for each material type at RFETS. Each flow was developed in isolation much like the prototype model. The rest of this section presents short discussions of issues pertaining to the integrated model.

### **Material Generation**

Each material flow includes its own volume and movement schedule. For several material types, the volume of material increases over time as it is generated from decommissioning processes. In these cases, individual transfers are initiated based on an estimated generation rate. These generation rates vary based on the decommissioning schedule.

### **Containers**

Many different containers are used to move material on and off the RFETS site. The model is capable of simulating the movement of material in several different types of drums, crates, and other containers. The estimated volume for each material type is converted to and from truckloads based on the average number of containers that can be loaded into an on-site truck.

### **Shipping Vehicles**

Off-site shipping vehicles do not always have the same capacity as the on-site trucks. When the off-site vehicles contain more than an on-site truck load, the model prevents the beginning of the loading process until a sufficient amount of material has arrived at the shipping building.

### **Resources**

Many material streams require the use of common resources. For example, the assay facility in Building B of Figure 1 may be used for different material types. The resources represented in the integrated model include dock space, building storage capacity, PA portal capacity, several assay and inspection processes, empty container availability, and off-site shipping vehicle availability. The integration of the material streams allows for the competition for these common resources.

## **THE CURRENT MODEL**

The current model has 700 activities, representing the on-site movement and off-site shipment of eight broad categories (and several sub-categories) of material:

- special nuclear material (plutonium and uranium),
- residues (byproduct material not yet designated as waste),
- transuranic and transuranic mixed waste,
- low-level waste,
- low-level mixed waste,
- hazardous waste,
- sanitary waste, and
- excess equipment.

The following assumptions have been used to simplify the model:

- Modeling the movement of individual waste containers has not been pursued. This would require an additional level of detail that is not necessary.
- Modeling of traffic on individual streets and intersections has not been incorporated.
- Except for TRUPACT trucks, truck fleet size is unlimited in the simulation. This makes it possible to report on the number of material movements for each type of vehicle in any requested time frame, but does not constrain the analysis to a single fleet management strategy.
- Similarly, although of great importance to some planners, there is no attempt to simulate crew assignment, utilization, or requirements.
- The model cannot be used for day-to-day projections of material movement. Day-to-day yield from a process will vary because it takes longer to assay one container than another, longer to

load one truck than another, longer to generate one crate of waste than another, etc. Other day-to-day variables such as weather delays and process down time cannot be simulated with such accuracy. Even when such delays are incorporated in average throughput rates, one cannot project when one process or another will be shut down. Simulation addresses such variability by introducing random variations in process time, but in the simulation as in real life, processes operate around the mean, not at the mean. Statistical characteristics of a process will be achieved over time, but not necessarily in the short term.

- Schedules for activities that generate waste (or other material) are typically rounded to the nearest month in the best of cases, and most projects are scheduled to end when funding concludes at the end of a fiscal year. Projections of waste (or other material) generation rates are provided as quarterly or annual averages.
- Greater precision is within the capability of the simulation software, and the model could be refined to use shorter-term averages, but the availability of comparably precise input is another limiting factor. Therefore, while for certain types of analyses, the model can be used to show activity patterns on an hourly basis (e.g., dock activity), in general, monthly rates of material movement and monthly quantities are about the limit of precision for this simulation.

## **MODEL VERIFICATION AND VALIDATION**

The validity of what the RFETS Integrated Logistics Simulation model appears to show is dependent on how accurately RFETS closure plans are represented in the logic and parameters that make up the model. This section describes several tools that have been used throughout this project to assess these issues.

The first is a reliance on a conceptually simple baseline for the model. It is much easier to explain that the model is “based on Case 5A” than to be changing parameters throughout to satisfy individual constituencies

The functioning of the model has been verified at regular intervals. This includes reviews to ensure the following:

- Input quantities of a material stream appear as shipments when the run is complete.
- Explanations can be found when queues build up.
- Explanations can be found when the curve on an output graph changes shape.
- The time frame in which tasks occur makes sense.
- Projections made by users and/or process experts can be reconciled with model predictions.

In addition, performing organizations review and validate the simplifying assumptions included in the model. This requires an investment of considerable time and effort, but there is no substitute in establishing credibility. Some people unfamiliar with simulation may question any results coming from a model that incorporates simplifying assumptions. The use of rounding and averages does preclude later recovery of some level of detail, but most people are open to the use of simplifying assumptions. What is more likely to be corrected in this type of review is the value for a parameter (e.g., 50 truckloads vs. 100; 40 drums per day vs. 25) or the omission of some constraining logic (e.g., budget constraints on the number of shipments per year).

Finally, a record of influential parameters spread throughout the model has been kept. This is a useful tool during analysis iterations across such a large model. In addition, it reduces the turnaround time in helping people who have questions about assumptions used in the model.

## **USING THE MODEL**

This section will demonstrate some of the analysis capabilities of this model. The examples that are included are not an exhaustive look at all the capabilities. The Micro Saint software allows the user to

readily perform different analyses as needed. Also, the results described are not reflective of the current situation, plans, projections, or requirements at the site. Rather, the examples are presented to describe analysis methodologies.

Although some understanding of a simulation run can be gained by watching activity on the computer monitor (buildup of queues, etc.), a more detailed analysis is possible. The model can record chosen parameters at intervals and report them in results files. These files are tab-delimited text and can be opened in analysis programs such as Excel. Basic analysis can include the number of shipments of each material type, and net inventories of each material, on site and in storage locations over time.

The process of analysis using simulation is one of iteration. The steps include running the simulation, reviewing the results, interpreting the results, and revising the model as necessary. This process is followed until the performing organization feels comfortable in drawing conclusions. A graph that appears to show disastrous conclusions may be based on outdated or incorrect assumptions, and assumptions may be more closely aligned with one planning scenario than another. The graph could also be revealing a subtlety in logic that has been overlooked but can be incorporated. Re-prioritizing work or advancing a change in equipment may resolve a constraint or it may only shift the focus to the next constraint down the line. The important thing is not what the initial run says, but what can be learned from using simulation as an analysis tool.

### **Assessing Feasibility and Identifying Constraints**

This example shows how simulation can be used to quantify constraints in material movement. The concept of virtual queues has come into the discussion because in real life, one would not load 500 trucks only to have them waiting in line for the next operation. But a queue length of 500 truckloads or 2,000 cubic meters in the model is a meaningful measure of backlog – the extent to which processing at the next step is behind where it could be if material moved freely.

Figure 3 is a graph of the buildup and reduction, over time, of queues at four material movement tasks.

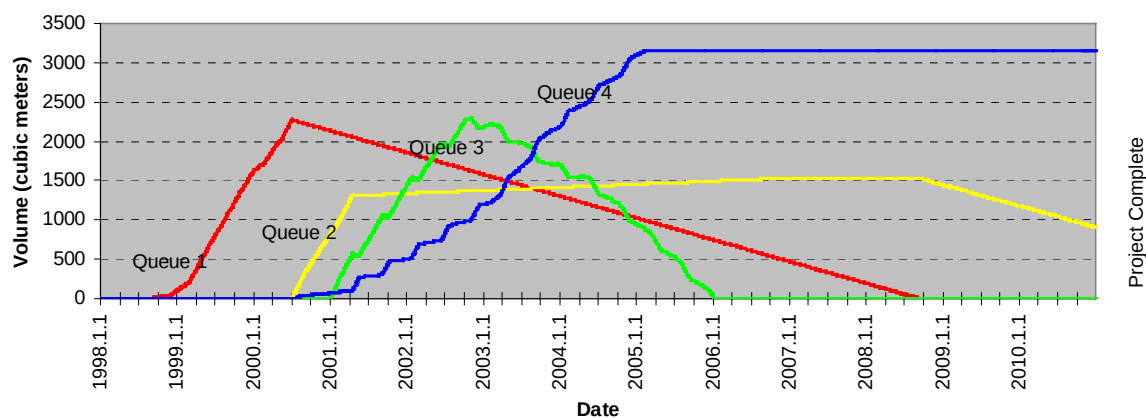


**Figure 3. Queues by Task**

Queue 1 shows a true constraint. This backlog builds up until capacity is increased at that task and the backlog is steadily worked off. Queues 1, 2, and 4 represent different material streams moving to the same operation with different schedules/rates, however. The work-off of queue 2 begins only when queue 1 is gone, and is not complete when the project is complete. And queue 4 is never worked off. In other words, movement of this material has not been finished at the scheduled project completion date. As planned, the project is not feasible.

Queue 3 builds at a different operation. The backlog starts later because that operation can handle a large volume at one time, even though each container moves through slowly. The queue is worked off early because the rate at which material comes out is driven by total capacity rather than the time required for a single container. Complicating the picture is the fact that task 3 precedes tasks 1, 2, and 4, so that when there is a backlog at 1, 2, and 4, material cannot come out of task 3. Adding capacity for tasks 1, 2, and 4 could resolve the backlog at task 3 also.

Another way to see constraints is to look at material in a building vs. storage capacity. To create Figure 4, the model is set to assume an unlimited capacity for Building X and to track the inventory as governed by rates in and rates out.

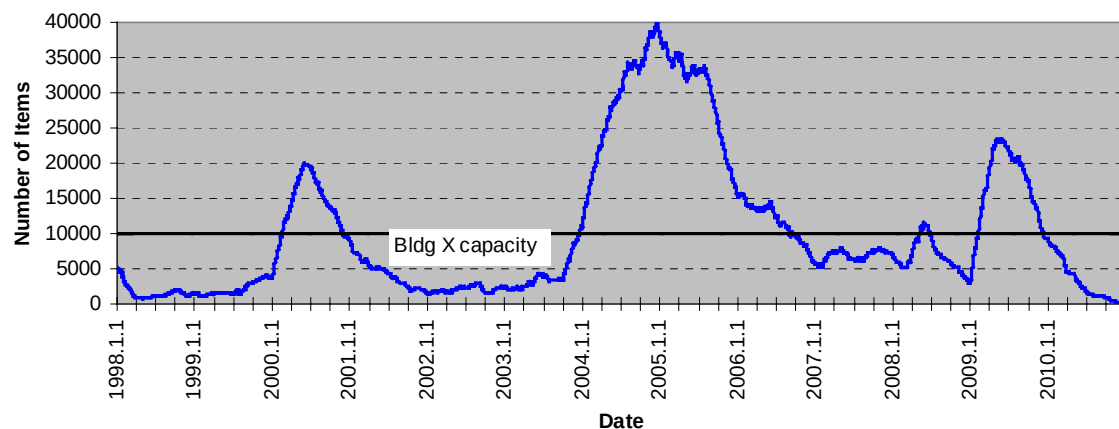


**Figure 4. Projected Building Storage vs. Actual Capacity**

A line is then added to the chart showing capacity in Bldg X. The simulation predicted that, with current assumptions, building capacity would be exceeded by a factor of four. It can also be concluded that workload leveling would be insufficient to make up the difference.

### Forecasting Requirements

The following is an example of the use of simulation to forecast off-site shipments, so that appropriate levels of support can be planned. Table I shows annual shipments for several material categories. Several types of information can be communicated including total annual shipping workload, year-to-year variation in annual workload by material type, and when the same material type will be shipped to different destinations.

**Table 1. Off-site Shipments by Type and Year**

|                                   | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|-----------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| <b>Excess Equipment</b>           | 100  | 300  | 100  | 50   | 200  | 600  | 500  | 300  | 200  | 200  | 300  | 100  |
| <b>SAN to Off-site Landfill</b>   | 700  | 1100 | 600  | 450  | 800  | 1000 | 1400 | 3000 | 3200 | 750  | 600  | 0    |
| <b>LLW to NTS</b>                 | 500  | 300  | 300  | 50   | 50   | 200  | 300  | 300  | 100  | 200  | 0    | 0    |
| <b>LLM to Hanford</b>             | 0    | 0    | 200  | 200  | 300  | 450  | 500  | 300  | 200  | 50   | 0    | 0    |
| <b>LLM to Commercial</b>          | 400  | 300  | 50   | 0    | 50   | 50   | 50   | 50   | 0    | 0    | 0    | 0    |
| <b>TRU/TRUM to WIPP</b>           | 100  | 250  | 150  | 100  | 100  | 100  | 50   | 50   | 0    | 0    | 0    | 0    |
| <b>SNM to Off-site Facilities</b> | 100  | 50   | 0    | 50   | 100  | 100  | 0    | 0    | 0    | 0    | 0    | 0    |
| <b>Total</b>                      | 1900 | 2300 | 1400 | 900  | 1600 | 2500 | 2800 | 4000 | 3700 | 1200 | 900  | 100  |

## CONCLUSIONS

Simulation should be done in partnership with organizations owning the work that depends on successful material movement so that they develop the right plans for their mission with the conviction that what they learn from simulation is helpful and not another obstacle to be overcome. This means that the simulation should be based on plans developed by the performing organizations and that the performing organizations support the effort by providing volumes, throughput rates, schedules, and logic as the basis for the simulation.

Simulation results are seldom 'the final word'. Those doing the simulation need consultation with the performing organizations on interpretation of results, to obtain updated assumptions, and to iterate the analysis to understand constraints, impacts, and alternatives.

This project has demonstrated that integrated logistics simulation can be a useful tool in the development of site closure plans. This is especially true for the analysis of logistic feasibility, the identification and analysis of constraints on material movement, and the analysis of alternative solutions and scenarios. Because of inevitable uncertainty in the projection of waste generation schedules, the meaningful resolution of most results will be at the monthly level.

Except for the need to add two more parts to the model – empty container handling and routine support services traffic – the model development phase is complete. The emphasis will be turned to verification, application, and scenario analysis. It must be recognized, however, that these tasks bring with them the need for further work on the model itself. Variables (and logic for tracking those variables) will have to be added, as new questions enter the discussion. Logic will have to be revised, as review with the performing organizations reveals that other constraints need to be addressed. Logic will have to be revised to create a more robust capability for dealing with on-site truck utilization and storage space utilization. In addition, the model will be altered as new capabilities and new uses for buildings appear in the site closure plans. Although the model is a functional analysis tool, increased collaboration with the performing organizations will require future work on the parallel tracks of application and model refinement.