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Title: DEVELOPMENT OF A NEAR-REAL-TIME ACCOUNTABILITY SYSTEM FOR FUEL FABRICATION FACILITIES

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Development of a Near-Real-Time Accountability System
for
Fuel Fabrication Facilities

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ABSTRACT

This paper discusses design issues for establishing a near-real-time accountability (NRTA) system for modern fuel fabrication facilities; however, the approach for developing an NRTA could be applied to many nuclear facilities planned for construction.

The proposed design is for a computerized materials accounting system capable of providing near-real-time materials balances and associated variances. The system must accommodate data from both destructive analysis (DA) and nondestructive analyses (NDA) of material-in-process and interim storage. DA and mass measurements are used by facility operations for process control and drawing material balances. NDA measurements will be used primarily by International Atomic Energy Agency (IAEA) inspectors for verification of inventories.

An essential component of the NRTA system is a software interface between the facility's process control computer and the NRTA computer. The purpose of the interface is to facilitate the use of process measurement and material transfer data to compute materials unaccounted for (MUF), limit of error of MUF (LEMUF), and covariance matrices for a sequence of MUFs. The design of the interface facilitates use of LANL developed software Materials Accounting with Sequential Testing (MAWST) for the NRTA calculations described above.

The basic approach involves a comprehensive systems analysis to evaluate the NRTA system design; development of simulation software for analysis of process flows, holdup, and MUF/LEMUF; development of evaluation software for analysis of NRTA systems; and preparation of design specifications for software to implement NRTA.

Development and application of a model of the process and measurement systems will allow evaluation of operating parameters (material flows, holdup, and effect of changes in throughput), as well as safeguards parameters (MUF and LEMUF). There are two possible approaches to developing a simulation model of the process: (1) simulate the measurement system, and (2) simulate the process and the measurement system. Simulation of the measurement system would concentrate on statistical functions of measurements in sequences of material balances, such as the propagation of variance. Simulation of the process and the measurement system would add process variability to the former approach, providing more data allowing various scenarios to be analyzed for their impact on safeguards and plant operations.

Because the NRTA data may be used by international inspectors, we will also consider evaluation of the inspector's attributes measurement plan and the variable measurement plan associated with the MUF-d statistic. The Los Alamos Inspection Optimization by Dynamic Programming (IODYN) computer program can be applied to develop plans that are either optimal for detection probability or for cost to the operator.

I. INTRODUCTION

This document discusses the design issues for establishing a NRTA system in a mixed oxide (MOX) fuel fabrication facility. The work includes a comprehensive systems analysis to design and evaluate an NRTA system, development of simulation and other evaluation software for analysis of NRTA systems, and design specifications for software to implement NRTA in the facility.

The approach will involve the use of design-basis information and a model of the operation of the fuel fabrication process to compute materials unaccounted for (MUF), limit of error of MUF (LEMUF), and covariance matrices for a sequence of MUFs. The Los Alamos Materials Accounting With Sequential Testing (MAWST) program[1] will be used for NRTA, and a simulation will be developed to study and evaluate various alternatives for material flow and process variations.

Section II briefly describes a MOX fuel fabrication process. Section III describes generic issues of materials accounting and the recommendations for the NRTA accounting strategy. The software tools for evaluating NRTA are described in section IV, and section V discusses NRTA simulation.

II. MOX FUEL FABRICATION

The MOX fuel fabrication facility has three major nuclear material handling areas in the facility: plutonium feed storage, the fuel fabrication process area, and fuel assembly storage. The discussion here is primarily about the fuel fabrication process area; details of the processes, including material flows, within this materials balance area (MBA); and inventories that are relevant to NRTA.

<u>A. Process Sequence and Material Flow</u>. Figure 1 provides a simplified overview of the fuel fabrication process. MOX feed and UO_2 are used to fabricate pellets which are, in turn used to fabricate fuel pins. Fuel assemblies are fabricated and stored until they are shipped.

<u>B. MBA Structure</u>. The most likely accounting structure would involve three MBAs: MOX Feed Storage (MBA-I), Fuel Fabrication (MBA-II), and Assembly (MBA-III). Activity in MBA-I is limited to receipt and storage of feed material, and MBA-III is used for fuel pin assembly, assembly storage, and shipping. All processing occurs in MBA-II, and the following sections (II. C through II. F) focus on this MBA.

<u>C. Process Input Streams</u>. The primary plutonium feed into MBA-II is a mixture of plutonium and uranium oxides (MOX). This input stream is referred to as "feed MOX". Other feed streams to this MBA include uranium oxide for feed preparation and fabricated uranium oxide pellets to complete the design requirements of fuel pins. Within the MBA, a portion of the blend material from failed production batches is expected to be recycled during subsequent fabrication preparations.

<u>D. Process Output Streams.</u> The primary output stream of MBA-II is completed fuel pins which are transferred to assembly and storage (MBA-III). Other measured output streams from this MBA are disposable wastes (solids and liquids). It is also assumed that the analytical laboratory will be treated as a part of MBA-II in order to avoid having to draw a separate balance for it. Laboratory waste streams would be included in the MBA-II waste streams.

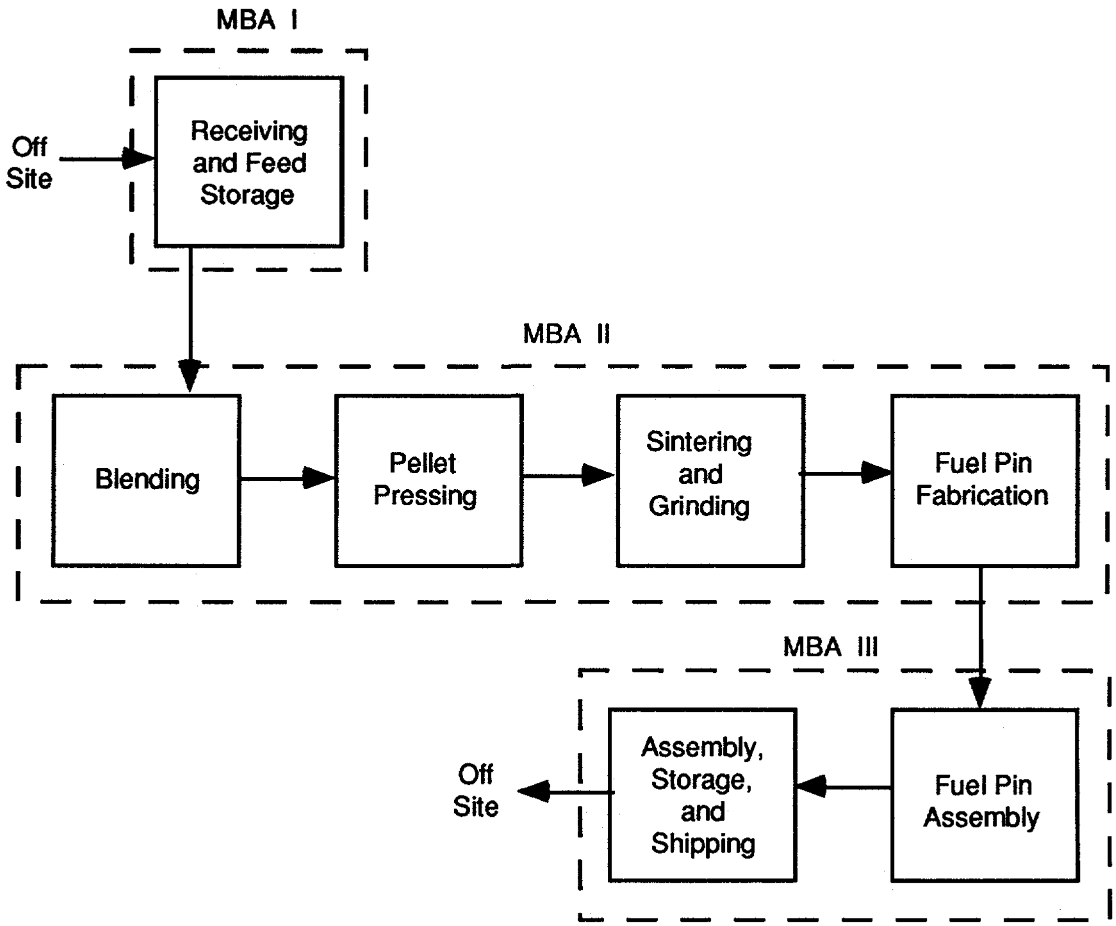

Figure 1: Process and MBA Structure for a Fuel Fabrication Facility

E. Fuel Fabrication Process to be Used for System Study.

Fuel fabrication processes consist of the following major steps:

- **Feed assay.** Sampling and analysis of input feed batches to determine concentrations and isotopics;
- **Blending.** Blending to produce a feed MOX and uranium oxide campaign lot with uniform isotopic and plutonium composition;
- **Pelletizing.** Pressing the blended MOX into green fuel pellets of specified dimensions;
- **Sintering and Grinding.** The green pellets undergo calcination and reduction in a sintering furnace to form a true ceramic material. The pellets are then ground to specifications;
- **Fuel Pin Fabrication.** The pellets are loaded into fuel pins of desired dimensions; and
- **Fuel Pin Assembly.** The pins are fabricated into assemblies.

In addition to the above process operations, MBA-II operations include recovery and recycling of clean scrap, analytical chemistry laboratory, and various waste streams.

F. Scrap, Holdup, and Waste. Several steps in the fuel fabrication process will produce recoverable scrap, holdup, and wastes. For the proposed system study we will assume some fraction of throughput for each of these process streams. Recoverable scrap will be reprocessed in the scrap recovery area which is included as a part of MBA-II. Small amounts of disposable solid and liquid wastes generated during these processes will be transferred out of the MBA-II as measured outputs. Solid wastes are measured by NDA.

III. NRTA DESIGN ISSUES

A. Materials Accountancy Measurements. Both destructive analyses and NDA are performed in the facility. The material balances drawn use chemical analyses and weights, except for solid wastes which are measured by NDA. The NDA measurements are used primarily by the IAEA inspectors. A possible exception to this assumption is the use of NDA holdup measurements as a part of the material balance. If holdup is measured and carried on the inventory, it will be necessary to modify the accounting approach.

B. Nuclear Decay and Plutonium Isotopic Composition. Nuclear decay loss is the amount of radioactive material that disappears as a consequence of radioactive decay. Accounting for nuclear loss for plutonium during each materials balance period (30 days) might be considered unnecessary because the decay losses are relatively small compared to measurement uncertainties. However, when there are large inventories and long residence times, the loss due to decay is significant for at least one of the isotopes of plutonium, 241Pu. The NRTA system will have the capability to calculate nuclear decay for all the isotopes of plutonium, irrespective of their half-lives. The proposed system study could utilize the data simulation to determine the specific isotopes for which nuclear decay correction should be applied.

C. Data Required by the NRTA. An essential component of the NRTA system is a software interface between the facility's process control computer and the NRTA computer. The purpose of the interface is to facilitate the use of process measurement and material transfer data to compute materials unaccounted for (MUF), limit of error of MUF (LEMUF), and covariance matrices for a sequence of MUFs. Typical types and sources of information collected by the interface by process area are as follows.

- **MOX Feed Storage (MBA-I)**. The required information for NRTA in the powder storage area is the shipper's values for plutonium in each container with associated measurement uncertainties, the NDA measurements on input and output transfers and associated uncertainties, a time stamp for all measurements and transfers, and the item/lot identification.

- **Fuel Fabrication (MBA-II)**. NRTA information for the MBA-II includes the plutonium concentration and isotopic concentration measurements on powder or pellet samples and associated measurement uncertainties; location, time and container identifications for sampling; tare weights of containers; location, time, and identification of weighed containers and containers measured by NDA; NDA measured values and associated uncertainties for transfers of containers to/from interim storage and material in the calciner; NDA measured values for holdup.

- **Pin Assembly and Assembly Storage (MBA-III)**. NRTA information for MBA-III includes NDA measurements and associated uncertainties on transfers to/from the MBA and time and container identification for transfers.

IV. EVALUATION SOFTWARE

Some of the software tools needed for evaluating NRTA are described below. Some of them were developed earlier and are directly applicable without modification.

- **MAWST**. Developed for variance propagation, this software can be applied to calculation of MUF and the variance of MUF, MUF-d, or any selected collection of measurements. The input data are measured values, random and systematic components of the measurement uncertainties, and calibration histories for measurement instruments. This software can be used as an evaluation tool or for analysis of operational data.

- **FACSIM**. This software has been used to model fuel cycle facilities such as fuel fabrication and reprocessing plants. It provides a detailed simulation of the process inventories and flows, usage of process equipment, operator time, and measurements. We propose its application to simulating the fuel fabrication process and sequences of MUFs. FACSIM is useful for evaluating the effect of operating and accounting strategies on loss detection sensitivity, investigation of holdup, and the effects of different throughput levels on plant operations.

- **NRTASIM**. This software accepts a covariance matrix for a sequence of MUFs and generates random sequences of MUFs with the correct correlation structure. Materials losses representing diversion scenarios can be introduced into the sequences. NRTASIM also applies statistical tests to the sequences and calculates detection probability and average time to detection.

- **STATISTICAL TESTS.** Sequential statistical tests available for analysis of accounting data are Page's test, probability ratio test, GMUF, and SITMUF. These tests detect a change in the mean of the MUF sequence that could indicate materials loss.

- **IODYN.** An evaluation of the effectiveness and resource requirements of inspector sampling plans for the materials strata in the process line requires a calculation tool capable of determining sample sizes and detection probabilities. IODYN software was developed for another fuel fabrication process, but should be applicable to any new line with minor modifications. It can calculate inspection/ plans that maximize detection probability under a resource constraint, or it can calculate a plan that minimizes the inspection time under a probability of detection constraint. The latter option is especially important to the facility operator because it can minimize the duration of process shutdown for State or international inspections.

V. SIMULATION

An essential element of the NRTA design approach is the development and application of an emulation model of the process and measurement systems. There are two possible approaches to developing a simulation model.

- **Simulation of the Measurement System.** A covariance matrix for a sequence of material balances is calculated and input to the NRTASIM code to generate random sequences of balances. The covariance matrix can be generated by running the variance propagation code MAWST. The data files for MAWST could be defined manually or a data generator could be developed to automate the generation of MAWST files.

The data generator is an interactive code that allows the user to play out a processing scenario. It keeps track of material movements and inventories at each process location and writes a MAWST input file that reflects the processing history emulated by the user.

- **Simulation of the Process and Measurement System.** This procedure would use the simulation program FACSIM to model the variability introduced by a nonsteady-state process and the measurement system. The results of many simulated process runs would be used to generate sequences of material balances. Selected loss scenarios are modeled by introducing appropriate loss sequences into the sequences of material balances. Statistical and other anomaly detection methods are applied to these sequences to determine the system's loss detection sensitivity. Among these methods are a comparison of MUF to LEMUF; sequential statistical methods such as the probability ratio test and Page's test; linear and nonlinear time series methods; and neural networks. Many of the statistical tests and software developed for other studies are applicable, whereas new tests based on time series analysis or neural networks can be added. These simulations provide estimates of the probability of loss detection and the average time for detection of a range of loss scenarios. Although a simulation is more complex than the other investigative tools, it provides much more data for analysis of process operations and safeguards.

Because the NRTA data may be used by international inspectors, we will also consider evaluations of the inspector's attributes measurement plan and the variable measurement plan associated with the MUF-d statistic. The IODYN software can be applied to develop plans that are either optimal for detection probability or for cost to the operator. In addition, software will be developed for sequential analysis of MUF-d to allow testing on sequences of MUFs with any desired loss scenario, thereby providing an improved analysis of the effectiveness of the NRTA system.

VI. CONCLUSIONS

An NRTA system for fuel fabrication facilities will be designed to include process and measurement simulation capabilities, and software for statistical analyses of process and inventory data. The system will serve both process operators and IAEA inspectors. Operators of future fuel fabrication facilities could use the NRTA system outlined here to plan their safeguards system to provide the IAEA inspectors with required safeguards data while minimizing the time lost from production. The IAEA could use the system in their negotiations with the operator and in conducting inspections thereby minimizing their intrusiveness during inspections. Finally, many parts of the design and much of the software could be modified or reused for other types of facilities.

REFERENCES

1. R. R. Picard and J. F. Hafer, "MAWST: Materials Accounting with Sequential Testing, Version 2.0," Los Alamos Safeguards Group document n-4/91-633, June 1991.