Title: SYSTEMS ANALYSIS AND SIMULATION OF FISSILE MATERIALS DISPOSITION ALTERNATIVES

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Submitted to: DOE Spent Nuclear Fuel & Fissile Material Management Conference, June 1996
Reno NV

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ABSTRACT

A detailed process flow model has been developed for use in the Fissile Materials Disposition program. The model calculates fissile material flows and inventories among the various processing and storage facilities over the life of the disposition program. Given existing inventories and schedules for processing, we can estimate the required size of processing and storage facilities, including equipment requirements, plant floorspace, approximate costs, and surge capacities. The model was designed to allow rapid prototyping, parallel and team development of facility and sub-facility models, consistent levels of detail and the use of a library of generic objects representing unit process operations.

I. INTRODUCTION

A. Fissile Material Disposition Program

The Fissile Material Disposition (MD) program of the Department of Energy (DOE) has as its mission the management and disposition of excess weapons plutonium and highly enriched uranium. As part of this mission, MD has been charged with recommending to DOE one or more disposition alternatives that meet the following general criteria:

1. to minimize the risk that either weapons or fissile materials could be obtained by unauthorized parties;

2. to minimize the risk that weapons of fissile materials could be reintroduced in to the arsenals from which they came, thereby halting or reversing the arms reduction process; and

3. to strengthen the national and international arms control mechanisms and incentives designed to ensure continued arms reductions and prevent the spread of nuclear weapons.

A number of disposition alternatives and strategies have been proposed; these are grouped into three general categories: conversion to reactor fuel, vitrification, and deep borehole emplacement. Systems analysis activities in support of the MD program have focused on identifying one or more preferred alternative disposition strategies for the Record of Decision (ROD), scheduled for the Fall of 1996. As part of this effort, simple process flow models were constructed for each of the disposition alternatives, and a detailed flow model was produced for the conversion to reactor fuel. It is this detailed process flow model that is the subject of this report.

B. Detailed Process Flow Model

This report describes the modeling of one particular MD processing alternative - the conversion of excess fissile material to oxide, the manufacture of mixed-oxide (MOX) reactor fuels, and the use of existing light water reactors (LWR) to convert the excess material to spent reactor fuel for disposition in a geologic
repository. The complete model consists of an object-oriented process flow model built with the EXTEND® software package and post-processors built using Excel® spreadsheets. In general, material flow calculations, plant sizing and equipment lists, process chemical requirements, waste generation estimates and scheduling information are calculated with the process flow model, while capital and operating costs, manpower and floorspace requirements are calculated with the post-processors.

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C. The Generic Object Library

The object-oriented process flow model was constructed using a group of generic processing objects developed at Los Alamos specifically for simulating the processing of actinide compounds. These generic processing objects were designed to allow rapid prototyping, parallel team development, and verification/validation by process technologists. By using a fixed library of model objects, it is possible to built simple models quite rapidly, while maintaining the option for easy expansion to more detailed modeling as required. Process data can be entered quickly into the process objects, usually in direct consultation with the technologists who verify the process and equipment simulations. Models of sub-processes or alternative facilities can be developed independently and quickly connected to form larger models of an entire processing system; this results from the consistent level of detail imposed by the use of generic library objects.

II. MODEL DESCRIPTION

A. Process Flow Model

There are three separate facilities modeled for the reactor fuel option: Initial or Front-End (FE) Processing, Manufacture of MOX fuel, and the consumption of the fuel in light-water reactors. The top-level flowsheet is illustrated in Figure 1. Material of various forms is transported from a storage facility to the Front-End processing facility. Processed oxide goes to the MOX fabrication facility, while liquid and solid waste are sent to processing facilities that are not explicitly modeled. MOX fuel is shipped to the light water reactors, which may be represented as individual plants or a combined facility. Spent fuel is stored on-site for a short time, then shipped to a geologic repository for final disposition. Each of the blocks shown in the top-level flowsheet represent dozens, or even hundreds of individual process objects. For the sake of brevity, we will use the FE facility to illustrate the modeling of the various processing facilities in the model.

The FE facility accepts existing forms of stored plutonium and recovers the plutonium as oxide suitable for feed to the MOX facility. The modeling of processes to convert excess fissile material to oxide is applicable to a wide range of disposal options, not only those involving fabrication of MOX fuel. The first level of detail of the FE facility is shown in Figure 2. Nuclear weapons "pits" are sent to a disassembly unit, while other metal forms, oxide and alloys are sent to a conversion/stabilization unit. Unirradiated reactor fuel is sent to a disassembly unit. It should be noted that any or all of these units may reside physically in a separate facilities, or may be combined into a single FE facility as shown here. The product oxide exits this part of the model on the right, while wastes are collected in "hoppers" to be shipped according to a schedule supplied by another part of the process model.

The next level of detail is illustrated by the flowsheet for the conversion/stabilization unit shown in Figure 3. This is the "glovebox" level of detail and represents the lowest practical level of detail for a model of this scope. We found that more detailed modeling, such as breaking the dissolution process into lower lever operations like "open can", "fill dissolver", "operate pump", "drain dissolver" added nothing to the analysis of MD disposition operations. Such intensively detailed modeling has found use in time-motion studies and radiation exposure estimation, however.

The glovebox level of modeling fits well with the ability of technologists to provide data to the modelers. Individual runs might vary widely in time required and resources used, but averaged over the glovebox and a roughly weekly
For this and other reasons, MD models were standardized on a weekly time scale and glovebox level of detail. Referring to Figure 3, material enters the unit through a series of material handling / non-destructive assay (NDA) gloveboxes, is processed into product oxide and sent to the shipping area in another part of the model. In some instances a single glovebox object in the flowsheet represents several actual gloveboxes on the facility floor, but from the point of view of data availability and consistency, are represented in the model by a single object. Regardless of the material's form, it enters the processing line via one or more material-handling gloveboxes, which may or may not include an NDA capability. Clean oxide is calcined, and clean metal is converted to oxide in single-glovebox units. Alloys and impure metals are separated and purified in a four-step process, which includes dissolution, anion exchange, solvent extraction (if required) and calcining. This four-step process is represented by only one model object because of limitations of data collection. The data for these processes provided by technologists was combined into a single report, so the model uses only one object to represent the line. Finally, rich residue is processed in an oxidation/wash process that represents the combination of two separate glovebox operations.

B. The Generic Object Library

The Generic Object Library (GOL) contains many process simulation objects that have information at the unit process or glovebox level of detail. Since the objects were built and tested by experienced systems analysts in consultation with technical operations personnel, most of the functionality required to model nuclear chemical facility operations such as those at the Los Alamos National Laboratory has already been implemented in this model. With a fixed set of such objects, it is possible to provide rapid prototyping and detailed characteristics of large process flow models.

Each of the glovebox objects is made up from much simpler unit objects found in the EXTEND® modeling package. An example is illustrated in Figure 4, which shows an actual screen shot of the underlying structure of a simple aqueous processing glovebox with recycle capability. GOL objects used in the model include several types of gloveboxes (e.g. dry, aqueous, recycle, multiple input), several material handling objects (e.g. loading / unloading docks, hoppers, accumulators, shipping / receiving units), accounting objects (e.g. on-line flow meters, manpower usage meters, utilization meters), as well as several specialized objects for modeling processes unique to nuclear chemical operations.

One very useful feature of this process model is the provision for rapid prototyping of complex flowsheets by different teams of analysts. By limiting the scope of time scales and types of objects involved, it was possible for three different teams to simultaneously build the detailed front end, MOX fabrication and reactor end-use models. Each team was responsible for the detailed model of their facility, while using a standard interface format made possible by standardized shipping / receiving objects. Model results could be collected systematically with the use of standardized accounting objects. The final versions of the model may be run separately, or as a whole, even at differing levels of detail, should that be required. For example, a simple reactor model consisting of little more than a schedule of fuel loading and changeout could be combined with the detailed front end / MOX model to determine an oxide production schedule. Or, simple front end and reactor models could be combined with the detailed MOX model to generate pellet, rod and assembly production schedules.

C. Post Processors

In addition to the process flow model discussed above, a detailed model has been developed to estimate capital and operating costs as well as manpower and floorspace requirements, given a detailed equipment list as input. This model is referred to as the Plutonium Post Processor (PuPP), and has been modified from that used with previous detailed models of the nuclear weapons complex. In general, material flow calculations, plant sizing and equipment lists, process chemical requirements, waste generation estimates and scheduling information are calculated with the process flow model, while capital and operating costs, manpower and floorspace requirements are calculated with the PuPP.

III. IMPACTS

Although work is still underway, a number of important results have already been produced in the development and use of this model. From the collection of detailed flowsheets, the authors have produced detailed equipment lists, cost
estimates, and production schedules for several disposition alternatives currently under consideration. We have investigated the effects of altering base assumptions on process flows, costs and schedules. In addition, we were able to identify a number of inconsistencies in processing and storage requirements among facilities, including the consideration of transportability and ease-of-handling of various forms of stabilized plutonium. A detailed report of these results will be published as part of the documentation for the ROD. The results have already been incorporated into DOE/MD's disposition alternative description reports and summary data reports. These documents form the basis of the ROD process and will help to provide a technically defensible basis for the DOE decision for a preferred disposition alternative.

IV. NEXT STEPS

Work is continuing, with a decision for a preferred disposition option to be made in the Fall of 1996. New systems analysis and modeling work in this program may have large payoffs, particularly in the study of hybrid disposition options. Hybrid options are combinations of disposition alternatives now considered separately. The combining of two or more alternatives, or even two or more options within a single alternative pose challenging technical difficulties both for analysts as well as those charged with implementing the hardware for a real-world alternative. Currently, a small amount of funding has been allocated for the examination of hybrid options in Fiscal 1996.

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the analytical and computer science expertise and assistance of the members of Los Alamos National Laboratory's Technology and Safety Assessment Division, the participating analysts at the Lawrence Livermore National Laboratory, and the MD program's Alternative Team for Reactor Alternatives.

REFERENCES

2. Imagine That, Inc., 6830 Via Del Oro, Suite 230, San Jose, CA 95119 (408)365-0305

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Figure 1 - Top Level Flowsheet

Figure 2 - Front End Processing Facility
Figure 3 - Conversion and Stabilization Unit

Figure 4 - Screen Shot of Actual Extend® Object
"Recycle Glovebox"