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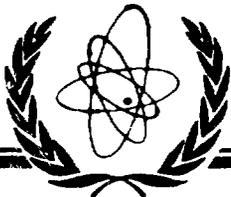
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**INTERNATIONAL
TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**

October 17-November 4, 1983

Santa Fe, New Mexico and Richland, Washington



PROCEEDINGS



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Course Director**

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International Atomic Energy Agency
Course Scientific Advisers**

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Los Alamos National Laboratory
Administrative Assistants**

MASTER

(*See footnote on page 1-5)

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

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J. Markin, Los Alamos
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R. Nilson, Exxon

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

FOREWORD

The fourth International Training Course on Implementation of State Systems of Accounting for and Control of Nuclear Materials (SSAC) was held October 17-November 4, 1983, in Santa Fe and Los Alamos, New Mexico, and in Richland, Washington. The SSAC courses are sponsored by the U.S. Department of Energy (DOE) in cooperation with the International Atomic Energy Agency (IAEA) to provide practical training in the design, implementation, and operation of national systems for nuclear material accounting and control.

Over 75 people took part in the 1983 course, including attendees, lecturers, workshop leaders, equipment demonstrators, and plant engineering personnel. Nations represented, in addition to the U.S., were Australia, Bangladesh, Brazil, Canada, Czechoslovakia, Egypt, France, India, Iraq, Japan, Korea, Libya, Malaysia, Pakistan, Philippines, Poland, South Africa, Sweden, Taiwan, and Thailand. Course Attendees are involved in nuclear safeguards at either the national or facility level in their home countries, and many hold positions of major responsibility.

The 1983 SSAC course was conducted by the Los Alamos National Laboratory and the Exxon Nuclear Company. Course lecturers were selected not only from Los Alamos and Exxon, but also from the IAEA, DOE, State Department, Nuclear Regulatory Commission (NRC), Sandia National Laboratories, Battelle Pacific Northwest Laboratory, and from nuclear organizations in Brazil, Japan, and Sweden. Emphasis for the 1983 course was on safeguards procedures for bulk processing facilities, such as low-enriched uranium (LEU) conversion and fuel fabrication plants.

The first half of the course was conducted in Santa Fe and Los Alamos, New Mexico. During this period, introductory course material was presented by lecturers from the State Department, NRC, the IAEA, and Sandia National Laboratories. Attendees made brief presentations regarding nuclear activities in their home countries, and there were panel and small group discussions of the IAEA/State System interface. Several technical lectures were presented by people from Los Alamos and two days were spent in Los Alamos safeguards laboratories where the attendees used nondestructive assay (NDA) instruments to measure typical nuclear materials.

The final week and a half of the course was conducted in Richland, Washington. This period involved lectures and demonstrations presented by senior employees of the Exxon Nuclear Company's LEU fuel fabrication plant. Two afternoons were spent touring the Exxon facility in Richland, and separate tours were made to the Battelle NDA van, the Westinghouse Fast Flux Test Facility Visitor Center, and to a 60% complete PWR facility in

the Richland area. Lectures were also presented in Richland by representatives of Battelle, NRC, and the IAEA. The course concluded with a two day workshop on safeguards system design for a LEU fuel fabrication plant. Attendees were divided into four subgroups, each with a staff advisor, and each subgroup was asked to define (in some detail) the elements of their proposed safeguards system. Rapporteurs from each subgroup presented the proposed designs, and the four approaches were summarized and compared by a member of the course staff.

The course was structured to encourage discussion among attendees and between attendees and course staff. The formal interactions during the lectures and workshops and the informal interactions outside the classroom were of great value to both students and staff. The SSAC courses offer an almost unique opportunity for the sharing of safeguards knowledge and experience among people with differing professional and cultural backgrounds.

These published proceedings of the 1983 SSAC course can be obtained by writing to:

Safeguards Training Program
Q-1 E540
Los Alamos National Laboratory
Los Alamos, N.M. 87545

Charles R. Hatcher
June 3, 1984



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

ABSTRACT

This report incorporates all lectures and presentations at the International Training Course on Implementation of State Systems of Accounting for and Control of Nuclear Materials held October 17 through November 4, 1983 at Santa Fe and Los Alamos, New Mexico and Richland, Washington, USA. Authorized by the U.S. Nuclear Non-Proliferation Act and sponsored by the U.S. Department of Energy in cooperation with the International Atomic Energy Agency, the course was developed to provide practical training in the design, implementation, and operation of a State system of nuclear materials accountability and control that satisfies both national and international safeguards requirements. Major emphasis for the 1983 course was placed on safeguards methods used at bulk-handling facilities, particularly low-enriched uranium conversion and fuel fabrication plants. The course was conducted by the University of California's Los Alamos National Laboratory and Exxon Nuclear Company, Inc. Tours and demonstrations were arranged at the Los Alamos National Laboratory, Los Alamos, New Mexico, and the Exxon Nuclear fuel fabrication plant, the Battelle Pacific Northwest Laboratory, Westinghouse Fast Flux Test Facility Visitor Center, and Washington Public Power System nuclear reactor facilities in Richland, Washington.

WELCOME



Jim Shipley, Los Alamos



Carlos Buechler, IAEA



Toby Johnson, DOE/OSS



Roy Nilson, Exxon Nuclear



AWARDS BANQUET

Bernardino Pontes, Special Assistant to the Chairman of the Brazilian Atomic Energy Commission, was the guest speaker at the 1983 awards banquet. From 1980 to 1983, "Dino" was the head of the Safeguards Training Section at the IAEA. In his remarks, Pontes gave an historical perspective of the evolution of SSAC training.



Course Director and Coordinators with Dino Pontes at the Awards Banquet. Left to right, Hastings Smith, Charlie Hatcher, Dino Pontes, and Dick Schneider.



Lectures



Tours



Workshops



Discussions

Administrative Support:
Left to right - Linda Robinson,
Joy Clark, Charlie Hatcher



Official Course
Photographer, Mitzie
Ulibarri with Charlie
Hatcher



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

TABLE OF CONTENTS

(Presentations in Santa Fe/Los Alamos)

WELCOME

James Shipley (Los Alamos) Toby Johnson (DOE/OSS)
Carlos Buechler (IAEA) Roy Nilson (Exxon Nuclear)

SESSION 1:

INTRODUCTION TO SSAC TRAINING COURSE
C. Hatcher, Los Alamos

SESSION 2:

DEVELOPMENT AND CURRENT TRENDS IN THE INTERNATIONAL
NUCLEAR NONPROLIFERATION REGIME
A. Sessoms, US Department of State

SESSION 3:

OVERVIEW OF IAEA GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING
FOR AND CONTROL OF NUCLEAR MATERIALS

OBJECTIVES, DIVERSION OF NUCLEAR MATERIAL, AND THE IAEA
SAFEGUARDS SYSTEM
C. Buechler, IAEA

SESSION 4:

THE U.S. NATIONAL MATERIAL CONTROL AND ACCOUNTING SYSTEM
C. Smith, US NRC

SESSION 5:

THE NATIONAL NUCLEAR MATERIAL CONTROL AND ACCOUNTING SYSTEM
IN SWEDEN
P. Ek, Sweden

SESSION 6:

WORKSHOP ON IAEA/STATE SYSTEMS INTERFACE -- BRIEF PRESENTATIONS
BY COURSE ATTENDEES

SESSION 7:

PANEL DISCUSSION ON IAEA/STATE SYSTEMS INTERFACE

SESSION 8:

FACILITY SAFEGUARDS AT AN LEU FUEL FABRICATION FACILITY
IN JAPAN
H. Kuroi, Japan

SESSION 9:

TYPICAL IAEA OPERATIONS AT A FUEL FABRICATION PLANT
S. Morsy, IAEA

TABLE OF CONTENTS (Continued)

SESSION 10:

PHYSICAL PROTECTION IN RELATION TO IAEA SAFEGUARDS
C. Sonnier, Sandia National Laboratories

SESSION 11:

THE IAEA SAFEGUARDS INFORMATION SYSTEM
J. Nardi, IAEA

SESSION 12:

PRINCIPLES OF NEAR-REAL-TIME MATERIALS ACCOUNTING AND
CONTROL SYSTEMS
J. Shipley, Los Alamos (Presented by J. Markin)

SESSION 13:

SAFEGUARDING NUCLEAR POWER STATIONS
G. Whan, University of New Mexico

SESSION 14:

ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY
C. Hatcher and H. Smith, Los Alamos

SESSION 15:

NDA MEASUREMENTS FOR LWR FUEL FABRICATION FACILITIES
R. Augustson, Los Alamos

SESSION 16:

TOUR OF LOS ALAMOS SAFEGUARDS R & D LABORATORIES: DEMONSTRATION
AND USE OF NDA INSTRUMENTS AND MATERIALS CONTROL AND ACCOUNTING
SIMULATION

(Presentations in Richland)

SESSION 17a:

BASIS OF PLANT ACCOUNTING SYSTEM
R. Schneider, Exxon Nuclear Corporation

SESSION 17b:

MODEL PLANT ACCOUNTING SYSTEM
M. Schnaible, Exxon Nuclear Corporation

SESSION 18:

DESCRIPTION OF MODEL PLANT MEASUREMENT AND CONTROL SYSTEM

SESSION 18a:

BRIEF PLANT DESCRIPTION
D. McAlees, Exxon Nuclear Corporation

SESSION 18b:

MODEL PLANT KEY MEASUREMENT POINTS
R. Schneider, Exxon Nuclear Corporation

SESSION 19:

GENERAL PLANT TOUR

SESSION 20:

DISCUSSION OF PLANT TOUR AND MODEL PLANT ACCOUNTING SYSTEM

TABLE OF CONTENTS (Continued)

- SESSION 21:
NUCLEAR INVENTORY CONTROL SYSTEM
A. Kraft, Exxon Nuclear Corporation
- SESSION 22:
DESCRIPTION AND EXAMPLE OF RECORDS, REPORTS, AND FORMS
D. Noss, Exxon Nuclear Corporation
- SESSION 23:
ASSIGNMENT OF ELEMENT AND ISOTOPE FACTORS
R. Schneider, Exxon Nuclear Corporation
- SESSION 24:
PROCEDURE FOR TAKING PHYSICAL INVENTORIES
R. Boston, Exxon Nuclear Corporation
- SESSION 25:
USE OF TAMPER-INDICATING SEALS AT MODEL FACILITY
R. Logsdon, Exxon Nuclear Corporation
- SESSION 26:
ANALYTICAL METHODS USED AT MODEL FACILITY
N. Wing, Exxon Nuclear Corporation
- SESSION 27:
NDA METHODS USED AT MODEL FACILITY
K. Johnson, Exxon Nuclear Corporation
- SESSION 28:
MEASUREMENT CONTROL PROGRAM AT MODEL FACILITY
R. Schneider, Exxon Nuclear Corporation
- SESSION 29a:
TOUR OF SAFEGUARDS EQUIPMENT VAN
B. Smith and J. Fager, Pacific Northwest Laboratory
- SESSION 29b:
TOUR OF MODEL PLANT AND DEMONSTRATION OF MEASUREMENT
TECHNIQUES
- SESSION 30:
CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES:
ERROR PROPAGATION
J. Jaech, Exxon Nuclear Corporation
- SESSION 31:
CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC
J. Jaech, Exxon Nuclear Corporation
- SESSION 32:
ESTIMATION OF MEASUREMENT VARIANCES
J. Jaech, Exxon Nuclear Corporation

TABLE OF CONTENTS (Continued)

- SESSION 33:
TOUR OF WNP-1 AND FFTF MUSEUM
- SESSION 34:
STATISTICAL SAMPLING PLANS
J. Jaech, Exxon Nuclear Corporation
- SESSION 35:
TYPICAL NRC INSPECTION PROCEDURES FOR MODEL PLANT
J. Blaylock, US NRC (Presented by L. Norderhaug)
- SESSION 36:
TYPICAL IAEA INSPECTION PROCEDURES FOR MODEL PLANT
W. Theis, IAEA
- SESSION 37:
INTRODUCTION TO MC&A SYSTEM DESIGN WORKSHOP
R. Schneider, Exxon Nuclear Corporation
A. Hakkila, Los Alamos
N. Harms, Pacific Northwest Laboratory
W. Theis, IAEA
- SESSION 37a:
DESCRIPTION OF REFERENCE (MODEL) PLANT
R. Schneider, Exxon Nuclear Corporation
- SESSION 37b:
PREPARATION OF A FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN
R. Schneider, Exxon Nuclear Corporation
- SESSION 37c:
PREPARATION OF A DESIGN INFORMATION QUESTIONNAIRE (DIQ)
FOR MODEL FUEL FABRICATION PLANT
R. Schneider, Exxon Nuclear Corporation
- SESSION 38:
MC&A SYSTEMS DESIGN WORKSHOP
R. Schneider, Exxon Nuclear Corporation
N. Harms, Pacific Northwest Laboratory
- SESSION 39:
REPORTS OF MC&A SYSTEMS DESIGN WORKSHOP SUBGROUPS
- SESSION 40:
COURSE EVALUATION, DISCUSSION, AND WRAP-UP



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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October 17-November 4, 1983

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Los Alamos/Santa Fe, New Mexico October 17-26, 1983
Richland, Washington October 27-November 4, 1983

COURSE SYLLABUS

MONDAY, OCTOBER 17, 1983, 3:00PM to 6:00 PM - REGISTRATION

TUESDAY, OCTOBER 18, 1983

AM

WELCOME AND ORIENTATION

Los Alamos

Session 1: INTRODUCTION TO SSAC TRAINING COURSE

Scope of Subjects to be Covered
Course Structure and Schedule
Course Materials and Facilities
Introduction to Course Staff
Administrative Arrangements and Support
Registration

Session 2: DEVELOPMENT AND CURRENT TRENDS IN THE INTERNATIONAL
NUCLEAR NONPROLIFERATION REGIME

History of IAEA Safeguards
Nonproliferation Treaty
U.S. Policy on Nonproliferation and Safeguards
Current Trends

PM

Session 3: OVERVIEW OF IAEA GUIDELINES FOR STATE SYSTEMS OF
ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS:
OBJECTIVES, DIVERSION OF NUCLEAR MATERIAL, AND
THE IAEA SAFEGUARDS SYSTEM

Objectives of IAEA Safeguards
Diversion of Nuclear Material
The IAEA Safeguards System
Guidelines for State Systems of Accounting & Control

Session 4: THE U.S. NATIONAL MC&A SYSTEM

The Need for National Nuclear Materials Safeguards
The U.S. National MC&A Regulations
Basic Elements of MC&A
Formation of a Fundamental Nuclear Material Control Plan
Relationship of National & International Safeguards Programs

IAEA Reception, 6:00PM to 8:00 PM

WEDNESDAY, OCTOBER 19, 1983

AM

Session 5: THE NATIONAL NUCLEAR MATERIAL ACCOUNTING AND CONTROL SYSTEM IN SWEDEN

Nuclear Activities and Facilities
Organization and Responsibilities of the SSAC
Records and Reporting Requirements
Auditing Procedures

Session 6: WORKSHOP ON IAEA/STATE SYSTEMS INTERFACE -- BRIEF PRESENTATIONS BY COURSE ATTENDEES

PM

Session 7: PANEL DISCUSSION ON IAEA/STATE SYSTEMS INTERFACE

Subgroup Meetings to Identify Questions for Panel
Panel Discussion

THURSDAY, OCTOBER 20, 1983

AM

Session 8: FACILITY SAFEGUARDS AT AN LEU FUEL FABRICATION FACILITY IN JAPAN

Facility Description
MC&A Plan (MBA's and KMP's)
Measurement Program
Inventory Procedures
Records and Reports
Inspections

Session 9: TYPICAL IAEA OPERATIONS AT A FUEL FABRICATION PLANT

Planning an Overall Verification Approach

- Goals and Objectives
- Plant Information
- Diversion Scenarios
- Practical Limitations

Session 9 (continued):

Inspection Activities

- Accuracy and Consistency of Records
- Material Flow Verification
- Physical Inventory Verification (counting, identification, measurement, seals)
- Review of Internal Measurement Program

PM

Session 10: PHYSICAL PROTECTION IN RELATION TO IAEA SAFEGUARDS

Safeguard System Structure
SSAC Interfaces
Physical Protection Equipment Overview

Session 11: THE IAEA SAFEGUARDS INFORMATION SYSTEM

Purpose of Safeguards Information System
Records for Different Types of Facilities
IAEA Reporting Requirements
Standardization of Reports
Auditing of Records and Reports

FRIDAY, OCTOBER 21, 1983

AM

Session 12: PRINCIPLES OF NEAR-REAL-TIME MATERIALS ACCOUNTING AND CONTROL SYSTEMS

Structure of Safeguards Systems
Process Design and Safeguards Systems
Advanced System Design Methodology

- Modeling and Simulation
- Decision Analysis

Session 13: SAFEGUARDING NUCLEAR POWER STATIONS

Characteristics of Nuclear Power Stations
Typical Fuel Inventories at Nuclear Power Stations
Safeguarding Light-Water Reactors
Safeguarding Heavy-Water Reactors

PM

Session 14: ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY

Role of NDA
Passive/Active NDA Methods
Gamma-Ray Techniques/Instruments
Neutron Techniques/Instruments
Calorimetry
Relative Advantages of Different NDA Techniques

Session 15: NDA MEASUREMENTS FOR LWR FUEL FABRICATION FACILITIES

Enrichment
Holdup
Waste and Scrap
Rod Scanners
Fuel Assembly Assay
Group Discussions of NDA Applications

MONDAY, OCTOBER 24, 1983

Session 16: TOUR OF LOS ALAMOS SAFEGUARDS R&D LABORATORIES:
DEMONSTRATION AND USE OF NDA INSTRUMENTS AND MATERIALS
CONTROL AND ACCOUNTING SIMULATION

Hands-on Demonstration of Gamma-Ray NDA Instruments
Hands-on Demonstration of Neutron NDA Instruments
Parallel Session Using Materials Accounting Simulator

TUESDAY, OCTOBER 25, 1983

AM

Session 16 (Continued):

Parallel Sessions:
NDA Workshop
MC&A Workshop

PM

Tour of Bradbury Science Museum and Bandelier National Monument

Dinner at Casa del Mirador

WEDNESDAY, OCTOBER 26, 1983

Travel to Richland Washington

Bus to Albuquerque Airport leaves Santa Fe Hilton at 0625 AM.

THURSDAY, OCTOBER 27, 1983

AM

WELCOME, INTRODUCTION, AND ANNOUNCEMENTS

Session 17a: BASIS OF PLANT ACCOUNTING SYSTEM

General Requirements
Design Considerations

Session 17b: MODEL PLANT ACCOUNTING SYSTEM

Specific Requirements
Accounting System Details

Session 18: DESCRIPTION OF MODEL PLANT MEASUREMENT AND CONTROL SYSTEM

Session 18a: BRIEF PLANT DESCRIPTION

Session 18b: MODEL PLANT KEY MEASUREMENT POINTS

Facility description
Measurements
MBA/ICA Structure

PM

Session 19: GENERAL PLANT TOUR

UF₆ Cylinder Storage
UF₆ to UO₂ Conversion
UO₂ Storage
Pelletizing Area (pressing, sintering, storage)
Rod Assembly and Storage
Fuel Bundle Assembly and Storage

FRIDAY, OCTOBER 28, 1983

AM

Session 20: DISCUSSION OF PLANT TOUR AND MODEL PLANT ACCOUNTING SYSTEM

Subgroups will consider a series of questions on the plant tour. Experts will be available to assist each subgroup.

Session 21: NUCLEAR INVENTORY CONTROL SYSTEM

System Design
Transactions
Data Base Files
Data Processing

Session 22: DESCRIPTION AND EXAMPLE OF RECORDS, REPORTS, AND
FORMS

Account Structure
Accounting Forms
Accounting Reports

PM

Session 23: ASSIGNMENT OF ELEMENT AND ISOTOPE FACTORS

Element Factors
Isotope Factors
Project Average Enrichment
Data Treatment

Session 24: PROCEDURE FOR TAKING PHYSICAL INVENTORIES

Requirements and Responsibilities
General Procedures
Item and Control Area Procedures
Material Balance Area Procedure
Post Inventory Procedure

Session 25: USE OF TAMPER-INDICATING SEALS AT MODEL FACILITY

Types of Seals Used
Procurement and Control of Seals
Hands-On Demonstration of Seal Application

MONDAY, OCTOBER 31, 1983

AM

Session 26: ANALYTICAL METHODS USED AT MODEL FACILITY

Uranium Analysis
Isotopic Analysis

Session 27: NDA METHODS USED AT MODEL FACILITY

Waste
Enrichment
Rod Scanner

Session 28: MEASUREMENT CONTROL PROGRAM AT MODEL FACILITY

Technical Requirements
Mass Measurements
Analytical Measurements
NDA Measurements
Statistical Analysis

PM

Session 29a: TOUR OF SAFEGUARDS EQUIPMENT VAN

Session 29b: TOUR OF MODEL PLANT AND DEMONSTRATION OF MEASUREMENT
TECHNIQUES

UF₆ Cylinder Weighing
Analytical Laboratory
Enrichment Measurements
Rod Loading and Weighing
Rod Scanner
Scrap and Waste Measurements

TUESDAY, NOVEMBER 1, 1983

AM

Session 30: CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES:
ERROR PROPAGATION

Sources and Types of Measurement Error
Uncertainties in Safeguards Indices
Variance of a function of Random Variables
Calculating the Variance of a Plant Inventory Difference

Session 31: CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC

Role of Statistics in Interpreting Inspection Data
Variance of Difference Calculations for Shipper/Receiver
and Facility/Inspector Differences

Session 32: ESTIMATION OF MEASUREMENT VARIANCES

Systematic Error from Standards Data
Random Error from Repetitive Measurements
Fluctuating Bias from Variance Analysis

PM

Session 33: TOUR TO WNP-1 AND FFTF MUSEUM

WEDNESDAY, NOVEMBER 2, 1983

AM

Session 34: STATISTICAL SAMPLING PLANS

Quantitative Aspects of Inspection
Attributes Inspection
Variables Inspection
Independent Verification
Evaluation of Sample Plan

Session 35: TYPICAL NRC INSPECTION PROCEDURES FOR MODEL PLANT

Goals and Objectives of NRC Inspections
Inspection Procedures for:

- Facility Organization
- Facility Operation
- Measurement Control
- Shipping/Receiving
- Internal Control Program
- Physical Inventory
- Inventory Verification
- ID/LEID Evaluation
- Records and Reports
- Nuclear Material Control Management
- Entrance/Exit Management Meetings
- Independent Inspection

Session 36: TYPICAL IAEA INSPECTION PROCEDURES FOR MODEL PLANT

Records and Reports
Physical Inventory Taking
Flow Verification
Inventory Verification
Sampling Plans
Measurements
Seal Verification and Replacement
Summary Statements

PM

Session 37: INTRODUCTION TO MC&A SYSTEM DESIGN WORKSHOP

Session 37a: DESCRIPTION OF A REFERENCE (MODEL) PLANT)

Session 37b: PREPARATION OF A FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN

Session 37c: PREPARATION OF A DESIGN INFORMATION QUESTIONNAIRE (DIQ) FOR MODEL FUEL FABRICATION PLANT

Goals and Objectives of Workshop
Model Plant Assumptions
Preparation of FNMCP and DIQ for Model Plant
Specific Instruction to Subgroups
Subgroup Discussions

Session 38: MC&A SYSTEMS DESIGN WORKSHOP

Subgroups Will Discuss:

- Selection of a Rapporteur
- Physical Inventory Topics
- Material Accounting Topics
- Internal Control Topics
- Management Topics
- Preparation of Subgroup Reports

AWARDS BANQUET 6:30

FRIDAY, NOVEMBER 4, 1983

AM

Session 39: REPORTS OF MC&A SYSTEMS DESIGN WORKSHOP SUBGROUPS

Subgroup Reports Presented by Rapporteurs
Discussion of Subgroup Reports - Course Staff and
Attendees

Session 40: COURSE EVALUATION, DISCUSSION, AND WRAP-UP

Completion of Detailed Course Evaluation Form by Attendees
Suggestions for Improving Follow-on Courses
Summary of Experience Gained, Benefits, and Lessons Learned



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS



REGISTRATION
MONDAY 17 OCTOBER
1500 - 1800

October 17-November 4, 1983

	TUESDAY 18 OCTOBER	WEDNESDAY 19 OCTOBER	THURSDAY 20 OCTOBER	FRIDAY 21 OCTOBER	SATURDAY 22 OCTOBER	SUNDAY 23 OCTOBER	MONDAY 24 OCTOBER	TUESDAY 25 OCTOBER	WEDNESDAY 26 OCTOBER
0730									* * * *
0830	WELCOME AND ORIENTATION (LOS ALAMOS, DOE, IAEA)	5 THE NATIONAL MC&A SYSTEM IN A COUNTRY OF MEDIUM SIZE (EKI)	8. FACILITY SAFEGUARDS AT AN LEU FUEL FABRICATION PLANT (KUROH)	12. PRINCIPLES OF NEAR-REAL-TIME ACCOUNTING AND CONTROL SYSTEMS (MARKIN)			16 LOS ALAMOS SAFEGUARDS ORIENTATION AND BRIEFING (SMITH, REILLY)	16. (CONTINUED) PARALLEL SESSIONS • NDA WORKSHOP • MC&A WORKSHOP	0625 BUS TO ABO AIRPORT 0850 WESTERN AIRLINES FLIGHT 415 TO PASCO WASHINGTON
0930	1 INTRODUCTION TO THE SSAC COURSE (HATCHER)	BREAK	BREAK (GROUP PICTURE)	BREAK			16. (CONTINUED) LOS ALAMOS NDA DEMONSTRATION AND MC&A SIMULATION (LOS ALAMOS STAFF)		
1000									
1030	BREAK	6 WORKSHOP ON SSAC. BRIEF PRESENTATIONS BY COURSE ATTENDEES (JOHNSON)	9. TYPICAL IAEA OPERATIONS AT A FUEL FABRICATION PLANT (MORSY)	13 SAFEGUARDING NUCLEAR POWER STATIONS (WHAN)					
1045									
1100	2 HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS (SESSOMS)								
1200	LUNCH	LUNCH	LUNCH	LUNCH	FREE TIME	FREE TIME - BUS TOUR OF NORTHERN NEW MEXICO	LUNCH	LUNCH	
1300									
1330	3 INTRODUCTION TO IAEA SAFEGUARDS (BUCHLER)	7 WORKSHOP ON IAEA/STATE SYSTEM INTERFACE (SUBGROUPS)	10. INTRO. DUCTON TO PHYSICAL PROTECTION OF NUCLEAR FACILITIES (BONNIER)	14. ELEMENTS OF NDA TECHNOLOGY (SMITH)			16. (CONTINUED)	TOUR OF LOS ALAMOS SCIENCE MUSEUM	1255 ARRIVE PASCO BUS TO RIVERSHORE HOTEL
1400								TOUR OF BANDELIER NATIONAL MONUMENT	
1430		BREAK							HOTEL CHECK-IN
1500	BREAK	7 PANEL DISCUSSION ON IAEA/STATE SYSTEM INTERFACE (SESSOMS)	BREAK	BREAK					
1530	4 THE UNITED STATES NATIONAL MC&A SYSTEM (SMITH)		11. THE IAEA SAFEGUARDS INFORMATION SYSTEM (NARDI)	15. NDA APPLICATIONS FOR LEU FUEL FABRICATION PLANTS (AUGUSTSON)					
1700									
1800	IAEA RECEPTION						DINNER AT CASA DEL MIRADOR	BUS TO SANTA FE	
2000								ADVANCE CHECK-OUT FROM SANTA FE HILTON	
							BUS TO SANTA FE		



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

SSAC SCHOOL LIBRARY

We assembled a number of books, reports, conference proceedings and journals pertaining to Nuclear Material Accounting and Control for the students' information. These items were placed in the lecture hall in Santa Fe, and all course attendees were invited to browse through the materials at any time. Extra copies of lecturers' handouts were also placed in the library display.

Listed below are the items which were provided in the library display:

PREVIOUS SSAC COURSE PROCEEDINGS:

"International Training Course on Nuclear Materials Accountability for Safeguards Purposes," LA-9620-C Volumes I and II (1980).

"Advanced International Training Course on State Systems of Accounting for and Control of Nuclear Materials," LA-8901-C (1981).

"International Training Course on Implementation of State Systems of Accounting for and Control of Nuclear Materials," LA-9609-C (1982).

PROCEEDINGS OF INMM MEETINGS (Institute of Nuclear Materials Management):

Palm Beach, Fla., June 30-July 2, 1980

San Francisco, Cal., July 13-15, 1981

Washington, D.C., July 18-21, 1982

"Measurement Technology for Safeguards and Materials Control," American Nuclear Society Topical Conference, Kiawah Island, S.C., November 26-30, 1979, NBS Special Publication 582.

Nuclear Materials Management (INMM Journal)

Summer 1982 Issue

Winter 1982 Issue

Spring 1983 Issue

INMM Membership Materials (Membership Application Forms)

Safeguards Library

SAFEGUARDS SYSTEMS:

- "The Structure of Safeguards Systems," J.P. Shipley, Los Alamos report LA-7337-MS (1978).
- "Some Safeguards Approaches and Evaluation Methods," J.P. Shipley, Nucl. Mat. Mgmt. VIII, No. 4 (1979).
- "Performance Analysis of Nuclear Materials Accounting Systems," D.D. Cobb and J.P. Shipley, Nucl. Mat. Mgmt. VIII (1979).
- "Coordinated Safeguards for Materials Management in a Mixed-Oxide Fuel Facility," Los Alamos Report LA-6536 (1977).
- "Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant," Los Alamos Report LA-6881 (Volumes I and II) (1977).
- "Materials Management in an Internationally Safeguarded Fuels Reprocessing Plant," Los Alamos Report LA-8042 (Volumes I, II, and III) (1980).
- "Coordinated Safeguards for Materials Management in a Nitrate-to-Oxide Conversion Facility," Los Alamos Report LA-7011 (1978).
- "Coordinated Safeguards for Materials Management in a Uranium-Plutonium Nitrate-to-Oxide Conversion Facility," Los Alamos Report LA-7521 (1979).
- "Concepts for Inventory Verification in Critical Facilities," Los Alamos Report LA-7315 (1978).
- "Integrated International Safeguards Concepts for Fuel Reprocessing," Los Alamos Report LA-8955; Sandia Labs Report SAND81-1311 (1981).

NUCLEAR SAFEGUARDS RESEARCH & DEVELOPMENT:

- "Safeguards in the Seventies - A Bibliography of LASL Safeguards R&D Publications," Los Alamos Report LA-8663-MS (1981).
- "Safeguards & Security Status Report August 1981-January 1982," Los Alamos Report LA-9373-PR (1982).
- "Safeguards & Security Status Report February-July 1982," Los Alamos Report LA-9595-PR (1983).
- Los Alamos Science, Vol I No 1., Reprint Issue on Nuclear Safeguards (1980).
[Copy supplied for each attendee]

Safeguards Library

NDA INSTRUMENTATION:

- "Description and Operation Manual for the Active Well Coincidence Counter," H.O. Menlove, LA-7823-MS (1979).
- "Description and Performance Characteristics for the Neutron Coincidence Collar for the Verification of Reactor Fuel Assemblies," H.O. Menlove, LA-8939-MS (1981).
- "Gamma-Ray Measurements with the Segmented Gamma Scan," Los Alamos Report LA-7059-M (1977).
- "Measurement of Uranium and Plutonium in Solid Waste by Passive Photon or Neutron Counting and Isotopic Neutron Source Interrogation," T.W. Crane, LA-8294-MS (1980).
- "Neutron Measurement Techniques for the NDA of Irradiated Fuel Assemblies," Los Alamos Report LA-9002-MS (1981).
- "The Feasibility of NDA Measurements in Uranium Enrichment Plants," R.B. Walton, LA-7212-MS (1978).
- "NDA Verification and Assay Systems for Spent Fuels," Los Alamos Report LA-9041 (1982).
- "Active Neutron Coincidence Counting for the Assay of MTR Fuel Elements," R. Sher, LA-9665-MS (1983).
- "Summary Report on Uranium Holdup Estimation," Draft Report, 1983.
- "The High-Level Neutron Coincidence Counter (HLNCC): Users' Manual," Los Alamos Report LA-7779-M (1979).

NDA TRAINING:

- "Fundamentals of Passive NDA of Fissionable Material," R.H. Augustson and T.D. Reilly, LA-5651-M (1974).
- "A Guide to Gamma-Ray Assay for Nuclear Material Accountability," T.D. Reilly and J.L. Parker, LA-5794-M (1975).
- "IAEA Safeguards Technical Manual, Part F: Statistical Concepts and Techniques," IAEA-TECDOC-227 (1980).
- Laboratory Manual: "Fundamentals of Nondestructive Assay of Fissionable Materials Using Portable Instrumentation," Last Given October, 1983.
- Laboratory Manual: "Neutron Assay of Nuclear Material," Last Given, June, 1983.
- Laboratory Manual: "NDA For IAEA Inspectors," Last Given in August, 1983.

Safeguards Library

BOOKS:

- A Guidebook to Nuclear Reactors, A.V. Nero (1979).
- Active NDA of Nuclear Materials, T. Gozani NUREG/CR-0602, (1981).
- The Detection of Fissionable Materials by Nondestructive Means, R. Sher and S Untermeyer II, ANS Monograph (1980).
- The Atomic Complex, B. Goldschmidt, ANS Monograph (1980).
- Nuclear Arms in the Third World, Brookings Institute (1979).
- Nuclear Proliferation: Breaking the Chain, G.H. Quester, ed. U. of Wisconsin Press (1981).
- Swords from Plowshares, The Military Potential of Nuclear Energy, U. of Chicago Press (1977).

ESARDA:

- Bulletin, Number 2, June 1982
Bulletin, Number 3, November 1982
Bulletin, Number 4, April 1983

- ESARDA 4th Symposium Proceedings 1982 (ESARDA 15)
ESARDA 5th Symposium Proceedings 1983 (ESARDA 16)

Safeguards Library

IAEA LITERATURE:

The Statute

Nuclear Safeguards Technology, 1978

IAEA Symposium Proceedings, Vols I and II (1978).

"The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," IAEA INFCIRC/153 (Corrected) (1972).

"The Agency's Safeguards System," IAEA INFCIRC/66/Rev. 2 (1968).

Safeguarding Nuclear Materials

IAEA Symposium Proceedings, Vol 1., 1975.

IAEA Bulletin, August, 1980

IAEA Technical Report #213: "TASTEX, Tokai Advanced Safeguards Technology Exercise," Vienna (1982).

"Non-Proliferation and International Safeguards," IAEA Public Information Booklet for the 1978 UN General Assembly Session on Disarmament (1978).

"The Physical Protection of Nuclear Material," IAEA INFCIRC/225 Rev 1., (1977).

"IAEA Safeguards Glossary," IAEA/SG/INF/1, (1980).

"Guidelines for States' Systems of Accounting for and Control of Nuclear Materials," IAEA/SG/INF/2, (1980).

"IAEA Safeguards, An Introduction," IAEA/SG/INF/3, (1981).
[Copies of INF/1,2, and 3 supplied to attendees]



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 1: INTRODUCTION TO THE SSAC TRAINING COURSE

The overall objective of the 1983 SSAC Course will be discussed and the structure and format presented, together with a brief survey of the curriculum. The major course components will be described, including lecture presentations, the workshop sessions, tours and demonstrations, and other activities. Various course materials and physical facilities to be used will be described.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 1: INTRODUCTION TO SSAC TRAINING COURSE

C. R. Hatcher
Los Alamos National Laboratory

I. INTRODUCTION

State Systems of Accounting for and Control of Nuclear Material (SSAC) are widely recognized as a vital element in achieving effectiveness and credibility for international safeguards. A nation's SSAC must also satisfy national objectives, such as accounting for all safeguarded material and detecting losses or unauthorized removal of material.

We use the term SSAC to mean all safeguards arrangements and activities at both national and facility levels that pertain to nuclear material accounting and control. Physical protection, the other important aspect of domestic safeguards, deals with prevention of and response to theft of materials and sabotage of facilities. An international training course on physical protection has been presented by Sandia National Laboratories each year since 1979 and was offered most recently in September 1983.

The purpose of our 1983 SSAC training course is to provide practical training in the implementation and operation of a national system of accounting for and control of nuclear materials that satisfies both national and international safeguards objectives. Major emphasis is placed on the principles and practical methods used in establishing and operating nuclear material accounting and control systems at bulk-handling facilities, in particular, low-enrichment uranium (LEU) conversion and fuel fabrication plants.

In recognition of the importance in achieving an adequate SSAC in each member state having safeguarded material, the IAEA instituted SSAC training at its Vienna headquarters in 1976. Table I shows the history of SSAC courses presented over the past eight years. The five courses offered in Vienna and Yalta in 1976, 1977, 1978, 1981, and 1982 cover and expand on the IAEA "Guidelines for States' Systems of Accounting for and Control of Nuclear Materials."¹ The courses in Yalta were presented under joint IAEA/USSR sponsorship.

In 1979, a more advanced SSAC course that emphasized safeguards at bulk-processing facilities was presented in Richland, Washington. Sponsored by the US Department of Energy (DOE) in cooperation with the IAEA, the 1979 course featured tours of the Exxon Nuclear Company fuel fabrication plant in Richland, as well as lecturers from the IAEA, Exxon, and Battelle Pacific Northwest Laboratories.

Starting in 1980, SSAC training courses in the US came under the auspices of the Nuclear Nonproliferation Act of 1978. Los Alamos National Laboratory was asked to take the lead in planning and presenting these courses, which have been sponsored by DOE

TABLE I

LIST OF SSAC TRAINING COURSES

<u>Year</u>	<u>Location</u>	<u>Course Emphasis</u>		
		<u>Basic</u>	<u>Item</u>	<u>Bulk</u>
1976	Vienna	•		
1977	Vienna	•		
1978	Yalta	•		
1979	Richland			•
1980	Santa Fe		•	
1981	Santa Fe/Richland			•
1981	Yalta	•		
1982	Santa Fe		•	
1982	Yalta	•		
1983	Santa Fe/Richland			•

in cooperation with the IAEA. The SSAC course working committees include representatives of DOE, IAEA, Los Alamos, US/NRC, US/DOS, ACDA, and Exxon Nuclear. Course lecturers have been provided by the IAEA, Los Alamos, US Government, foreign governments, and industrial organizations, as well as other US national laboratories and US industry. The emphasis of SSAC courses offered in 1980 and 1982 was on safeguarding item-dominant facilities, such as power and research reactors and spent-fuel storage facilities. The 1981 and 1983 course material emphasizes safeguards techniques at bulk facilities, and in both 1981 and 1983 (as in 1979), Exxon Nuclear provided many of the technical lecturers and allowed access to their plant for tours and demonstrations.

II. COURSE CONTENT

A. Course Manual

The 1983 SSAC course manual contains essentially all the material to be presented in the course. The manual is organized into sessions 1 through 40, pages are numbered according to session, and each session begins with a statement of objectives.

A copy of the course syllabus, previously mailed separately to course participants, is at the front of the manual. The syllabus provides a fairly accurate summary of subject matter for quick reference, but session titles listed in the syllabus occasionally differ from those chosen by the authors.

Perhaps the most useful outline of course activities is the two-page schedule near the front of the manual. It not only lists all subjects and lecturers, but also includes extracurricular activities.

B. First Week

Sessions 1 through 5 provide an introduction to the 1983 SSAC course. Allen Sessoms of the US Department of State will speak on "Development and Current Trends in the International Nuclear Nonproliferation Regime." Carlos Buechler from the IAEA will give an "Overview of IAEA Guidelines for State Systems of Accounting and Control." Mike Smith from the US Nuclear Regulatory Commission plans to talk on the "US National Material Control and Accounting System," and Paul Ek of Sweden will lecture on the "National Nuclear Material Control and Accounting System in Sweden."

Following the introductory lectures, we will devote most of Wednesday, October 19, 1983, to a workshop on the IAEA/State Systems Interface. The workshop is divided into three parts:

- brief presentations by course attendees
- subgroup meetings to identify questions for the panel
- a panel discussion

This is the second year in which we have asked course participants to make a brief presentation on any subject of interest, such as nuclear technology and SSAC activity in their home countries. We hope to have one or more presentations from every country represented. Because of time constraints, we must limit presentations to three minutes each. O. B. Johnson of DOE will chair this session, which should get our workshop off to an interesting start.

After lunch on Wednesday, participants and panel members will be divided into four subgroups. Each subgroup will develop a short list of questions for the panel. Following the afternoon break, the panel will be convened under Allen Sessoms to respond to subgroup questions as well as questions from the floor.

During the final two days of this week, we will have four technical lectures each day. The lectures on Thursday will examine several specific activities related to the IAEA/State Systems interface. Hideo Kuroi of Japan will lecture on "Facility Safeguards at a LEU Fuel Fabrication Plant," and Samir Morsy of the IAEA will discuss "Typical IAEA Operations at a LEU Fuel Fabrication Plant." Cecil Sonnier from Sandia will address "Physical Protection in Relation to IAEA Safeguards," then Joe Nardi of the IAEA will speak on the "IAEA Safeguards Information System."

The four speakers on Friday, October 19, 1983, are all involved in safeguards at Los Alamos. The primary purpose of these lectures is to prepare you for two days at Los Alamos the following week. Jack Markin will present a lecture on "Principles of Near-Real-Time Materials Accounting and Control Systems." Glenn Whan from the University of New Mexico will discuss "Safeguarding

Nuclear Power Stations." Finally, Hastings Smith and Ron Augustson will talk about nondestructive assay technology.

C. Second Week

The second week starts with two days in Los Alamos, where participants will get some hands-on experience operating non-destructive assay instruments and near-real-time accounting simulators. Following a brief orientation, subgroups will be assigned to each of five work stations. Subgroups will then rotate so that participants can become familiar with the equipment at each work station. Time will be allotted for discussion and special exercises.

On Wednesday, October 26, 1983, we will fly from Albuquerque to Richland, Washington aboard Western Airlines flight WA415. The bus for Albuquerque will leave from the main entrance of the hotel at 0625.

During the last two days of the second week, we will be led by Dick Schneider and others from Exxon into the intricacies of the model plant material accounting and control system. Topics to be covered include

- general requirements
- system design
- inventory control system
- accounting forms and reports
- element and isotope factors
- procedure for taking physical inventories
- use of tamper-indicating seals

There will be tours of the Exxon fuel fabrication plant on October 27 and October 31.

D. Third Week

The third week begins with lectures and a tour covering model plant material measurement methods. Four lectures will then be presented by John Jaech of Exxon on statistical methods as they are applied to material accounting at bulk facilities.

On Wednesday, November 1, we conclude the section on statistics and move on to specific inspection techniques for the model plant. Leroy Norderhaug will speak on typical NRC inspection procedures and Willi Theis will discuss IAEA inspection procedures. Both will be speaking from first-hand experience. These talks will lead into the introduction to the final workshop in which subgroups will be asked to design a materials accounting and control system for a hypothetical LEU fuel fabrication plant. Participating as instructors in the workshop will be Dick Schneider of Exxon, Arnie Hakkila of Los Alamos, Neil Harms of Battelle, and Willi Theis of the IAEA.

All day Thursday, November 3, will be spent in subgroup discussions and in preparation of an MC&A system design. The final day, November 4, 1983, will open with rapporteurs presenting each subgroup's system design in talks of approximately one-half hour. Activities will conclude with a discussion of workshop results and an evaluation of the training course.

Tours and demonstrations are interspersed throughout the course, including visits to:

- Los Alamos
- Exxon
- Battelle
- WPPS/WNP-1
- FFTF visitor center

III. EXTRACURRICULAR AND ADMINISTRATIVE MATTERS

Several extracurricular activities are planned, to which all course participants are invited. These include

- IAEA Reception (October 18, 1983)
- Bus Tour of Northern New Mexico (October 23, 1983)
- Los Alamos Dinner (October 24, 1983)
- Auto Tours in Richland Area (October 30, 1983)
- Exxon Reception (November 4, 1983)
- Awards Banquet (November 4, 1983)

Informal discussions among course participants (including lecturers) can be an extremely valuable supplement to the formal sessions. One of the reasons for choosing Santa Fe and Richland and for holding class sessions at the hotel is to encourage this informal interaction. We hope that our guests will join us in creating a relaxed atmosphere that promotes the open exchange of ideas and information.

The 1983 course staff includes the IAEA Scientific Advisor Les Thorne,* course coordinators Hastings Smith from Los Alamos and Dick Schneider from Exxon, and the administrative specialist from Los Alamos, Joy Clark. The Los Alamos photographer, Mitzi Ulibarri, has been involved in these courses since 1980. Those of us on the course staff look forward to becoming better acquainted with each participant during the coming days. If any of you have problems during your stay in the US, please contact us so that we can be of assistance to you.

REFERENCE

1. "Guidelines for States' Systems of Accounting For and Control of Nuclear Materials," IAEA/SG/INF/2, IAEA Press, Vienna (1980).

*Bernardino Pontes is listed on the course manual cover as one of the IAEA scientific advisors because he contributed to planning the 1983 SSAC course until he left the IAEA in September 1983. He will be participating in the 1983 SSAC course, not as an IAEA scientific advisor, but as the awards banquet speaker and representative of Brazil.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 2: DEVELOPMENT AND CURRENT TRENDS IN THE
INTERNATIONAL NUCLEAR NONPROLIFERATION REGIME

This session will describe the circumstances surrounding the establishment of the IAEA, including an overview of the development of the nuclear nonproliferation regime. The role of the Agency and IAEA safeguards in the development of this regime will be discussed. Key elements of the regime, with emphasis on the NPT and its effect on the Agency's safeguards role, will be examined. Current U.S. nonproliferation policy and U.S. approaches to improving IAEA safeguards will be reviewed. Trends in U.S. policy on safeguards and on improving the nonproliferation regime generally will be outlined.

After the session, participants will be able to:

1. assess the importance of internationally recognized safeguards in helping to prevent the spread of nuclear weapons,
2. trace the development of international safeguards and the role of the IAEA in implementing international safeguards inspection and verification,
3. describe the various roles played by technology, international arrangements, national policies, and other aspects of international security arrangements, and
4. discern the political framework within which current initiatives to strengthen the Agency and its safeguards system are developed.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

**SESSION 2: DEVELOPMENT AND CURRENT TRENDS IN THE
INTERNATIONAL NONPROLIFERATION REGIME**

Allen L. Sessoms

Office of Nuclear Technology and Safeguards, State Department

I. INTRODUCTION

In this paper I would like to put the IAEA and its safeguards system into a historical perspective. I will also try to give you my personal perspective on the nonproliferation regime and on the Agency's role in it. This will be done initially by discussing some of the landmark events in the history of the nonproliferation regime. Subsequently some of the history of arms control agreements and of the role of the IAEA will be noted. Then political motivations of states and ways the Agency has an impact in the political nonproliferation sphere will be addressed.

II. NUCLEAR CHRONOLOGY

Figure 1 gives a brief chronology of some important events in the development of the nonproliferation regime as we know it today.

III. THE NONPROLIFERATION REGIME

The major component in the present regime is the restraint shown by nations in not developing weapons and the confidence other nations have that their neighbors will continue to act with restraint in this area. Making legally binding international commitments such as those embodied in the NPT and Treaty of Tlatelolco lend significant weight to a nation's statements about not developing nuclear weapons. However, as is clear in all such arrangements, some form of independent verification is essential if the regime is to be stable.

Figure 2 tries to put this independent verification scheme into context. The problem of proliferation is clearly political. The motivations that lead a state in this direction are clearly countered by motivations on the other side. These motivations result from a complex of factors such as those shown in Figure 3. The purpose of bilateral and multilateral economic and security assistance programs and arrangements is to reduce, to the extent possible, pressures on states to develop nuclear weapons or other nuclear explosive devices. International commitments also increase the disincentives to proliferation. It is the purpose of detection systems, of

A NUCLEAR CHRONOLOGY

1938	HANS BETHE DISCOVERY OF THE THERMONUCLEAR PROCESS OF THE SUN	1970	FIRST FRENCH H-BOMB TEST
1939	HAHN, MEITNER AND FRISCH DISCOVERY OF FISSION	MAY 1972	SEABED TREATY
1940	EINSTEIN/SZILARD LETTER TO ROOSEVELT	OCT 1972	SALT I
1941	ESTABLISHMENT OF THE MANHATTAN DISTRICT	OCT 1972	ABM TREATY
1942	FIRST CHAIN REACTION	MAY 1974	INDIAN TEST
JUL 1945	TRINITY TEST	JUL 1974	THRESHOLD TEST BAN TREATY (NOT RATIFIED)
AUG 1945	HIROSHIMA	MAY 1975	FIRST NPT REVIEW CONFERENCE
AUG 1945	NAGASAKI	MAY 1976	PROTOCOL TO ABM TREATY
AUG 1949	THE FIRST SOVIET TEST	MAY 1976	UNDERGROUND THRESHOLD TREATY (NOT RATIFIED)
MAR 1952	THE FIRST BRITISH TEST	APR 1977	CARTER NON-PROLIFERATION STATEMENT, INFCE INITIATED
NOV 1952	THE FIRST U.S. H-BOMB TEST	AUG 1977	SOVIET UNION SATELLITE PHOTOGRAPHS OF POSSIBLE TEST SITE IN THE SOUTH AFRICAN KALAHARI DESERT
AUG 1953	THE FIRST SOVIET H-BOMB TEST	1978	U.S. NON-PROLIFERATION ACT
DEC 1953	EISENHOWER ATOMS FOR PEACE PROGRAM	JUN 1979	SALT II (NOT RATIFIED)
JUL 1957	ESTABLISHMENT OF THE IAEA	SEP 1979	SOUTH ATLANTIC FLASH
FEB 1960	THE FIRST FRENCH TEST	NOV 1979	PUBLICATION OF THE PROGRESSIVE ARTICLE ON H-BOMB DESIGN
1961	IRISH PROPOSAL AT THE UN FOR CONTROL OF NUCLEAR WEAPONS - PRECURSER OF NPT	MAR 1980	CONCLUSION OF INFCE
JUN 1961	ANTARTIC TREATY	AUG 1980	SECOND NPT REVIEW CONFERENCE
OCT 1963	LIMITED TEST BAN TREATY	JUN 1981	ISRAELI BOMBING OF IRAQ REACTOR
OCT 1964	THE FIRST CHINESE TEST	JUL 1981	REAGAN STATEMENT ON NON-PROLIFERATION
MAY 1966	THE FIRST CHINESE H-BOMB TEST	SEP 1982	U.S. REASSESSMENT OF PARTICIPATION IN IAEA
FEB 1967	TREATY OF TLAPELOLCO (SIGNED)		
OCT 1967	OUTER SPACE TREATY		
MAR 1970	NON-PROLIFERATION TREATY		

Figure 1.

The Context of Independent Verification

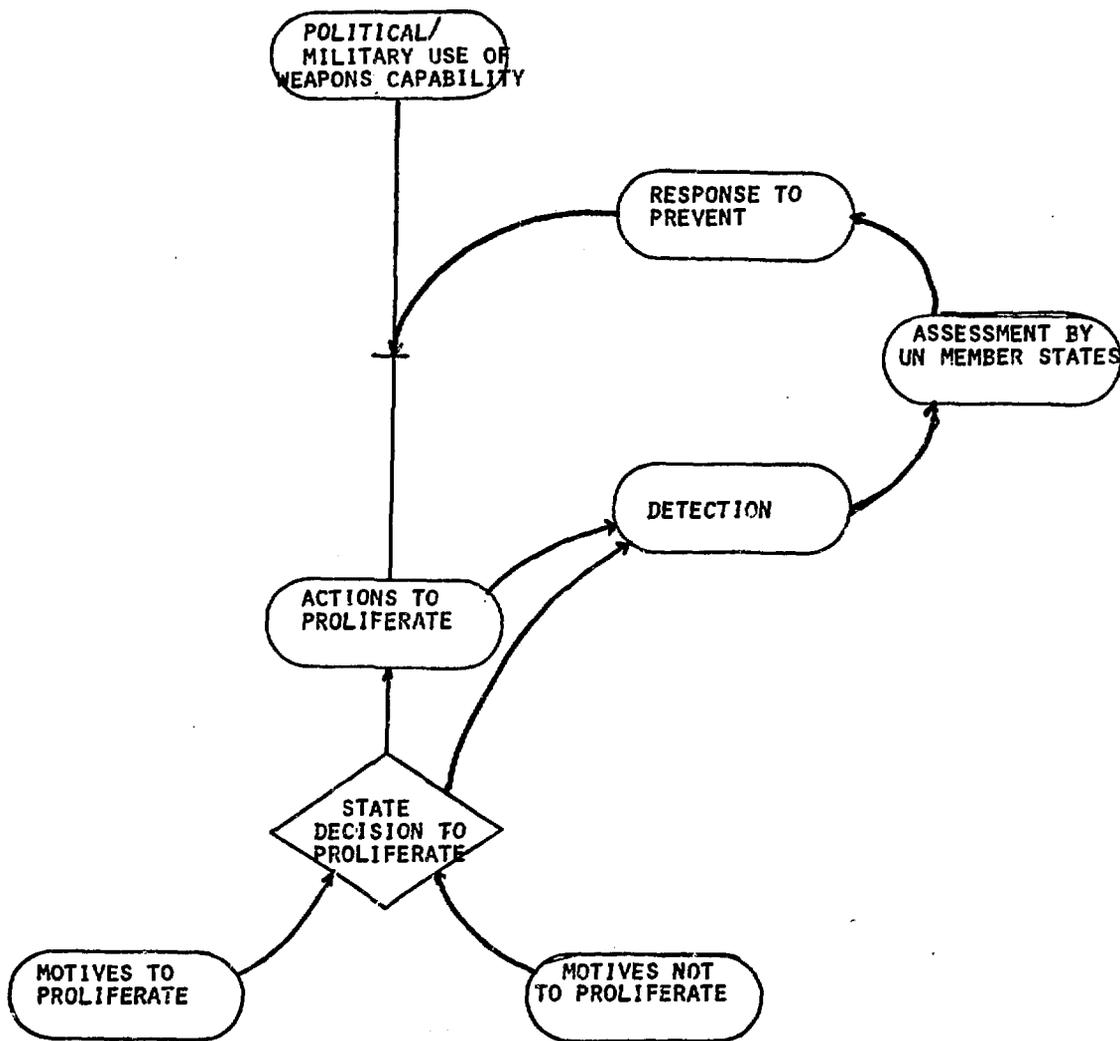


Figure 2.

Factors Influencing the Proliferation Decision

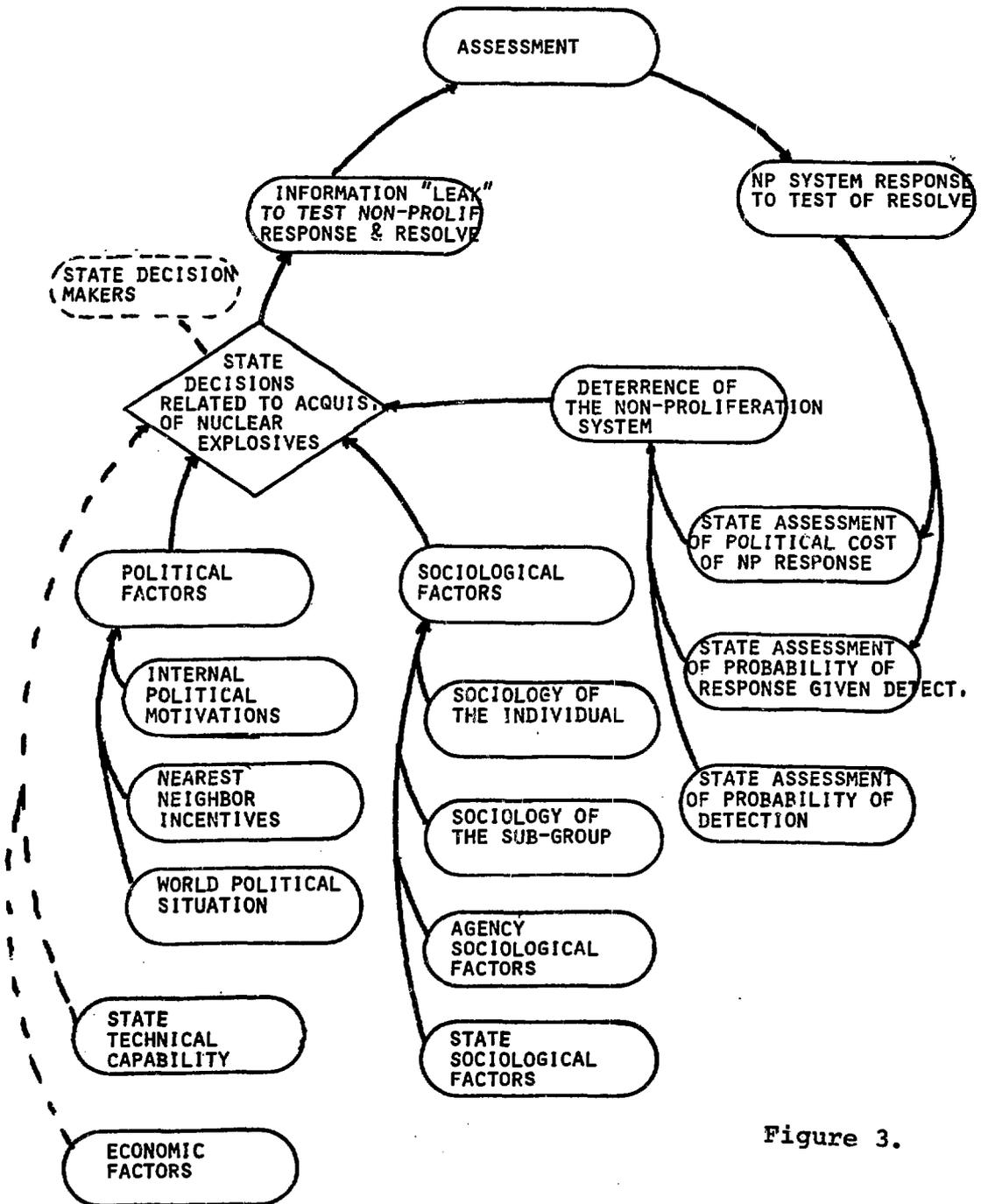


Figure 3.

which the IAEA safeguards system is the key, to insure that states are living up to their international commitments not to use civil nuclear facilities to support nuclear explosives development. A clear result of efforts at independent verification are increased disincentives to proliferation.

It should be emphasized that the IAEA safeguards system is but one part of the independent verification regime. National technical means of monitoring events play a vital role in keeping the international community aware of activities that might be cause for concern.

In spite of assurances given by the nonproliferation regime, circumstances may exist where one nation will not feel comfortable about its neighbor's intentions. This may result from a long history of hostility in certain regions or from concerns about political stability. That nation may then take actions outside of the regime, or in spite of it, to get the assurance it seeks. Generally, this should not be seen as a condemnation of the regime but rather more likely as a statement about relations between nations. It is not possible to construct a regime among sovereign nations that is all things to all people. We should endeavor to ensure that what we do in the safeguards area and more generally in the nonproliferation regime maximizes the assurance that can be given and minimizes the chance of misinterpretation of a nation's actions by its neighbors.

It is important to note that the independent verification efforts of the nonproliferation regime do not stop with, nor are they limited to, the detection of the diversion of nuclear material from civil programs. These efforts also do not stop with respect to a proliferating state should that state actually test an explosive device. However, the nature of the efforts may change.

I think it is clear that "the decision" to build a nuclear explosive device is actually made up of a series of decisions as illustrated in Figure 4. This series can be made more specific in the hypothetical decision process given in Figure 5.

IV. ROLE OF THE IAEA

As has been mentioned several times already, the IAEA's safeguards system plays a well defined and vital role in the nonproliferation regime. That is, to ensure, as far as it is able, that civil nuclear materials and facilities under IAEA safeguards are not misused. Clearly there are things the Agency can do and things it cannot do with the tools at its disposal. This illustrated schematically in Figure 6. The boundary between regions where IAEA coverage is essential and where it is impractical is not well defined. Judgments must be made depending on circumstances. This boundary should be illuminated somewhat during this course.

Generalized Sequence

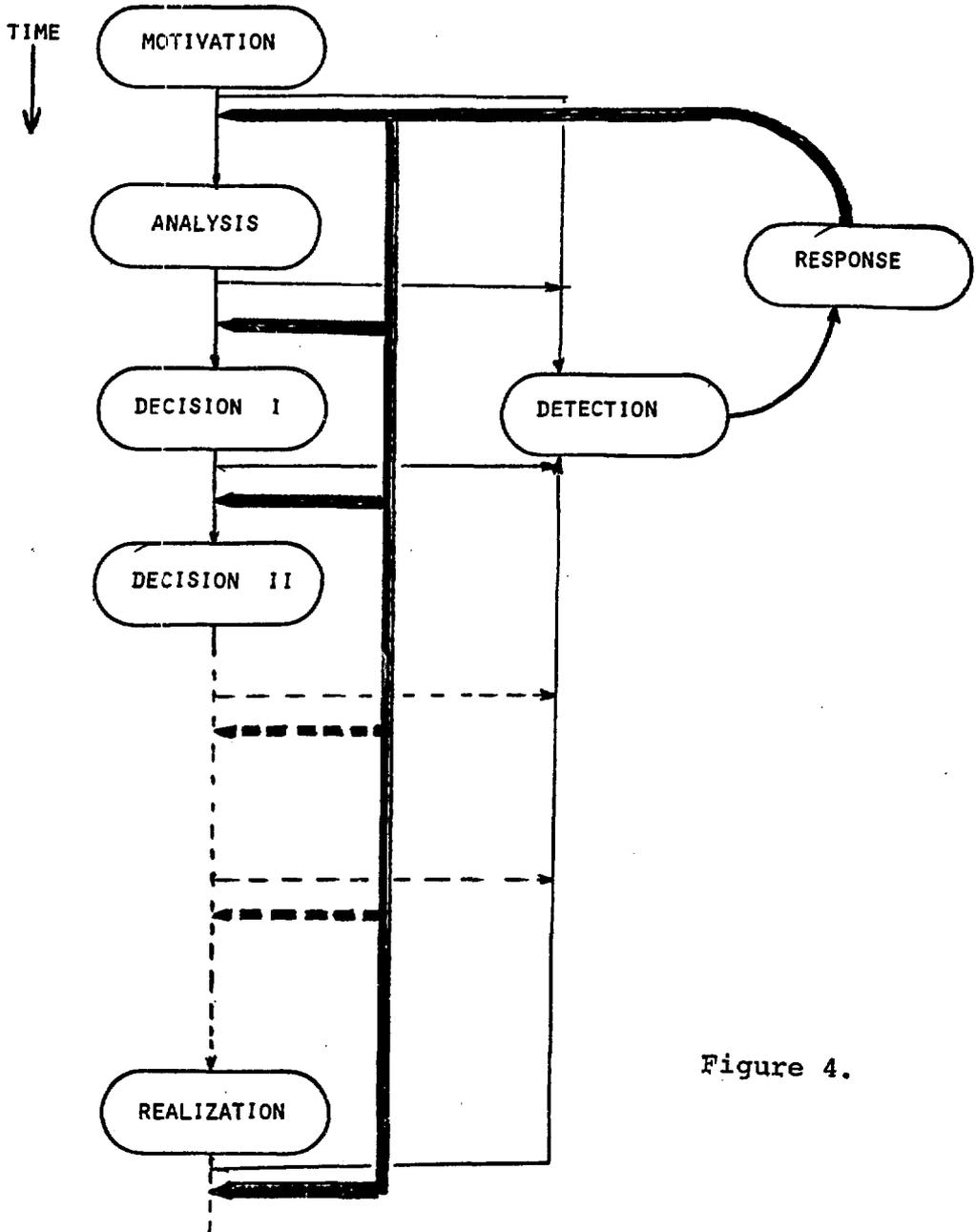


Figure 4.

Distributed Decision and its Review

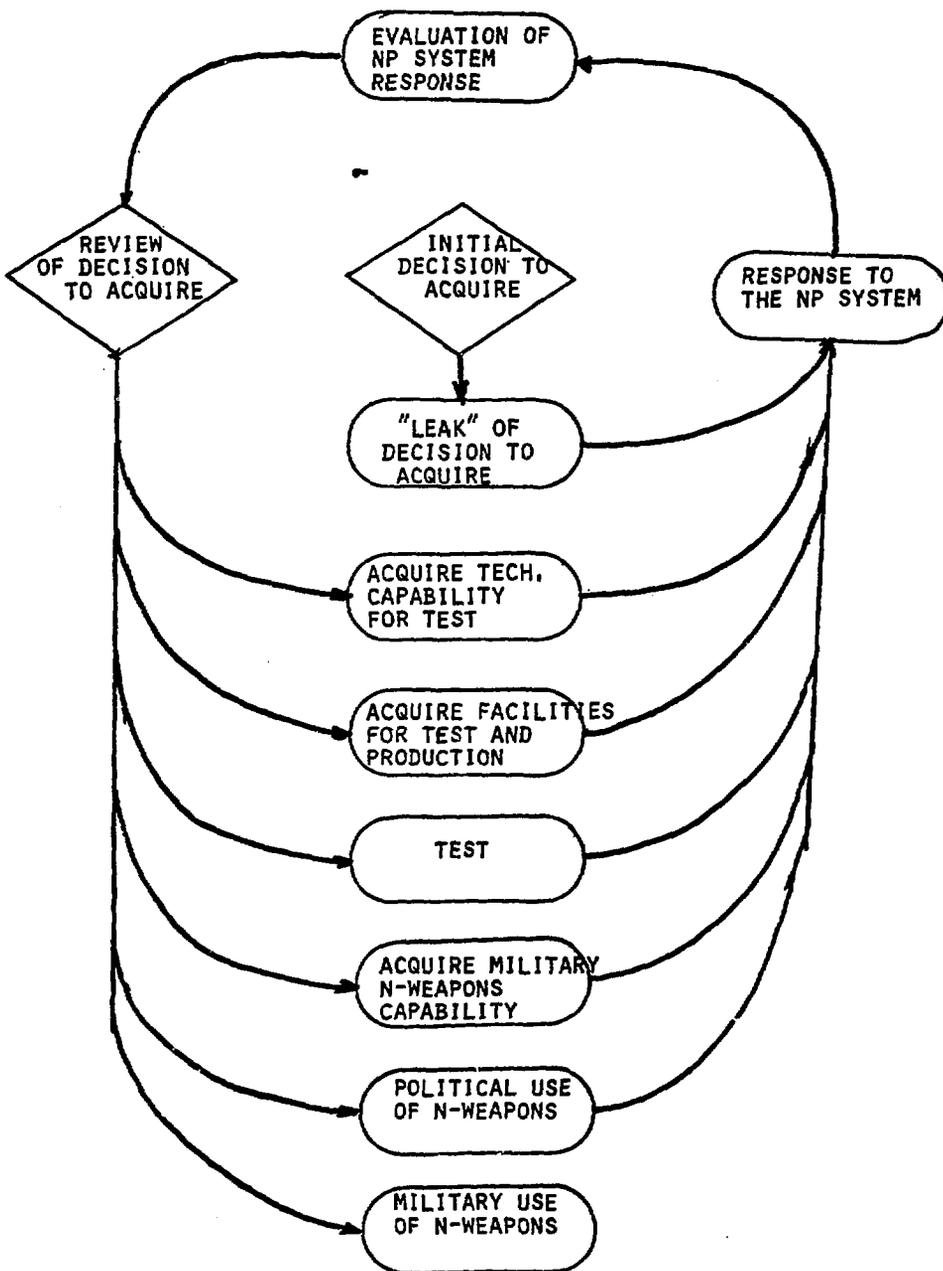
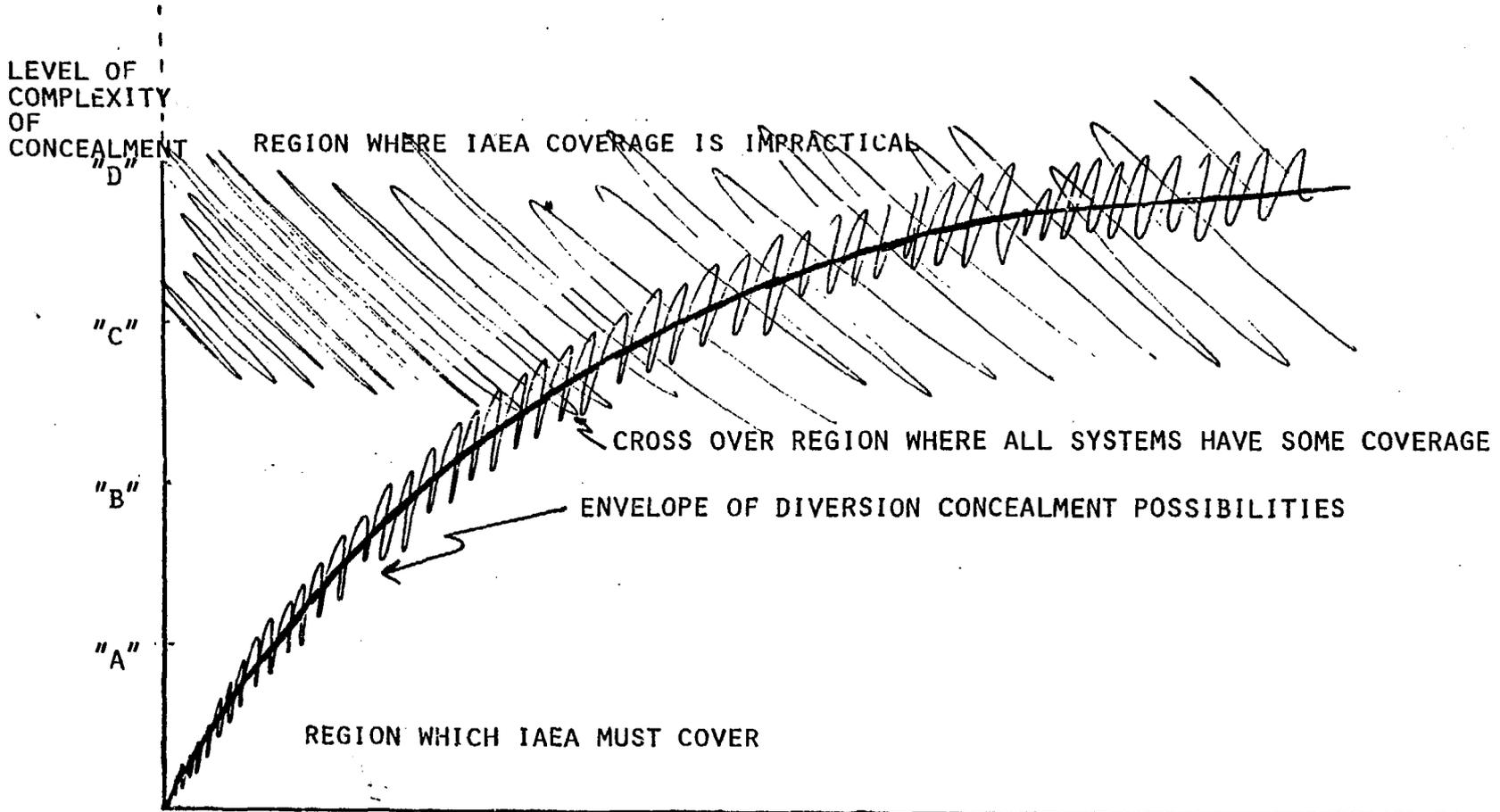


Figure 5.



2-8

INTRUSIVENESS, BURDEN TO THE STATE, COST TO THE IAEA... SHOULD THE IAEA COVER THE PARTICULAR CONCEALMENT POSSIBILITY?

Figure 6.

A Schematic of the IAEA Safeguards System

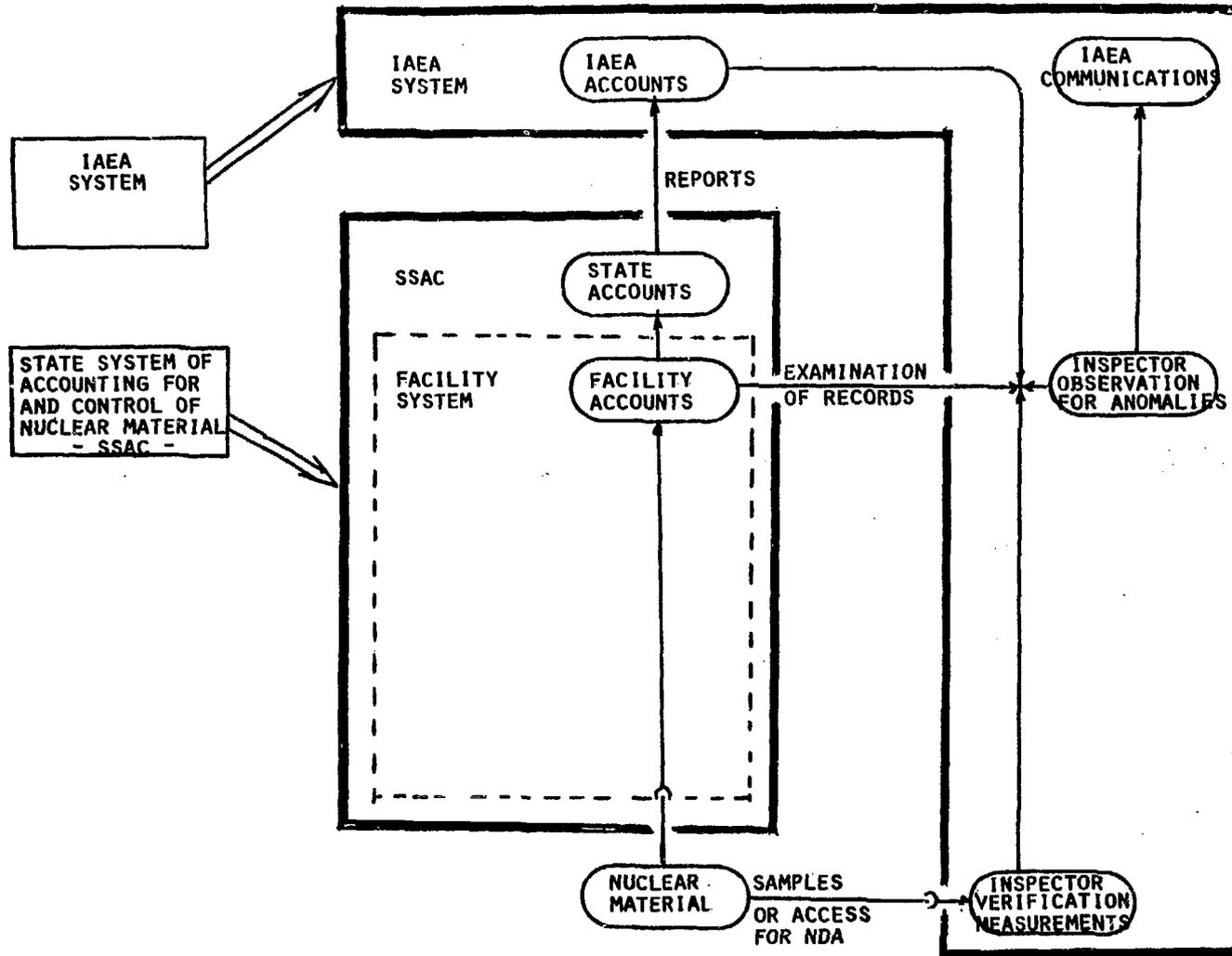


Figure 7.

Since 1976, the U.S. has had a large program of technical assistance to IAEA safeguards (POTAS), the specific goal of which is to push back this boundary to the point where the assurances given by the Agency's safeguards system are not subject to dispute. Under POTAS the U.S. has spent over \$30 million at IAEA request on equipment and software development and implementation, efforts to improve safeguards techniques and procedures, inspector training, and the development of management tools specifically designed to aid the department of safeguards. The philosophy of this program has been to work with the IAEA to identify critical needs and to bring necessary resources to bear to solve problems in as expeditious a manner as possible.

POTAS has now been emulated by six other national programs in support of safeguards improvements. I think this speaks well of our efforts so far, but much remains to be done. In particular, facilities capable of producing or using materials of direct weapons significance, such as separated plutonium or highly enriched uranium, must get more attention from a safeguards perspective.

V. CONCLUSION

I hope this brief overview of the nonproliferation regime and the IAEA's role in it has helped to put things into perspective. I trust this will be of use as you examine in detail the procedures and processes that will be presented during the next several weeks.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

**SESSION 3: OVERVIEW OF IAEA GUIDELINES FOR STATE SYSTEMS
OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS**

**OBJECTIVES, DIVERSION OF NUCLEAR MATERIAL,
AND THE IAEA SAFEGUARDS SYSTEM**

After the session, the participant will be able to:

1. recognize the political and technical objectives of IAEA safeguards,
2. understand the various ways in which nuclear material can be diverted from peaceful purposes,
3. know the basic method and procedures of IAEA safeguards, and
4. understand the role of the SSAC within the framework of IAEA safeguards and the basic guidelines issued by the Agency in this respect.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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OBJECTIVES, DIVERSION OF NUCLEAR MATERIAL,
AND THE IAEA SAFEGUARDS SYSTEM

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I. OBJECTIVES OF IAEA SAFEGUARDS

A. Introduction

Nuclear and non-nuclear material, services, facilities, equipment and information which are to be used for legally defined purposes may be deliberately diverted from these purposes. The actions aimed at the detection and deterrence of this diversion are known as safeguards.

Potential diverters are facility operators, individuals or groups of individuals, and States. IAEA safeguards are aimed at the timely detection of diversion in or by States having undertaken to accept safeguards in accordance with an agreement between the IAEA and the State and at the deterrence of such diversion by the risk of early detection by the IAEA.

B. Safeguards in the Statute of the IAEA

The Statute authorizes the IAEA "to establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information made available by the Agency or at its request or under its supervision or control are not used in such a way as to further any military purpose; and to apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement, or at the request of a State, to any of that State's activities in the field of atomic energy."¹ The Statute, therefore, limits the application of safeguards to IAEA-sponsored projects and to activities for which a specific request is made by a State.

The IAEA shall, according to the Statute,² enter into an agreement with the State or group of States submitting a project, which agreement shall include undertakings that "the assistance provided shall not be used in such a way as to further any military purpose;" and that "the project shall be subject to the safeguards provided for in Article XII, the relevant safeguards being specified in the agreement."³

Furthermore, the Statute specifies the IAEA safeguards rights and responsibilities concerning projects and arrangements.³ These rights and responsibilities include, inter alia, the use of inspectors "who shall have access at all times to all places and data, as necessary to account for source and special fissionable materials supplied and fissionable products and to

determine whether there is compliance with the undertaking against use in furtherance of any military purpose."⁴

C. Project Agreements, Safeguards Transfer Agreements and Unilateral Submissions to IAEA Safeguards

Since 1961 the IAEA has entered into "projects agreements" for the supply of materials, equipment and facilities made available by or through the IAEA; "safeguards transfer agreements" in which the States transfer to the IAEA their safeguards responsibilities set forth in their cooperation agreements; and agreements for "unilateral submissions" by a State to IAEA safeguards of certain facilities, nuclear material or all the State's nuclear activities.

All such agreements are based on the safeguards system which the IAEA set up in 1961,⁵ extended in 1964,⁶ revised in 1965,⁷ and extended in 1966⁸ and in 1968.⁹ This system⁵⁻⁹ does not specify further than the Statute does⁴ either the objective of safeguards or the conclusion of the IAEA verification activity in stipulating that nuclear material, facilities and equipment shall not be used to further any military purpose and that the IAEA shall determine whether there is compliance with the terms of the agreements. The undertaking by a State has been explicitly stated in "safeguards transfer agreements" concluded since 1975^{10,11} as not to use nuclear material, facilities and equipment for the manufacture of nuclear weapons or to further any other military purpose, or for the manufacture of any other nuclear explosive device.

D. Safeguards Agreements Pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) entered into force in March 1970.¹² Each non-nuclear weapon State party to the Treaty undertakes to accept safeguards, as set forth in an agreement to be negotiated and concluded with the IAEA in accordance with the statute of the IAEA and the IAEA safeguards system, for the exclusive purpose of verification of the fulfillment of its obligations assumed under the Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices.¹³ Procedures for the safeguards required shall be followed with respect to all source or special fissionable material whether it is being produced, processed or used in any nuclear facility or is outside any such facility. The safeguards required shall be applied on all source or special fissionable material in all peaceful nuclear activities within the territory of such a State, under its jurisdiction, or carried out under its control anywhere.

Each State party to the Treaty also undertakes not to provide source or special fissionable material, or equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to any non-nuclear weapon State for peaceful purposes, unless the source or special fissionable material is subject to the required safeguards.¹⁴

At the time of the entry into force of the NPT, most of the governments concerned expressed the view that the IAEA safeguards system was insufficiently defined. All members of the IAEA were therefore invited to take part in a specially convened "Safeguards Committee." The Committee agreed on "the structure and content of the agreements between the Agency and States required in connection with the Treaty on the Non-Proliferation of Nuclear Weapons,"¹⁵ which has served as a basis for every agreement concluded in connection with the NPT.

The basic undertaking by the State in NPT safeguards agreements is to "accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices."¹⁶

The objectives of safeguards are further defined in these agreements to be the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."¹⁷ The inclusion of the expression "for purposes unknown" is very important for the practical application of safeguards for it means that the IAEA does not have to attempt to determine the use to which diverted material is put and, in particular, does not have to determine whether diverted nuclear material is for "the manufacture of nuclear weapons or of other nuclear explosive devices." In addition, it is not an objective of IAEA safeguards to determine who is responsible for any diversion.

The agreements provide for "the use of material accountancy as a safeguards measure of fundamental importance, with containment and surveillance as important complementary measures"¹⁸ and also provide that "the technical conclusion of the Agency's verification activities shall be a statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."¹⁹

E. Implementation of Safeguards by the IAEA

The IAEA safeguards system is laid down in two IAEA documents, INFCIRC/66/Rev. 2⁹ and INFCIRC/153.¹⁵ The first document forms the basis for bilateral agreements, transfer agreements and unilateral submissions under which equipment, facilities, nuclear material, other material and information are subject to safeguards. The second document forms the basis of all agreements required by Article III.1 of the NPT, under which all nuclear material in all peaceful nuclear activities of a State is subject to safeguards. INFCIRC/153 obliges the IAEA to draw from its verification activities a technical conclusion in respect to nuclear material for each material balance area. INFCIRC/66/Rev. 2 does not include the required specifics of a conclusion, but the IAEA is obliged by the Statute to make a determination of

compliance and, where non-compliance has been concluded, to report to the Board of Governors. INFCIRC/66/Rev. 2 provides the IAEA with names to draw in respect to nuclear material the same type of technical conclusion as required by INFCIRC/153. The IAEA has to judge in each particular situation whether the application of its nuclear material verification procedures permits it to fulfill the responsibility of safeguarding equipment, facilities, non-nuclear material or information.

Implementation of nuclear material safeguards requires quantification of the objectives for each situation. To provide guidelines for the implementation requires identification of the possible strategies that a State may adopt for diverting nuclear material and specification of the measures that the IAEA must employ in its safeguards system in order to be able to counter successfully these diversion strategies. These subjects are treated in the following sections.

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1. IAEA Statute, as amended up to 1 June 1973, Article III, Item A.5, p. 6.
2. IAEA Statute, Article XI, Item F.4, p. 25.
3. IAEA Statute, Article XII, pp. 26-29.
4. IAEA Statute, Article XII, Item A.6, p. 27.
5. INFCIRC/26, The Agency's Safeguards, 30 March 1961.
6. INFCIRC/26/Add. 1, The Agency's Safeguards, 9 April 1964.
7. INFCIRC/66, The Agency's Safeguards System (1965), 3 December 1965.
8. INFCIRC/66/Rev. 1, The Agency's Safeguards System (1965, As Provisionally Extended in 1966 and 1968), 16 September 1968.
9. INFCIRC/66/Rev. 2, The Agency's Safeguards System (1965, As Provisionally Extended in 1966 and 1968), 16 September 1968.
10. IAEA Board of Governors, Document GOV/1751.
11. IAEA Board of Governors, Document GOV/1754, 7 August 1975, and Gov/1754 (Corr. 1), 15 September 1975, Safeguards (a) The Application of Safeguards by the Agency, the Safeguards Agreement between the Agency, France and the Republic of Korea.
12. INFCIRC/140, Treaty on the Non-Proliferation of Nuclear Weapons, 22 April 1970.
13. INFCIRC/140, Article III.1.
14. INFCIRC/140, Article III.2.
15. INFCIRC/153 (Corr.), The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, June 1972.
16. INFCIRC/153, Article 1.
17. INFCIRC/153, Article 28.
18. INFCIRC/153, Article 29.
19. INFCIRC/153, Article 30.

II. DIVERSION OF NUCLEAR MATERIAL

A. Introduction

In the context of IAEA safeguards, the State with its corresponding capabilities and resources is considered as the potential diverter, and the probability of attempted diversion is considered small but finite. The purpose of diversion is assumed to be the acquisition of nuclear material for uses proscribed by the relevant safeguards agreement.

B. Diversion Strategies

The plans for diverting nuclear material and for either delaying the detection of the diversion or avoiding it are known as diversion strategies.

Diversion strategies could involve a single facility or a number of facilities cooperating in the diversion and its concealment. Diversion could involve material already in a form suitable for the intended use or in a form requiring further processing before such use. This further processing could be undertaken immediately or the diverted material could be stockpiled for processing and use at a later time. The diverter may attempt to use safeguarded facilities to process material which has been diverted at another safeguarded facility, or material which either is at the starting point of safeguards or has already undergone some processing and which must be under safeguards but has not been declared by the State. Such an attempt would provide the IAEA with a chance to detect at a facility material which had not previously been in a safeguarded facility or material which had been previously diverted.

The material might be diverted in either a single removal or repeated removals. Immediate detection by the IAEA can only be possible if it applies strict containment and surveillance measures. Verification of the physical inventory and of the material balance provides for a delayed opportunity for detection of diversion.

To conceal the removal of nuclear material the diverter may present evidence that the material:

- Was never received at the facility in question;
- Was shipped to some other facility or facilities;
- Was discarded or accidentally lost; or
- Is still present at the facility:
 - With complete items missing;
 - With part of the items missing;
 - With portions of materials from all items missing;
 - With a combination of the above three possibilities;
 - By substituting, for the diverted material, non-nuclear material or material of lesser value to the diverter;
 - By presenting material for counting more than once;
 - By borrowing the needed quantity of material from another facility and returning it after inventory verification has passed.

The strategy of concealment that gives the inspector only one opportunity to detect the concealment may be called final concealment, as opposed to temporary concealment. The recording of fictitious discards is an example of final concealment. If the fictitious discard is not detected at the time of the discard itself, it will never be detected, because no second opportunity for verification will exist. The falsification of inventory data, in contrast, is an example of temporary concealment and transfers the diversion into the next material balance period, where it has a second chance of being detected. In temporary concealment the facility operator must continue to attempt to conceal the removal until he can achieve final concealment.

1. Falsification of Records and Reports. The concealment of the removal of nuclear material which has previously been included in the records and reports available to the IAEA would presumably involve some falsification of these documents as part of the diverter's attempts to conceal the shortage from the IAEA and, in particular, to avoid detection by audit. Such falsification can be classified as understatements or overstatements of inventory or flows and introduction of "mistakes" in the transcription of data or in calculations.

In cases where the facility receives material from unsecured facilities, the operator may understate receipts by not recording all receipts or by recording smaller than actual quantities for some receipts. Another possibility would be to arrange for a receipt to arrive just prior to a physical inventory to replace material already removed and to record the transfer as a receipt which occurred after the inventory.

There are many possibilities for the falsification of records by the introduction of "mistakes:" recording a number and reporting a different one, recording an incorrect total, recording a correct net weight and analysis and recording an incorrect total, etc.

2. Deceiving IAEA Measurements. Concealment strategies could also involve attempts to deceive IAEA measurements with respect to either the completeness or the correctness of the measurements. Examples are partial or periodic bypassing of flow key measurement points, alteration of containers, biasing of instruments, and biasing of sampling devices.

3. Declaring Diverted Material as MUF. A diverter could choose to divert material without alteration of the inventory and inventory change data and allow the removal to be shown as MUF. This strategy may, or may not, be supported by inflation of the measurement uncertainties and might be supported by explanations designed to portray the MUF as being due to legitimate causes.

C. Importance of Diversion

The importance of the diversion depends on the type and amount of the diverted material. Materials, e.g., plutonium and highly enriched uranium, which are of immediate use for nuclear explosive devices, represent a greater hazard than does material

which requires a lengthy and complex process to be used for these devices.

Rough estimates of the times required to convert different materials to material suitable for nuclear explosive devices are given in Table I. The times listed in Table I are dependent, among other factors, upon the amount of materials involved and the capabilities of the facilities carrying out the processing. If the necessary processing is carried out in a large unsafeguarded facility, the shorter times in each range would apply. If done in a large safeguarded facility by unreported introduction and removal of the material at less than full capacity rate, the intermediate times in each range might apply. If the processing is carried out in small unsafeguarded facilities or activities, the longer times would apply. These times provide the basis for the requirements for the timeliness of detection by the IAEA of diversion and, hence, for the frequencies of verification by the IAEA of its containment and surveillance measures and of physical inventories.

TABLE I
IMPORTANCE OF DIVERSION*

<u>Required Conversion of Nuclear Material to the Manufacture of Nuclear Explosive Devices</u>	<u>Material Form</u>	<u>Approximate Range of Times Required to Convert Nuclear Material to the Form Suitable for Manufacture of Nuclear Explosive Devices</u>
Physical change; or chemical and physical change, but no purification	Plutonium and highly enriched metal, oxide or solution	Days to weeks
Chemical and physical change with purification	Irradiated fuel, radioactive solution, cold scrap	Weeks to months
Isotopic, chemical and physical change	Natural and low enriched	Up to one year

*Based on the approximate time required to convert the material suitable to manufacture of nuclear devices.

III. THE IAEA SAFEGUARDS SYSTEM

A. Introduction

The IAEA safeguards system must enable the IAEA to verify that a State has complied with its undertaking as specified in the relevant safeguards agreement. The safeguards responsibilities and rights of the IAEA cannot, therefore, be delegated to the State or to any organization to which the State has delegated the State's responsibilities. The IAEA system has been conceived to ensure the timely detection of diversion that might be attempted by the wide range of strategies described in Sec. II. For these reasons the IAEA must verify the completeness, formal correctness and validity of the information (including all records and reports) made available by the State, regardless of the nature or level of the verification activities carried out by the State.

By means of its safeguards system, the IAEA shall be able to verify, in particular, that:

- The quantities of nuclear materials imported into a State, produced within a State or otherwise becoming subject to safeguards in any peaceful nuclear activity are not understated by the State;
- The quantities of nuclear materials on which safeguards are to be terminated, for example, exports or consumption, are not overstated by the State; and
- Physical inventories are not overstated by the State, at intervals appropriate for satisfying the requirement for the timely detection of diversion.

Essential elements of the IAEA safeguards system are:

- A Safeguards Agreement between the IAEA and the State, including Subsidiary Arrangements and Facility Attachments;
- Provision by the State to the IAEA of all information relevant to the operator's accountancy, containment and surveillance of the material according to State's regulations, which must be in compliance with the terms of the Agreement; and,
- Verification by the IAEA that the State is complying with the basic understanding as laid down in the Agreement.

The different types of safeguards agreements have been described in Sec. I. Section III-B describes the operator's measures of accountancy, containment and surveillance. Sections III-C and D describe, respectively, the information to be provided by the State and the verification to be carried out by the IAEA.

B. Accountancy, Containment, and Surveillance of Nuclear Material

Accounting for nuclear material is defined as the knowledge of the material's identity, composition, quantity, and location.

Agreements of the INFCIRC/153 type require that "the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards."¹ They prescribe that the system shall be based on a structure of material balance areas, a measurement system, a records and reports system and a system of control by the State that the accounting procedures are being operated correctly. INFCIRC/66/Rev. 2² does not refer explicitly to a State's system of accounting for and control of nuclear material or to some of the above elements of such a system, but it does prescribe the accounting and operating records to be kept by the State and the accounting and operating reports to be submitted by the State to the IAEA.

The undertaking by a State in an INFCIRC/153 type agreement requires the State "to accept safeguards.., on all source or special fissionable material."³ Such agreements also specify the starting point of safeguards⁴ and the conditions for the termination of safeguards⁵ and for exemptions from safeguards.⁶ Similar provisions exist in the agreements of the INFCIRC/66/Rev. 2 type.

The basic principle of the accountancy system required by INFCIRC/153 is the operator's recording at the facility and the State's reporting to the IAEA, for each material balance area, initial inventories of nuclear material and subsequent inventory changes. Additions to and subtractions from the initial inventory yield the "book inventory,"⁷ the amount of nuclear material which, according to the operator, is expected to be in a given facility or a given material balance area. Periodically, the facility operator takes a physical inventory⁸ in the material balance by measuring the nuclear material which "is" actually present. For facilities having nuclear material in unsealed bulk form, because of the measurement uncertainties, there is usually some difference between the book inventory and the physical inventory. There may also be discrepancies for other reasons, for example, failure to measure parts of the inventory or an unmeasured loss of material. The difference between book inventory and physical inventory is the "material unaccounted for,"⁹ abbreviated to "MUF." As a variable derived from measurements, MUF is, like the measurements themselves, subject to uncertainties.

INFCIRC/153 provides definitions for the fundamental concepts of material accountancy, namely, book inventory;⁷ physical inventory,⁸ material unaccounted for,⁹ adjustment,¹⁰ batch,¹¹ batch data,¹² corrections,¹³ enrichment,¹⁴ inventory change,¹⁵ key measurement point,¹⁶ material balance area,¹⁷ nuclear material,¹⁸ shipper/receiver difference,¹⁹ and source data.²⁰

Containment, as employed by the State or the operator, is understood as the restriction of the movement of or access to nuclear material. Containment measures are used by facility operators for physical protection of the material, safety of personnel and convenience of operational procedures. In general, containment measures are not provided specifically for safeguards purposes, but their existence in a facility often simplifies surveillance for safeguards.

Surveillance means instrumental or human observation to indicate the movement of nuclear material. Surveillance may

indicate the effectiveness of containment and, therefore, has for the operator the same use as containment.

Both containment and surveillance are, for the IAEA, important measures complementary to material accountancy.²¹ They should not impose any physical restriction on the movement of or access to material; but they have to provide to the IAEA information as to whether such movement or access occurred while inspectors were not present, in order to preserve the integrity of prior measurements of nuclear material by the IAEA and to provide the IAEA with knowledge of material flows at important points in a fuel cycle.

C. Information

Both documents, INFCIRC/66/Rev. 2 and INFCIRC/153, require that the State:

- Provide the IAEA with information in respect to facility design features and other information relevant to safeguards;
- Arrange that records are kept in respect of each material balance area; and
- Provide the IAEA with reports in respect of nuclear material based on the records kept.

INFCIRC/153 prescribes the required design information²² and the required systems of records²³ and of reports.²⁴ Member States have further advised the IAEA on the detailed design information to be provided by the States.²⁵ The IAEA Secretariat has prepared design information questionnaires for different types of facilities.²⁶ The IAEA Secretariat has established model Subsidiary Arrangements and Facility Attachments,²⁶ which contain, inter alia, reporting forms and explanations for their use.²⁷

D. Verification

Although INFCIRC/153 does not contain a formal definition of verification, it does specify the activities, including independent measurements, to be used by the IAEA for achieving verification and it does specify that verification applies to the location, identity, quantity, and composition of all nuclear material subject to safeguards.^{28,29,30.}

Accordingly, the IAEA's verification process consists of:

1. Examination of the information provided by the State in:
 - Design information;³¹
 - Accounting reports;³²
 - Special reports;³³
 - Amplification and clarification of reports;²⁴ and
 - Advance notifications of international transfers.^{35,36}
2. Collection of information by the IAEA in:
 - Inspections for verification of design information;³⁷

- Ad hoc and routine inspections;^{38,39} and
- Special inspections.⁴⁰

3. Evaluation of the information provided by the State and collected in inspections for the purpose of determining the completeness, correctness, accuracy, and validity of the information provided by the State.

The purpose of inspections of facilities "to verify design information"³⁷ is to enable the IAEA to evaluate the validity of the design information made available to the IAEA. This verification is carried out with respect to design information submitted for existing and new facilities and for subsequent modifications of these facilities. The purpose of the examination of design information is:

- To identify the features of facilities and nuclear material relevant to the application of safeguards to nuclear material in sufficient detail to facilitate verification;
- To determine material balance areas to be used for IAEA accounting purposes and to select those strategic points which are key measurement points and which will be used to determine the nuclear material flows and inventories;
- To establish the nominal timing and procedures for taking of physical inventory for IAEA accounting purposes;
- To establish the records and reports requirements and records evaluation procedures;
- To establish requirements and procedures for verification of the quantity and location of nuclear material; and
- To select appropriate combinations of containment and surveillance measures and the strategic points at which they are to be applied.

Accounting reports provide information on the initial inventory,⁴¹ inventory changes,⁴² and material balances.⁴³

The ad hoc inspections by the IAEA are carried out in order to verify the information contained in the initial report and to identify and verify changes that have occurred since the date of the initial report. Ad hoc inspections are also carried out for the purpose of identifying and, if possible, verifying the quantity and composition of nuclear material involved in international transfers.³⁸ In the case of transfers out of a State, these inspections, including the affixing of seals by the IAEA, are to be carried out at the time the material is being prepared for shipping. In the case of transfers into a State these inspections are to be carried out at the time the material is unpacked.^{44,36}

The purpose of routine inspections by the IAEA is:

- To verify that the information contained in the reports submitted by the State to the IAEA is consistent with the accounting and operating records maintained by the State;

- To verify the location, identity, quantity and composition of all nuclear material subject to safeguards; and
- To verify information on the possible causes of material unaccounted for, shipper/receiver differences and uncertainties in the book inventory.³⁹

Special inspections are to be carried out by the IAEA:

- To verify information contained in special reports; and
- To collect additional information when the IAEA considers that the information provided by the State and the information obtained through routine inspections are not adequate for the IAEA to fulfill its responsibilities.⁴⁰

The activities of the IAEA in the course of ad hoc, routine and special inspections are in general for the purpose of collecting information whereby the IAEA can independently establish that the information provided by the State is:

- Complete in that it covers all nuclear material that has been present in the material balance area;
- Formally correct in terms of being free of mistakes;
- Valid with respect to the actual location, identity, quantity and composition of all nuclear material subject to safeguards; and
- Accurate in terms of the conformity of the measurement data of the State (random and systematic errors) with internationally accepted measurement accuracy.

These activities include: examining records, making independent measurements on all nuclear material subject to safeguards using IAEA equipment and also State's or operator's equipment by verifying its proper functioning, calibration and procedures; obtaining samples and ensuring their proper collection, treatment, handling, and shipping; using and servicing IAEA surveillance equipment; affixing and removing IAEA seals; and using other objective methods which become available.^{29,30} Containment and surveillance measures in particular are to be used to help ensure the completeness of flow measurements.⁴⁵

The right of access,⁴⁶ frequency,⁴⁷ and notice⁴⁸ of inspections, designation⁴⁹ and visits⁵⁰ of inspectors are provided for in INFCIRC/153. INFCIRC/66/ Rev. 2² contains similar provisions.

The IAEA shall "make every effort to ensure optimum cost-effectiveness"⁵¹ and, in order to ensure it, should use, among other means, "the concentration of verification procedures in those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear explosive devices could readily be made, and minimization of verification procedures in respect of other nuclear material on condition that this does not hamper the IAEA in applying safeguards."⁵² Therefore, the statements on material unaccounted for and its limits of accuracy must not

necessarily be based on equally intensive verification activities in all types of facilities or for all types of nuclear material. These activities must, however, in all cases enable the IAEA to satisfy the objective of safeguards, that is, the timely detection of diversion of significant quantities of nuclear material."⁵³ In structuring its verification system, the IAEA takes into account not only whether material can be readily made into nuclear weapons or explosives but also the relationship between various parts of the nuclear fuel cycle. For example, although low enriched uranium cannot be directly fabricated into nuclear weapons, its value as a starting point for the production of plutonium or for further enrichment cannot be overlooked.

To achieve optimum cost-effectiveness while ensuring the capability to detect the range of diversion strategies indentified in Sec. II., the IAEA's verification system involves two different types of approaches, depending upon the type of nuclear facility. For facilities in which nuclear material is produced, such as enrichment facilities and power reactors and the larger research reactors, and for chemical reprocessing facilities where the material produced in reactors is separated from the other components of the irradiated fuel, the verification of all flows is of critical importance. In other types of facilities, the primary inspection activity is inventory verification.

The technical conclusion of the IAEA's verification activities shall be "a statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."⁵⁴ It is important as a measure of the degree of agreement between the measurements of the operator and those of the IAEA and as a measure of the extent and accuracy of the IAEA's measurements that the technical conclusion of the IAEA's verification activities includes the operator's MUF adjusted for any differences between the IAEA's and the operator's measurement and an estimate of the combined measurement uncertainties.

The IAEA shall inform the State of the results of inspection and the conclusions it has drawn from its verification activities in the State, in particular, by means of statements in respect of each material balance area.⁵⁵

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34. INFCIRC/153 (Corrected) Article 69
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37. INFCIRC/153 (Corrected) Article 48
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39. INFCIRC/153 (Corrected) Article 72
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42. INFCIRC/153 (Corrected) Articles 63, 64, 65
43. INFCIRC/153 (Corrected) Article 67
44. INFCIRC/153 (Corrected) Article 93
45. INFCIRC/153 (Corrected) Article 46 (b) (ii)
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50. INFCIRC/153 (Corrected) Articles 87-89
51. INFCIRC/153 (Corrected) Article 6
52. INFCIRC/153 (Corrected) 6 (c)
53. INFCIRC/153 (Corrected) 28
54. INFCIRC/153 (Corrected) 30
55. INFCIRC/153 (Corrected) 90



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

**SESSION 4: THE U.S. NATIONAL MATERIAL CONTROL
AND ACCOUNTING SYSTEM**

This session will center on the State System of Accounting and Control (SSAC) for fuel cycle facilities in the licensed, commercial sector of the U.S. nuclear community. Details of the material control and accounting measures dealing with the national safeguards program will be discussed. The concept and role of the Fundamental Nuclear Material Control (FNMC) Plan will be discussed with the participants. Also, the relationship will be described between the national safeguards program and the international safeguards program of the U.S. SSAC.

After the session, participants will be able to:

1. understand the need for a State System,
2. understand the basic MC&A elements in an SSAC,
3. understand which MC&A elements serve the country's national interests and those that serve IAEA safeguards.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

**SESSION 4: THE U.S. NATIONAL MATERIAL CONTROL
AND ACCOUNTING SYSTEM**

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I. INTRODUCTION

The purpose of Session 4 is to provide course participants with details of the U.S. national material control and accounting (MC&A) system. Each of the basic elements of the national MC&A system will be discussed in some detail in this paper. The purpose served by the Fundamental Nuclear Material Control (FNMC) Plan will be developed and the participants will be provided with information concerning the level of detail and information currently required in the FNMC Plan. The relationship will be described between the national safeguards program and the international safeguards program of the U.S. SSAC.

Two handouts will be utilized to aid course participants in understanding the U.S. national MC&A system. The first handout is a consolidation of all of the U.S. national MC&A regulations. The purpose of this document is to provide the participants with a single document of the various sections of the U.S. national MC&A regulations which, by the way, were implemented in three different time periods during the 1970's. The arrangement of the regulations in the consolidated regulations document has been made the same as that for the second handout, Regulatory Guide 5.45, "Standard Format and Content for the Special Nuclear Material Control and Accounting Section of a Special Nuclear Material License Application." The Regulatory Guide 5.45, which was developed and published by the U.S. Government in 1974, is intended to provide the licensed sector of the nuclear community with information regarding the amount and level of detail that must be provided by the facility in its FNMC Plan. This FNMC Plan is required by the national regulations.

II. U.S. NATIONAL MC&A REGULATIONS

In order to deter, detect, prevent, and respond to subnational attempts at theft of nuclear material or sabotage of facilities, an organized, national program of materials accounting and control and physical protection is needed. While these are terms that are generally used to describe the basic components of the U.S. national safeguards program, many aspects in the area of material control and accounting are similar and complimentary to the international safeguards program that is generally considered to be a part of a State's System of Accounting and Control.

In the U.S. national MC&A system, we generally define material control as that part of the safeguards program encompassing management and process controls to (1) assign and exercise responsibility for nuclear material, (2) maintain vigilance over the material, (3) govern its internal movement, location, and utilization, and (4) monitor the inventory and process status of all nuclear material. Material accounting is defined as that part of the safeguards program encompassing the procedures and systems to (1) perform nuclear material measurements, (2) maintain records, (3) provide reports, and (4) perform data analysis to account for nuclear material.

The material control system should contribute to deterrence by providing a means of readily detecting unauthorized removals of SNM, and tracing and identifying suspects, thus deterring those who fear exposure. By maintaining continuous vigilance over material, monitoring process operations, and establishing cross-checks over material movements, material transactions, and administrative controls, the material control system can provide early warning of attempt at theft or diversion. Full use of process monitoring information can provide additional safeguards alarms and can improve data analysis capabilities. Thus, the material control system should contribute to the prevention function by providing timely information to improve material loss alarm responsiveness, leading to the interruptions of attempts to steal or divert material. The material control system, by continuous monitoring and vigilance, should play a major response role in the rapid discovery of a loss of material. Material control should also play an important short-term assurance role by providing continuous indication of effective system operations and by confirming material status between physical inventories.

The material accounting system should contribute to deterrence by providing an after-the-fact detection capability for significant material loss and by discouraging those who desire anonymity after committing a theft. In the case of a hoax, the material accounting system plays an important prevention role in combating the alleged theft by providing records of material quantities and locations to assist in the verification of plant holdings. With respect to the response function, the material accounting system, especially the records, can contribute in a major way to after-the-fact loss detection, to the precise assessment of losses or alleged losses, and to the identification of suspects. However, it is in the area of assurance that material accounting makes its greatest contribution to safeguards. The primary role of material accounting is to provide long-term assurance, through records of holdings verified by physical inventories, that material is present in assigned locations and in correct amounts. In addition, shipper-receiver comparisons provide assurance that material has not been lost or stolen in-transit and that overstatements of a plant's shipments or understatements of receipts are not being used to disguise a material loss or theft.

The national material control and accounting regulations of the U.S. Nuclear Regulatory Commission (NRC) are contained in Part 70, Title 10 of the U.S. Government Code of Federal Regulations, Chapter 1 (10 CFR Part 70). Since 10 CFR Part 70 deals with all aspects of special nuclear material (SNM), it also contains regulations for applications, licensing, inspection, violations, health and safety matters, etc., in addition to national MC&A requirements. These MC&A regulations apply to special nuclear material in all licensed phases of the nuclear fuel cycle. For example, a few of the MC&A requirements apply to the power reactor phase of the fuel cycle, and to facilities with sealed SNM sources. However, most of the MC&A regulations in 10 CFR Part 70 apply to the bulk-handling facilities involved with conversion, fabrication, scrap recovery, and/or reprocessing operations. The emphasis in this paper will be on the MC&A system for U.S. licensed, bulk-handling facilities which are authorized to possess and use special nuclear material in a quantity exceeding one effective kilogram.

The national regulations in 10 CFR Part 70 include requirements for the following MC&A elements:

1. Records
2. Reports
3. Written Procedures
4. Facility Organizational Structure
5. Material Control Areas
6. Measurement System
7. Measurement Quality Assurance Program
8. Limit of Error Calculation
9. Physical Inventory
10. Accounting System
11. Internal Controls
12. Management Activities
13. Submission of FNMC Plan

Now I will discuss some details of each of the above MC&A elements and give references to the applicable requirements in 10 CFR Part 70. The requirements in some of the MC&A elements are different for low enriched uranium than for high enriched uranium or plutonium.

The records regulations, which are under 10 CFR 70.51(b) and (e), and 70.57(b), address the need for records of SNM receipts and shipments, beginning and ending SNM inventories, material added to or removed from process, material balance components, data and information from the measurement system and its quality assurance program, etc. Also, records must be maintained for training and measurement qualifications. The regulations also address the period of time which the various records must be retained by the facility.

The regulations dealing with national level reports are found in 10 CFR 70.52, 70.53, and 70.54. These reports concern the loss or theft of SNM, material unaccounted for (MUF) exceeding its measurement uncertainty (LEMUF), LEMUF exceeding specified limits, the semi-annual Material Status Reports (Form NRC-742), and the Nuclear Material Transaction Reports (Form NRC-741) for transfers of SNM.

Written procedures, 10 CFR 70.51(c), are required to be established, maintained, and followed for all material control and accounting activities at bulk-handling facilities.

10 CFR 70.58(b) and 70.57(b)(1) contain the facility organizational requirements which address the roles of the safeguards manager and the measurement quality assurance manager, the need for separation of functions within the organization, and the need for written delegation of MC&A responsibilities and authority.

The material control area regulations, which are contained in 10 CFR 70.58(d), address the need for physical and administrative controls for SNM by establishing material balance areas (MBA) and item control areas (ICA) within each plant. The custody of the SNM within each MBA or ICA is the responsibility of a single individual.

10 CFR 70.58(e) contains the MC&A regulation concerning the measurement system which each facility must establish, maintain, and follow so that the SNM present at the facility can be measured. The measurement system must have the capability to determine the element and fissile isotope content of special nuclear material received, produced, transferred between MBAs, shipped, on inventory, etc. One objective of the U.S. national MC&A regulations is to assure that all inputs to the material balance calculations are based on measurements and that the material unaccounted for (MUF) value resulting from the material balance is a meaningful value.

Each bulk-handling facility is required to have a quality assurance program for the MC&A measurement system (also called a measurement control program). The requirements in 10 CFR 70.57(b) (3-11) address the need to obtain representative samples, the calibration of each measurement technique, the monitoring and control of each technique during its use throughout the material balance period, the generation of bias correction data, the generation of information for random and systematic errors for use in determining the measurement system uncertainty (limit or error), etc.

The limit of error associated with the material unaccounted for (LEMUF) represents the uncertainty in the facility's measurement system as applied to the special nuclear material involved in the facility's operations during a material balance period. The requirements concerning LEMUF are found in 10 CFR 70.51(e). It should be noted that the U.S. only requires LEMUF calculations associated with the entire plant. LEMUF is expressed in the same units as MUF; e.g., in grams or kilograms uranium, uranium 235, or plutonium, as appropriate.

The LEMUF calculation is complex compared to the calculation of the MUF value. Since many of the inputs to the material balance expression (from which the MUF value is determined) are related, there are covariance effects which have to be dealt with properly in the LEMUF calculation in order to obtain a meaningful LEMUF value. Session 30 of this course will provide more information on the subject of calculation of the LEMUF.

The regulations in 10 CFR 70.51(e)(3) and 70.51(f) address the subject of physical inventory. In the U.S., the licensed, bulk-handling facilities usually take a physical inventory every two (2) months for plutonium and high enriched uranium ($\geq 20\%$ enriched) and every six (6) months for low enriched uranium ($< 20\%$ enriched). The inventory requirements include procedures to assure that the quantity of SNM in each item on inventory is a measured value, each item is only listed once on the inventory, all material containing SNM is inventoried, etc. Also, the requirements specify that the book inventory record must be reconciled and adjusted to the results of the physical inventory; note that if this requirement is not carried out, there is no way of obtaining the MUF value.

The basic accounting system required in the U.S. provides records and reports necessary to locate SNM and to close a measured material balance around each material control area and the total plant. The accounting system includes centralized records using double-entry bookkeeping practices, subsidiary accounts for each MBA and each ICA, and procedures for reconciling subsidiary accounts to control accounts as well as reconciling the accounts to the results of the physical inventory. Accounting records are required for quantities of SNM on inventory and for quantities added to and removed from the facility's various processing operations. The accounting system regulations also require that the MUF value, resulting from reconciling the book inventory to the results of the physical inventory, be calculated within 30 calendar days after the start of the physical inventory. The U.S. regulations concerning the accounting system are found in 10 CFR 70.51(e) and 70.58(k).

The requirements concerning internal controls for SNM are contained in 10 CFR 70.51(e)(1), and 70.58(g), (h) and (i). These requirements address procedures for SNM received by the facility operator and for SNM shipped from the facility, including the evaluation of shipper/receiver differences. Each facility must maintain a system to provide knowledge of the identity, quantity and location of all items containing SNM, including the generation and disposition of each item. There are requirements for limiting the accumulation of scrap materials, controlling and using tamper-safing seals, and the documentation of all transfers between material control areas including authorized signatures.

The management activities deal with development, revision, implementation and enforcement of control and accounting procedures at each facility. The safeguards manager and other facility management must approve in writing the MC&A procedures and revisions to the procedures. The regulations in 10 CFR 70.57(b)(2) and 70.58(c) also require a review and audit of the entire MC&A program at the facility every twelve (12) months by knowledgeable, independent persons. The results of the review and audit must be documented and reported to the corporate and facility management. The NRC also reviews the reported findings as part of its inspection program.

Finally, the MC&A regulation 10 CFR 70.58(1) requires each bulk-handling facility to submit a description of the program for control of and accounting for SNM to the U.S. NRC for review and approval. This submittal has become known as the Fundamental Nuclear Material Control (FNMC) Plan.

Each of the above 13 elements comprising the U.S. national MC&A regulations plays a role in the overall U.S. safeguards program which is designed to deter, detect, prevent, and respond to the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion, and the sabotage of nuclear materials and facilities.

III. THE FNMC PLAN

Now that you have some idea of the types of MC&A information required by the national program under 10 CFR Part 70, I want to discuss the relationship of the regulations and the FNMC Plan.

The facility's FNMC Plan plays an important role in the U.S. SSAC program. Essentially the FNMC Plan describes "what is done and how it is done" in the facility in order to meet or accomplish the intent of the national MC&A regulations in 10 CFR Part 70. Therefore, while each FNMC Plan addresses the same MC&A elements, the measures described in each FNMC Plan for each MC&A element can be different from facility to facility.

One of the functions that the NRC Licensing staff must perform is to evaluate the measures described in the FNMC Plan by the facility operator in order to assure that the facility's MC&A measures meet the MC&A requirements in the national regulations. When all of the MC&A measures in the FNMC Plan have been determined by the NRC Licensing staff to be acceptable, the FNMC Plan is incorporated as a part of the facility's license. This means that the facility must follow all of the MC&A measures described in the approved FNMC Plan for all of its material control and accounting activities. The NRC Inspection staff inspects the licensed facility against its approved FNMC Plan, the MC&A regulations in 10 CFR Part 70, and any applicable license conditions. The NRC inspection program will be discussed in detail in Session 35 of this course.

As one might expect, there can be a lot of activity associated with keeping an approved FNMC Plan up to date. Changes made to the FNMC Plan by the facility operator have to be submitted in writing to the NRC for evaluation and approval. When a facility makes changes to existing processing operations, installs new operations, or decides to stop handling SNM, the FNMC Plan has to be revised to describe the activities involving control and accounting of the SNM for the modified or new operations or for the decommissioning effort.

Now I would like to discuss briefly how the licensed, bulk-handling facility operator prepares the FNMC Plan. As mentioned before, each U.S. facility authorized to possess and use SNM in a quantity exceeding one effective kilogram must have an approved FNMC Plan. The basic guidance document, which each facility uses in preparing its FNMC Plan, is the Regulatory Guide 5.45. Chapters 3-11 of Regulatory Guide 5.45 provide the level of detail required for the MC&A elements that must be included in the FNMC Plan. The facility's FNMC Plan will usually contain 9 chapters, with each chapter addressing one of the 9 MC&A elements discussed above. The FNMC Plan currently does not contain chapters on Records, Reports, and Written Procedures since these three MC&A elements are straightforward and do not need elaboration in the FNMC Plan. In addition to Regulatory Guide 5.45, there are many other NRC regulatory guides which provide information on specific MC&A elements. In Session 37 of this course, the preparation of the FNMC Plan will be discussed in more detail.

IV. U.S. INTERNATIONAL MC&A REGULATIONS

For completeness I want to briefly mention international safeguards and its relationship to the national safeguards program. 10 CFR Part 75, Safeguards on Nuclear Material-Implementation of U.S./IAEA Agreement, contains the international safeguards requirements for the private sector nuclear facilities in the U.S. Essentially, the regulations in 10 CFR Part 75 correspond to the articles in the IAEA document, INFCIRC/153. The eight basic elements for implementing international safeguards are:

- A measurement system for the determination of the quantities of nuclear material received, produced, shipped, lost or otherwise removed from inventory, and the quantities on inventory;
- The evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty;

- Procedures for identifying, reviewing, and evaluating differences in shipper/receiver measurements;
- Procedure for taking a physical inventory;
- Procedures for the evaluation of accumulations of unmeasured inventory and unmeasured losses;
- A system of records and reports showing, for each material balance area, the inventory of nuclear material and the changes in that inventory including receipts into and transfers out of the material balance area;
- Provisions to ensure that the accounting procedures and arrangements are being operated correctly; and
- Procedures for the provision of reports to the Agency.

A comparison of these international MC&A elements with the U.S. national MC&A elements shows a strong relationship between the two sets. In the U.S., many of the MC&A procedures that have been implemented for national MC&A purposes (to satisfy the requirements in 10 CFR Part 70) are also used for purposes of international safeguards (to satisfy the requirements in 10 CFR Part 75).

It should be pointed out that the IAEA approved Facility Attachment for the licensed facility is incorporated as a condition of license, just like the FNMC Plan. Therefore, licensees in the U.S. that have been selected under the U.S./IAEA Agreement must follow the Facility Attachment for international safeguards as well as the FNMC Plan for national safeguards.

V. SUMMARY

The U.S. national MC&A system has been described, including details of each basic MC&A element and the role of the licensed facility's FNMC Plan.

The relationship between the U.S. national MC&A requirements in 10 CFR Part 70 and the U.S. international MC&A requirements in 10 CFR Part 75 has been described.

The U.S. SSAC for licensed facilities consists of the national MC&A system and, when applicable, the international safeguards program.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

**SESSION 5: THE NATIONAL NUCLEAR MATERIAL CONTROL
AND ACCOUNTING SYSTEM IN SWEDEN**

This session will briefly describe the Swedish SSAC and the nuclear activities to which it is related. The session will give information about the legal and organizational background to the SSAC as well as the objectives that guided its design, implementation, and operation. The national authority, the Swedish Nuclear Power Inspectorate, the SKI, will be described with respect to organization and its relationship to the SSAC, the nuclear facilities, other authorities and the general public.

After the session, the participant will have knowledge about:

1. the Swedish nuclear program
2. legal background to the SSAC
3. the objectives of the SSAC in a state with a medium-sized nuclear program
4. the structure of such a SSAC
5. the role of the Swedish Nuclear Power Inspectorate.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 5: THE NATIONAL NUCLEAR MATERIAL
CONTROL AND ACCOUNTING SYSTEM IN SWEDEN

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I. GENERAL

As a member of the Treaty on the Non-Proliferation of nuclear Weapons (NPT), Sweden is committed to an overall international control of all nuclear material processed, used, stored or otherwise kept in Sweden. Since 1975, when the NPT Safeguards Agreement between Sweden and the International Atomic Energy Agency (IAEA) was signed, the IAEA has controlled all nuclear material in Sweden.

However, Sweden had long before decided not to produce nuclear weapons, a decision documented in the national legislation, the Atomic Energy Act and in various bilateral agreements in the field of nuclear energy. A commitment to non-military use has been a requirement for bilateral supply of nuclear material, facilities etc.

This requirement in bilateral agreements was one of the major demands for a national atomic energy law in the early 1950's. The Atomic Energy Act was established in 1956, and is still valid, with some amendments. The act has four major paragraphs. The first one stipulates that it is mandatory to have a licence to acquire, possess, process, transfer or otherwise handle nuclear material. The second one stipulates the obligation to have a licence to construct, possess or operate a nuclear reactor or any other facility meant for the processing or treatment of nuclear material or waste. These licences are always issued by the Government. The third major paragraph of the law stipulates that all exports of nuclear material or equipment and material intended for nuclear use requires a licence also issued by the Government or, in some cases, by the national authority appointed by the Government, i.e. the Swedish Nuclear Power Inspectorate (SKI). The fourth paragraph stipulates that all requirements and guidelines that are issued by the SKI are to be followed as conditions for the licence. These conditions could be altered or new conditions could be added at any time of the licences' duration. These changes or additions are done by the SKI. Furthermore, the Act comprises a number of paragraphs which are of a supporting character. The Safeguards Regulations are issued in this way and are consequently to be adhered to as a condition to the operating licence. The bilateral agreements Sweden has concluded with states supplying nuclear material or equipment are also part of the legal background for safeguards. Today, the most important supplying countries are the USA, Canada and Australia. We have recently concluded new modern bilateral Control Agreements with them.

The Swedish Nuclear Power Inspectorate and the corresponding authority in the supplying countries have concluded Administrative Arrangements to the Control Agreements. These Arrangements qualify and quantify how to implement the various undertakings in the Agreements, e.g. records to be kept, reports to be issued, information to be given and prior consent to be obtained. These Arrangements resemble the General Part of the IAEA Subsidiary Arrangements.

Sweden ratified the Non-Proliferation Treaty in 1972, and subsequently in 1975 the Safeguards Agreement with the IAEA was concluded. Consequently, it took three years to reach an agreement due to time-consuming negotiations with the IAEA. Here I would like to emphasize that the IAEA already since 1972 conducted safeguards activities in Sweden in accordance with a Safeguards Transfer Agreement (STA) concluded in 1972 between Sweden, the USA and the IAEA. Although this agreement covered only nuclear material subject to USA/Sweden Agreement it covered by far the major quantity of nuclear material used or stored in Sweden at that time.

A. The Organization and the Role of the Swedish Nuclear Power Inspectorate

Licences issued by the Government to possess or use nuclear material or to construct or operate a nuclear facility, are connected with various conditions of general nature. To supervise these conditions stated by the Government, or to issue additional conditions and requirements for the licence is the responsibility of the SKI, by appointment of the Government. These conditions could be for safety reasons or for any other reason determined by the SKI. The fulfilment of safeguards undertakings made in bilateral Safeguards Agreements and in the Agreement with the IAEA are included in the duties of the SKI.

The SKI is since 1981 organized in two technical offices, the Office of Inspection and the Office of Regulations and Research. The Office of Inspection is responsible for the operational related matters within the Swedish nuclear fuel cycle and the Office of Regulations and Research is responsible for licencing and safety assessment, system analysis, waste handling and research and development. The Division of Nuclear Materials, within the Office of Inspection, is the organizational unit dealing with safeguards, transportation of nuclear material, physical protection and general handling with nuclear material in bulk-facilities including the relevant criticality safety aspects. These issues are all interrelated. We have found that these issues can be handled within the same organizational unit with great advantage. In some countries "safeguards" include physical protection as well as nuclear material accountability and control.

Matters related to radiation protection are the responsibility of the National Institute for Radiation Protection (SSI). Since the interests of the SSI and the SKI are often closely linked, there is a substantial need for co-operation. We believe that the advantages with separate responsibility for radiological concern versus nuclear safety and safeguards are outweighing the disadvantages of having two national authorities partly operating within the same area.

B. The Nuclear Programme

Sweden has a relatively large nuclear programme, which includes twelve power reactors (two are still under construction), 9 500 MW electrical effect total, a low enriched uranium fuel fabrication plant with a maximum of 400 metric tonnes annual throughput, two research reactors of MTR type and some research laboratories. At present an Away-From-Reactor Storage (AFR) is under construction. The capacity is 3 000 metric tonnes of spent fuel (can be increased to 9 000, if needed), and it is scheduled to come into operation early 1985. Nine of the reactors are boiling water reactors (BWR) of ASEA-ATOM design, and three are pressurized water reactors (PWR) of Westinghouse design. The major part of the nuclear material in Sweden is located at the power reactors. ASEA-ATOM's fuel fabrication plant produces fuel assemblies, starting from low enriched uranium-hexafluoride. All initial loadings of the BWRs and most of the reloads for all twelve reactors are produced by ASEA-ATOM. In addition initial loadings as well as reloadings for the two power reactors in Finland, of ASEA-ATOM design, are produced by ASEA-ATOM.

C. The Swedish Nuclear Power Inspectorate and the General Public

The ultimate obligation of the SKI is towards the general public. The work of the SKI is to prevent nuclear accidents that could lead to release of radioactivity or diversion of nuclear material. It is therefore in the interest of the general public that the work of the SKI is conducted in a manner to fulfill these obligations. To meet that interest of the General Public the board of the SKI includes three members of Parliament. Furthermore, three advisory committees are linked to the SKI. One of these advises the SKI on matters related to safeguards, physical protection, transports and bulk material handling. In this committee another two members of Parliament are included.

II. PRINCIPLES OF SWEDISH SAFEGUARDS

A. The Swedish State System of Accountancy and Control (SSAC)

The main objectives of the Swedish SSAC conform with the Swedish principles regarding non-proliferation of nuclear explosives, that is:

- to assure that nuclear explosives are not manufactured in Sweden or outside Sweden by the help or use of Swedish nuclear material or equipment, and
- to fulfil all obligations undertaken in various bilateral Control Agreements in the field of nuclear energy and in the NPT Safeguards Agreement with the IAEA.

The SSAC consists of a system of regulations and guidelines issued by the SKI and a Safeguards Description prepared by the facility based on those regulations and guidelines. The Safeguards Description is subject to approval by the SKI. After approval, the system will become a condition for the operating licence.

In the SSAC two main parts can be distinguished. One part containing the administrative rules valid for all facilities and one part containing the technical requirements valid for each type of facility.

The administrative part settles all requirements concerning recording, registration etc., in a manner similar to the General Part of the IAEA's Subsidiary Arrangement. The technical part specifies for each type of facility special requirements and guidelines concerning technical measures to be applied such as weighing, chemical analysis etc.

One basic intention of the SSAC is to provide the necessary means to be able to apply the same control measures over the entire fuel cycle in Sweden irrespective of the location of the material. For this purpose the nuclear material is stratified according to the same principle in all facilities. The nuclear material is stratified according to its chemical and physical properties. For example, UO_2 -powder, sintered pellets, scrap etc., make up different strata. Nuclear material in each stratum will be determined by weight, element concentration and isotopic composition (enrichment) with pre-defined methods and/or equipment. The measurement errors associated with each method or equipment used are evaluated and random and systematic error contributions are determined and stated in the Safeguards Description.

For each facility, each key measurement point (KMP) used for IAEA purposes is defined as one material stratum. Information about a KMP automatically gives information about measurement accuracy and precision. For example, the measurement error associated with a fuel assembly will follow it to the reactor station and will be one of the parameters to consider when the amount of plutonium produced is calculated.

B. Operational Means of the SSAC

The basic element of the system is the central register of nuclear material, established and maintained by the SKI. The register contains information of the inventory of nuclear material of various types in Sweden, sub-divided into facilities and MBAs. The register is kept batchwise. Material quantities subject to various bilateral obligations could of course be distinguished. At each facility a similar register should be maintained with respect to material quantities kept at the facility. The facility's register contains much more detailed information than the central one at the SKI. The aim being to require that only the information needed for the SKI's own work or for reporting purposes should be transmitted to the central register. Initially, the central register was kept manually. In 1978 a small computer was introduced and programmes developed to automate the processing of data. Since then the same minicomputer system has expanded gradually. However, at present the system is not sufficient to cover the need and therefore a more powerful system is scheduled to be in operation during 1984.

All reports are based upon the central register at the SKI and prepared in accordance with concluded bilateral agreements and the Safeguards Agreement with the IAEA. This implies that

copies of the ICRs, MBRs and PILs used with respect to the IAEA safeguards system are normally not available at the Swedish facilities. On the other hand, all source data related to each material batch are available at the facility. The information in the central register is also used as a means of support for inspections, export and import follow-up, registration of ownership etc.

The inventory change document (ICD) is the basic and most important document in the SSAC for reporting inventory changes. This document is used for reporting all inventory changes including transfers of nuclear material and shall include all relevant data necessary for both international and national safeguards. The form is issued in English and so are our other forms used for international transfers or for international safeguards purposes. Declared quantities for shipments and receipts will be given both by the shipper and the receiver. Each of them will submit a signed copy to the SKI. They will also retain one copy. For further details of the use of the ICD as well as other documents included in the SSAC, I would like to refer to a separate paper "Nuclear Material Control in Sweden" (Reference 1). Reference is also made to my last year's paper titled "Materials Accountancy and Control for Power Reactors and Associated Spent Fuel Storage". (Reference 2.)

The administrative part of the SSAC comprises also general principles for accountancy requirements at the facilities and reporting procedures in connection with physical inventory takings. It also includes conditions for export and ownership of nuclear material and procedures for requests for approvals of exports and for other transfers of such material.

The technical parts of the SSAC, containing guidelines and requirements concerning accountancy and control of nuclear material, are directed to each type of facility. Following requirements are included:

- organizational responsibilities
- internal control system for nuclear material
- frequency and scope of physical inventory takings
- reporting procedures
- measurements system for nuclear material including control programme
- statistical treatment and evaluation of facility generated data
- programme for training of operations personnel assigned to nuclear material control functions.

It is, however, the responsibility of the operator to determine how to meet the requirements in the SSAC and to submit to the SKI for approval a facility Safeguards Description in which he proposes his adopted measures. After approval the Description becomes a condition for the licence. If the Description is not followed, the licence could be withdrawn. Attached to the Safeguards Description is the Design Information, reflecting those parts of the facility system relevant to the IAEA safeguards system.

SSAC stipulates the content of the Safeguards Description, inter alia:

- facility organization and responsibility structures, including names and organizational positions of responsible safeguards officers at the facility,
- general description of the facility and description of the material flow including equipment and points where nuclear material is determined with regard to quality and quantity,
- internal administrative system for control of nuclear material describing accountancy system, internal reports, dataflow, internal MBA structure etc.
- system for quantitative and qualitative determination of nuclear material such as procedures for receipt control, determination of products (UO₂, fuel rods, etc.) and waste streams, procedures for shipment control etc.,
- measurement system including calibration procedures and control programme, giving a description of scales and analytical methods, sampling methods and the use of standards. Frequencies and procedures for calibration and maintenance shall also be given,
- procedures for physical inventory taking including frequencies and arrangements for verification activities and calculations of the result.

C. Physical Inventory Taking

A Physical Inventory Taking (PIT) is a fundamental action in each facility. In the Swedish SSAC, the minimum frequency for PITs is once per year for all facilities, except the fuel fabrication plant where there is a PIT twice a year. A PIT is always verified by the SKI, while the IAEA makes one PIV per year and facility (for a power reactor a refuelling period is 12-18 months). All material at the facility is listed on an itemized list, which will be the basis for verification by the SKI and the IAEA.

The procedure of a PIT is fairly complex at a fuel fabrication plant. The production is stopped and the process lines are emptied and the equipment, pipelines etc. cleaned out. Listing, weighing and analysing the material requires considerable working time. The itemized list contains information both for internal use by the facility and for strict safeguards applications. All items are automatically stratified by the inventory KMP-code on the list. A PIT at a fuel fabrication plant is always planned well in advance by the operator and the SKI in co-operation. This is to minimize the time needed for the PIT and the preceding verification. When the IAEA is verifying the PIT (once a year) the actions to be taken are coordinated between the IAEA and the SKI. During the Physical Inventory Verification (PIV) several working teams are formed by representatives from the facility, the SKI and the IAEA. They work in parallel.

Normally, the production is stopped only for one day and during the following day the normal production can restart.

Additional time, about two days, is needed for calculations and accountancy control.

At a reactor station fuel assemblies are listed separately while rods with the same physical and chemical composition comprise one batch. Burn-up and plutonium production must be calculated for each fuel assembly. The verification activities performed by the SKI and the IAEA will include identification of each fuel assembly by the use of an under-water TV-camera. For PWR fuel a correlation has to be made between the top-number which can be seen, and the unique identification number engraved on one of the vertical sides. This correlation is normally done at the time when the assemblies are received at the facility. Fuel rods that are stored at the reactor station make up an increasing problem because of the growing quantity. At present it is not possible to verify these rods satisfactorily.

One of the problems of the PIV at a nuclear power plant is timing. Because of tight time schedules for restart of the reactor the work has often to be done during inconvenient hours. Delays often mean waiting at a reactor site.

The itemized list produced by the facility during the PIT is the base for the PIV as well as for the Physical Inventory Listing (PIL) that is issued later and subsequently forwarded to the IAEA. As mentioned earlier the Swedish SSAC does not specify the location for the fuel since the system is material oriented. Therefore, during a PIV charts are normally available from which the inspectors can identify the exact location for each batch.

D. Inspections Performed by the SKI

In a control system, inspections must be made on a regular basis. The verification of the physical inventory is only one part of the inspection programme. Flow verification is equally important. The facilities' records must be checked regularly. The SKI inspections are normally done simultaneously with the IAEA's. Inspections carried out by the IAEA always start at the office of the SKI in Stockholm. There the latest print-outs of the inventory changes are given to the IAEA inspectors to allow updating of their records. Source documents kept at the SKI could also be checked. By this arrangement we have been able to minimize the time the inspectors need to spend at the facility which is essential to us. These (preparatory) meetings also provide good opportunities to discuss various problems and plans.

From the SKI, both accountancy and technical inspectors perform inspections. We believe that experts in accountancy are best fitted to verify the accountancy records and that technical experts are best aimed to perform other measures necessary for the control of actual quantities of material. At least one staff member from the SKI is always present when the IAEA is performing inspections in Sweden. Although the purposes of inspections often are common, differences can be identified. The co-operation between the IAEA and the SKI in carrying out inspections simultaneously is, in our opinion, of great advantage to both sides, as well as to the facility.

One of our basic philosophies is to have an open relationship between the IAEA and the facility. This includes a re-

sponsibility for the SKI to guard both parties' interests (or rather all three) so that each one can perform its safeguards function in accordance with concluded agreements. Whenever a need for consultations arises, all parties must be prepared to contribute in a constructive way, which also means that open relationships between the inspectors are necessary. Our experience with this philosophy is very good.

E. Working with the SSAC

As previously mentioned, only one division in the SKI is working with safeguards, which means that 15 persons are involved in both administrative and technical safeguards. It is evident that a staff with both technical and administrative background is needed. We have been very careful to select people with varying educational background in order to give means and motivation to personnel to fulfill work at different levels. One important principle is that everyone should be able to perform inspections at the facilities. Even a very sophisticated SSAC has its shortcomings. Ad hoc solutions must always be possible to use, and those working with safeguards should be qualified and motivated for their work to achieve that aim.

A staff of 15 is a minimum for such a workload. However, the SKI is organized in such a way that the number of employees is kept at a minimum. To compensate for this the SKI has funds for ad hoc purposes. When special needs arise, consultants can be assigned for a specific type of work. The system has the advantage that each individual of a small permanent staff has a possibility to be acquainted with others' work and to improve and advance.

F. Some Notes about the Safeguards Agreement with the IAEA

The Agreement and, in particular, the General Part and the Facility Attachments are based on the specific principles of the Swedish SSAC. The basic one being that stratification of nuclear material is made according to the principle briefly described above and is the same for the fuel fabrication plant, the nuclear reactors and for other locations. In the Facility Attachments for Swedish facilities "the KMP code" identifies a stratum. Material belonging to that specific stratum could be kept or stored at several places. The geographical location is consequently not a parameter for stratum identification. In the Design Information data regarding stratum associated measurement errors should be given.

During the negotiations of the Safeguards Agreement it was found that the number of code words for Material Descriptions was almost unlimited. An adequate number of Material Description Codes were chosen for each facility. These covered the KMP-codes for the flow of nuclear material as well as for the inventory. Since then there has been no need to change these code words and therefore the original codes chosen continue to be unchanged, in spite of the new code system that has been proposed by the IAEA.

Safeguards cover a broad area where several different sciences interact. New methods and procedures are constantly

developed. In order to have a possibility to improve safeguards and to introduce new methods into agreed and applied safeguards, Sweden and the IAEA have agreed to meet periodically on an annual basis to discuss the validity of the subsidiary parts of the Agreement and to review proposals for changes or additions. So far, this arrangement has proven valuable to both parties.

Even though we are very open-minded to participating in work that aims to improve the efficiency of the current IAEA safeguards system, we feel very strongly that there should be no mixture of measures that are actually approved for use by the IAEA inspectors on a routine basis and those measures that are still subject to development. The annual discussions with the IAEA are intended to cover this situation. Consequently, when the IAEA proves that a newly developed method or procedure has reached the stage where it can be applied by the inspectors on a routine basis, we are prepared to include it in our Agreement with the IAEA. This, on condition that we do feel that there is a need to do so, which is not always the case. For measures that are still under development we try to assist the IAEA within our ability but under a separate R&D project.

G. IAEA as a Contributor to the Swedish Safeguards System

When Swedish nuclear material is exported, it is of vital Swedish interest that the material will not be used in or contribute to the production of nuclear weapons or other nuclear explosives when it has left Sweden. For Sweden, the only way to obtain such assurances is to export to countries that are party to the NPT and, consequently, where full-scope safeguards are applied by the IAEA. Where this is the case, the IAEA will be able to verify the exported material in the receiving country and, indirectly, provide assurances that the material is used for peaceful purposes only. Also from other aspects, the activities performed by the IAEA are important to improve national safeguards. The IAEA administrates a lot of research activities, arranges conferences and panel discussions with an aim to solve important safeguards problems and thereby improve the effectiveness of safeguards and thereby also the reliability. These activities are vital for the continuous improvement of the effectiveness of international safeguards as well as of national safeguards.

REFERENCES

1. Nuclear Material Control in Sweden, SKI/TM(33)83.
2. "Material Accountancy and Control for Power Reactors and Associated Spent-Fuel Storage," Los Alamos National Laboratory Conference Proceedings, LA-9609-C, Session 15 (1982).



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 6: WORKSHOP ON IAEA/STATE SYSTEMS INTERFACE --
BRIEF PRESENTATIONS BY COURSE ATTENDEES

In this session, we ask the course participants to make brief presentations on any subject of interest, such as nuclear technology and SSAC activity in their home countries. This is an opportunity for all to become better acquainted with their fellow participants and learn something about nuclear activities in the nations participating in this course. We hope to have one or more presentations from every country represented.



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BRIEF PRESENTATIONS BY COURSE ATTENDEES

Compiled by Linda B. Robinson and C. R. Hatcher
Los Alamos National Laboratory

Course participants responded enthusiastically to the opportunity to give brief presentations regarding the status of nuclear technology and SSAC activities in their home countries. A total of 23 presentations were made in approximately 1-3/4 hours. O. B. Johnson of DOE/OSS outlined the format, introduced speakers, and kept the workshop on schedule.

Most of the participants began their presentations with a summary statement regarding their safeguards duties in their home country. Many of the attendees hold national level positions in government. Typically, these positions come under the atomic energy branch of the Ministry of science and Technology. Other participants hold positions of major responsibility at nuclear facilities. Some in this category are in charge of safeguards activities at one or more facilities. Others hold positions in management of operations or research activities.

Essentially all of the speakers summarized the status of nuclear facilities within their home country. A few countries represented at the course have no major nuclear facilities currently in operation, although all have plans for major facilities within a few years. One country represented now has 50 power reactors (in addition to all other types of nuclear fuel cycle facilities) in operation. Several of the countries represented have one materials testing reactor (MTR) in operation and have plans in various stages of development for a nuclear power program. A number of participants were present from countries that have 1 to 10 power reactors in operation. A few of the participants from countries with established nuclear power programs discussed the nuclear and non-nuclear power generating capability of their homeland.

Many of the participants commented on the status of their country's State System of Accounting and Control (SSAC). Here again, a wide range of experience was discussed. Some of the speakers indicated that state level materials accounting is moving from a manual operation to a computer operation. Several stated that their concern at the national level is almost entirely with item accountancy. Some of the participants from states with more advanced nuclear programs discussed aspects of their interface with the IAEA.

Experience with the 1982 and 1983 SSAC courses has shown that presentations by course participants is one of the more effective ways to stimulate dialogue among participants and between course participants and course staff. There is little difference in the level of experience between some of the "students" and the course staff. Acknowledging this early in the course leads to more productive interaction.



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October 17-November 4, 1983

Session Objectives

SESSION 7: PANEL DISCUSSION ON IAEA/STATE SYSTEMS INTERFACE

Participants and panel members will be divided into five subgroups. Each subgroup will develop a list of questions for the panel. Then, following a short break, the panel will be convened under the session chairman to respond to subgroup questions, as well as questions from the floor. Discussion will focus on safeguards interactions between the IAEA, state authorities, and facility operators. Full participation by course attendees is encouraged.



Subgroup developing questions for panel.



The panel consisted of (left to right) H. Kuroi, Paul Ek, A. Sessoms (moderator), C. Buechler, P. Morrow, and R. Schneider.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 7: SUMMARY OF PANEL DISCUSSION ON IAEA/STATE
SYSTEMS INTERFACE

Compiled by C. R. Hatcher
Los Alamos National Laboratory

PANELISTS

Allen Sessoms, Moderator, Department of State
Carlos Buechler, International Atomic Energy Agency
Paul Ek, Swedish Nuclear Power Inspectorate
Hideo Kuroi, Japan Atomic Energy Research Institute
Paul Morrow, Nuclear Regulatory Commission
Richard Schneider, Exxon Nuclear Company, Inc.

I. INTRODUCTION

To open Session 7, course participants and panel members were divided into five subgroups and given approximately 1 hour to develop a list of questions for the panel. Following a short break, panel moderator Allen Sessoms opened the discussion by introducing panel members and explaining the format. Each panel member would be asked to respond to one of the questions developed by his subgroup. Questions and comments from the floor and from other panel members were to be accepted at any time.

Hideo Kuroi selected the question: What are the mechanisms for communication between the IAEA and individual states? In addressing this question, Kuroi pointed out that safeguards measures are unique. They represent the first experience in which states withdraw their sovereignty in order to allow on-site inspections. Successful safeguards require intense cooperation on both a formal and an informal basis between the inspector and inspectee. Communication is sometimes difficult, not only because of cultural differences, but also because the safeguards vocabulary is difficult to understand. Kuroi expressed the need for both sides to use simple words and examples to improve communication.

II. ESTABLISHING AND UPDATING SSACS

A number of questions generated by the subgroups related to establishing and updating State Systems of Accounting and Control (SSAC).

A. Assistance Available From The IAEA

Carlos Buechler chose the question: What specific advise and expertise is available from the IAEA to assist states in setting up a SSAC? Buechler indicated that the IAEA provides

help of a general nature to all states. This includes guidelines and recommended procedures such as those found in the green book (IAEA/SG/INF/2) and in information circulars. In addition to general assistance, the IAEA also furnishes more specific help. For example, under the heading of technical cooperation, the IAEA provides (a) experts to go to countries to give advice on setting up SSACs, (b) training fellowships for people from countries who want assistance, and (c) equipment to be utilized as a result of (a) or (b). Under its safeguards program, the IAEA provides (a) training courses such as the present course and (b) informal advice from the IAEA safeguards staff. Buechler said that the IAEA is interested in helping the states with their SSACs as a matter of self-defense because it makes the IAEA's job possible.

B. Procedures For Updating Subsidiary Arrangements

The following question was chosen for discussion by Paul Ek: What procedures does the IAEA have for updating subsidiary arrangements with member states? In answering this question, Ek described the procedure followed for updating subsidiary arrangements in Sweden. Sweden's view is that subsidiary arrangements should reflect only what can be actually applied at present. The IAEA may send a written proposal to Sweden at any time during the year, suggesting changes in subsidiary arrangements. Such proposals are discussed only once per year at a meeting between representatives of Sweden and the IAEA. Sweden does not accept modifications to subsidiary arrangements that involve procedures that are not ready for routine implementation by the IAEA. No changes to subsidiary arrangements are accepted until they have been discussed with facility operators, although state authorities sometimes overrule operator objections. Unless there is agreement between the IAEA and the state authorities, the old subsidiary arrangements stand. This way of handling discussions between the representatives of Sweden and the IAEA facilitates updating of subsidiary arrangements and works well for both sides, Ek said.

C. Standardization Of Software

Several of the subgroups had raised questions regarding standardization of computer software for materials accounting. This subject led to an open discussion among course participants and panel members. Joe Nardi said that standardization of materials accounting software is technically possible, but he questioned whether people would make the effort required to standardize. Nardi offered to go to states in order to advise them on how to make their materials accounting system more compatible with the IAEA system. Somajajulu Gandikota indicated that so much time is spent in fitting the data into the proper format, it might be desirable to develop a uniform software system for all bulk facilities. Cecil Sonnier suggested that standardization of accounting data could make inspection planning easier. Samir Morsy noted that standardized accounting reporting formats are used in NPT countries.

Paul Ek said that there will be problems in handling material accounting on a computer unless you have previously operated a good manual system. Johannes Moritz pointed out that it would be difficult to have a standardized accounting system that would satisfy the IAEA and also suit all of the peculiar bilateral reporting requirements. Dick Schneider said that because Exxon's accounting system was well developed and not quite compatible with IAEA requirements, it was cheaper for Exxon to establish two accounting systems when Exxon's fuel fabrication plant came under IAEA safeguards. A common report for both the IAEA and NRC would be impractical he said, because this would make a 2-page report turn into a 50-page document. Joe Nardi explained, with Schneider's concurrence, that Exxon used two reporting formats based on one accounting system. Paul Ek indicated that this is a good example of what states establishing SSACs should try to avoid. Carlos Buechler summarized by saying that the IAEA experiences problems because of the nonuniformity of accounting systems. These problems are worse in states that had a SSAC long before the IAEA came into the picture. No state wants to make their system different.

III. IAEA/STATE SYSTEM INTERFACE PROBLEMS

Most of the latter part of the panel discussion was spent discussing operational problems that arise between the IAEA and states whose facilities are being inspected.

A. Chemical Sampling

Dick Schneider reported that his subgroup developed several questions relating to cost effectiveness. He selected the question: Is it possible to obtain chemical sampling results such as isotopic composition from the IAEA? As an example of why it is desirable for facilities to receive such information, Schneider told of how there had been an apparent disagreement between measurements made at Exxon and measurements made at the IAEA Safeguards Analytical Laboratory (SAL) near Vienna. However, the disagreement was due to sample aging, and it was resolved by delaying measurements at Exxon to coincide with the measurements at SAL. Moderator Allen Sessoms asked if others in the audience had experienced difficulty in obtaining analytical results from the IAEA. Samir Morsy indicated that there are delays of up to 6 months in the IAEA receiving chemical samples. The problem comes mainly from the airlines and is worse for plutonium than for uranium samples. Paul Ek agreed that there are sometimes long delays in getting samples shipped to the IAEA. Ek said that delays are sometimes caused by national restrictions on "selling" and "exporting" nuclear material, including chemical samples. States should find methods so that chemical samples can be transferred immediately, including ownership, according to Ek. Hideo Kuroi noted that Japan has a licensing problem with regard to the transport of plutonium samples, and said that the PAT-2 shipping container has not been approved in Japan.

B. Advance Notice Of IAEA Inspections

Paul Ek put forward the question: How does the IAEA know that states have adequately prepared for an inspection? Ek noted that it is difficult for anyone to get into a nuclear power plant without advance notice. He said that state authorities should receive a notification from the IAEA at least 1 week before the inspection. Somajajulu Gandikota said that, from his experience, advance notice of 6 weeks is given, which is entirely adequate. Nancy Lee said that a 2-day notice is more typical of what is experienced at reactor facilities in Taiwan. Carlos Buechler indicated that the IAEA gives 1 week advance notice for routine inspections, but not necessarily for ad hoc and special inspections. Buechler said that in most cases the IAEA gives more advance notice than is required by INFCIRC 153. Paul Morrow noted that the adequacy of information contained in the notification is more important than timing. States need to know what the extent of the inspection will be so they can arrange to have the appropriate people present, Morrow said.

C. Problems With New Equipment

Jae Hong Lee said that states should be given advance notice when the IAEA plans to ship equipment such as cameras, batteries, and film into a country. This will allow state authorities to expedite passage through customs. Samir Morsy indicated that such problems usually occur when new equipment is being utilized by the IAEA, and said that the state should work these matters out in advance with the IAEA country officer for the state in question.

Hideo Kuroi explained that, generally, new equipment from the IAEA improves credibility (of IAEA verification) but compromises intrusiveness; new equipment from the operator reduces intrusiveness, but compromises independent verification. Kuroi stressed the need to maintain good communication between the IAEA and the states during the early stages of equipment development.

D. Inspection Anomalies

Allen Sessoms asked the group to return to a question that had been raised earlier by Paul Ek: What becomes of unresolved anomalies that are found during an inspection? Carlos Buechler said that the IAEA has never found an anomaly of greater than one significant quantity that could not be resolved. Sessoms asked what happens if there are a large number of anomalies, each affecting a small amount of material. Buechler indicated that the IAEA can propagate the material balance and accumulate MUF. Cecil Sonnier asked if there are procedures to be followed regarding significant anomalies that remain unresolved. Buechler said that, should such anomalies or inconsistencies remain unresolved, they would be reported to the IAEA Director General and to the IAEA Board.

E. Nonuniformity of NPT

Paul Morrow said that his subgroup had asked the question: Under the NPT, why do some countries have all facilities under

IAEA safeguards, while other countries do not have all facilities under safeguards? Morrow indicated that nonnuclear-weapons states, which are party to the NPT, have all facilities under IAEA safeguards. Weapons states, which are party to the NPT, may voluntarily offer to have certain facilities put under IAEA safeguards. The U.S. voluntary offer allows for all commercial facilities to be placed under IAEA safeguards and for all weapons facilities to be excluded. Thus, the IAEA has the option of inspecting all commercial facilities in the U.S. But, because of limited resources, the IAEA has decided to inspect only a few U.S. facilities. The IAEA inspection procedures followed in the U.S. are the same as those followed in nonnuclear-weapons states, according to Morrow.

F. Self-Regulation

Pilar Rocoles noted that in the Philippines the AEC regulates its own research reactor. Rocoles asked if any other state had experience with the problem of self-regulation. Toby Johnson said that self-regulation does present a problem from the perspective of the public because of the possibility of the regulatory agency using a double standard. Johnson said there is no reason why self-regulation cannot be done effectively. The question is: will it withstand public criticism? Rocoles asked if the IAEA would require information supplied by the Philippine AEC to be sent through the SSAC? In response, Paul Ek said that the state, not the IAEA, should decide such questions.

G. Common Interest

Following the discussion of self-regulation, Paul Ek objected to the concept of the IAEA placing requirements on individual states. He said that the IAEA's needs are the states' needs. States voluntarily enter into safeguards agreements with the IAEA because "if everybody does, we all get assurances." In closing, Ek noted that the states and the IAEA have the same basic interest: to determine a common way of providing assurance.



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October 17-November 4, 1983

Session Objectives

SESSION 8: FACILITY SAFEGUARDS AT AN LEU
FUEL FABRICATION PLANT IN JAPAN

This session provides:

- Facility description of an LEU BWR-type fuel fabrication plant focusing on safeguards viewpoints.
- Procedures and practices of MC&A plan, measurement program, and inventory taking.
- Report and record system.
- Procedures and practices of safeguards inspection.
- Lessons learned from past experiences.

After this session, participants will be able to:

1. know specific features in safeguarding LEU fuel fabrication plants,
2. construct practical safeguards measures for LEU fuel fabrication plants, including MCA and KMP structures, relevant measurement program and reporting system for accommodating safeguards inspection,
3. evaluate staffing and resources necessary for implementing facility safeguards for LEU fuel fabrication plant,
4. identify problem area needed for improvement on equipment as well as procedural matters for effective implementation of safeguards.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



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FACILITY IN JAPAN

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I. INTRODUCTION

In order to understand the problems of safeguarding LEU fuel fabrication facilities in comparison with fuel cycle facilities, let us list nuclear fuel cycle facilities widely encountered in safeguards in the order of safeguardability:

- Research reactors and critical assemblies
- Power reactors
- Spent fuel storage facilities
- LEU fuel fabrication facilities
- Enrichment facilities
- MOX fuel fabrication facilities
- Fuel reprocessing facilities

Economical production of nuclear energy depends on an appropriate fuel cycle in each country. It is generally acceptable for many countries to utilize fuel cycle facilities up to and including LEU fuel fabrication. However, it may be controversial to make a national decision to construct spent fuel reprocessing plants and enrichment plants to meet purely economical objectives without other political implications.

Since the LEU fuel fabrication facilities are distributed over many countries (roughly speaking, one fuel fabrication facility for 5 to 10 nuclear power plants), accumulated inspection efforts allocated for all LEU fuel fabrication facilities need about the same amount of effort allocated for all power plants. As a consequence, about 20% of the total inspection effort is actually allocated for the LEU fuel fabrication facilities. Considering the nature of bulk handling facilities and their population, the LEU fabrication facility is one of the major concerns in safeguards both for the State and the IAEA.

In contrast with the item-dominated facilities, the "material unaccounted for" (MUF) interpreted from measurements of nuclear material, quantities and qualities, plays an important role for verification of nuclear material at the bulk handling facilities. It should be emphasized that the type of measurements needed for safeguards are also necessary for process and quality control of plants.

Since the LEU fuel fabrication facility is categorized as a bulk handling facility, safeguards concepts applied to the bulk handling facility are of course, important. But we should not overlook that many discrete items containing nuclear material are

also located on the site of such a facility, for example, thousands of UO₂ powder containers, thousands of fuel pins and hundreds of fuel bundles. Therefore, safeguards techniques for itemized facilities are also important for full implementation of safeguards at the LEU fuel fabrication facility.

As indicated by the title of this session, let us discuss the SSAC at a bulk handling facility focussing on the current practice of the SSAC at a BWR type LEU fuel fabrication facility owned and operated by the Japan Nuclear Fuel Company "JNF."

The lecture considers the following items in sequence:

- Requirements of the SSAC at the LEU fuel fabrication facility.
- An example of the facility MC&A at LEU fuel fabrication facility.
- Resources and staffing.
- Problems encountered and lesson learned.

II. REQUIREMENT OF SSAC AT LEU FUEL FABRICATION FACILITY

It is well known that a Safeguards Agreement conforming to INFCIRC/153 is required to provide that the State shall establish and maintain a system of accounting for and control of all nuclear materials subject to safeguards.

A. Relation between the IAEA Safeguards and SSAC

The relation between the IAEA safeguards and the SSAC can be interpreted in Provisions 7 and 31 of INFCIRC/153 as:

- The SSAC shall be applied in such a manner as to enable the IAEA to verify findings of the SSAC. The IAEA's verification shall include, inter alia, independent measurements and observations conducted by the IAEA.
- The IAEA, in carrying out its verification activities, shall make full use of the SSAC and shall avoid unnecessary duplication of the SSAC activities.

In this context, the SSAC shall be established and maintained in such a way to harmonize efficiently with the IAEA verification activities.

B. Technical Elements of SSAC

The elements of the SSAC shall accommodate the following items (recommended by IAEA/SG/INF/2;1980).

1. Organizational and Functional Elements at the Level of State.

- Authority and Responsibility.
- Laws and Regulations.
- SSAC Information System.
- Establishment of Requirements of SSAC.
- Ensuring Compliance.
- Technical Support.

2. Organization and Operation at the Level of Facility.

- Initial Information of SSAC.
- Establishment and Operation of Facility MC&A.

Since the general features of these elements are covered in other sessions of this course, I will skip procedural matters and proceed to focus on technical elements which are important for implementing the SSAC at an LEU fuel fabrication facility. These elements are:

- MC&A at facility level.
- State inspection.
- Records and reports.

In the following section, we will discuss the rather general requirements of these technical elements at the bulk handling facility, focussing on the LEU fuel fabrication facility. And then, practice and experiences obtained at the JNF fuel fabrication facility will be mentioned.

C. Requirements for MC&A at an LEU Fuel Fabrication Facility

For safeguards, material accounting should be interpreted as the activities carried out in a timely manner to establish the quality and quantity of nuclear material present within a defined environment and the change in the quantity and quality of nuclear material taking place within defined periods of time. Essential elements of this are material measurements, evaluation of measurement data and record keeping. Although their objectives are different, these activities not only are necessary for safeguards purposes, but also are of vital importance for process and quality control in the plant. It is important to establish a well-defined facility MC&A system which can accommodate the dual purpose of safeguards and quality control in the plant.

Next, I am going to discuss some of the important requirements for facility MC&A at an LEU fuel fabrication facility.

In Japan, Article 61-8 of the "Law for Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Nuclear Reactors" (hereinafter referred to as the Law) describes that a facility operator is responsible for establishing the MC&A, conforming to the Regulatory Order Part 50 of Prime Minister's Office.

The Regulatory Order Part 50 is formulated conforming to all international commitments concluded not only on the Safeguards Agreement with the IAEA, but also on any Bilateral Agreements with the United States, Canada, Australia, UK and France.

Requirements at the facility level set forth in the Regulatory Order Part 50 are given below, together with comments dealing with specific features of the LEU fuel fabrication facility.

Requirement 1: The facility operator shall establish the organizational unit responsible for MC&A at the facility level.

Comment: At LEU fuel fabrication facilities, MC&A activity is necessary not only for safeguards but also for quality control process control and plant safety purposes. Compatibility among Organizational units responsible for safeguards purposes and the

other facility objectives is important to achieve cost effectiveness of safeguards implementation.

Requirement 2: The facility operator shall establish and maintain MBA and KMP structures.

Comment: The size of the material balance area (MBA) should be related to the accuracy with which the material balance can be established, and be designed to localize losses, if any occur, within a facility. Looking at existing LEU fuel fabrication facilities under the IAEA safeguards, we can see variety of one, two and three MBA facilities depending on different interpretation of KMP's.

Requirement 3: The facility operator shall define batch data used as a unit for accounting purpose at KMP's.

Comment: A batch is a portion of nuclear material handled as a unit for accounting purposes and for which the composition and quantity are defined by a single set of specifications or measurements.

In addition, compatibility with bilateral agreements, material of a given form from a single supplier country should be regarded as a single batch. Examples of batches at the LEU fuel fabrication facilities are:

- Several drums of UO_2 powder with the same specification and supplier country.
- One fuel assembly.

Requirement 4: The facility operator shall provide for a measurement system for determination of the quantities of nuclear material received, shipped and discarded as well as produced or lost due to nuclear transmutation or accidents.

Comment: It is intrinsic to a bulk handling facility that compositions and quantities of nuclear material in a batch are measurements either by analytical or non-destructive measurement. In this context, the measurement system plays an important role in the MC&A system.

Requirement 5: The facility operator shall establish procedures for the physical inventory verification "PIV".

Comment: The frequency of PIV depends on throughput and enrichment of uranium of the LEU fuel fabrication facility. Roughly speaking, the cut-off point for choosing one or two PIV/year would appear to be 300 ton U throughput. A facility shutdown and clean-out of plant process unit as far as practicable are necessary for conducting the PIV. Normally the PIV is therefore carried out at the end of production campaign of the plant.

Requirement 6: The facility operator shall establish procedures for evaluation of precision and accuracy of measurements and the estimation of measurement uncertainty.

Comment: For bulk handling facilities, quantitative indications of possible missing material are expressed in terms of the MUF which is dependent on measurement uncertainties.

Requirement 7: The facility operator shall establish a system of records and reports for each MBA conforming to the Regulatory Order Part 50.

D. State Inspection

Compliance of the facility operator with the requirements of the SSAC must be assured by inspection conducted by State's inspectors. As mentioned already, the MC&A depends to great extent on activities of facility. In this context, the State activities are focussed on inspections activities.

1. Degree of Assurance. There are two alternative State inspection modes; Level I and Level II, depending on different degrees of assurance required. Briefly, Level I activity includes only examination and observation of the operator's measurements and records to assure facility compliance with the SSAC. Level II activity includes not only the Level I Activity but also independent measurements conducted by the State inspector.

A group of States, the European Atomic Energy Community (EURATOM), has decided to conduct Level II activity by using EURATOM inspectors. Japan has also decided to conduct Level II activity by using State inspectors. It was a great challenge for a single State to establish and maintain an independent measurement capability by State inspectors; it is still a significant challenge.

2. State Inspection. In Japan, Article 68 of the Law describes, inter alia, that:

- The Prime Minister may cause state inspectors to enter the nuclear facilities so as to inspect records, documents and other necessary items, ask questions of a responsible person of the facility, and take samples of nuclear material in the minimum amount requested for measurements.
- The IAEA inspectors and persons designated by the governments of countries supplying nuclear material to Japan, with the accompaniment of officials appointed by the Prime Minister, may, within limits specified by Agreements, enter into the nuclear facilities so as to inspect records, documents and other necessary items and take samples of nuclear materials in the minimum of amount required for measurements.
- The Prime Minister may cause state inspectors to install seals or relevant surveillance/monitor devices to detect unauthorized movement of nuclear materials under safeguards.
- The IAEA inspector accompanies with officials appointed by the Prime Minister, may also, within limits specified by Agreements install seals or relevant surveillance/monitor devices to detect unauthorized movements of nuclear material under safeguards.

3. Inspection Goal. There has been no agreed-upon consensus on goal values for use in the SSAC yet. Some investigations have been made for clarifying the relationship between those goals used by the IAEA and the SSAC. General trends found in these investigations suggested that the detection goal used in the SSAC will be approximately 30% smaller than that used in the IAEA.

4. Escort and Facility Operation for Inspection. In Japan the Safeguards Agreement was concluded between the Japanese Government and the IAEA. Strictly speaking, the facility operator is the third party to the Agreement. Facility operators are responsible for conforming not only to the domestic law and regulations of the SSAC but also to other laws and regulations concerning plant safety, radiation exposure control, etc. In this context, there is a certain constraint for conducting inspections:

- Neither the State inspector nor the IAEA inspector can operate any parts of the facility. Facility operation can be done only by operator personnel upon request of the State Inspectorate.
- Agency inspectors should be accompanied by State inspectors, provided that the IAEA inspectors are not thereby delayed or otherwise impeded in the exercise of their functions.
- Both State inspectors and IAEA inspectors must be escorted by facility operator personnel during inspection of a facility.

5. Coordination of Inspection Plan. A facility is inspected by two different authorities, namely, the IAEA and the State. Since both the State and IAEA inspections include independent measurements, an appropriate coordination of inspection plan between the IAEA and the State is very important to minimize the burden of inspection on the operator.

III. AN EXAMPLE OF FACILITY MC&A AT LEU FUEL FABRICATION FACILITY (THE JNF) FUEL FABRICATION PLANT IN JAPAN)

A. Outline of Facility

The JNF fuel fabrication facility is a typical LEU, BWR fuel fabrication facility. Conversion from UF₆ to UO₂ is not made at this facility; therefore, the input material to the facility is UO₂ powder. The maximum enrichment handled by this facility is 4%. The production capacity is now 570 tons of uranium/ year.

This facility consists of six major manufacturing processes as shown in Fig. 1, and nuclear material flow in the facility is represented in the following sequences;

1. Green Powder Receiving. UO₂ powder contained in a five gallon transport container enters into a buffer storage located in a warehouse. The UO₂ powder produced in the same lot by a conversion plant is counted as the same batch for accounting purposes. One batch consists of approximately twenty transport containers of UO₂ powder.

2. Weighing and Sampling of Green Powder Received. After the gross weight measurement of the five gallon transport container at the ceramic area of the facility, UO₂ powder is transferred from the transport container into a five gallon bucket belonging to the facility. At the same time, one sample for each batch is taken and sent to the analytical laboratory located at

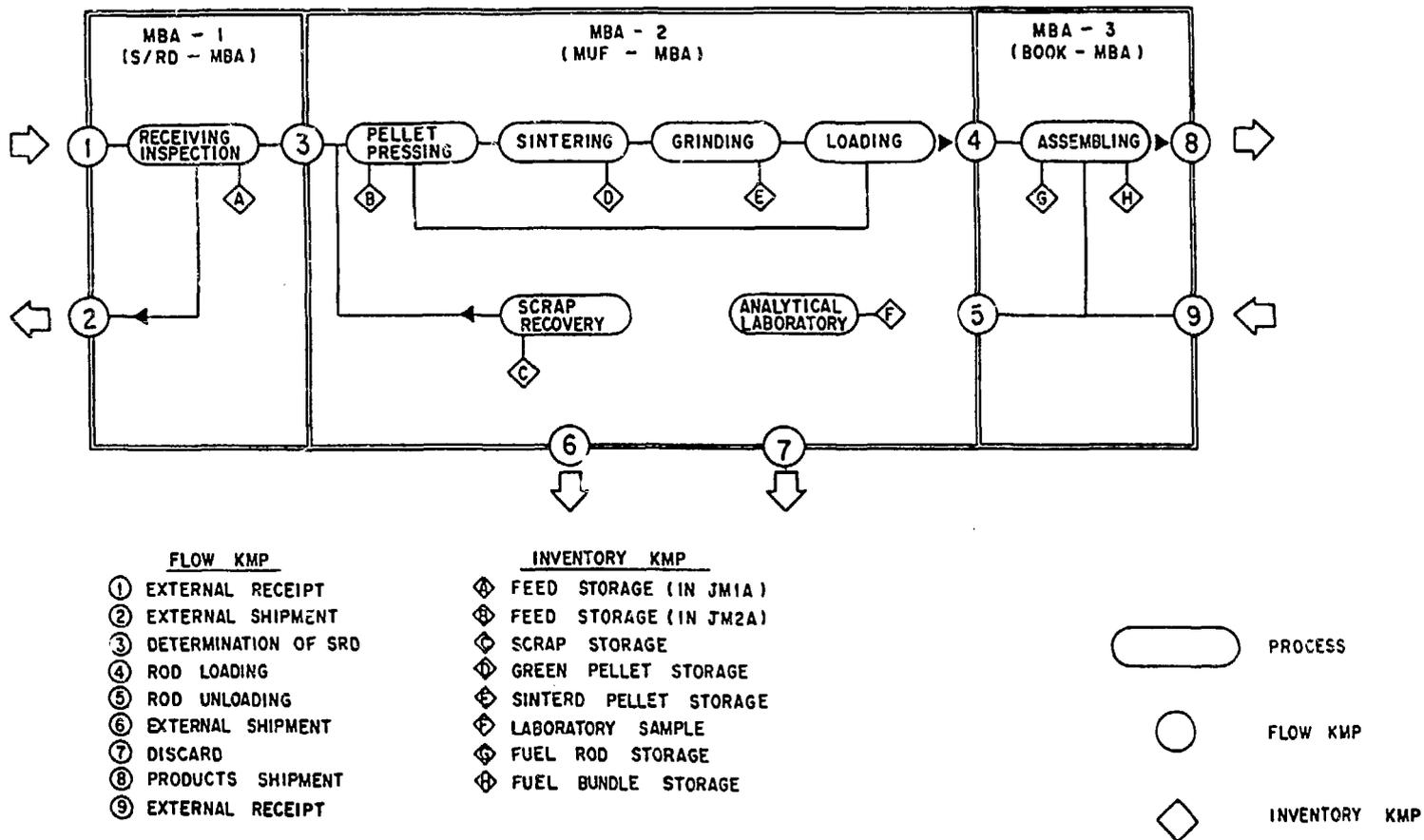


Figure 1. Material Flow and MBA/KMP

a corner of the ceramic process area for measurements of uranium content and enrichment. The tare weight of the transport container is measured in a random sampling basis in order to confirm reliability of the shipper's data. After fixing the shipper/receiver difference, the UO_2 contained in the bucket is sent to the temporary storage located at the ceramic area.

3. Powder Treatment. The UO_2 powder is blended to adjust grain size in a cell if necessary. After this process, the batch process vessel is limited to be less than about 30 kg by Safety Regulations.

4. Pelletizing. The UO_2 powder is pressed mechanically to produce green pellets by a pelletizing machine. The UO_2 powder is fed to the machine in one bucket increments. The green pellets are put on a boat and placed in a temporary storage area.

5. Sintering. The green pellets are sintered in high temperature furnaces.

6. Grinding. Sintered pellets are ground by a wet grinder to size specification.

7. Drying. Pellets ground by wet grinder are dried in elevated temperature furnaces.

8. Pellet Examination. Visual examination is carried out to eliminate pellets with cracks, and finished pellets are stored in trays.

9. Rod Loading. Columns of finished sintered pellets are weighed and loaded into fuel rods, and then plugged by welding.

10. Fuel Rod Inspection. Finished fuel rods are examined according to quality control guidelines of the facility. The examination includes non-destructive assay of fuel enrichment for each fuel rod.

11. Bundle Assembling. Finished fuel rods are transferred to the assembling area near the ceramic process area of the facility. Then, the rods are assembled into a bundles and temporarily stored on hangers.

12. Shipping. Bundle assemblies are packaged in shipping containers and temporarily stored at a shipping yard.

13. Waste. Bulk handling facilities usually generate not only solid waste but liquid waste as well. The solid waste generated from the JNF fuel fabrication facility consists mainly of contaminated filters, gloves, papers, plastics and clothes. These contaminated materials are put into drum cans and stored on the facility site. One drum contains up to 15 g of ^{235}U . The total amount of solid waste is about 0.1% of throughput at the JNF fuel fabrication facility.

Liquid waste is mainly washing water used for decontamination and involves material in minor quantities of approximately 1 g per month.

14. Scrap Recovery. Scrap material consists mainly of grinder slag, defective sintered pellets, etc. This recoverable scrap is converted to U_3O_8 dissolved and processed through scrap recovery (which produces green powder), and is recycled. The scrap recycle rate at the JNF facility is about 7% of throughput.

B. Policy on the Design of the Accountability System

The design objectives of the facility's accountability system may be broadly divided into the following two aspects. One is to have the accountability system contribute to the nuclear material inventory control, material balance determination, manufacturing process control, quality control, safety control, physical protection, and other managerial operations of the facility. The other is to have this system satisfy the regulatory requirements of national and international safeguards. The above two aspects regarding the function of the accountability system are interdependent, and the system must be so designed that information necessary for the managerial operation and for the regulatory requirements is readily available for both. Figure 2 shows an example of the conceptual design of the accountability system.

C. Material Balance Area

In accordance with national and international safeguards requirements, the low enriched uranium fuel fabrication facility in Japan is required to establish three MBA's for accounting and controlling of the materials in the facility. As shown in Figure 1, the JNF facility is divided into three MBA's; (1) Shipper/Receiver Difference MBA, (1) a MUF MBA in which MUF will be generated and (3) Item MBA in which all materials will be accounted for by the measured values in the preceding MBA.

From the safeguards point of view, the MBA can be defined as a functional area and not as a specific area separated by any physical barrier or building structure.

- MBA-1 Shipper/Receiver Difference Area. This MBA includes all the nuclear material that is kept on shipper's data.
- MBA-2 This MBA includes the fuel fabrication process up to pellet loading, the chemical laboratory and storage of intermediate materials.
- MBA-3 This MBA includes the fuel bundle assembling process and storage of fuel rods and products kept on the basis of the facility's own measurements that were performed previously at the MBA-2.

D. Key measurement Point

Strategic points that serve as key measurement points are to be established for determination of material flow and inventory. At the JNF facility there are nine KMPs for determination of material flow at the boundary of MBAs which relate to inventory changes of the MBAs and eight KMPs to determine the inventory of each stratum which is classified by chemical and physical configuration of the material. (Refer to Fig. 1.)

Flow KMPs (1-9) and INVENTORY KMPs (A-H)

- KMP-1 Receipt of external nuclear material into MBA-1.
- KMP-2 Shipment from MBA-1 to a destination outside the facility.

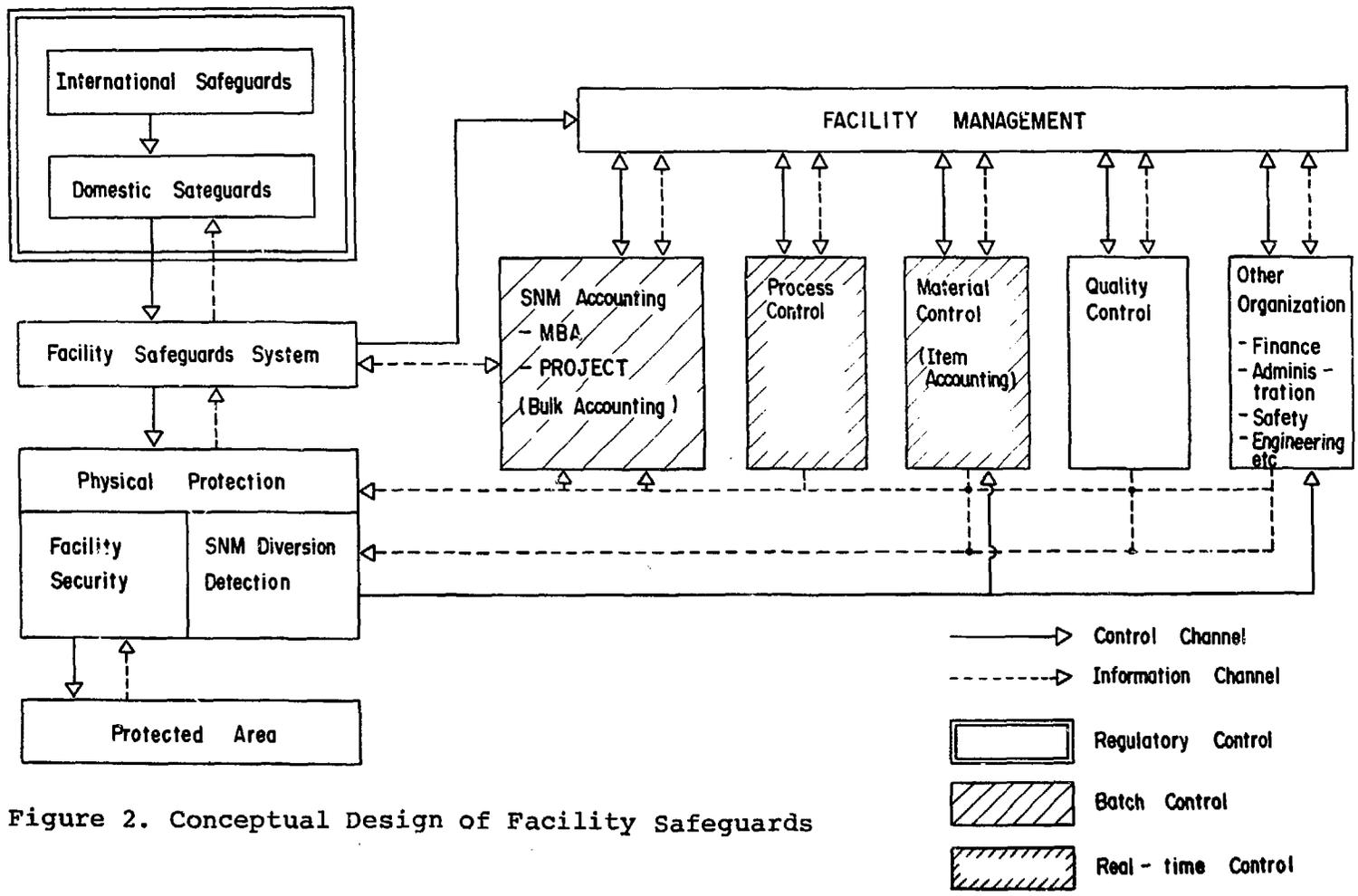


Figure 2. Conceptual Design of Facility Safeguards

- KMP-3 Shipment of nuclear material from MBA-1 to MBA-2 and determination of S/R Differences. This KMP also is used for receipt of nuclear material at MBA-2 from MBA-1.
- KMP-4 Shipment of loaded fuel rods from MBA-2 to MBA-3.
- KMP-5 Reshipment of loaded fuel rods from MBA-3 to MBA-2.
- KMP-6 Shipment of various materials from MBA-2.
- KMP-7 Measured discard and retained waste.
- KMP-8 Shipment of final products from MBA-3 to outside of the facility.
- KMP-9 External receipt.
- KMP-A Storage of feed material kept based on shipper's data.
- KMP-B Storage of feed material kept on the basis of facility's measurement.
- KMP-C Storage of recoverable scrap.
- KMP-D Storage of green pellets.
- KMP-E Storage of sintered pellets.
- KMP-F Storage of various analytical samples.
- KMP-G Storage of fuel rods.
- KMP-H Storage of fuel bundles.

E. Material Balance Accounting

The material balance accounting for each MBA shall be accomplished by determining changes in material inventory with such methods as item counting, weighing, volume measurement, sampling and analysis at the KMP's and by accounting through computerized data processing system. This system consists of four sub-systems as described below.

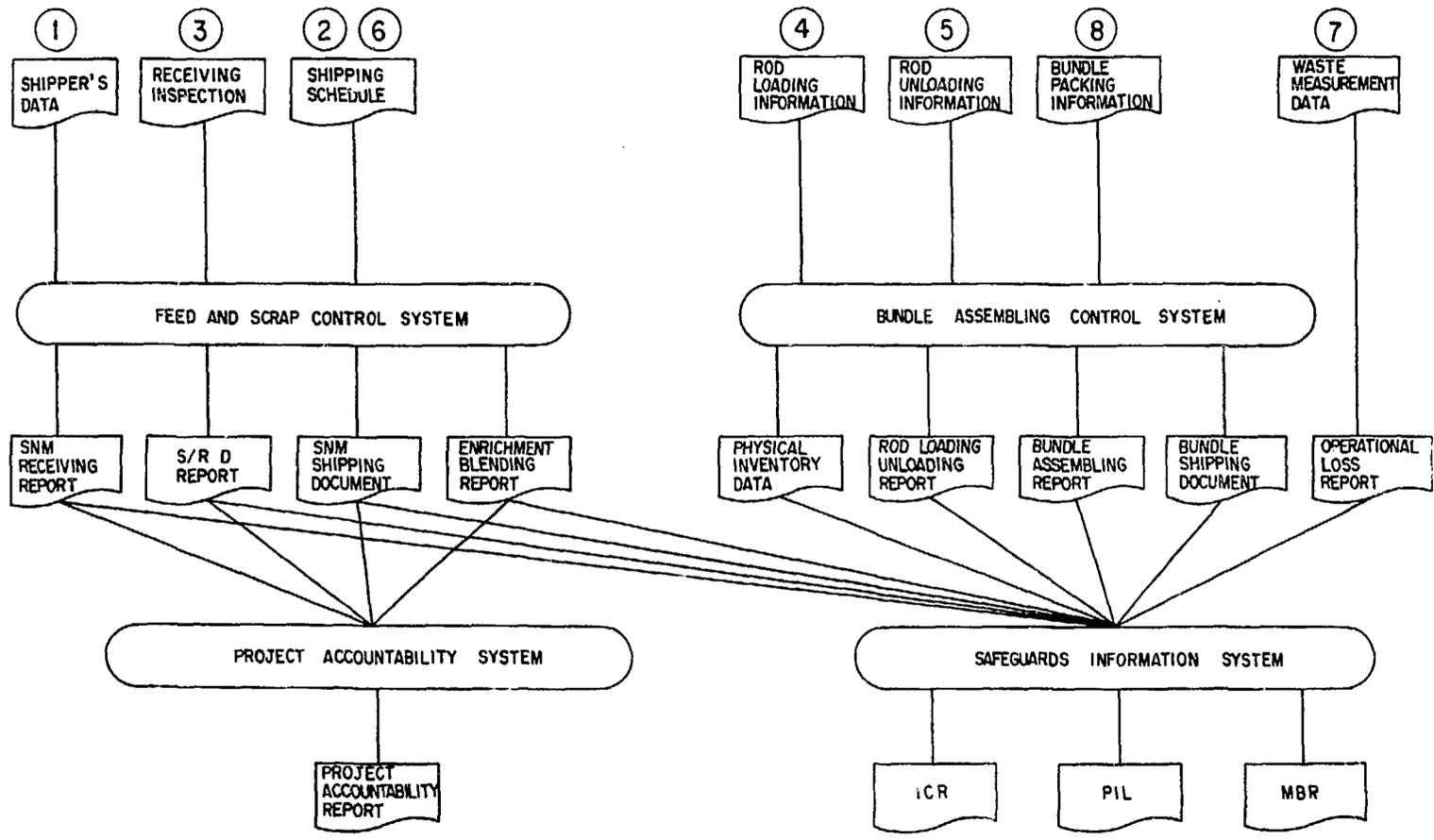
1. Feed Material and Scrap Control System (FASCS). This system is designed for maintenance of inventory control, as well as for calculation and statistical evaluation of shipper/receiver differences for both feed material and recoverable scrap material. This system also provides an itemized listing for the purpose of taking the physical inventory.

2. Bundle Assembling Control System (BACS). This system is designed to control the accountability information regarding the fuel rod and fuel bundle. The calculation of uranium and isotopic weight for each fuel bundle and preparation of the shipping document for the product are also made through this system. The system can provide an itemized list of fuel rods and fuel bundles for taking the physical inventory.

3. Safeguards Information System (SIS). This system is programmed to generate various regulatory reports such as the ICR, PIL, and MBR as needed.

4. Project Accountability System (PAS). This system is intended to control and maintain material balance accounting for specific project material. The system is to provide project material accountability reports for the project and maintain perpetual inventory for the project material.

The Data Transaction Diagram of this material balance accounting system is shown in Fig. 3.



8-12

Figure 3. JNF's SNM Accountability System Data Transaction Diagram

○ : KEY MEASUREMENT POINT

F. Measurement System

Various measurement methods for determination of nuclear materials for each of the flow and inventory key measurement points are established in consideration of chemical and physical characteristics of the nuclear materials. The material descriptions and measurement methods are summarized in Table I.

1. Measurement Methods.

a. Mass Measurements. Weight measurements at KMPs are performed with electronic scales with digital display of the weight value. The range of these scales is from 10 kg to 50 kg with divisions ranging from 1 g to 20 g. The scale is selected depending upon the weight of the items to be weighed.

b. Analytical Measurements.

Percent Uranium

- Dichromate Titration - This type of determination is based on the techniques devised by Davies and Gray which allow the determination of uranium in dilute nitrate and in the presence of large quantities of impurities.
- Gravimetric Determination of Uranium - This technique is used for relatively pure uranium compounds and is based on oxidation of the sample to U_3O_8 . The final value is then corrected for non-volatile impurities.

Enrichment

- Gamma Spectrometry - This technique is used for determination of the percent of Uranium-235. Samples are converted into relatively pure U_3O_8 to make their geometry constant.

Impurities

- Trace metallic impurities are determined using a standard emission spectrographic technique.

Nuclear Poison (GD_2O_3)

- Nuclear poison as an additive in fuel is determined using an energy-dispersive X-Ray fluorescence technique.
- Alpha Counting is employed for measurement of uranium in atmospheric discharge and effluent discharged to the sewer.
- Passive Gamma Counting (SAM-II) is employed for counting containers of waste and used filters which are stored as retained waste.

2. Measurement Control Program.

a. Weight Measurement Control. All scales at KMPs are checked daily for zero setting and calibrations with standard weights. In addition, the scales are checked and calibrated once per month with the first class standard weights by personnel who are qualified by the government to perform the measurements. The standard weights are inspected by the Inspection Institute of Weights and Measures.

b. Analytical Measurement Control. Uranium content measurement; Analytical reagents for measurement are qualified with the national standard. Analytical balances are calibrated once every six months.

Measurement/Analysis at Each KMP

KMP	Description of Nuclear Fuel Material				Type of Measurement	Method of Measurement/Analysis or Equipment
	Type	Chemical Form	Physical Form	Subject		
1	Feed material	U ₃ O ₈	Powder	BU-Type shipping container	Item count	/
	Retained waste	Various	Various	Drum, Filter, etc.	Item count	
	Nuclear fuel material other than feed material	UO ₂ U ₃ O ₈	Powder Pellet Sludge Others	Shipping container and others	Item count	
2	Same as KMP-1 above					
3	Feed material	UO ₂	Powder	5 Gal. can	Weight	Scale
					U-w/o	Oxidation method
	Nuclear fuel material other than feed material	UO ₂ U ₃ O ₈	Powder Pellet Sludge Others	5 Gal. can 2.5 Gal. can Others	U235-w/o	Enrichment analyzer-measurement
					Weight	Scale (exclude less than 10g-U235)
				U-w/o	Oxidation or titration method	
				U235-w/o	Enrichment analyzer-measurement	
4	Fuel rod	UO ₂	Pellet	Fuel rod	Weight	Scale
					U-w/o	Oxidation method
					U-235-w/o	Enrichment analyzer-measurement
5	Same as KMP-4 above					
6	Nuclear fuel material other than fuel rod and fuel bundle	UO ₂ U ₃ O ₈ UO ₄	Powder Pellet Sludge Others	5 Gal. can 2.5 Gal. can Others	Weight	Scale (Except less than 10g-U235)
					U-w/o	Oxidation or titration method
					U235-w/o	Enrichment analyzer-measurement
7	Exhaust loss	-----	-----	-----	U-Concentration	Scintillation counter
	Sewage loss	-----	-----	-----	U-Concentration	Scintillation counter
	Retained waste	UO ₂ U ₃ O ₈ UO ₄	Powder Others	50 # or 200 # drum Used filter	U235-quantity	measurement by SAM-II

8-14

TABLE I (1/2)

Measurement/Analysis at Each KMP

KMP	Description of Nuclear Fuel Material				Type of Measurement	Method of Measurement/Analysis or Equipment
	Type	Chemical Form	Physical Form	Subject		
8	Fuel rod or fuel bundle	UO ₂	Pellet	Fuel rod	Weight U-weight U ₂₃₅ -weight	Measured value at KMP-4 above
9	Fuel rod or fuel bundle	Same as KMP-8 above				
A	Feed material (by shipper's data)	UO ₂	Powder	NU-Type shipping container	Item count	
B	Feed material (by JNF's data)	UO ₂	Powder	5 Gal. can	Weight	By transfer card
					U-w/o	Measured value at KMP-3 above
					U ₂₃₅ -w/o	
C	Scrap	UO ₂ U ₃₀₈ UO ₄	Powder Pellet Sludge	5 Gal. can or 2.5 Gal. can	Weight	By transfer card
					U-w/o	Oxidation or titration method
					U ₂₃₅ -w/o	Enrichment analyzer-measurement
D	Green pellet	UO ₂	Pellet	Metal pellet boat	Same as KMP-C above	
E	Sintered pellet	UO ₂	Pellet	Metal boat or tray	Same as KMP-C above	
F	Various lab. sample	UO ₂ U ₃₀₈ UO ₄	Various	Various	Weight	By record
					U-w/o	Average U-w/o
					U-235-w/o	Average enrichment or actual measured value
G	Fuel rod	UO ₂	Pellet	Fuel rod	Item count	
H	Fuel bundle	UO ₂	Pellet	Fuel bundle	Item count	

TABLE I (2/2)

Enrichment measurement: Gamma spectrometry equipment is calibrated with the national standards. The equipment is calibrated at the beginning of each shift. The working standards are analyzed after every eleven samples. If the average of three such readings is out of control limits, the equipment is recalibrated.

c. Nondestructive Measurement Control. Calibration standards of this nature are not available from either national or international sources. The calibration is performed once every month with a known standard gamma source that is prepared by the facility.

3. Laboratory Correlation Program. As a part of the measurement control program, this facility has participated in the Safeguards Analytical Laboratory Evaluation (SALE) Program. Also various laboratory correlation programs are being conducted between related facilities.

G. Physical Inventory Verification

The purpose of taking a physical inventory is to determine the quantities of nuclear materials on hand at a given time within a material balance area and to derive the differences between the book inventory and physical inventory that are called Book Physical Inventory Differences (BPID) or Materials Unaccounted For (MUF). The MUF is a very important figure both for plant management and for safeguards because the MUF gives a useful indication of the effectiveness of the facility's nuclear materials accountability system. It is also useful to indicate no significant loss of nuclear material and no diversion of nuclear material.

In order to meet the safeguards requirements, the physical inventory must be taken twice a year. The inventory verification frequency can be reduced when the annual throughput is less than 300 tons of uranium and when the safeguards authority has continued assurance that the plant material balance is closed with limits of error of MUF of not more than 0.3% relative.

The requirements further demand that the physical inventory verification must be conducted under the complete shutdown status of the process; and all material movement which might change the inventory balance of each MBA must be ceased after the book inventory cut-off for the inventory verification. In addition to this complete physical inventory verification, interim inventory will be taken upon completion of each fuel fabrication project to determine the material balance for the project accounting.

The physical Inventory Verification consists of four major procedures, as follows:

1. Equipment Clean Out and In-process Inventory Determination. All process equipment and systems containing nuclear material are thoroughly cleaned to minimize hidden inventory and equipment hold-up. However, in the case of the equipment or a system that cannot be disassembled for technical or economic reasons, the equipment hold-up will be estimated by means of appropriate NDA equipment or past experience.

2. Inventory Item Count. This portion of the inventory will involve item identification and accounting for all nuclear materials. With respect to discrete items visually located, their item identification number, project number, enrichment, material type, and gross, tare and net weights will be recorded.

3. Weight Verification. In order to test the gross weight assigned to inventory items, randomly selected containers are reweighed, and if only systematic bias is detected throughout this examination, the tag weight will be corrected.

4. Analytical Verification. A statistically based sampling plan is developed for various types of recoverable scrap to reconfirm the applicability of the standard uranium contents for each type of recoverable scrap.

The standard sequence of events for physical inventory is shown in Fig. 4.

H. Records and Reports

Records and reports for accountability and safeguards purposes can be categorized as follows:

1. Accounting Records. Four major types of accounting records are maintained by the facility:

a. For Inventory Changes. Record all external shipments and receipts, material transferred between MBAs within the facility, measured discards, retained waste, accidental loss or gain, and all information concerning changes in the MBA inventory.

b. For Physical Inventory Verification. Record all information used for determination of ending physical inventory, including sampling and analytical results, weight verification data, etc.

c. Adjustment and Correction. Record any shipper/receiver differences and MUFs as adjustment and corrections due to detection of errors in previous records or due to more precise later measurements, and corrections for measurement bias.

d. Changes in Batch Identities. Where a batch identification is changed, its previous batch identification and new batch identification must be recorded with traceability.

2. Operating Records. At least 6 types of operating records are to be maintained in accordance with regulations:

a. Rod Loading Operation. All accountancy data relevant to determination of the uranium and isotope weight for each fuel rod are recorded.

b. Bundle Assembling Operation. All the relevant data for the fuel rods assembled into each fuel bundle and the uranium and isotope weight for each fuel bundle are recorded.

c. Removal of Seal or Equipment. Whenever a facility operator removes a seal which has been installed by a safeguards official for any safeguards purpose, the date, seal identification number and the reason for removal are recorded.

d. Enrichment Blending Operation. Whenever enrichment blending is performed, accountancy data on the original materials used for blending including the name of the country or origin and on the material created by the enrichment blending are recorded.

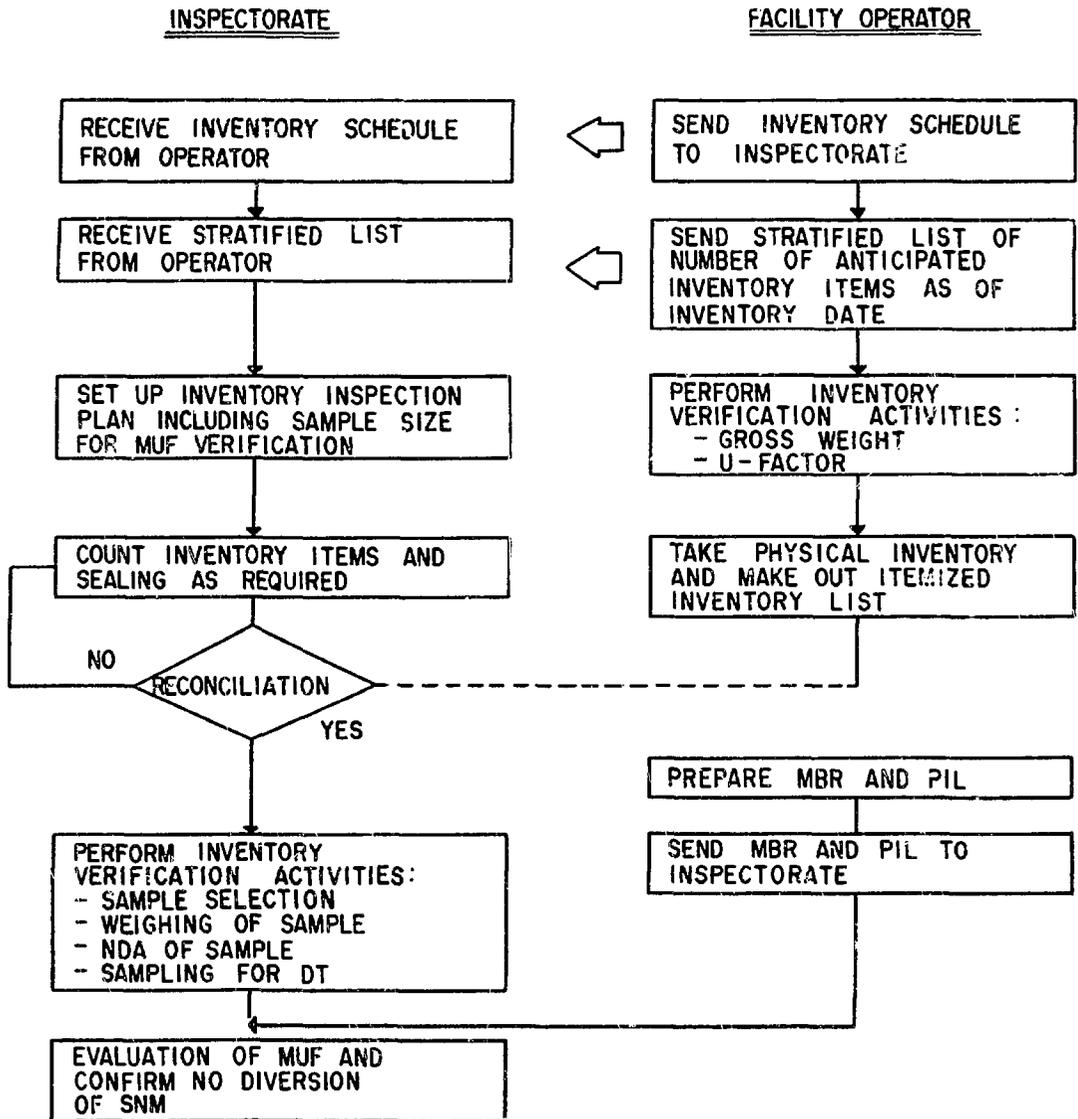


Figure 4. Standard Sequence of Events for Physical Inventory

e. Accident that Results in Loss or Gain. For accidental losses or gains of nuclear material, information relevant to the accident including date, cause and features of the accident, and estimated or known amount of nuclear material which has been lost or gained are recorded.

f. Measurement Control. With respect to measurement equipments and instruments, all relevant data for the facility measurement control program used for determination of random and systematic errors in each inventory change are recorded.

3. Regulatory Reports. Regulatory reports are required by the Regulatory Order Part 50 in connection with the Safeguards Agreements. The specific requirements on reports are stipulated in the Regulatory Order Part 50 in connection with code 10 of the Subsidiary Arrangements and Facility Attachment. These reports are:

a. Inventory Change Report (ICR). This report is used to report all inventory changes of MBA's including changes of batch identification and those due to blending, adjustment and corrections. The report must be submitted to the government office within 15 days after the end of the month in which the inventory changes occur.

b. Material Balance Report (MBR). This report is used to report the material balance of each MBA for the period between two physical inventory verifications. The report must be prepared for each type of nuclear material for which the facility keeps a separate account and submitted to the government office within 15 days after the completion of the verification.

c. Physical Inventory Listing (PIL). This report shall be attached to each MBR. All accountancy data for each batch of physical inventory must be entered.

d. Concise Note. This note shall be attached to ICR, MBR, and PIL to explain any unusual inventory changes or corrections to their previous reports respectively.

e. Special Report. This report must be prepared whenever any operational losses exceed the allowable limits or any other circumstance which might affect the safeguards concerns.

4. Project Accountability Report. This report is required to be in accordance with the fuel fabrication commercial contract. The report is prepared upon completion of each fuel fabrication project to determine project material balance accounting and to assure operational losses have not exceeded the allowance which is stipulated in the contract.

IV. SAFEGUARDS INSPECTION OF THE FACILITY

The scope and frequency of inspections are stipulated in the Article 68 of the "Law", the Regulatory Order Part 50 and the Facility Attachment of the Safeguards Agreement.

The inspection mode is categorized as monthly flow verification and the physical inventory verification. The frequency of the inventory verification, which was once a year until 1980, is now twice a year due to increase of throughput.

Inspection Schedule is decided by the State Inspectorate taking into consideration the plant operation schedule, which is submitted to the State Inspectorate six months in advance. The IAEA inspection usually takes place concurrently with the State inspection.

A. Flow Verification

The scope of flow verification activities are summarized below:

- Examination of records on verification for self-consistency and consistency with the reports which were previously submitted to the safeguards authorities. This includes source data examination.
- Item identification, counting and measurement.
- Calibration of measurement equipment used for accountability.
- Verification of the quality of the facility's measurements
- Taking representative analytical samples.
- Flow verification of nuclear material at flow KMPs.
- Application, examination, removal and renewal of seals.
- Servicing and review of surveillance equipment.

B. Inventory Verification

Normally, three days of plant shutdown are required for inventory verification activities carried out by the State inspectors and the Agency's inspectors. The detailed facility inventory verification plan shall be submitted to the State Inspectorate, a minimum of 30 days prior to the date of verification and the Stratified List approximately one week prior to the date. It is very important to discuss at this stage the details of the operator's inventory verification and the inspector's verification plan in order to eliminate potential problems that might surface at the time of inventory verification.

This discussion shall cover the availability of operator's man-power to assist inspector's measurements, appropriate location for setting of inspector's measurement equipment, background of gamma rays in the measurement area, the facility's power supply voltage fluctuation which may affect the inspector's instruments, etc. (Refer to Fig. 4.)

The scope of inventory verification activities which are stipulated in the Facility Attachment is as follows:

- Verification of the operator's physical inventory taking for completeness and accuracy.
- Weighing of containers with nuclear material on the basis of a random sampling plan.
- Taking measurement samples.
- Identification and counting of fuel assemblies and the use of NDA techniques.
- Use of in-line NDA systems.
- Application, examination, removal and renewal of seals.
- Servicing and review of surveillance equipment.

The inspector's sampling plan for inventory measurement will be established for two types of measurement methods. One is an instrumental method for quick detection of medium size to gross discrepancies of individual items with a high degree of certainty. The other is a more accurate measurement capable of detecting small discrepancies. These two methods are referred to as the attribute method and the variable method, respectively. For reference purposes the actual number of samples taken at the 1983 physical inventory at JNF facility is shown in Table II.

One physical inventory verification requires about six State inspectors for four days and a 200 man-day manpower commitment by the operator.

V. STAFFING AND RESOURCES

The facility MC&A for safeguards was first implemented in 1978 conforming to the "Law" as amended. Before that time, material accounting and control activities were conducted for process, quality and safety control purposes. Therefore, the major activities newly introduced for implementing the MC&A are mostly associated with the PIV, the routine inspection and compilation of regulatory records and reports of the MC&A in a timely manner.

A. MC&A Organization and Staffing

The manager of nuclear Material Management Section administered by the Director of Quality Assurance Department of the JNF is responsible for implementing the facility MC&A.

The Quality Assurance Department consists of five sections: Engineering, Inspection, Laboratory, Audit and Nuclear Material Management. The number of employees allocated to the Division is about 10% of the total employees at the facility. This Division is responsible for all aspects of plant process and product quality control including the MC&A for Safeguards.

Four staff members have been allocated to the Nuclear Material Management Section as a full-time assignment for engaging in the facility and plant quality assurance activities. Their duties include planning the facility MC&A implementation, collecting and recording relevant data obtained by the other sections in the Department, evaluating these data for safeguards viewpoints, preparing regulatory reports of MC&A, necessary administrative arrangement for inspection etc. Besides routine activities mentioned above, about two man-days of operator time is used for making administrative arrangements and escorting the State and IAEA inspectors who enter the plant for monthly inspections.

About 200 man-days of operator manpower are necessary to conduct each PIV. Most staff members of the Quality Assurance Division are involved actively in the PIV when it occurs.

TABLE II An Example of PIV Sample Size at Each Strata

MBA	KMP	Strata	Inventory in Kg of U	No. of Item	Verification Sample		
					Weight	NDA	Sample Taking
JM1A	A	Feed Green Powder	60,000	2,700 Cans	20	75	20
JM2A	B	Feed Green Powder	70,000	3,500 Cans	30	70	30
JM2A	C	Recoverable Scrap	23,000	1,800 Cans	9	18	9
JM2A	D	Green Pellet	1,800	309 boats	9	9	6
JM2A	E	Sintered Pellet	40,000	6,800 Trays	50	50	20
JM2A	F	Lab. Sample	150	-	-	-	-
JM3A	G	Fuel Rod	54,000	20,000 rods	-	56	-
JM3A	H	Fuel Bundle	160,000	915 bundles	-	-	-

B. Resources

The resources needed at the facility level for implementing the MC&A are categorized into two parts; initial investments and operating cost.

1. Initial Investment. Since most of the equipment and devices utilized by the MC&A system have been built for process and quality control purposes, there is only a small amount of other equipment exclusively devoted to safeguards. Examples are a solid waste drum monitoring equipment and computer software for compiling the MC&A records and reports. The total expenditure used for them is estimated to be about ¥20,000,000 (1US\$=¥250).

2. Operating Cost. Routine operating costs are given in terms of man-years of effort, since the cost of salaries, fringe benefits and other relevant administrative cost can vary over wide range. The commitment allocated for the MC&A at the JNF is four man-years of qualified staff members.

3. PIV Cost. The estimated cost burden to the operator involved in a PIV that requires plant shut-down can vary over wide range depending on assumptions used. One example indicates the cost burden to the operator is approximately ¥70,000,000, when the loss associated with plant shut-down is taken into account.

In any case, the PIV requires considerable cost burden to the operator.

4. Total Safeguards Cost. Estimation of the total safeguards cost burden of operator is also a difficult problem, but on an average, about 0.2% of the fuel bundle cost seems to be a reasonable estimation obtained from our experiences.

VI. PROBLEMS ENCOUNTERED AND LESSONS LEARNED

Specific technical lessons learned in implementing the SSAC for the LEU fuel fabrication facility in Japan are discussed in this section.

A. Technical issues

1. Operator MC&A for Medium Size LEU Fuel Fabrication Facility. The JNF facility MC&A satisfies the current regulatory requirements in both national and international safeguards, conforming to the IAEA Agreement and other Bilateral Agreements. This is partly due to quality control and safety control requirements other than the safeguards requirement in Japan which are, in many cases, more strict than the MC&A requirements.

However, it should be noted that this is a conclusion for a medium scale fabrication facility like the JNF facility. In the future, as required by increased plant throughput, the MC&A system needs to be improved or modified by introduction of new measurement techniques, use of computerized material control system, etc., focusing on maintenance of safeguards effectiveness while optimizing the use of limited safeguards resources.

2. Itemized fuel in a Bulk handling Facility. Whereas the fuel fabrication facility is categorized as a bulk handling facility, many itemized fuel materials are located inside the facility: for example, feed green powder, fuel rods, fuel bundles, etc. As shown in Table II, in June 1983, there were about 35,000 items in the facility. Therefore, we should not forget that considerable effort is necessary for itemized fuel MC&A in the fuel fabrication facility, and improved verification methods for itemized fuel at the fuel fabrication facility are still needed.

3. Utilization of the Operator's Equipment/Devices. In order to minimize intrusiveness to the operator and effective use of limited resources, it is important to explore a concept to utilize operator's equipment and devices for inspection. For effective implementation of safeguards in the future, this will be increasingly important because automation is the current trend of modern plants. On many occasions, the inspector will have difficulty accessing all nuclear material in the plants. One typical example can be seen at a fully automated green powder bucket warehouse in which there is no space for the inspector to gain access to inspect green powder buckets visually.

4. Relation between Safeguards Inspection and Safety Inspection. Whereas the Japanese public is accepting nuclear power as one of the major national energy sources, the public is particularly sensitive to assurances of the safety of nuclear plants, due to the unfortunate experience of once suffering from a nuclear explosion.

Considering this particular public feeling, to some extent emotional, the Japanese safety licensing authority applies very strict inspection criteria for inspecting fuel rods and bundles.

As a consequence, the facility operator is reluctant to accept any procedures that might damage fuel pins or bundles, even if its possibility is very slight and expected damages are very minor, such as a slight scratch.

Although safeguards are of vital importance, long tradition and practice in safety regulation are not easily altered. We are trying to harmonize safety and safeguards inspection practices, but it takes a time.

5. Comments on Future Large Fabrication Facility. In order to implement effective safeguards for future large scale fuel fabrication facilities, consensus on facility MC&A design criteria is needed prior to design and construction of the plant. The criteria should include, inter alia, the following considerations:

- Trends of international policy against nuclear proliferation and the associated safeguards requirements,
- Allowable allocation of resources for operator, state and IAEA,
- Harmonization among safeguards, safety and operator's production control requirements.
- Policy on utilization of operator's equipment/devices for inspection.

B. Effective, Reliable, Non-Intrusive Safeguards and Training

In my lecture at the SSAC training course last year, I illustrated a problem in safeguards by using an interpretation of the rock garden in Kyoto Japan which formerly provided the Zen meditator with a place for meditation. To carry this thought one step further, I would like to try to interpret the state of Zen meditation a bit more scientifically in order to illustrate effective, reliable and nonintrusive safeguards and training. Let me first describe brain waves in very general terms. Since brain waves are being emitted from the brains of all of us, I hope what I am going to discuss will be of interest to you.

Brain waves are fluctuations of electrical potential in the brain, as shown in Fig. 5. These can be measured by the electroencephalograph or "EEG". Phenomenologically, brain waves are classified into four different types: delta, theta, alpha, and beta waves. Delta waves, characterized by an amplitude of about 100 microvolts with a frequency of 0.3 to 4 Hertz, appear in deep sleep. Theta waves, characterized by an amplitude of about 70 microvolts with a frequency of 4 to 8 Hertz, appear in moderate sleep. Beta waves, characterized by an amplitude of about 30 microvolts with a frequency higher than 13 Hertz, appear during ordinary mental activity. Alpha waves, characterized by an amplitude of about 50 microvolts with a frequency of 8 to 13 Hertz appear to be related to an altered state of consciousness, or sleeping-wakefulness continuum.

It is interesting to note that steady alpha waves appear when people are sitting calmly with their eyes closed, and disappear when the eyes are opened. Many scientists have investigated the behavior of alpha waves in connection with human intellectual activity, emotional tension, and anxiety. For many years, psychological and neurophysiological studies on altered states of consciousness have focussed on understanding the relation between brain mechanisms and consciousness in general.

The practice of Zen meditation is said to emancipate man from the dualistic bondage of subjectivity and objectivity of mind and body. Recent advances in electronics now make it possible to investigate the state of meditation in a more scientific way. Using brain wave analysis, Drs. T. Hirai, N. Takemura, S. Tazawa et al. at Tokyo University have been investigating mental and physical states that occur during Zen meditation.

Now, I would like to discuss some pictures of brain wave topographs obtained by Dr. T. Hirai et al. Figure 6 shows electrodes for measuring brain waves attached to the head of a priest engaging in Zen meditation. Figure 7 (A) shows a typical brain wave topograph of an ordinary person engaging in ordinary mental activity. Figure 7 (B) shows a topograph of a well trained meditator engaging in meditation with his eyes open. Figure 7 (C) shows a topograph of an ordinary person sitting calmly with his eyes closed. These topographs in Fig. 7 have been slightly simplified by the investigators to illustrate clearly the main results and significance of their complex measurements.

The very interesting findings obtained by Dr. Hirai et al. using measured brain wave analysis of Zen meditation are as follows:

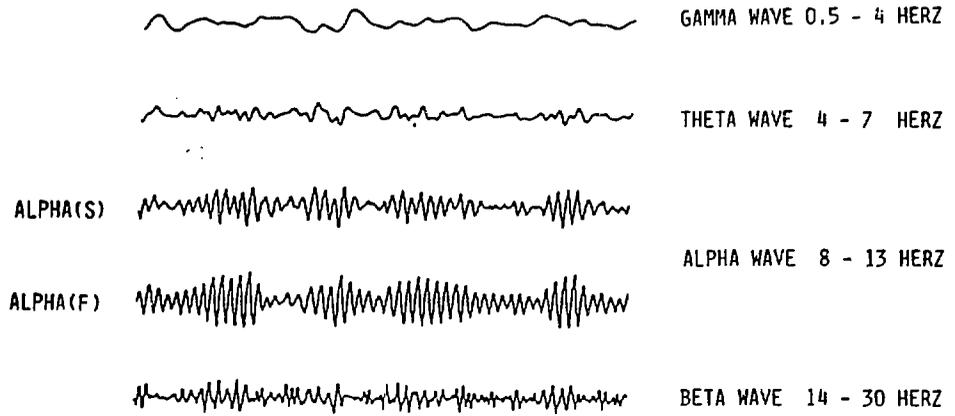


Fig. 5. Brain Wave Characteristics



Fig. 6. Electrodes attached to head of meditator for brain wave measurements.

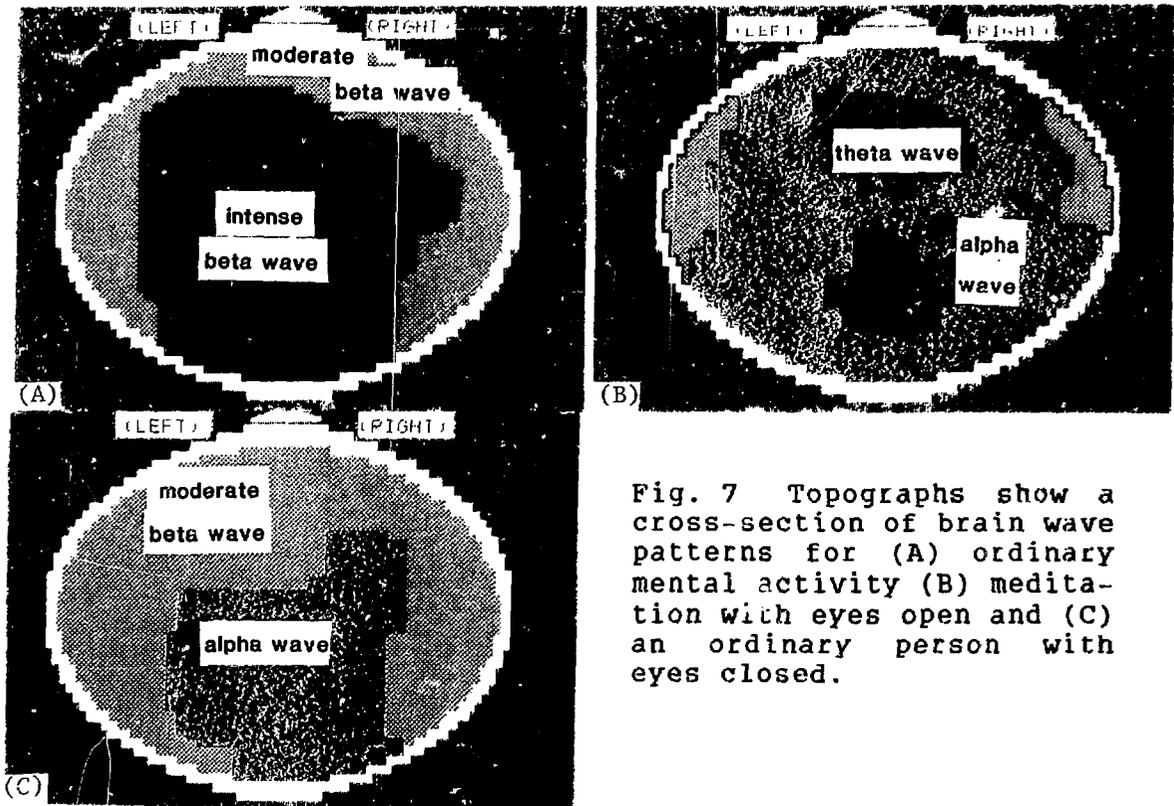


Fig. 7 Topographs show a cross-section of brain wave patterns for (A) ordinary mental activity (B) meditation with eyes open and (C) an ordinary person with eyes closed.

- A well trained meditator has his eyes open and is concentrating his attention inward. Although his eyes are open, the alpha and theta waves are conspicuous. This result had not been expected, because alpha waves are not observed from the brain of an ordinary person whose eyes are open.
- Although brain waves emitted during Zen meditation are similar to the brain waves of ordinary people asleep, an audio stimulus experiment performed in connection with brain wave analysis (Fig. 8) proved that Zen meditation is not merely a state of sleep. During Zen meditation the well trained meditator is relaxed as when sleeping but ready to accept and to respond positively to any stimulus that may reach him. This means that the alpha and theta parts of the brain in Fig. 7 (B) change to intense beta immediately after stimulus. This response will not be seen in ordinary people asleep.
- The behavior of alpha waves emitted by the brain of a well trained meditator engaging in Zen meditation is different from the behavior of the alpha wave emitted by a person who is sitting with his eyes closed. As shown in Fig. 8, although an ordinary person with his eyes closed becomes so accustomed to the periodic clicking

sound that he gradually fails to react to it, a Zen meditator reacts unfailingly to each click, no matter how many times it is repeated.

All of these findings show that the particular state of a person engaging in Zen meditation is characterized as follows:

- The state is similar to sleep; which is analogous to being non-intrusive to another person,
- but the state is different from usual sleep; the subject has his eyes open and is ready to accept and to respond positively to stimuli; this is analogous to a high degree of effectiveness,
- the subject responds reliably to each stimulus without any accustomed trends no matter how many times it is repeated; this is analogous to a high degree of reliability.

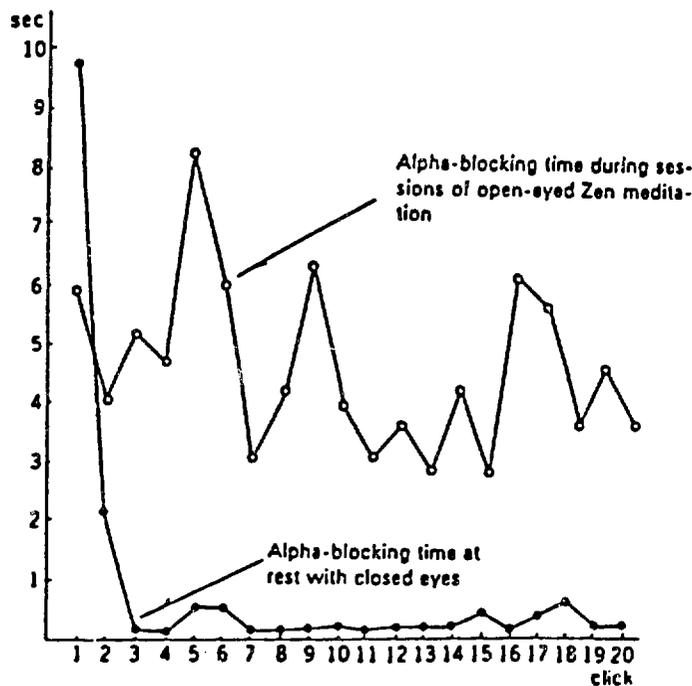


Fig. 8. Response to Click Stimulus (the alpha wave blocking time) for an ordinary person at rest with closed eyes and a well-trained meditator at meditation with open eyes. (Dr. T. Hirai: Zen and Mind, 1978)

These characteristics are all very important factors for the effective implementation of safeguards.

Although the safeguards issue is related to the safety issue, there is a substantial difference between the underlying nature of these two issues. Safety hazards are due to unknown phenomena, mechanical problems, or human errors; but safeguards hazards are always accompanied by intentional human behavior. In this context, although technology is an important element of safeguards, we should not overlook the correlation between technology and human nature for effective implementation of safeguards. Sometimes, the study of human nature provides valuable insight and intuition for solving difficult technical issues in the safeguards field. Brain wave analysis is now being used for diagnostics of brain diseases and for therapy of neuropsychological diseases, as well as for "brain washing". Current brain science is remarkable. Brain waves can tell whether or not you are falling in love, but please do not worry -- it is still impossible to tell whom you are loving.

Safeguards, for the purpose of nuclear non-proliferation, involves so many complicated factors (philosophical, political, technical and economic) that its implementation is still far from being fully solved. I am convinced that a solution of this difficult problem can be found. I have just shown an example that three essential factors (effectiveness, reliability and non-intrusiveness) which are considered to be difficult to satisfy at the same time, do (in fact) exist in the state of Zen meditation. But, it should be stressed that this state of meditation can be accomplished only through intensive training in order to concentrate one's attention inward.

Using this analogy and interpretation, I would like to close my lecture by emphasizing that the training of persons who are engaged in planning and implementing safeguards is of vital importance if we are to accomplish our common goal of effective safeguards in all types of nuclear facilities.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 9: TYPICAL IAEA OPERATIONS AT A
FUEL FABRICATION PLANT

After the session, participants will be able to:

1. describe the basic features of the LEU fuel fabrication plants under safeguards,
2. describe the specific features of interest to inspectors regarding safeguards,
3. describe the most plausible scenarios of how diversion might occur,
4. explain detection strategies to detect diversion,
5. identify real and potential inspection problems that inspectors are likely to encounter, and
6. describe typical inspection activities for this type facility.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 9: TYPICAL IAEA OPERATIONS AT A
FUEL FABRICATION PLANT

Samir Morsy
International Atomic Energy Agency

I. INTRODUCTION

In this session the IAEA operations performed at a typical Fuel Fabrication Plant will be explained. To make the analysis less general the case of Low Enriched Uranium (LEU) Fuel Fabrication Plants will be considered. Many of the conclusions drawn from this analysis could be extended to other types of fabrication plants. The safeguards objectives and goals at LEU Fuel Fabrication Plants will be defined followed by a brief description of the fabrication process. The basic philosophy behind nuclear material stratification and the concept of Material Balance Areas (MBA's) and Key Measurement Points (KMP's) will be explained. The Agency operations and verification methods used during physical inventory verifications will be displayed.

II. SAFEGUARDS OBJECTIVES AND GOALS AT LEU FUEL FABRICATION PLANTS

In general terms the primary objectives of safeguards are outlined in paragraph 28 of INFCIRC/153 as "Timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons and deterrence of such diversion by the risk of early detection".

For the specific case of LEU fuel fabrication plants the significant quantity was set as 75 kg U-235. Because the nuclear material involved in such plants is not directly convertible to metallic components for an explosive device, the detection time of a significant quantity has been set at one year.

The Agency's goals also in general terms are specified in paragraph 30, "The technical conclusion of the Agency's verification activities shall be a statement, in respect of each material unaccounted for over a specified period giving the limits of accuracy of the amounts stated."

The object of this lecture is to explain how to achieve the above mentioned goals based on the Agency's practical experience in safeguarding this kind of bulk facility.

III. PROCESS-OVERVIEW

A simple block diagram of the basic process is shown on Figure 1. It consists of converting UF_6 to UO_2 powder, pressing the powder in UO_2 pellets and sintering the pellets, loading the pellets into cladding tubes to form fuel rods, and inspecting the rods and combining them into fuel assemblies. There is a scrap recovery plant for purifying and converting scrap to UO_2 for recycle back to the pellet pressing operation. Solid and liquid wastes are processed and prepared for shipment offsite. Samples are analyzed in the analytical laboratory and archive samples are kept as references.

IV. STRATIFICATION OF NUCLEAR MATERIALS

Based on the above explained process one way of stratifying the nuclear material in LEU conversion and fuel fabrication plants appears in Table 1. The two strata with asteriks may require further break down. For example the in-process inventory at the fabrication plant can be considered as the sum of the following strata:

1. UO_2 Powder
2. Green Pellets
3. Sintered Pellets

Quite often burnable poison material (e.g., Gadolinium) is added to the LWR fuel. In this case a new stratum with different chemical and physical properties (UO_2 , Gd_2O_3) should be considered. When more than one enrichment is involved the stratification should also take this into account.

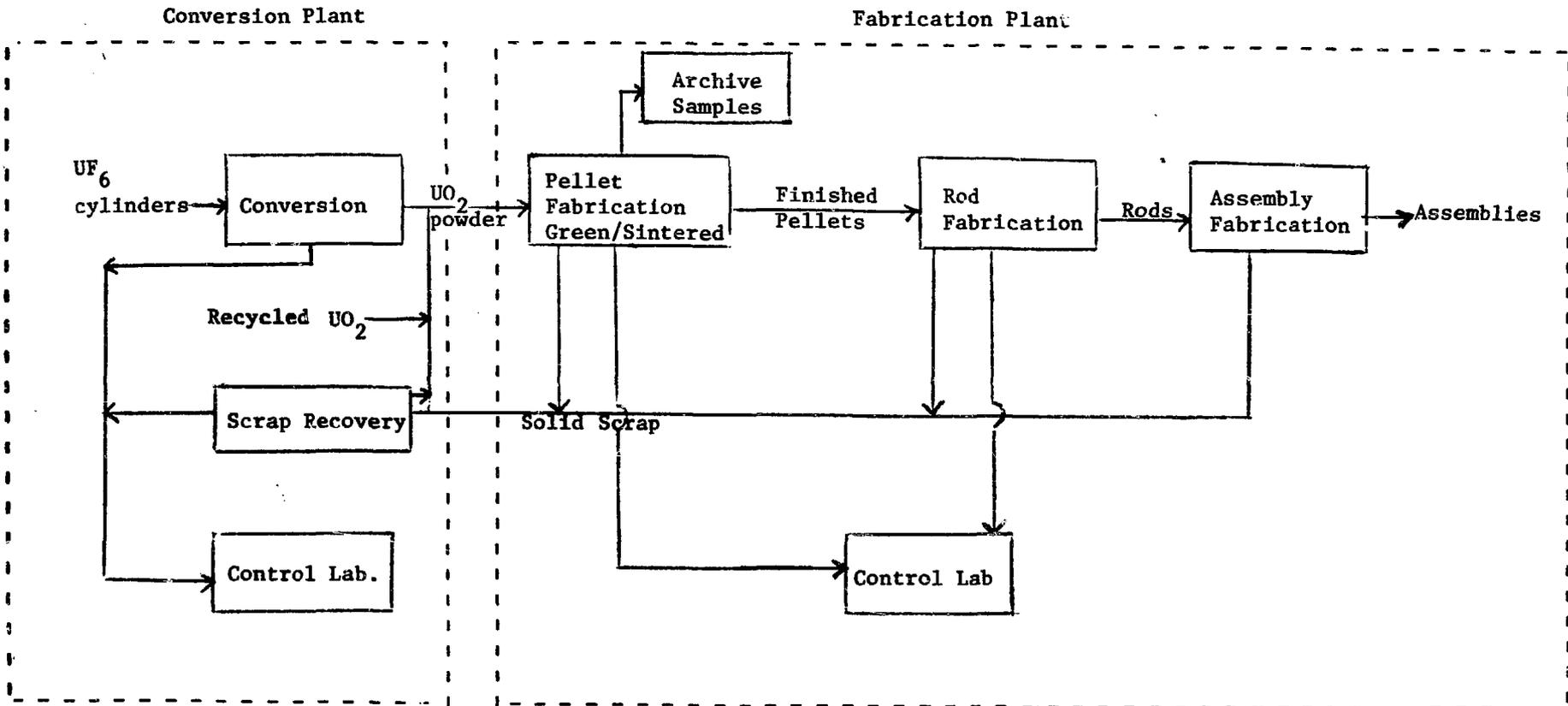


Figure 1. Process Overview

TABLE I STRATIFICATION OF NUCLEAR MATERIAL AT LEU
FUEL CONVERSION AND FABRICATION PLANTS

I) CONVERSION PLANT

- 1) UF₆ Cylinders
- 2) In-Process *
- 3) Control Lab.

II) FABRICATION PLANT

- 1) UO₂ Powder
- 2) In-Process *
- 3) Finished Pellets
- 4) Rods
- 5) Bundles
- 6) Solid Scrap
- 7) Archive Samples
- 8) Control Lab.

V. MATERIAL BALANCE AREAS (MBA's) AND KEY MEASUREMENT POINTS (KMP's)

After nuclear material stratification and to make the task of nuclear material accountancy more manageable the facility is divided into areas - so called material balance areas - where the quantity of nuclear material in all inputs, outputs and the inventory can be determined. The boundaries of MBA's are chosen whenever possible to facilitate the measurement of all nuclear material transfer relevant to Safeguards and help ensure the completeness of flow measurements. Coupled with the concept of MBA's are the Key Measurement Points (KMP's) which are the locations where nuclear material appears in such a form that it may be measured to determine material flow (inputs, outputs, measured discards) or inventory.

VI. VERIFICATION METHODS

In order to achieve the Agency's goals (MUF, σ MUF) a careful consideration should be given to the verification methods. In fact the verification methods are the corner stone for all the safeguards activities in these bulk facilities, since:

1. The measurement errors associated with these verification activities contributes directly towards the principle parameter σ MUF;
2. the acceptance or rejection of a certain stratum on site which was subject to attribute verification is based on the 4σ criterion (σ is the systematic and random components of the measurement errors of the verification technique used).

It is also important to mention that the stratification of nuclear material should be performed keeping the verification methods under consideration.

Table 2 shows the verification methods that are used in LEU fuel fabrication plants.

VII. DIVERSION ROUTES

a. Diversion Possibilities

In a low enriched fuel fabrication plant few special precautions are required for the handling of material. The possibility exists therefore at all times and at all stages for material to be diverted simply by direct removal from storage or process.

b. Concealment Possibilities

Since containment and surveillance measures are impractical to detect diversion, reliance must be placed on materials accountancy. The inspector's strategy must be to carefully compare the operator's claims for the amount of material received, shipped, stored or lost with his own observations. The operator's strategy could be either to

TABLE I VERIFICATION METHODS

Strata	Identifi- cation	Weighing	NDA	Sampling & Analysis
<u>CONVERSION PLANT</u>				
1. UF ₆ Cylinders	Yes	Yes	Yes	No
2. In-Process	*	*	No	Yes
3. Control Lab.	Yes	Yes	No	Yes
<u>FABRICATION PLANT</u>				
1. UO ₂ Powder	Yes	Yes	Yes	Yes
2. In-Process	Yes	Yes	Yes	Yes
3. Finished Pellets	Yes	Yes	Yes	Yes
4. Rods	Yes	Yes	Yes	No
5. Assemblies	Yes	No	Yes	No
6. Solid Scrap	Yes	Yes	Yes	Yes
7. Archive Samples	Yes	Yes	Yes	Yes
8. Control Lab.	Yes	Yes	Yes	Yes

rely on the failure of the inspector to detect discrepancies between records and inventories or to conceal the diversion by falsification of records. The scope for concealment can be analysed for each term of the material balance equation as follows:

- i) Receipts of UF₆
 - Understating the shippers data in the records
- ii) Shipments of fuel assemblies
 - Invention of shipment by producing false shipping documents
 - Overstating U content in records
 - Falsifying process measurements
 - Removal of declared material from the rods
- iii) Inventory
 - Recording non-existing items.

The safeguards approach should therefore involve the following principal components:

- Audit of records
- Check of the operator's measurement system (scales or chemical analysis)
- Verification of the inventory
- Follow-up of the material under safeguards in the new MBA.

VIII. PHYSICAL INVENTORY VERIFICATION

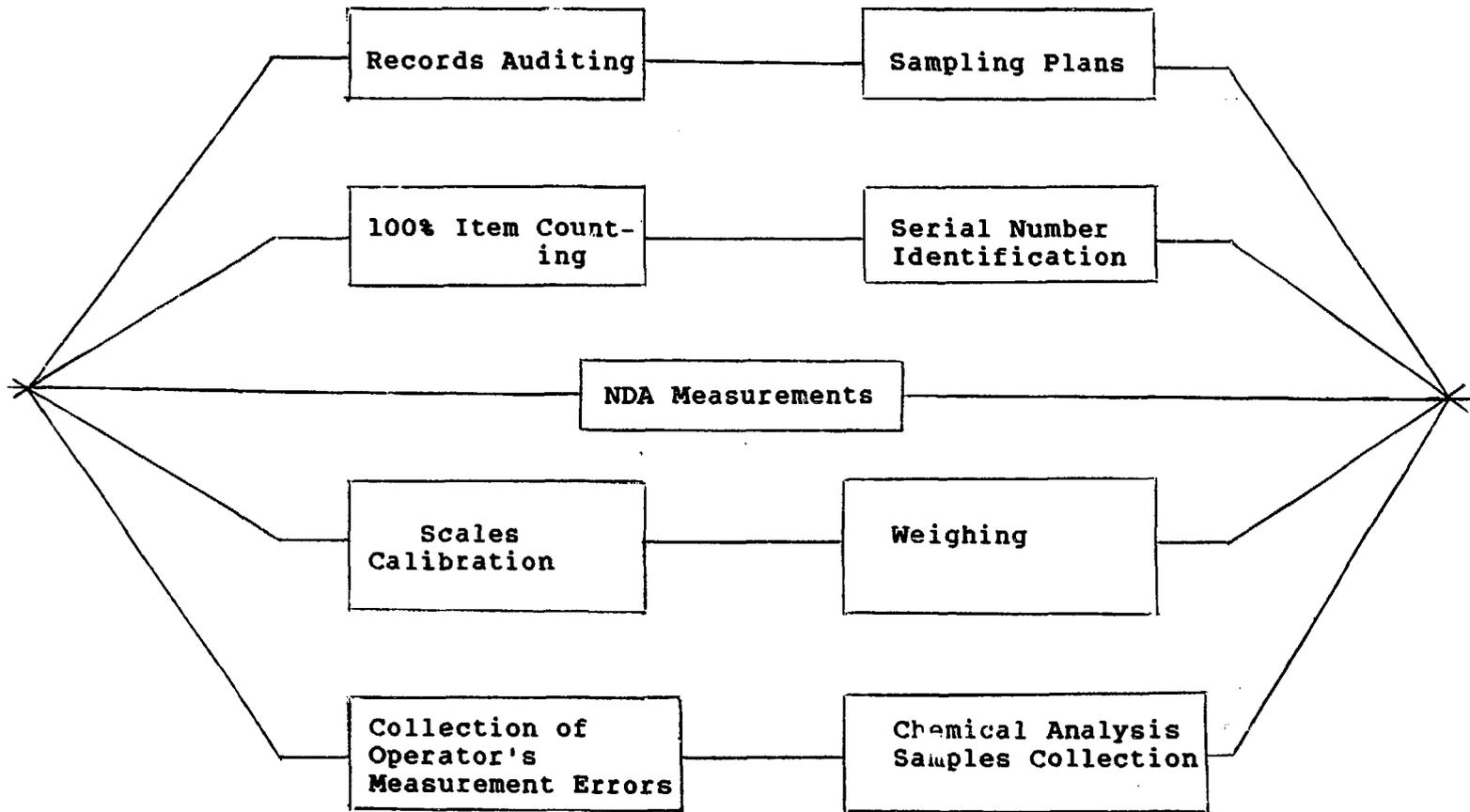
In this section the activities associated with physical inventory verification of a LEU fuel fabrication plant will be discussed.

a. Pre-inspection activities

For a bulk facility which has been under safeguards for some time, the nuclear material is already stratified and the verification techniques for attribute and variable verification are specified. Usually there is little to be done in connection with these activities. However, there is always room for improvements and developments but this is a rather long term activity that is not directly related to the routine of pre-inspection activities. However, a complete understanding of the philosophy behind stratification of nuclear material and its methods of verification is necessary.

The most important activities before Physical Inventory Verification are the calculations of sample size for attribute and variable verification, which are based on previous experience forecast for the material balance during a certain period, with breakdowns of the beginning, ending inventories and the changes occurred and performed. These, together with the measurement errors standard deviations of the inspector and operator, are introduced to the existing computer codes at the Agency to produce an estimate of the sample size. This planning information proved to be of great help in the field. A hybrid combination of the planning information based on sophisticated computerial approach, the field experience and some simple calculation in the field will be very effective indeed.

Fig. 2. INSPECTION ACTIVITIES



b. Inspection Activities and Manpower Allocation

Figure 2 shows a block diagram of the different inspection activities, mainly:

- 1) Records auditing
- 2) Sampling plans
- 3) 100% item counting
- 4) Serial number identification
- 5) NDA measurements
- 6) Scales calibration
- 7) Weighing
- 8) Chemical analysis samples collection
- 9) Collection of operator's measurement errors

These interrelated activities are to be performed during a specified length of time. A Coordinator Inspector will insure the integrity of the whole inspection activities. The following is a typical distribution of the activities involved:

- i) Coordinator Inspector: Integrity of the whole inspection plus sampling plans plus Record Auditing plus collection of Operator's measurement errors;
- ii) Inspector 1: 100% item counting, serial number identification;
- iii) Inspector 2: NDA Measurements;
- iv) Inspector 3: Scales calibration plus weighing plus samples collection.

These activities are conducted in parallel and the coordinator inspector will ensure a proper timing for the occurrences of these events.

Figure 3 shows a schematic self-explanatory block diagram of the way the operator's records, accounting records and state reports are connected to the IAEA chain.

c. Post-Inspection Activities

With data based on the actual sample size chosen during the inventory verification together with the associated standard deviation of the measurement methods of the inspector and operator an estimate of σ_{MUF} could be obtained.

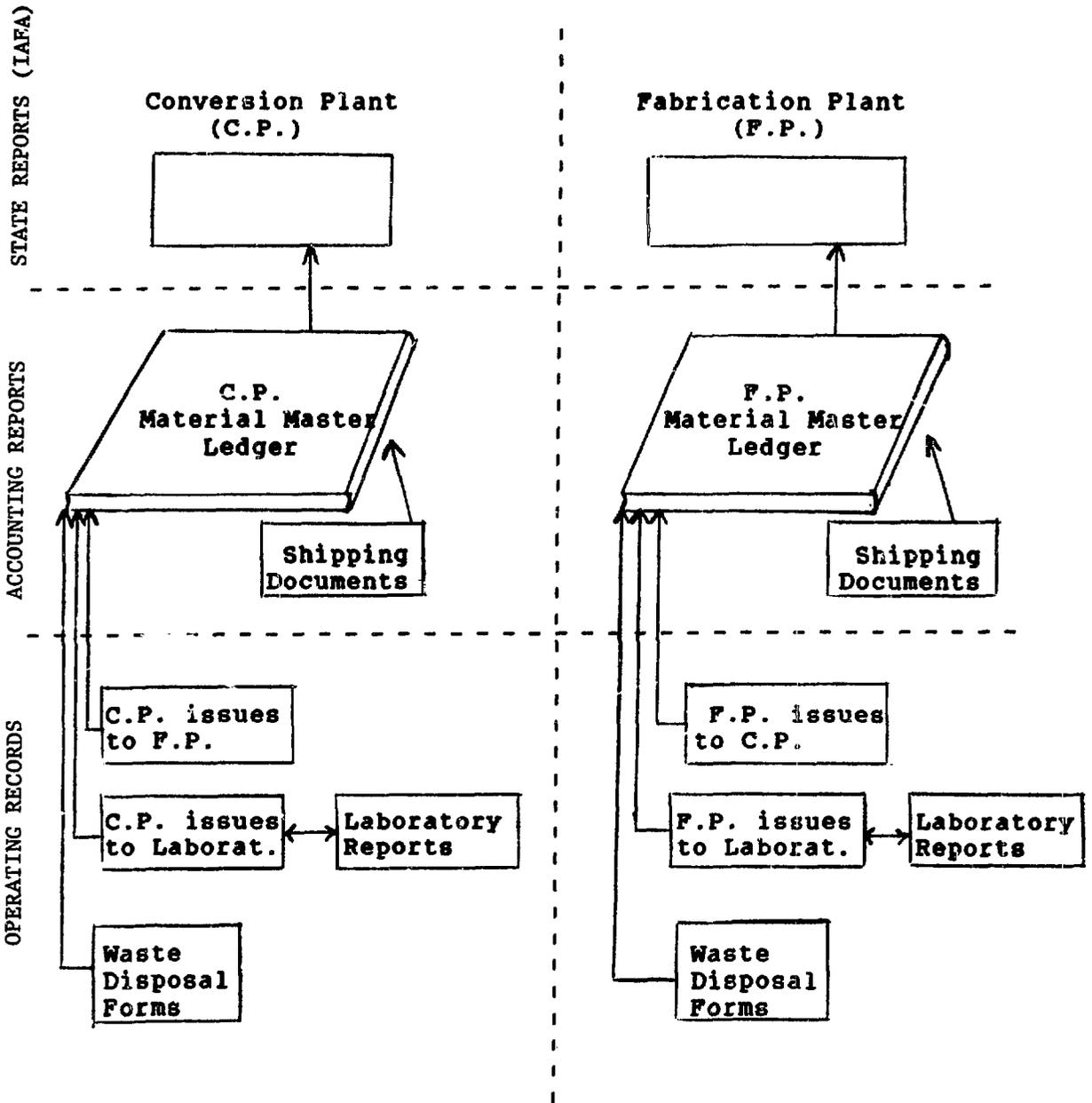


Figure 3. Inspection Activities: Records Auditing



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 10: PHYSICAL PROTECTION IN RELATION
TO IAEA SAFEGUARDS

Overview

This session reviews the general structure of the safeguards system, the SSAC interfaces, and physical protection principles, equipment, and techniques. In addition, the interactions between the State, the facility operator, and the IAEA are described.

After the session, participants will:

1. understand the relationship of physical protection to the IAEA safeguards measures of material accounting and containment and surveillance.
2. understand the responsibilities of the State, the facility operator, and the IAEA, in the application of these measures, and
3. understand the basic physical protection principles, equipment, and techniques.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 10: PHYSICAL PROTECTION
IN RELATION TO IAEA SAFEGUARDS

Cecil S. Sonnier
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Sandia National Laboratories

I. INTRODUCTION

State Systems of Accounting for and Control of Nuclear Material (SSAC) are a fundamental part of the State's and the IAEA's safeguards systems. This session describes how the part of the safeguards system that is operated directly by the IAEA in carrying out its verification activities, including field inspections, relates to the systems operated by the individual States. In particular, the physical protection function in the State system and the related equipment and techniques will be discussed. The differences between Containment and Surveillance (C/S), which is an integral part of the IAEA operational system, and physical protection, which is not, will be described.

II. GENERAL STRUCTURE OF THE SYSTEM

What is loosely referred to as "IAEA safeguards" is based on the IAEA statute and later documents that define the system in more explicit terms. The statute provides that safeguards shall be established and administered so as to ensure, insofar as the Agency is able, that peaceful nuclear activities do not contribute to any military purpose. The states have direct responsibility for dealing with the possibility that para-military or guerilla groups or terrorist organizations might divert safeguarded resources for weapon use.

A distinction must be made between the overall system of safeguards and the component parts that are operated respectively by the IAEA and by the State. It is apparent that some of the concerns are actions by groups that are subject to the police and internal-security authority of the state; other concerns relate to the State itself. The system therefore operates on two levels:

1. The State ensures physical protection and regulates the handling, control, and accounting of nuclear materials.
2. The IAEA promotes high standards of physical protection and material accounting, and independently verifies the material accounting data provided under State direction.

Physical protection is a matter that involves the State's internal security, and hence an area where the State's sovereign authority is most carefully recognized and maintained. For that reason, the Agency's role in physical protection is limited to the promotion of guidelines and high standards, and the provision, upon request from the State, of training and advisory assistance.

III. SSAC INTERFACES

The State System of Accounting for and Control of nuclear material (SSAC) consists of organizational arrangements on the national level to ensure the achievement of safeguards objectives, inter alia:

An international objective, to provide the basis essential for the application of IAEA safeguards pursuant to the provisions of a safeguards agreement between the State and the IAEA.

A national objective, to contribute to the deterrence, prevention and detection of theft or unauthorized use of nuclear material by individuals or subnational groups.

The international component of an SSAC consists of three principal elements: a legal framework within which the State exercises its control, and organizational and functional infrastructures at State and facility operator levels. The SSAC reports accounting data to the IAEA, and its findings are subject to independent verification by the IAEA.

The two principal national functions of the SSAC are nuclear material accounting and control, and physical protection.

IV. NUCLEAR MATERIAL ACCOUNTING AND CONTROL

The objective of nuclear material accounting and control is to maintain current information on types, quantities, and locations of material. Essential elements of nuclear material accounting are material measurements, record keeping, preparation and submission of accounting reports, and verification and analysis of these accounting data to determine correctness, accuracy of MUF, and evaluation of causes of MUF.

In the area of nuclear material accountancy, the State specifies the accountancy requirements, which are implemented by the facility operator. The accounting data are provided to the State for evaluation.

In nuclear material accounting there is a direct involvement of the IAEA. IAEA safeguards approaches are based on nuclear material accounting as a measure of fundamental importance, with containment and surveillance as important complementary measures.

Nuclear material accounting within the framework of IAEA safeguards begins with the material accounting activities which are undertaken by or on behalf of facility operators in response to requirements set by the SSAC, arising from agreements between

the IAEA and the State. These activities and the corresponding accounting information generated are verified through independent IAEA verification and inspection. These efforts, after evaluation, provide one of the means of detecting diversion and of deterring diversion by the risk of early detection. They also provide the basis for statements regarding assurance that no diversion has occurred.

Nuclear material control within the framework of the State system is a set of measures for assigning responsibilities and maintaining awareness of the status and location of nuclear material.

V. CONTAINMENT AND SURVEILLANCE

Containment and Surveillance (C/S) provides the IAEA with information on movements of nuclear material and on the integrity of items (e.g., equipment, containers, etc.). C/S equipment includes seals, optical surveillance, and monitors. Those devices, supplied by the IAEA, are operated in an unattended mode for time intervals between IAEA inspections--often for periods of three months. Such unattended use places high importance on tamper resistance and reliability. In some cases C/S measures employed by the IAEA use the same technology as that used in physical protection systems, although the function or purpose is different.

In the use of C/S equipment, there are interactions with the facility operator and possibly the State. In all cases, the facility operator must be assured that the C/S equipment will not affect or impair facility operations and safety. In some cases, the facility operator arranges for the installation of the C/S equipment.

VI. PHYSICAL PROTECTION

Physical protection measures are employed by States and facility operators to prevent sabotage of nuclear facilities and unauthorized removal of nuclear materials. The functions of physical protection systems are to control authorized and unauthorized personnel, restrict access to nuclear material, and provide rapid and comprehensive response measures to locate and recover missing material. The physical protection systems are designed to provide an effective balance between the basic elements of detection, delay and response.

In the United States, the Nuclear Regulatory Commission (NRC) specifies the required physical protection measures to be applied to commercial nuclear facilities. The facility operator installs and operates the physical protection system. The NRC periodically inspects the facilities, insuring that specified physical protection measures are maintained on a continuing basis and that regulations and standards are complied with. The entire system is governed by a set of regulations to which all

facilities must adhere in order to obtain and retain an operating license. In the case of government owned facilities, the Department of Energy (DOE) performs functions similar to the NRC.

In general, then, the flow of physical protection responsibilities is from the State to the facility, commercial or State owned: the State specifies the required physical protection systems, and the facility operator installs and operates the systems, including response actions as required. This general flow of responsibility is typical for most IAEA member States which engage in nuclear activities.

The IAEA has no responsibility for the provision of a State's physical protection system or for the supervision, control, or operation of such a system. However, in order to promote uniformly high standards for the protection of nuclear material, the IAEA provides recommendations in INFCIRC/225 on the requirements for physical protection of nuclear material in use, transit and storage. Also, at the request of the State, the IAEA provides advice to State authorities with respect to their physical protection systems. The specific physical protection measures which are applied to a particular facility are determined by the State. That determination is based on factors specific to the State, including threat perception, economics and political infrastructure.

To further the goal of achieving effective physical protection, the IAEA and the U.S. DOE sponsor a comprehensive international training course on physical protection, which is conducted at Sandia National Laboratories on a regular basis. The attendees, which include personnel from the developing nations, are given comprehensive information on physical protection principles, techniques, and equipment. Workshops are held to provide participants with experience in design of comprehensive physical protection systems for various types of nuclear facilities.

VII. SUMMARY OF SYSTEM INTERACTIONS

The physical protection, material accounting and C/S measures, responsibilities, and interactions that have been discussed are summarized in Figure 1. The principal elements of the SSAC are material accounting and physical protection.

In material accounting, the IAEA provides recommendations and advice to the State on the structure and format of the accounting system. The State specifies, regulates, and inspects the accounting system used by the State or commercial facility operator. The operator implements the system, providing the accounting data to the State. Finally, the State supplies the accounting data to the IAEA for independent verification. This verification is achieved through review of the State supplied data, together with inspections to compare data, perform independent measurements, and to review the complementary

Containment and Surveillance



- Seals
- Optical Surveillance
- Monitors

Complement

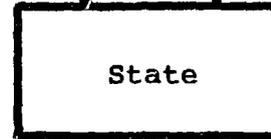
Nuclear Material Accounting



- Recommend
- Advise
- Negotiate Agreements

- Independent Verification Including Inspection

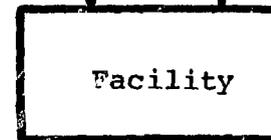
Data Flow



- Review

- Specify
- Regulate
- Inspect

Data Flow



- Install
- Operate

- Records
- Measurements

Complement

Physical Protection

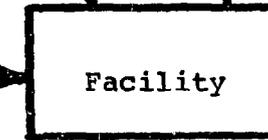


- Recommend
- Advise



- Specify
- Regulate
- Inspect

Report



- Install
- Operate

- Control Personnel
- Restrict Material Access
- Respond

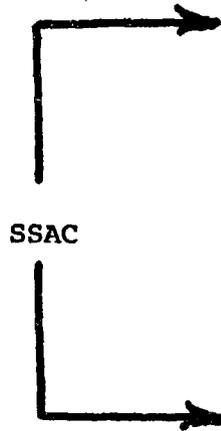


Figure 1. The Safeguards System Structure

information from the C/S equipment. From all of these operations, it can be seen that material accounting involves strong interaction between the IAEA, the State, and the facility operator.

Physical protection presents a different picture. The State and facility operator interactions are essentially the same as for material accounting. In physical protection, however, the State or facility operator has no responsibility to the IAEA. Related data is kept within the State. However, upon request the IAEA will assist the State with physical protection system recommendations and advice.

The main functions of the physical protection system are to detect, delay, and respond. In some cases, data from the physical protection system is used to complement the material accounting system in a manner similar to the C/S measures used by the IAEA.

VIII. PHYSICAL PROTECTION EQUIPMENT AND TECHNIQUES

Physical protection is realized through the use of a variety of equipment and techniques. For approximately ten years, Sandia National Laboratories has had a comprehensive program to develop and test a wide variety of physical protection equipment. Principal equipment and techniques included in that program are:

1. Exterior intrusion detectors - Used to provide an indication of entry into restricted exterior areas. Technologies include microwave, electric field disturbance, active infrared (beam breakers), buried line (seismic, magnetic, balanced pressure, ported co-axial cable), and taut wire.
2. CCTV equipment - Used to provide continuous coverage of interior and exterior areas of safeguards interest, and used to assess the causes of alarms generated from physical protection equipment.
3. Portal monitors - Used to identify personnel and to detect unauthorized movement of shielded and unshielded nuclear material through passage ways of safeguards interest. Technologies include neutron detection, gamma detection, metal detection, and personnel identification (see item 6 below).
4. Interior intrusion detectors - Used to provide an indication of entry into restricted interior areas. Technologies include microwave, passive infrared, sonic, ultrasonic, balanced magnetic, continuity, capacitance, strain, and pressure.
5. Credential verification - Used to verify credentials. Technologies include photograph, tuned-loop, and magnetic code.
6. Personnel identification - Used to identify individuals. Technologies include fingerprint, voice, hand geometry,

- palm print, and signature recognition; and passwords, access codes, and photo matching.
7. Seals - Used to provide a positive indication of entry into a secured area or containers. Technologies include adhesive paper, metallic, fiber optic and electronic.
 8. Electromechanical devices - Used to prevent unauthorized use of facility equipment which is necessary to move or control nuclear material. Technologies include power interruption and valve actuation.
 9. Passive and active barriers - Used to prevent or delay unauthorized entry into facility areas of safeguards interest. Passive barrier technologies include walls, fences, gratings, vaults, locking mechanisms, tiedowns, containers, and hardened doors. Aqueous foam and remotely controlled doors are the principle active barrier technologies. Active barriers are used to obstruct, on command, normal access areas.
 10. Obscurants - Used to prevent or delay unauthorized entry into facility areas of safeguards interest. Smoke and aqueous foam are the principal obscurant technologies.
 11. Guard force - Used to monitor personnel and equipment movement within the facility, and to assess and respond to safeguards alarms. Principal efforts involve equipment development and evaluation, and training.

A comprehensive physical protection system could use many of these types of equipment, with the specific technology being chosen to match the particular use-environment. Such a system must be carefully integrated to provide effective monitoring, alarm assessment, and response initiation. These functions are generally performed with display, control, and communications equipment located in a guard force control center.

IX. SUMMARY

In this session, physical protection, nuclear material accounting and control, and containment and surveillance have been discussed, with emphasis on the interactions of these measures within the context of IAEA safeguards. In addition, the current physical protection equipment and techniques have been reviewed.

The interactions can be summarized as follows:

Physical protection is solely a State/facility operator responsibility. While the IAEA has an interest in promoting the implementation of effective physical protection systems, it serves only in an advisory capacity.

Nuclear material accounting directly involves the State, facility operator, and the IAEA. Facility records and reports provided by the State are independently verified by the IAEA. The SSAC is of fundamental importance in this process.

Containment and surveillance measures are used by the IAEA. Installation and routine use of C/S equipment must be approved by the State and facility operator, and must not affect facility operations or safety.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 11: IAEA SAFEGUARDS INFORMATION SYSTEM

Overview

This session will discuss the basic concepts, structure, and operation of the Agency Safeguards Information System with respect to its role in accomplishing the overall objectives of safeguards.

At the end of this session, the participants shall be able to:

1. understand the basis and purposes of the Agency's information system,
2. understand the structure and flow of information within the Agency's system,
3. understand the relationship of the components in the Agency system,
4. understand the requirements of Member States in respect of their reporting to the Agency, and
5. understand the relationship of accounting data vis-a-vis facility and inspection data.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 11: THE IAEA SAFEGUARDS
INFORMATION SYSTEM

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International Atomic Energy Agency

I. INTRODUCTION

The International Atomic Energy Agency headquartered in Vienna, Austria, has the unique responsibility and authority for obtaining information on all nuclear and other materials subject to safeguards under the terms of the general types of agreements. Four basic documents pertinent to the Agency in general and to safeguards information in particular are the Statute¹, the Non Proliferation Treaty², INFCIRC/153 corrected³, and INFCIRC/66/Rev.2⁴.

Safeguards information and the treatment thereof is a broad subject. It is confined in this paper to accountancy data as defined in INFCIRC/153 and the specific agreements based on INFCIRC/66/Rev.2, to design information, and to data resulting from the verification activities of the Inspectorate.

The processing and analysis of safeguards information can be explored on a facility level, a state level and an international level. Each information system has different safeguard aims and different methods of achieving them. This paper confines its scope to the international safeguards information system and discusses the other types only for the purposes of contrast with the international system.

II. PURPOSES OF A SAFEGUARDS INFORMATION SYSTEM

Under the terms of the various Safeguards Agreements concluded with Member States, the International Atomic Energy Agency receives Safeguards Information for all nuclear and other materials subject to Safeguards. The Agency's authority to request and obtain such information can be traced back to its Statute Article III.A.5. The Non Proliferation Treaty (NPT) in Article III.1 reinforces this authority and the model agreement INFCIRC/153 between the Agency and Member States which are a party to the NPT provides details and definitions relative to the implementation and application of safeguards. For Member States which are not a party to the NPT, there are approximately 40 individual agreements for applying safeguards to nuclear and other material. The Agency's safeguards system for States reporting under non-NPT agreements is described in

INFCIRC/66/Rev.2. When discussing safeguards information, therefore, the distinction must be made between data submitted in compliance with NPT requirements and all other data.

The Agency is, inter alia, responsible not to disclose safeguards information which may contain proprietary data on inventories and flows of nuclear materials. This obligation is of particular importance for the development and operation of a computerized system. Particular types of data security measures, which have been implemented at the Agency include:

- administrative measures as contained in the safeguards manual;
- computer hardware measures, i.e. a restricted access remote entry station for exclusive use by safeguards personnel, and
- software measures such as issuing protection passwords and cyphering of computer files.

Safeguards information can mean many different things. Inspection plans, operating records, accounting reports, design information, man days of inspection effort, etc., all provide information relevant to safeguards. For the purpose of this paper, the expression "Safeguards Information" will include accountancy data as defined either in INFCIRC/153 or the individual safeguards agreements, design information, and data resulting from the verification activities of the Inspectorate.

Not only the distinction between NPT and non-NPT type reporting should be kept clear, but also the distinction between a facility information system, a state information system and an international information system should be emphasized. A facility information system is for the purpose of serving the facility. Such a system can be used to control the inventory, manage the nuclear material, analyze material unaccounted for (MUF), provide calculations for calibration of measurement systems, provide cost/benefit analysis, balance shipments and receipts, etc. A facility information system often controls material only because control results from other specific management decisions considering the content of the information system. Facilities cannot afford the luxury of having a nuclear material control system for the sole purpose of answering the needs of a state regulatory agency. The facility system must pay for itself by providing valuable production, accounting and management information to the facility.

A state information system is concerned with inventory control, measurement systems, material management and material unaccounted for (MUF), also, but for the State as a total entity. A state system should follow all shipments until they are received at their proper destination and be able to identify or locate all nuclear material under its jurisdiction within a very short time. A state system should analyze shipper/receiver differences and indicate when resolution at the State level is required. The state system should co-ordinate the safeguards information of all its facilities. It is often a regulatory system assuring that supply and demand of precious nuclear resources are kept in balance among its several facilities. It can be a schedule

determining regional output requirements within the state. Further, the state system has the responsibility to provide proper safeguards information from all of its facilities to the international system in a timely and efficient manner adhering to previously agreed upon parameters as stated in subsidiary arrangements and facility attachments.

An international system is concerned with inventory changes, material balance and MUF for the entire state, and shipments and receipts between states. Activities within a state are of concern only to the extent that they affect the safeguards position of that state regarding inventory and unresolved domestic shipments. An international organization is not a regulatory body nor does it concern itself with efficient or economical use of nuclear resources. It establishes, rather, the requirements for the receipt of timely, complete and consistent safeguards information in order to be able to report abnormalities, failures and/or diversions of nuclear material to the appropriate authorities as provided for in existing agreements. Materials management, health and safety, production rates, cost analysis and all other sources of information not directly related to safeguards are not included in the Agency's information system.

The safeguards aim of each of these three general types of systems is also different. The facility level is concerned primarily with diversion within the facility by a single individual or by several individuals working in collusion. The state level of safeguards normally is concerned with preventing diversion of nuclear material by a single purposed group. An international safeguards information system has its purpose to verify that safeguarded material is not diverted to any non-peaceful purpose. INFCIRC/153 asserts strongly that accountancy is a safeguards measure of fundamental importance. The international system, therefore, concerns itself primarily with inventory, changes to inventory, composition of inventory, shipments in transit between and within states, MUF analyses, compatibility of state's data with design information, inspector's verification results, etc., to determine whether or not nuclear material has been diverted for use in non-peaceful activities.⁵

III. REQUIREMENTS OF MEMBER STATES

One of the most important features of the INFCIRC/153 accounting system is the concept of a Material Balance Area (MBA). An MBA is the basic accounting unit for striking and evaluating material balances. All facilities and other locations under NPT safeguards are structured in such MBAs. INFCIRC/153 requires that the State, in establishing a national system of accounting for and control of nuclear material, shall arrange that records are kept in respect of each material balance area. It further requires that the State shall provide the Agency with certain reports, as described below, based on the records maintained in the national system.⁶

In INFCIRC/153 the reporting system is based on the principle of material balance evaluation combined with double book-keeping system principles. For this purpose a number of concepts and definitions had to be introduced to standardize and structure the flows and inventories of nuclear material. The most important of these are the "batch" concept - to portion the nuclear material -, the material description code concept - to describe the physical and chemical form as well as the package and the use -, and the simplified element categorization of the nuclear material, i.e. three categories of uranium - depleted, natural and enriched - plutonium and thorium.

The reporting of the flows of nuclear material and of material on hand required of Member States for each MBA and in terms of batches are Inventory Change Reports (ICR) and Physical Inventory Listings (PIL). Consolidated transactions and sums of the physical inventory are required in Material Balance Reports (MBR) once a physical inventory has been taken and a material balance has been struck.

ICRs comprise all the necessary information to identify:

- the MBA, country and facility;
- the dates of the transactions;
- the batches;
- the materials, elements, etc.;
- the weights of total element and fissile isotopes;
- correction information, when applicable.

PILs comprise the same data elements as the ICRs except for the transaction type, which is always, by definition, a batch in the inventory.

MBRs comprise consolidated transactions and the ending physical inventory and contain fewer data elements:

- the MBA, country and facility;
- the consolidated transportation;
- the period of the material balance;
- the elements and related total and fissile weights;
- correction information, when applicable.

To any accounting report one or more concise notes may be supplied giving explanations of the data elements, processing instructions or other information the country wants to provide for clarification purposes.

Specific requirements in respect of the format and content of data elements in these three reports are given in Code 10 of the Subsidiary Arrangements. The format of the accounting reports depends on the reporting medium, i.e. hard copy or magnetic tape, on which the reports are provided. Presently, about 70% of all reports are provided using magnetic tapes, the rest are provided on standard report forms (Appendix 1).

INFCIRC/153 details the requirements in respect of the timeliness with which these reports should be forwarded to the Agency. In particular, ICRs shall be dispatched as soon as possible and in any event within 30 days after the end of the month in which the inventory changes occurred or were established. An MBR shall be dispatched as soon as possible and in any event within 30 days after the physical inventory has been taken.⁷

Requirements of Member States reporting under INFCIRC/66 are spelled out in the different agreements and therefore large variations exist. In all cases different forms, formats and data elements are provided to the Agency. The only common features are the type of reports, not the content or format. The type of reports are the "Joint Notifications", the "(material) balance reports" and letters. This data cannot be processed fully automatically but requires constant and extensive human processing and interaction. Joint notifications show the confirmations of both the receiving and the shipping state for international transfers of nuclear material. Balance reports show normally only the consolidated receipts, shipments and use of nuclear material.

Design information is required by the Agency under both INFCIRC/153⁸ and INFCIRC/66. The latter requires a design review with the State submitting sufficient information for the Agency to carry out its responsibility regarding Safeguards. The NPT model agreement, in contrast, specifies that design information in respect of each facility shall include its general character, purpose, nominal capacity, geographic location, the form, location and flow of nuclear material, the general layout of important items of equipment which use, produce or process nuclear material, a description of features of the facility relating to material accountancy, containment and surveillance and many more such detailed requirements. Design information is submitted at the time when the facility first comes under Safeguards and is updated as required by operations changes. The purpose of the design information, provided for each facility under safeguards prior to the conclusion of the Facility Attachment, is threefold:

- to allow the structuring of the fuel cycle into MBAs and to define batches, etc.;
- to serve as an "authority file", against which the validity of data is checked during all types of safeguards data processing;
- to serve as a data base for statistical evaluation related to planning, manpower evaluation and other management-oriented tasks.

It should be noted that the Agency must also meet certain requirements with respect to the reports system as outlined in INFCIRC/153.⁹ In particular, the Agency shall provide the State with semi-annual statements of book inventory of nuclear material subject to safeguards, for each material balance area as based on the inventory change reports for the period covered by each such statement. A further requirement which is normally covered in the Subsidiary Arrangements in Code 4.1 is that a statement of material in transit be furnished to the State at the same time as the semi-annual statement of book inventory. Under INFCIRC/66 agreements an annual statement of inventory is required to be furnished for each type of material under each agreement.

IV. THE IAEA SAFEGUARDS INFORMATION SYSTEM - ISIS

An essential part of the overall safeguards activity of the Agency is the collection, processing and evaluation of information about nuclear material flows and inventories and about the facilities where these material are used or stored or from which they originate. This information is received from several sources:

- as discussed above, from States who are parties to safeguards agreements who furnish the Agency facility design information and nuclear materials accounting reports;
- information collected by inspectors in the process of their verification activities which consists of inspection working papers, inspection reports, analytical data, non-destructive assay data, etc.;
- information generated through internal Agency safeguards functions, e.g. data concerning surveillance equipment, seals, etc.

ISIS operates primarily through a Data Base Management System (DBMS) called ADABAS which is commercially developed software. ADABAS provides controlled access to the data, stores the data in a compact manner and enables the data base to be extended, to accommodate new types of data, with only a minimal amount of change to existing software.

All data for the Safeguards Information System is stored in the Safeguards Data Base. It is maintained separately from all other Agency computerized data and can only be accessed by staff members having the required authorization. The Data Base consists of a number of files each pertaining to a particular aspect of the Agency Safeguards System. They can be divided into groups such as:

- Accounting Data files, e.g. Physical Inventory Listing (PIL) file and Material Balance Report (MBR) file;
- Authority and Design Data files, e.g. Country Safeguards Status file, Installation file, MBA file, KMP file;
- Inspection Data files, e.g. Inspection Plan/Summary Data file and Inspection Report and Working Papers files;
- Equipment Data files, e.g. Seals file;
- Management Data files, e.g. Inspection manpower utilization file;
- test files, used for software development and testing;
- control files, e.g. User registration file;
- training files, for NATURAL language training;
- special files set up for individual users, e.g. for System Studies and Safeguards Evaluation Section.

Table 1 shows the growth and size of the data base since 1977. ISIS is divided into several functionally-oriented systems (Fig.1). The ISIS Accounting Data system manages the data from Inventory Change Reports (ICRs), Physical Inventory Listing report (PILs) and Material Balance Reports (MBRs) received from states reporting in NPT format and data from Joint Notifications, balance reports and letters received from

non-NPT states. The system provides for loading and quality controlling the data and for the matching of domestic and foreign transfers. An important feature of this system is the trail which is kept of all corrections received to previously submitted reports.

The ISIS Authority and Design Data System manages the data submitted by the Operations sections on the basis of the Design Information Questionnaires completed by Member States and Attachments to Agreements. The data is used primarily for quality controlling the accounting reports and inspection data and also for preparing management reports concerning installations.

The ISIS Inspection Data System manages the inspection data provided by the Operations sections. This includes inspection plan and summary data and the data from inspection reports.

The ISIS Equipment Data System manages data provided by the Section for Technical Services and the Operational Sections. This presently includes seals data and containment and surveillance data.

The ISIS Management Data System manages data required by management for such areas as inspection manpower utilization and forecasting resources requirements.

Each of these systems contains four sub-systems which accomplish the functions of data entry, data base loading, quality control and production output. Peculiar to the Accounting Data System is a fifth one which accomplishes the confirmations of domestic and international transfers of nuclear material.

The initial ISIS development produced the system for accounting data. As it was developed, data arriving on a variety of carriers is input to temporary holding areas called input buffers. Immediately upon input to these buffers the appropriate records are created which will maintain the life history of that data during its existence in the data base. A major design consideration dictated that no data would be physically purged, but rather that an historical trail would be maintained. The purpose of the holding area is to get the data into the machine as quickly as possible so that it may be operated upon in order to get it to its final form. Thus if data is not in the prescribed standard format, it is converted to this format upon its transfer from the input buffers to the data files, where it will reside for the remainder of its logical existence in the data base. If for any reason data is unidentifiable, it is placed in a special file where it will be investigated by a system analyst for corrective action to be taken and then re-input to the system. Periodically, the holding area is archived on magnetic tape. After the loading process, it should be noted that the data is available for use. In this sense all data received is "usable". Subsequently, in the Quality Control process the data is subjected to certain checks, the results of which are stored with the data to indicate the "level of usability" of the data. In order to ensure the adaptability of the system to

future needs, all data fields are variable. That is to say, no inherent system limitations are built-in.¹⁰ Figure 2 gives an overview of the functional processing of ISIS.

V. INFORMATION FLOW AND PROCESSING

Figure 3 shows the sources and types of information and a general overview of its flow. Based on reports from the facility operator to the State system for the accountancy and control of nuclear material, the State furnishes the Agency with reports (ICR, PIL, MBR) as previously described. During inspections, Agency inspectors gather data which is recorded in working papers. In addition, samples are taken which are then sent for analysis. All data is then evaluated, after which a statement in accordance with the provisions of paragraphs 90(a) and (b) of INFCIRC/153 and Code 4.1 of the Subsidiary Arrangements are provided to the State. The totality of data is evaluated, the results of which are reported to the Board of Governors once a year in the Safeguards Implementation Report. Figure 4 shows in more detail the flow of information within the Agency and the purposes it is used for by units within the Department of Safeguards.

These two presentations give a broad overview and represent the treatment of all data that is received in or collected by the Department of Safeguards. Not all this data is computerized and therefore not treated directly by ISIS. I would like to cover now that portion of the data that is computerized and is subjected to the various processes of ISIS.

Considering first the accounting data that is reported to the Agency, a fundamental principle of the system must be understood. The Agency system of accounting is a retroactive one, i.e., corrections to previously recorded entries in the system are made by what is known as the Virtual Replacement Correction Principle (VRCP).

Under the VRCP, the correcting line logically replaces the corrected line. (As the corrected line is retained in the ISIS data base, it can still be accessed and used for special purposes; however, the default for all calculation will be the most recent correcting line).

Using the VRCP, any information on the corrected line can be modified, except:

- the report number and line entry number;
- the "continuation" status;
- the "concise note" status;
- the "correction to" report number/line entry columns.

Specifically, it is possible to modify the non-quantity (e.g., batch name, material description codes, type of inventory change) as well as the quantity (weights, number of items) data. Thus, unless it is intended to alter the date of an inventory change, the dates on the correcting and the corrected line must be identical. (PIL and MBR dates can only be modified by changing the dates specified in the relevant header records).

If it is necessary to correct a correcting line entry, the new correcting line must refer to the previous correction line, not to the original nor any other previous correction line. The new correcting line then logically (virtually) replaces the previous correction line and thus, becomes the only valid line for all normal purposes.

It is important to realize that, as the VRCP involves (logically) retroactively modifying data, any report which relied upon the incorrect data will probably require correction. Specifically, it may be necessary to submit correction lines to any PILs or MBRs which were based upon a corrected ICR.

For the sake of completeness of the discussion, a few words should be said about another system approach which is the By-Difference Correction Principle (BDCP). Under the BDCP, the correcting line may only update quantity data (weights and number of items). As opposed to VRCP corrections in which the corrected record is superseded, a BDCP correction line indicates that a correction has been applied to the books on a specified date and that the quantities reported in the correction line are considered to be correct as of that date. Effectively, a BDCP correction indicates that on the specified date, a transaction occurred equal to the difference between the quantities on the correcting and the corrected lines.

If it is necessary to correct a correcting line entry, the new correcting line must refer to the previous correction line, not to the original nor any other previous correction lines. The date specified will be that on which the reported values were entered into the books. Thus, the new correcting line indicates another accounting entry for the same, original transaction.

As the date specified on the correcting record indicated the date on which the reported quantities were entered into the accounting books, it is obvious that it is not possible to correct the date of a transaction using the BDCP. Similarly, it is not possible to use the BDCP to correct any non-quantitative data (e.g. batch name, inventory change code, material description code).

In contrast to the VRCP, the BDCP does not involve (logically) retroactively modifying data; rather, it records subsequent accounting alterations to a single physical transaction. Thus it is possible to determine both the accounting (based upon the dates of the correcting lines) and the physical (based upon the date of the original transaction) inventories at any time. Additionally, as the correcting date is not restricted to the date of the original transaction, but rather specified the date when the correction was made in the books, it is frequently unnecessary to propagate corrections through previously closed material balance periods.

It is important to realize that the BDCP could only be used for correcting inventory change data; corrections to PILs and MBRs must be accomplished using the VRCP. It shall also be pointed out shortly, how the VRCP system philosophy influences certain inspection activities vis-a-vis the facility records.

First, a brief discussion of the treatment of States data in ISIS will be presented.

One of the major objectives in processing States accounting data is to determine if the material balance period is "closed". To accomplish this, two major functions are required. One is the calculation of Book Inventory and the other is a material balance evaluation. (Many other functions are carried out which support these two major ones, e.g. syntactical correctness of data, validity of names and dates, consistency of data, etc.). Several features of the Agency algorithm for the calculation of book inventory should be mentioned. If no beginning inventory can be established because no MBRs can be found in the data base, the beginning inventory is established from the most recent PIL reported prior to the end date for which the book inventory is being calculated. All original ICR line entries which have an inventory change date before the date on which the beginning inventory was valid or after the end date are excluded from the calculation. Similarly, line entries which have associated with them an unacceptable status for purposes of book inventory calculation are also excluded. (These line entries are listed on the printout which shows the book inventory). Correction line entries subsequent to the end date but which affect entries prior to the end date are included.

The MBR is a Consolidated Statement of data already reported to the Agency in ICRs and PILs, and is therefore of utmost importance to the Agency's accounting system, in that it closes all accounts and produces a definite statement of Material Unaccounted For (MUF). The MBR is, furthermore, an extremely useful tool in checking for errors that might have occurred during transmission or during data entry at the Agency. The "closing of accounts" also means that measurement errors, clerical errors and other reporting errors which have accumulated during the material balance period can be discovered and the problems taken care of, so that the books are finally "closed". The Agency uses the ICRs and PILs received to calculate a kind of material balance of its own for checking purposes. If all data are correct (and if quantities are not rounded), then the material balance calculated by the Agency should match exactly the MBR submitted to the Agency. This matching confirms that the MBRs are true, consolidated statements.

In evaluating a material balance, the following comparisons are made:

- the "physical ending" (PE) of the latest MBR with the latest PIL;
- the "physical beginning" (PB) of the latest MBR with the PE of the previous MBR;
- the summaries of the inventory changes in the latest MBR with the ICRs of the material balance period.

This comparison, of course, presupposes an internally consistent MBR. (Figure 5 summarizes the above-described process).

It might be appropriate at this time to mention several points concerning the MBR for which the Agency has made some observations through its experience in processing them. If, for the purpose of reporting, data are rounded, then an automatic (computer) comparison of the Agency and state calculation would not be possible. To adjust for these differences and permit a matching of the reported material balance with the one calculated by the Agency, special entries are needed in the material balance reports. These are the rounding adjustments. (Unfortunately, however, these are also sources of reporting errors). It is in all cases desirable to report weight data to the Agency in unrounded figures (e.g. as 2.76 kg of natural uranium instead of rounding this up to 3 kg). Such reporting of quantity data to the same precision (same number of decimals) as in the records at the facility can save time and errors at the time of the reporting and also when the material balance is prepared. Weight data have historically, however, been reported in whole units of accounting (grams or kilograms, depending upon the kind of material). The Agency discourages reporting in rounded figures. If the MBR is to be sent in rounded terms, individual batch weights reported in ICRs should first be added up and only then should the sum be rounded for reporting.

When material balance periods are prepared, it should be noted that category changes influence the material balance for both element categories; they decrease the inventory of one kind of material and increase it for the other. If separate material balances for all elements are included in the same MBR (report), the category change line (e.g. NE) must be included only once. The Agency system will automatically add/subtract the amount in the other elements. When, however, separate MBRs (reports) are prepared for each element, the category change line must be reported in both MBRs in question (for NE, in the MBR for E and the MBR for N). A frequent observation made is the incorrect use of a minus sign in the MBR for the element category which is 'losing' material (for NE, the MBR for N). The category change entries should always be reported without a minus sign in ICRs and MBRs, as would an entry for SD.

Finally, assume the ending physical inventory (PE) of the MBR agrees with the PIL. It cannot be emphasized strongly enough that the difference then between adjusted ending book inventory and PE is MUF and not RAPE, i.e., a rounding to PE.

Paragraph 30 of INFCIRC/153 states "... that the technical conclusion of the Agency's verification activities shall be a statement, in respect of each material balance area, of the amount of material unaccounted for over a specific period ...". The production of this statement requires integration of the foregoing elements of information in the planned inspection activities of the facility.

To begin with, the first step in carrying out an inspection is the making of an inspection plan. This plan is based on information from two sources. These are the previously carried out inspection and accounting data as stored in the ISIS data base. These two sources will specify the time period to be covered by the inspection as well as the type of records to be verified.

An essential part of the actual inspection is the comparison of accounting reports as stored in the Agency data base (ICR, PIL, MBR) against the operator's records as kept in the facility. To fulfil this task, the inspector takes a certain portion (as specified in the inspection plan) of accounting data in the form of computer printout to the facility to perform the report/record comparison. With this activity, the inspector would be able to detect any inconsistencies between the operators accounting records for the period and the actual line entries as reported to the Agency. Figure 6 shows the relationship between the various components and activities.

A possible source of inconsistencies is the fact that the facility operator may have corrected his records after submitting the accounting reports to the Agency. Therefore, the time factor is an important component to be considered. Figure 7 shows the relationship of reports sent to the Agency with the various activities performed in respect of time. In practice, the inspector requires an explanation from the operator, if any inconsistencies are found. If it turns out that the inconsistency is due to a correction made subsequent to the date of dispatch of the data from the State, the amounts are reconciled. This and any other inconsistency is fully investigated with follow-up action at the facility if necessary.

Inconsistencies due to reporting problems which are discovered at Headquarters are usually discussed between the data analyst and inspectors and relevant notes and problem analyses are carried to the field by the inspectorate for discussion there. In most cases, the inconsistencies appear to be clerical errors or misunderstandings of reporting rules and the solution can be reached in the discussion between the Agency inspector and the facility operator, who then submits relevant corrections to the Agency. When the solution warrants it, formal notification is made to the State.

VI. ACKNOWLEDGEMENT

The author wished to particularly acknowledge the following persons with whom he has co-authored other papers, parts of which have been used here. They are: F. dell'Acqua, Y. Ferris, W. Gmelin, G. Hough, L. Issaev and V. Schmelev. The author also wishes to acknowledge the assistance of Department of Safeguards staff in preparing this paper and in particular, M. Asunta-Johnston, B. Cross, P. Frauenberger and R. Kristinus.

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TABLE I NUMBER OF RECORDS IN THE COMPUTERIZED SAFEGUARDS DATA BASE AT THE END OF THE YEAR

Content of data base	1977	1978	1979	1980	1981	1982
Accounting data records	172 000	384 000	575 000	806 000	1 140 000	1 600 000
Inspection data records	2 000	6 000	10 000	36 000	75 000	150 000
Other data records ^{*/}	6 000	10 000	35 000	158 000	130 000	250 000
TOTAL	180 000	400 000	620 000	1 000 000	1 345 000	2 000 000

^{*/} Records with facility design information and with development, evaluation, management and test data.

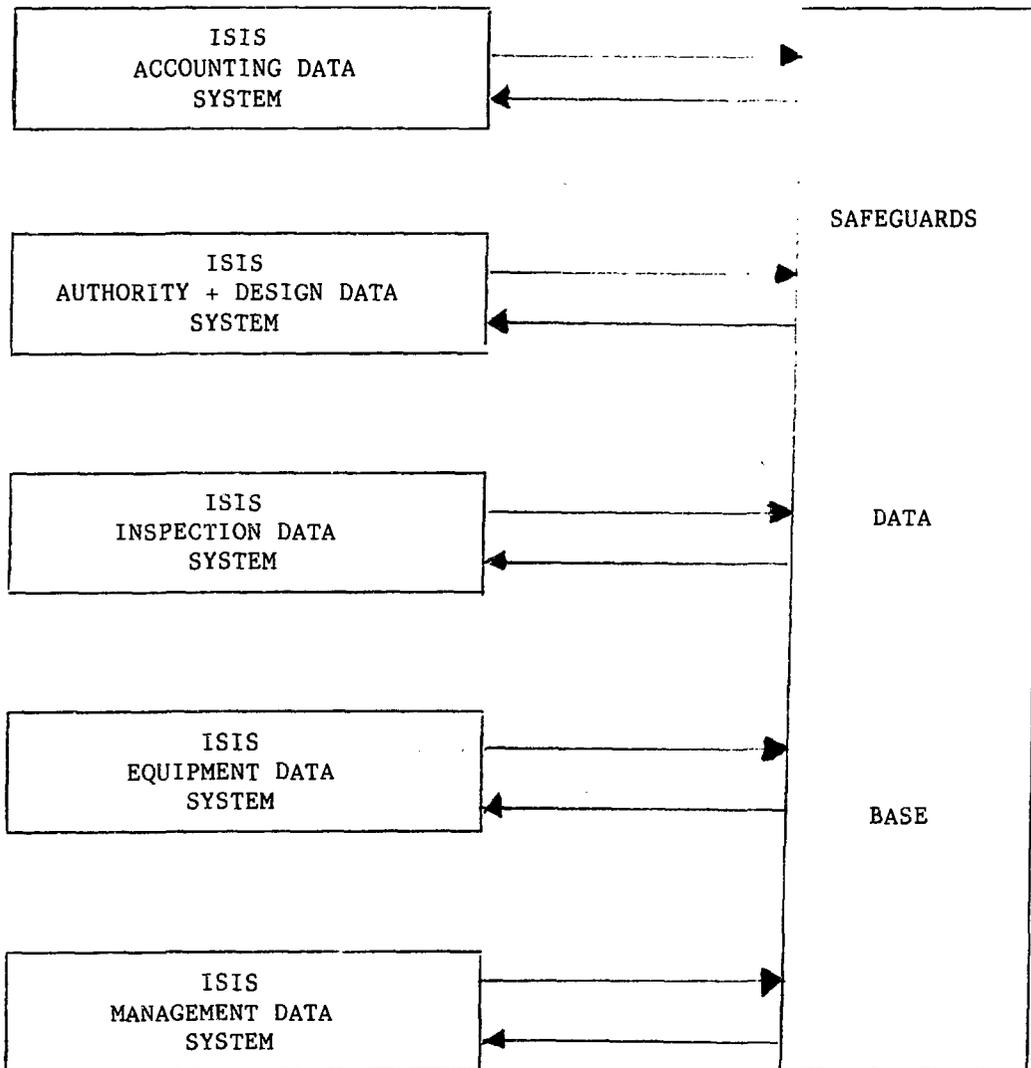


Figure 1. The IAEA Safeguards Information System

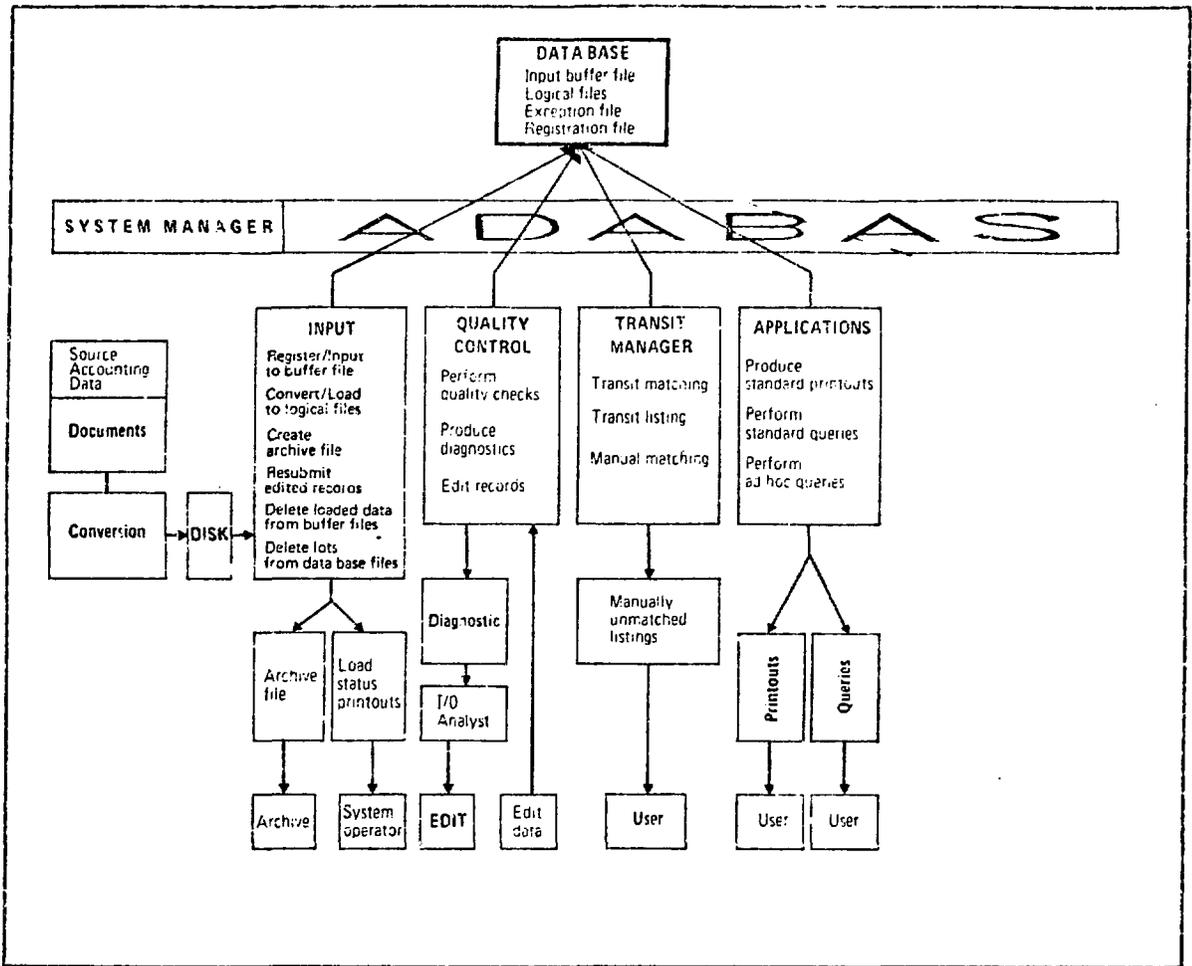
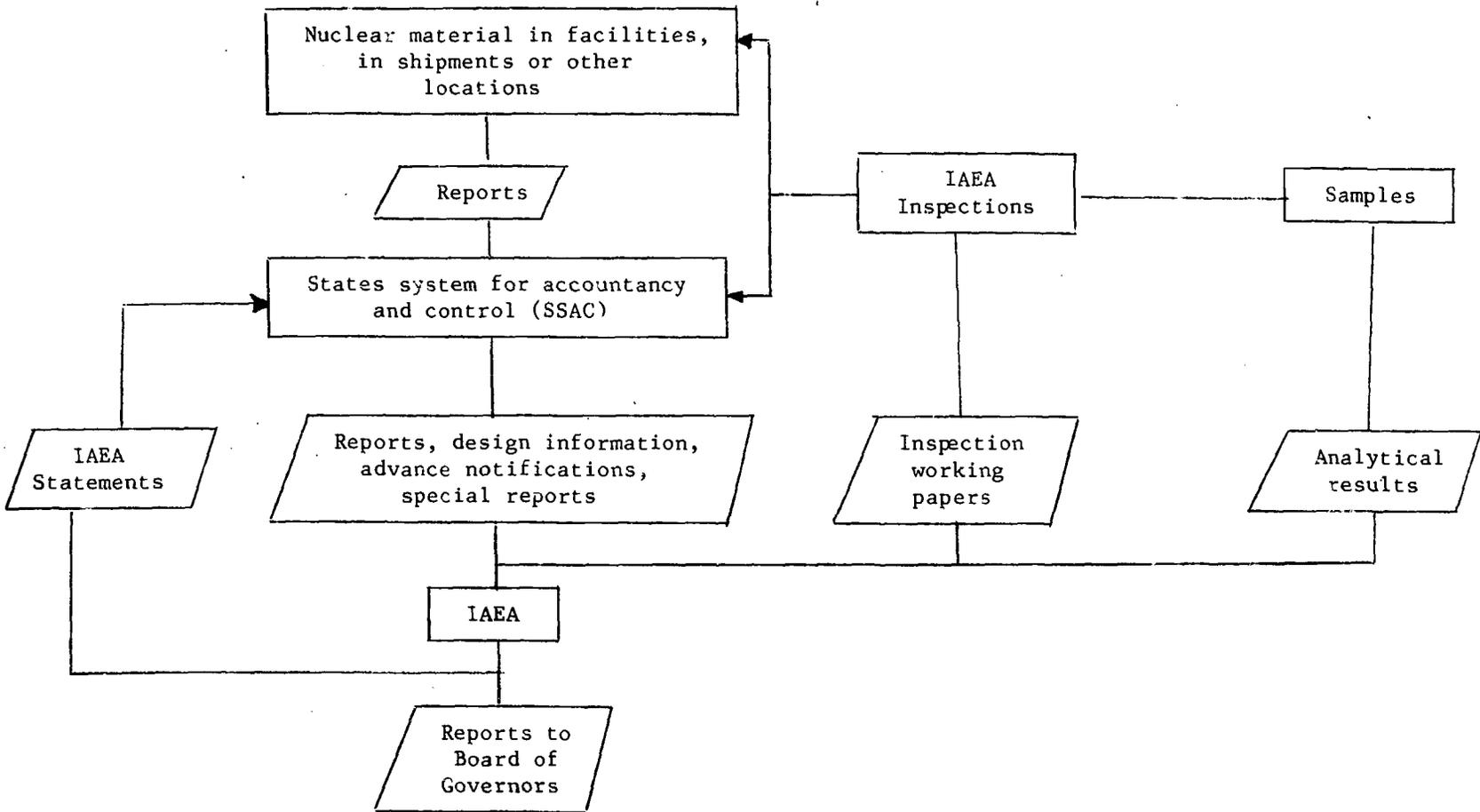


Figure 2. ISIS Functional Overview



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Figure 3. Sources and Types of Safeguards Information

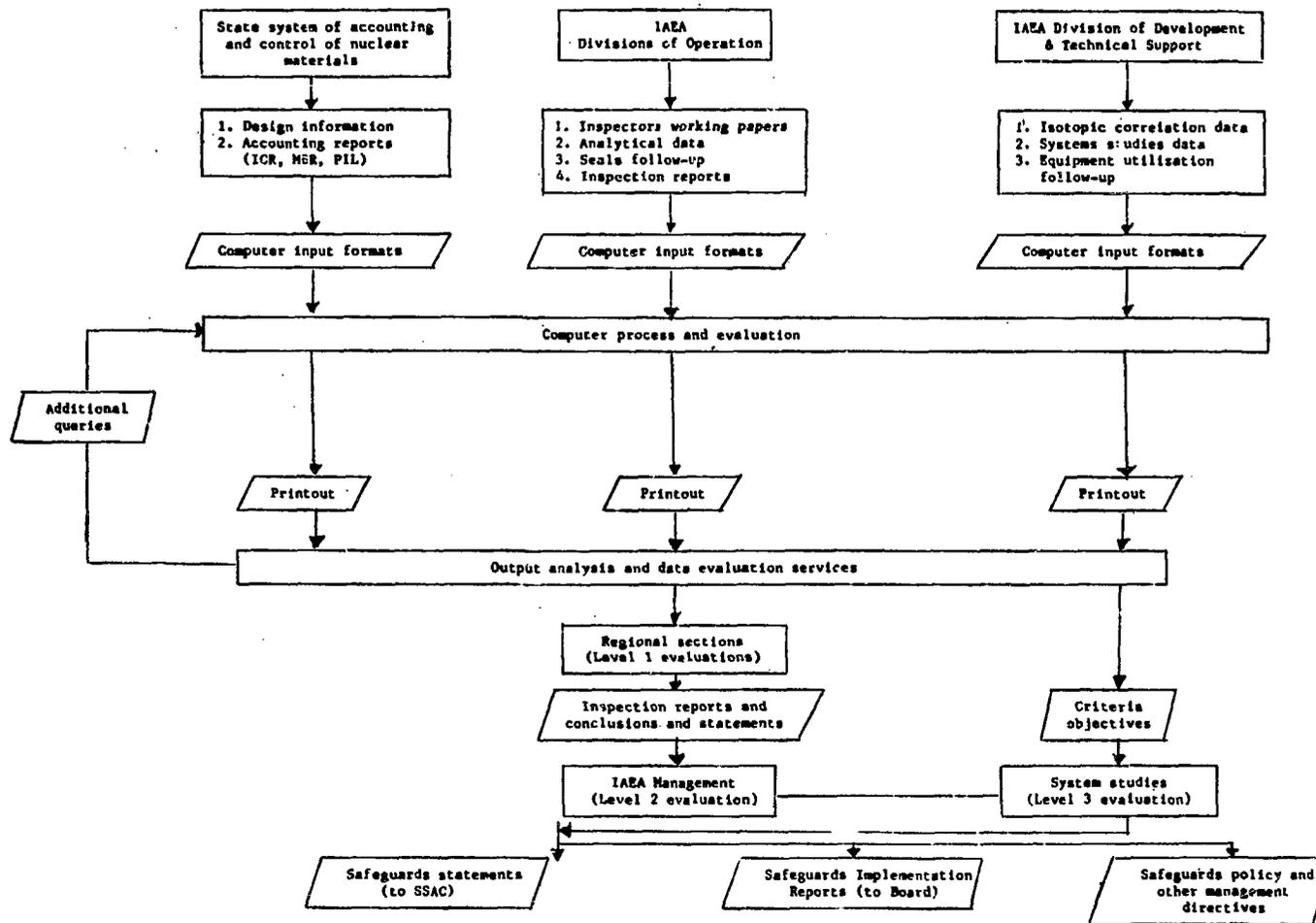


Figure 4. Information Flow

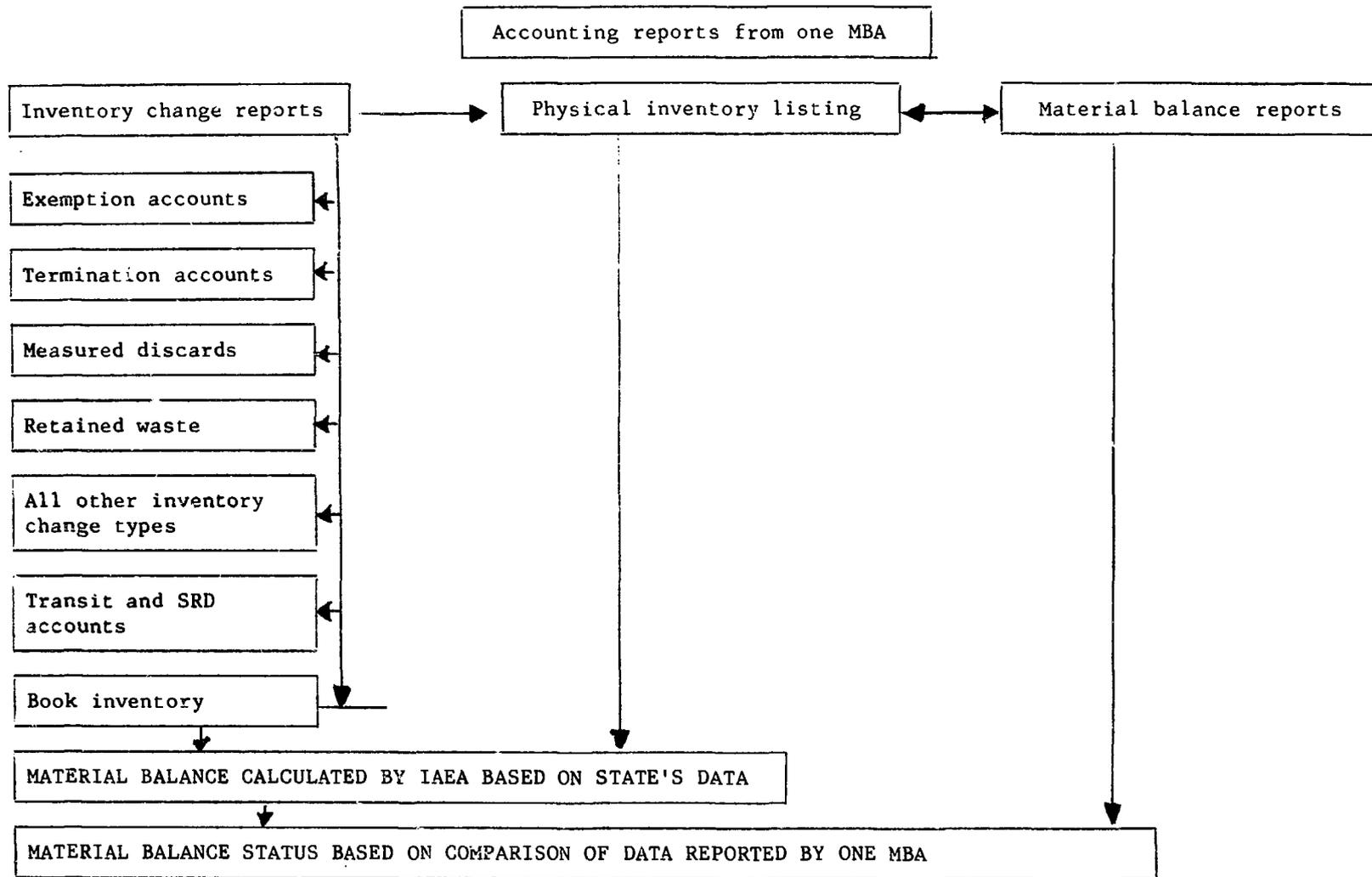


Figure 5. Processing of State's Accounting Data

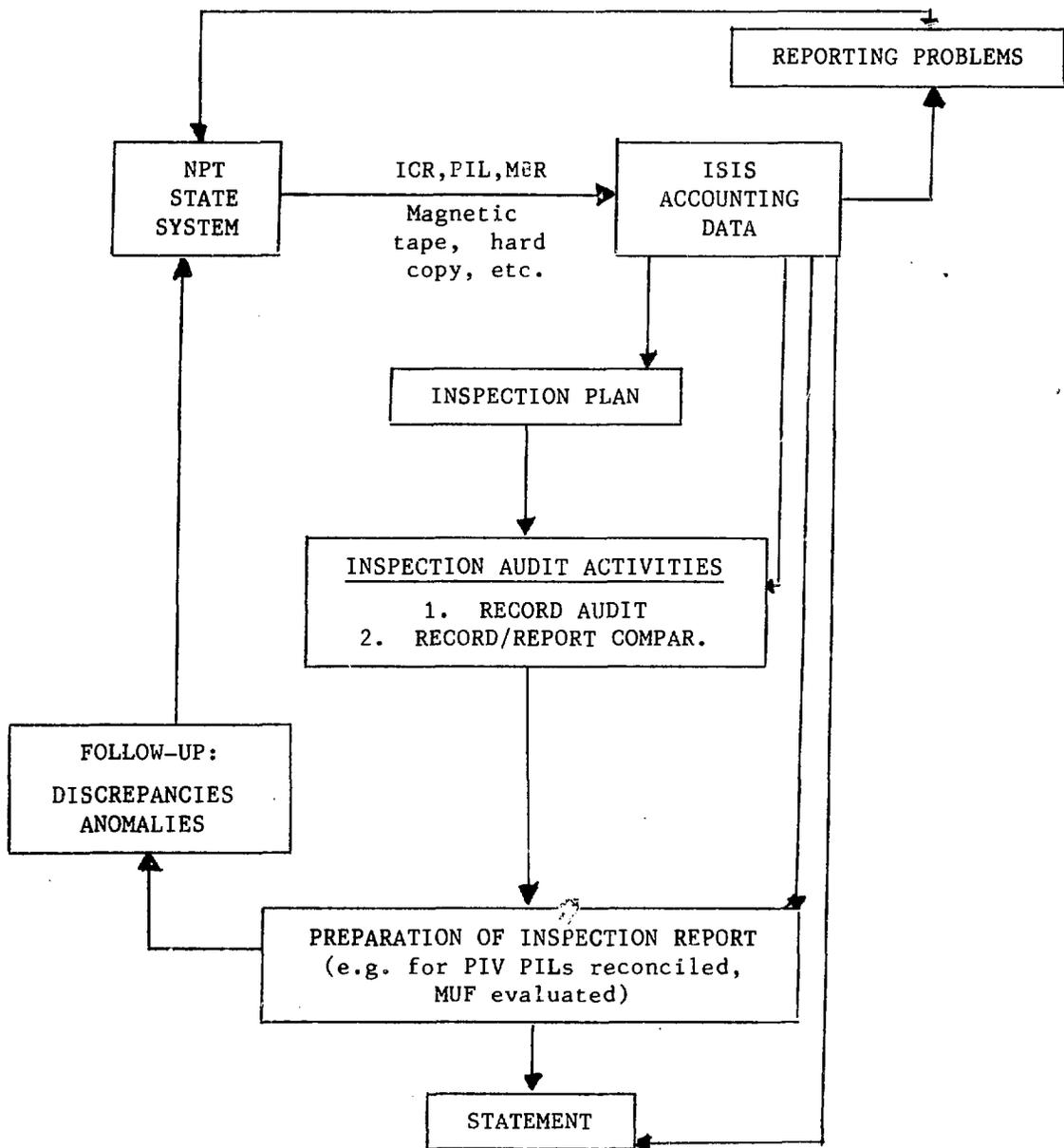


Figure 6. Data Vis-a-vis Activities

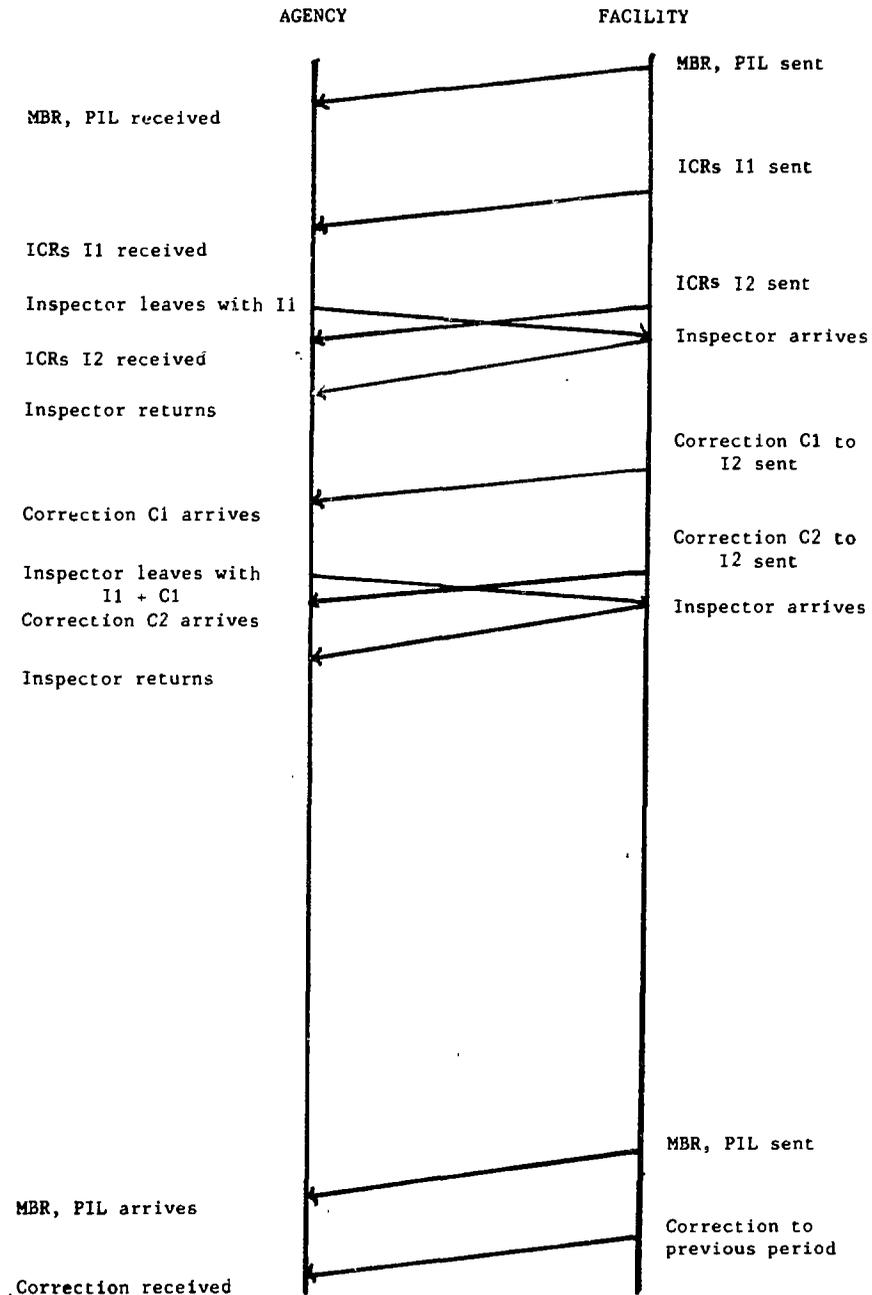


Figure 7. Time Factor in Records/Reports Comparison



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 12: PRINCIPLES OF NEAR-REAL-TIME MATERIALS
ACCOUNTING AND CONTROL SYSTEMS

The general structural features of a national system of accountability and control and the interfaces with the IAEA safeguards system are considered. Techniques for carrying out the design of such systems, including modeling and simulation, are discussed. Measures of systems performance and methods for evaluating those measures are described. Examples of the safeguards design process for selected fuel-cycle facilities will be presented.

After the session, participants will be able to:

- (1) identify the major components of an effective national system of accountability for nuclear materials,
- (2) describe qualitatively methods for designing an accountability system,
- (3) describe suitable performance measures for an effective accountability system, and
- (4) identify special safeguards design considerations and applications to selected fuel-cycle facilities.



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SESSION 12: PRINCIPLES OF NEAR-REAL-TIME
MATERIALS ACCOUNTING AND CONTROL SYSTEMS

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I. INTRODUCTION

The nuclear fuel cycle consists of a series of operations beginning with the mining of uranium ore and ending with the interment of radioactive waste (Fig. 1). As much of the world moves toward large-scale utilization of nuclear energy during the last decades of this century, more stringent controls are required on the nuclear materials used by the nuclear power industry. There are several reasons for this--the increased incidence of organized, overt terrorism; the potential widespread use of plutonium and highly enriched uranium as nuclear fuels; publicity about the fabrication of crude nuclear bombs; the hazards of malevolent dispersal of radioactive material; and worldwide concern over the proliferation of nuclear weapons.

The problem of maintaining strict accounting and control over all nuclear material will be exacerbated by the nuclear power demands of the future, which will require high-throughput facilities possibly supporting any of several alternative fuel cycles. Spent-fuel reprocessing facilities having the capability to process over 100 kg of plutonium per day have been built, and even larger ones are being designed. The scale of these operations has forced a reassessment not only of facility design, construction, and process operation, but also of the safeguards methods employed to prevent unauthorized use of the nuclear materials contained therein.

This paper describes principles that can serve as guidelines for the design of effective nuclear materials control and accounting systems. These guiding principles should be of particular value to those contemplating future nuclear processes and facilities that must meet stringent safeguards criteria. After a brief review of the objectives and the structures of national and international safeguards systems, features of advanced materials control and accounting systems are described.

II. THE STATE'S SAFEGUARDS SYSTEM

The essential purpose of any nuclear fuel-cycle plant is to produce, process, or consume nuclear materials safely and economically. Coordination between plant and safeguards designers at the earliest design stages is the most efficient and effective means of achieving both plant and safeguards goals. A comprehensive safeguards strategy includes four principal functions:

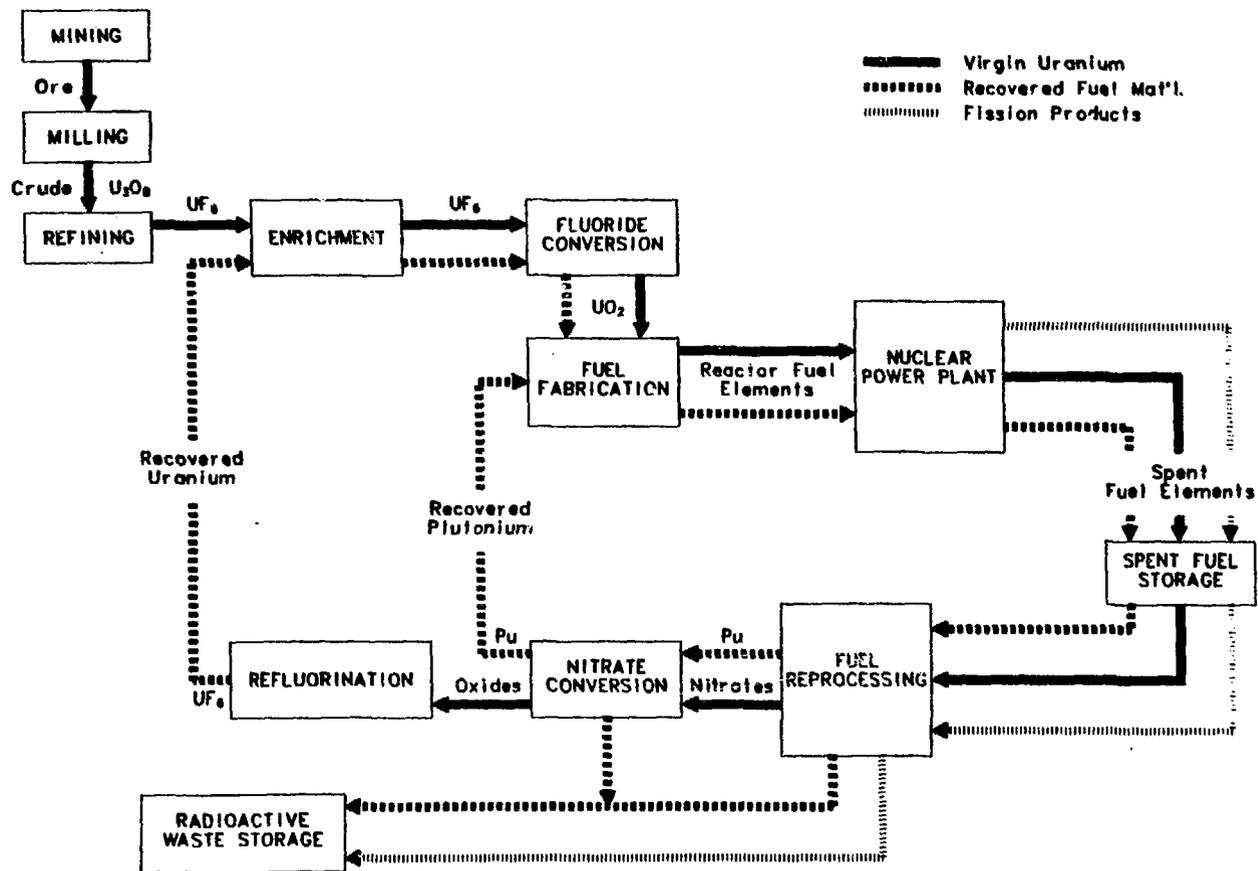


Fig. 1.
The power reactor nuclear-fuel cycle.

1. Excluding all unauthorized persons from the facility and selectively excluding others from sensitive areas within the plant;
2. Monitoring all activities involving nuclear material to determine whether each such activity is consistent with safeguards requirements and with normal expected facility operation;
3. Accounting for all nuclear material in the facility to determine whether the correct amounts of all materials are present in their proper locations;
4. Responding to the safeguards status of the facility and reporting to the regulatory authority.

These functions are accomplished by several subsystems, including the physical protection system (PPS), the process monitoring system (PMS), and the materials measurement and accounting system (MMAS).

Figure 2 shows a safeguards system structure that has been developed through numerous interactions with the U.S. nuclear industry and the safeguards community. The safeguards coordination unit (SCU) supervises nuclear material safeguarding in the plant. As the focal point for safeguards decisions, the unit interacts with management and process control coordination to

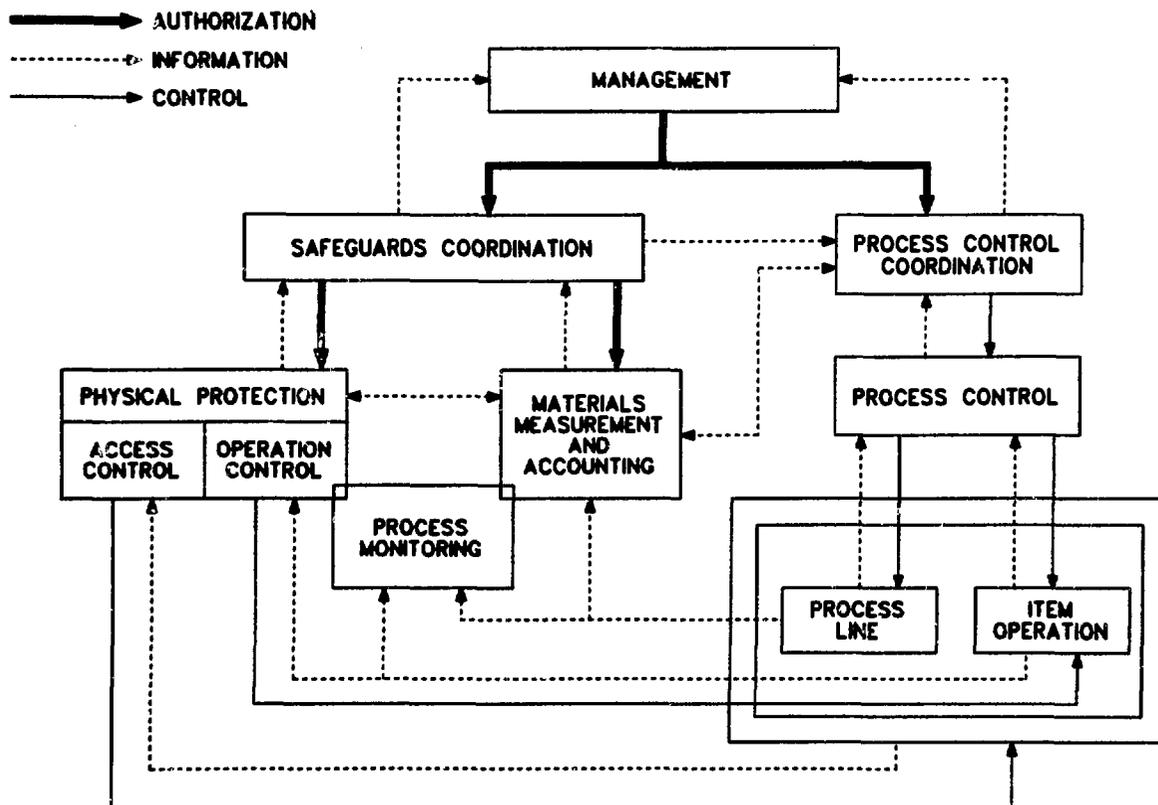


Fig. 2.
Structure of the safeguards system.

ensure effective safeguards while minimizing process disruptions. The SCU has three primary functions: (1) data collection and processing, which is required for (2) safeguards condition assessment, which in turn is the basis for (3) the response decision.

The physical protection system controls personnel entry and exit for the plant and for restricted areas inside. The system emphasizes the use of automated equipment and sufficient guard forces to provide the initial response in an emergency. The PPS expands the conventional security functions, such as access control, to include control of item-handling operations. Item operations control is applied to those portions of the facility, such as feed and product storage areas, that are outside the closely coupled process line and in which uninterrupted material flow is not critical to process operation.

The process monitoring system combines elements of both physical protection and materials accounting and provides supplementary information regarding compliance of actual process operating modes with approved procedures. The concept may be regarded both as an extension of physical-protection monitoring and surveillance functions into the process line, and as an upgrading of process-control monitoring devices (or appropriate placement of them) to allow gross materials accounting. The PMS collects timely information to detect process abnormalities. The system uses plant-grade instrumentation wherever possible to assess materials balances on transfers of process materials.

The materials measurement and accounting system combines conventional chemical analysis, weighing, and volume measurements with the timely measurement capability of on-line non-destructive assay (NDA) instrumentation to provide rapid and accurate assessment of the locations and amounts of material.

III. THE INTERNATIONAL SAFEGUARDS SYSTEM

In the early 1960s, as more and more countries acquired nuclear power plants, there was increasing concern worldwide over the possible misappropriation of nuclear material, facilities, and technology for use in weapons. As a result, safeguarding of nuclear material became important internationally. The basis for most current international safeguards arrangements is the Treaty on Non-Proliferation of Nuclear Weapons (NPT), which has been agreed to by more than 100 nations. The detailed terms and conditions under which specific facilities are safeguarded are negotiated with the IAEA, in accord with the general conditions of Article III of the NPT, as set forth in IAEA document INFCIRC/153. The objective of international safeguards, as declared in these documents, is the "...timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities..., and the deterrence of such diversion by the risk of early detection." The details of compliance are negotiated between the IAEA and the host nation on a facility-by-facility basis and are documented in so-called "Subsidiary Arrangements" and "Facility Attachments."

Agreements conforming to INFCIRC/153 require that "...the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards..., and that such safeguards shall be applied in such a manner as to enable the Agency (the IAEA) to verify, in ascertaining that there has been no diversion of nuclear material from peaceful uses to nuclear weapons or other nuclear explosive devices, findings of the State's system." Furthermore, the IAEA "shall make full use of the State's system of accounting for and control of all nuclear material subject to safeguards under the Agreement, and shall avoid unnecessary duplication of the State's accounting and control activities."

Thus, a major role of the international safeguards system is the independent verification of the validity and integrity of facility-generated materials accounting data as a means of confirming that the State's undertakings to limit nuclear activities to peaceful purposes are being fulfilled. Figure 3 indicates the relationships between the State and the IAEA safeguards systems. Clearly, the effectiveness of the international safeguards system depends on the quality of the State's safeguards system that supplies the input data. The Agency must make full use of the State's safeguards system and avoid unnecessary duplication. The inspector's verification activities consist of independent, confirmatory measurements of materials and audits of facility records, as well as independent observations of the integrity of

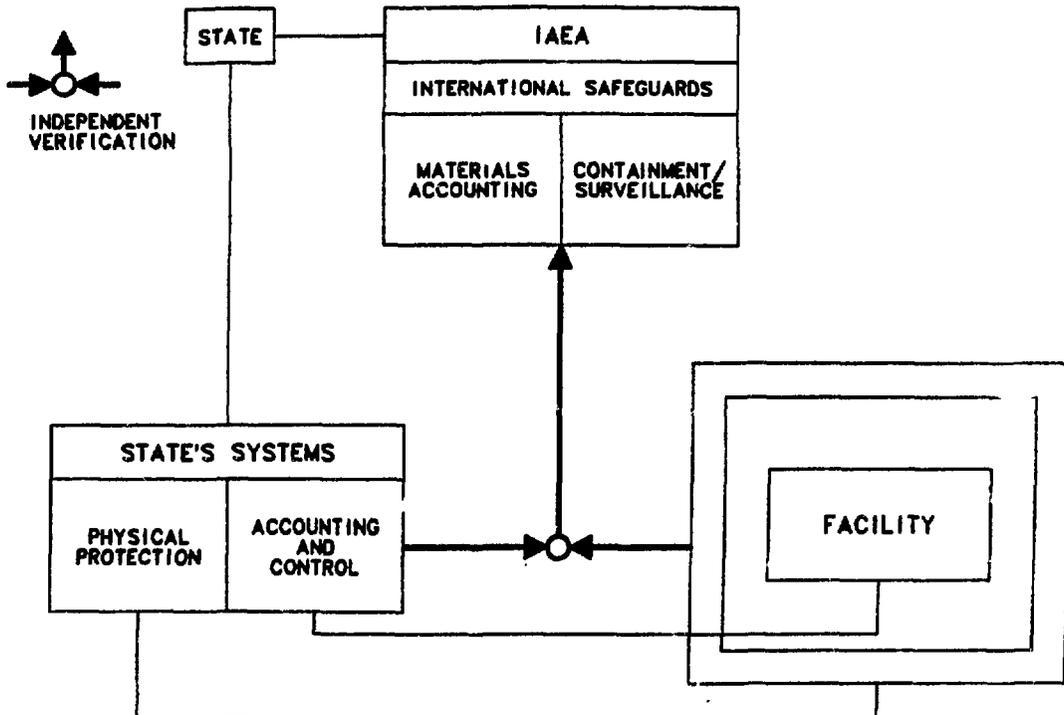


Fig. 3.
Relationship between the State and IAEA safeguards system.

the containment. The result of the Agency's verification activities is "a statement, in respect of each materials balance area, of the amount of material unaccounted for over a specific period, giving the limits of accuracy of the amounts stated."

Effectiveness criteria for international safeguards are negotiated between the IAEA (Agency) and the State (operator) on a case-by-case basis and are not quantifiably documented. Values of "goal quantities" for the detection of diversion have been proposed by the IAEA, but have not been generally accepted by Member States. These "goals" are derived from estimates of the quantities of nuclear materials required to produce an explosive device and the times necessary to convert these materials to that purpose. The goals include the detection of the diversion of:

- 8 kg of plutonium in irradiated fuel in 1-3 months.
- 8 kg of plutonium in unirradiated material in 1-3 weeks ("abrupt diversion").
- 8 kg of plutonium over a period of 1 year ("protracted diversion").
- 75 kg of uranium-235 contained in low-enriched (<20%) uranium over a period of 1 year.
- 25 kg of uranium-235 contained in high-enriched (>20%) uranium in 1-3 weeks.
- 25 kg of uranium-235 contained in high-enriched uranium in 1 year.

IV. THE MATERIALS MEASUREMENT AND ACCOUNTING SYSTEM (MMAS)

A. Materials Accounting

The function of materials accounting is to provide assurance that no nuclear material has been diverted for unintended uses. This is accomplished by verifying that the locations and amounts of material agree with facility records, that material, instruments, and data have not been tampered with, and that a materials balance is sufficiently close to zero. Materials accounting is based on the law of conservation of mass. Compliance of facility operations with this law is verified by separating the facility into materials balance areas (MBAs), well-defined physical areas of the facility admitting measurement of in-process inventories and measurement of all materials transfers across the area boundary. For a particular MBA and a specified time interval, the material unaccounted for or the materials balance is

$$\text{MB} = \text{initial inventory} - \text{final inventory} + \text{input transfers} \\ - \text{output transfers} ,$$

where the first two terms represent the measured amount of material in the MBA at the beginning and end of the time interval, and the last two terms represent the measured amounts of material transferred into and out of the MBA.

Under ideal conditions in which there is no missing material and all measurements are error free, the materials balance is

zero. However, in practice, not all materials are measured, and the terms in the MB equation are random variables reflecting statistical uncertainties in the measurement process. Thus, the MB is an estimate of the true state of accountancy in the MBA, which requires a statistical analysis to determine its significance.

A facility may have several MBAs determined by regulatory requirements and/or the physical movement of material within the process. Sometimes in facility or State accounting systems, additional areas called unit process accounting areas (UPAAs) are defined within an MBA. These UPAAs, constructed to allow a materials balance to be closed about each one, are implemented to control smaller amounts of material over smaller time intervals than is possible with a single, larger MBA structure.

B. Accounting Strategies

Conventional materials accounting relies on materials balance closure following a periodic shutdown and cleanout physical inventory. This form of materials accounting has balance periods determined by the allowable frequency of physical inventories, which is typically 6 months to 1 year. The physical inventory consists of shutting down the process, transferring all nuclear materials into suitable locations for measurement, and measuring the materials.

Near-real-time accounting (NRTA) uses in-process inventory estimation to supplement shutdown, cleanout physical inventories so that materials balances are closed during the interval between physical inventories. Thus, NRTA can be more responsive and more sensitive to materials loss than is possible with conventional accountancy. Implementing NRTA requires a determination of in-process inventories in process equipment. For example, in a reprocessing facility these inventories may reside in feed, buffer, and storage tanks or pulsed columns. Methods for measuring these quantities are based on (1) volume measurements using load cells or measurement of liquid level and density, (2) concentration measurements are made using conventional analytical methods off-line or with on-line NDA instruments, and (3) flow measurements using process control equipment.

Real-time accounting (RTA) may be defined as NRTA in which all measurements of materials transfers and in-process inventories are made on-line so that a materials balance could be, in theory, closed continuously. Thus, RTA is distinguished from NRTA by its avoidance of potential delays in obtaining laboratory analyses through use of NDA and other measurement methods with fast response times. RTA shares with NRTA the advantages of timely and sensitive materials balances and, in addition, offers the possibility of verifying the consistency of process operations through real-time monitoring of material movements within the process.

C. Example Applications of Conventional and NRTA

For the purpose of comparing conventional accounting and NRTA, we will examine their implementation in a spent-fuel reprocessing facility. This choice was made to highlight those

differences in timeliness and sensitivity between the two accounting methods that are most evident in high-throughput facilities processing nuclear materials in bulk form. In addition, because a reprocessing facility provides a more difficult environment for implementing NRTA than any other facility type in the nuclear fuel cycle, this choice assures that all significant issues for implementing NRTA will be addressed in our example.

1. Facility Description. The reference large fuel-reprocessing plant for this example is based on the Allied-General Nuclear Services (AGNS) chemical separations facility. The AGNS plant uses conventional Purex technology and is designed to process 1500 MTHM/yr of nuclear fuel, recovering 15 MT of plutonium as nitrate solution. The following describes briefly the process and measurement requirements in the reference facility.

Spent-Fuel Receiving and Storage. The spent-fuel assemblies arrive at the reprocessing facility by rail or truck and are held in a fuel-storage pool to await processing. All operations that involve handling bare spent-fuel assemblies, from cask-unloading to the transfer of assemblies into the chemical separations area, are performed underwater in a series of pools, using various overhead bridge cranes. Fuel assemblies are removed from the casks and stored underwater in baskets until they are required for processing. At that time, assemblies are removed one at a time from the baskets and transferred individually by underwater conveyor to the adjacent remote process cell.

Chop/Leach. In the remote process cell spent fuel is mechanically sheared and dissolved with concentrated nitric acid. The remote process cell and remote maintenance and scrap cell are mechanically maintained by a crane and remote manipulation; under normal conditions there is no provision for personnel access once operation begins. Shielding doors and hatches are provided between the cells and a crane equipment and maintenance gallery. When the doors are closed, the gallery may be entered by personnel for maintenance of the crane and other equipment.

Chemical Separations. The dissolver solution is contacted with tributyl phosphate (TBP) in a normal paraffin hydrocarbon solvent (dodecane) to separate most of the fission products from the plutonium and uranium. The solvent stream containing plutonium and uranium enters the partitioning step where the bulk of the uranium is separated from the plutonium. The uranium stream is further decontaminated with a solvent-extraction, aqueous-strip cycle and is then concentrated. The concentrated uranyl nitrate passes through silica-gel beds to remove traces of zirconium and niobium and is stored in the uranyl-nitrate storage area. The plutonium stream from the partitioning cycle is further purified in two separate solvent-extraction and acid-strip process steps. The plutonium-nitrate solution is concentrated and transferred to the nitrate storage area. Solvents used in the purification process are treated to remove fission products and degraded organics and are recycled to the plant. Wastes

from the processes are treated in either liquid- or solid-waste processing systems, and off-gases are treated before being vented to the atmosphere.

The operations discussed above are performed in five remotely operated, contact maintenance process cells: the high-level, high-intermediate-level, intermediate-level, plutonium product, and uranium product cells. Thick concrete walls, ceilings, and floors provide biological shielding from various highly active process solutions. The uranium product cell and plutonium product cell have exterior gloveboxes for sampling purposes.

A sample and analytical cell is provided for sampling other process solutions; normal operations are performed using remote manipulators. Samples from this cell as well as from the gloveboxes are bottled and transferred pneumatically to the analytical laboratory for analysis.

Plutonium-Nitrate Storage. The plutonium-nitrate storage area provides interim storage of plutonium nitrate between the separations area and a colocated conversion facility. The solution is stored in slab tanks until needed by the conversion process. These storage tanks are located within two plutonium-nitrate storage cells that are shielded by their heavy concrete construction. Solution is pumped between tanks, to sampling tanks, back to the chemical separations area for recycle, and to the conversion facility. Valves, piping, and pumps for the sampling and transfer operations are housed within gloveboxes. Samples are bottled in gloveboxes and then sent to the analytical laboratory through pneumatic transfer tubes.

2. Accounting Strategies for Conventional and NRTA. For materials accounting in the reference reprocessing plant, it is convenient to consider four MBAs: fuel receiving, storage, and the chop/leach area (MBA 1); chemical separations process area (MBA 2); uranyl-nitrate product storage area (MBA 3); and plutonium-nitrate product storage area (MBA 4). Generally, this MBA structure is the one implemented for conventional accounting. NRTA also employs this structure, but materials balances are drawn more frequently by measuring or estimating in-process nuclear material without draining and cleaning equipment. Additionally, some of the MBAs may be subdivided into UPAAAs for operator's and State's accounting systems.

As an example of the differences in MBA structure, measurement techniques, and accounting data for conventional and NRTA, we shall describe in detail the implementation of these two forms of accounting in the fuel receiving, storage, and chop/leach (MBA 1) and chemical separations areas (MBA 2) of the facility. The process vessels and flow streams within the chemical separations area are described in Figs. 4 and 5.

3. Conventional Accounting.

a. MBA 1. The fuel receiving, storage, and chop/leach MBA is treated as an item accounting area. Key measurement points (KMPs) for MBA 1 include:

- KMP 1: transfer of fuel bundles to the storage pool,
- KMP 2: transfer of fuel bundles from the fuel pool to the chop/leach area; accountability tank measurements,
- KMP 3: discarded waste (leached hulls), and
- KMP 4: recycle acid from the process MBA.

b. MBA 2. The MBA for the chemical separations area includes the solvent-extraction operations from the accountability tank to the uranyl-nitrate and plutonium-nitrate product sample tanks. The flow KMPs are:

- KMP 5: transfers to MBA 2 from MBA 1,
- KMP 6: recycle to MBA 1,
- KMP 7: measured discards and retained waste,
- KMP 8: transfers from MBA 2 to MBA 3
(uranyl-nitrate storage)
- KMP 9: recycle from MBA 3,
- KMP 10: transfers from MBA 2 to MBA 4
(plutonium-nitrate storage)
- KMP 11: recycle from MBA 4, and
- KMP 12: transfers to MBA 2 from MBA 5
(conversion process).

The inventory KMPs are (1) those tanks in which reliable volume measurements can be made when the process is drained and flushed (KMP A) and (2) the analytical laboratory (KMP B).

The flow KMPs required for conventional materials accounting in the reference facilities are given in Table I. All discards and retained wastes are transferred out of this MBA through KMP 7. Concentrated liquid wastes are sampled and volumes are measured in sample or check tanks before transfer to on-site storage. Nuclear materials content in solid-waste drums is checked by NDA techniques. Gaseous wastes are filtered, then checked for nuclear materials content before venting.

Uranyl-nitrate product solution is transferred out of MBA 2 through KMP 8. Product batches (~4460 L, ~374 g uranium/L) are transferred approximately every 8 h. The volume of each batch is measured in the uranium sample tank and samples are taken for chemical analysis.

Plutonium-nitrate product is transferred out of the chemical separations MBA through KMP 10. Product batches (~394 L, ~250 g plutonium/L) are transferred to the plutonium-nitrate storage facility from one of three interim product storage tanks. The batch volume is measured in the interim storage tanks and samples are taken for chemical analysis of plutonium concentration and isotopics.

A physical inventory in this MBA includes a shutdown and flushout of the separations process area (KMP A) and a cleanout of extraneous samples and a piece-count verification of remaining materials in the laboratory (KMP B). The process line is drained and flushed into ~26 primary accountability tanks that have been calibrated so that reliable volume measurements can be made and samples can be taken for analysis. The tanks are equipped

TABLE I
 FLOW KEY MEASUREMENT POINTS FOR CONVENTIONAL MATERIALS ACCOUNTING
 IN THE REFERENCE FACILITY

Measurement Point	Material Description	Measurement Type	Instrument Precision (% 1σ)	Calibration Error (% 1σ)
Accountability tank	Dissolver solution 300 g U/L 3 g Pu/L	Volume	0.3	0.1
		Mass spectrometry	1	0.2
		Mass spectrometry	1	0.3
MBA 1 laboratory samples	U, Pu, fission products in HNO ₃	Chemical analysis	--	
Dissolver acid surge tank	HNO ₃ (Recycle Acid) Trace of U Trace of Pu	Volume;	2	3
		Fluorimetry or spectrophotometry	20	10
		NDA, α	10	5
HLW sample tank	Concentrated high-level waste 3 g U/L 0.1 g Pu/L	Volume;	5	3
		Mass spectrometry	1	0.5
		Mass spectrometry	1	0.5
General process waste check tank	Concentrated low-level waste 13 g U/L Trace of Pu	Volume;	5	0.5
		Mass spectrometry	1	0.5
		Mass spectrometry	1	0.5
Solid-waste drums	Very low-level solid waste Traces of U, Pu	NDA γ,n	50	10
Solvent-burner feed tank	Waste solvent Trace of U Trace of Pu	Volume	1	0.5
		Fluorimetry or spectrophotometry	20	10
		NDA, α	10	5
Central stack	Off-gas Traces of U, Pu	Volume	20	10
		NDA ?	40	20

12-12

TABLE I (cont)

<u>Measurement Point</u>	<u>Material Description</u>	<u>Measurement Type</u>	<u>Instrument Precision (% 1σ)</u>	<u>Calibration Error (% 1σ)</u>
U product sample tank	Uranyl nitrate 370 g U/L	Volume	0.3	0.1
		Gravimetry	0.25	0.1
U rework tank	Uranyl nitrate 370 g U/L	Volume	0.5	0.5
		Gravimetry	0.25	0.1
Laboratory samples	Uranyl nitrate	Chemical analysis	--	
Pu product sample tank	Plutonium nitrate 250 g Pu/L	Volume	1	0.5
		Amperometry or coulometry	0.2	0.1
Pu product interim storage tanks (3)	Plutonium nitrate 250 g Pu/L	Volume	0.3	0.1
		Amperometry or coulometry	0.2	0.1
Pu rework tank	Plutonium nitrate 250 g Pu/L	Volume	1	0.5
		Amperometry or coulometry	0.2	0.1
Laboratory samples	Plutonium nitrate	Chemical analysis	--	
Pu rework tank	Plutonium nitrate	Volume	1	0.5
		Amperometry or coulometry	0.2	0.1
Laboratory samples	Plutonium nitrate Plutonium oxalate Plutonium oxide	Chemical analysis	--	

with air-spargers and sampling devices for measurements of nuclear materials content. The flushing process reduces the residual nuclear materials in tank heels, pipes, and so forth as much as is practicable.

A materials balance is taken after each physical inventory by adding all measured receipts (KMPs 5, 9, 11, and 12) to the initial inventory (KMPs A and B, initial) and subtracting all measured removals (KMPs 6, 7, 8, and 10) and the final inventory (KMPs A and B, final).

4. NRTA. Conventional materials accounting in bulk handling facilities such as MBA 2 (the chemical separations area) can be augmented by NRTA methods to provide more timely detection of materials loss and thus short-term detection sensitivity. Implementing NRTA requires measurements of in-process inventory in addition to the inventory and flow measurements needed for conventional accounting. These additional measurements are in most instances already available from existing process instrumentation such as flow, level, density, and temperature. In a few instances additional instruments are needed, especially for on-line measurements of concentrations in streams. These measurements are obtained by adding nondestructive measurements, such as x-ray fluorescence or x-ray absorption-edge densitometry, to appropriate sampler lines from the process.

Under NRTA a process MBA is composed functionally of discrete accounting envelopes, or UPAA's. A UPAA can include the entire MBA or portions of the MBA. The distinguishing feature of a UPAA is that materials balances are closed in near-real-time by measuring all significant materials flows and in-process inventories. By comparison, conventional materials balances are closed once each physical inventory.

For international safeguards, the chemical separations process area (MBA 2) is treated as a single UPAA (referred to as UPAA 1 2). For operator or State considerations, it can be subdivided into two UPAA's: the codecontamination-partition process (UPAA 1) and the plutonium purification process (UPAA 2). These two UPAA's are shown in Figs. 4 and 5, respectively. The flow measurement separating these two UPAA's is on the LBP stream, which is the first separated plutonium-nitrate stream in the standard Purex flow sheet.

a. UPAA 1 2--Chemical Separations Process. The chemical separations process MBA is treated as a single UPAA (UPAA 1 2) by combining in-process inventory and flow measurements to form a dynamic materials balance approximately every 2 days. On the average, under normal operating conditions, $\sim 2\frac{1}{2}$ accountability batches (~ 5 tonnes of uranium fuel) and 1 product batch (~ 50 kg of plutonium) are processed every day. Therefore, process logic suggests taking a materials balance approximately every 2 days to include an integral number of feed and product batches. Smaller batches, for example, to high-level waste, are included in the materials balances when the measurements become available. Alternatively, a materials balance could be taken around UPAA 1 2

after each feed batch (approximately every 9.6 h), if on-line flow and concentration measurements were added to the plutonium concentrator product stream.

b. UPAA 1--Codecontamination-Partitioning Processes. A separate UPAA (Fig. 4) could be formed around the codecontamination-partitioning processes if flow-rate and concentration measurements were added to the intermediate plutonium product (1BP stream). A dynamic materials balance can be formed for each feed accountability batch (every 9.6 h) by combining measurements of the concentration and volume of the feed batch, the concentrations and flow rates in the intermediate product, recycle, waste streams, and the intervening in-process inventories in the process vessels.

c. UPAA 2--Plutonium Purification Process. Dynamic materials balances could be formed about the plutonium purification process (Fig. 5), if flow and concentration measurements were added to the aqueous and organic recycle streams. Process control measurements of the inventories in process tanks are available, and the inventories in the pulsed columns can be estimated by combining suitable engineering models with available process data on flow rates and concentrations of inlet and outlet streams. One of two product measurements can be used: concentration and volume measurements in the plutonium product sample tank or integrated flow-rate and concentration measurements on the product stream of the plutonium product concentrator.

d. Materials Accounting Measurements in MBA 2. Table II shows the additional information necessary for NRTA. Most of this information is already available from existing or upgraded process instrumentation. In a few instances, additional instruments are needed, especially for on-line measurements of concentrations in streams. These measurements are obtained by adding nondestructive measurements, such as x-ray fluorescence or x-ray absorption-edge densitometry, to appropriate sampler lines from the process.

V. MMAS DESIGN METHODOLOGY

A. Modeling and Simulation

Because large fuel-cycle plants are not yet in operation, computerized modeling and simulation of each process and measurement system are used in developing preliminary MMAS designs. The modeling and simulation approach requires a detailed dynamic model of the process based on actual process design data. Design concepts are evolved by identifying KMPs and appropriate measurement techniques, comparing possible materials accounting strategies, developing and testing appropriate data-analysis algorithms, and quantitatively evaluating the proposed MMAS's capability to detect losses. By using modeling and simulation

TABLE II

MEASUREMENTS FOR NEAR-REAL-TIME ACCOUNTING IN THE
CHEMICAL SEPARATIONS PROCESS

Measurement Point	Material Description	Measurement Type	Instrument Precision (% 1 σ)	Calibration Error (% 1 σ)
HA feed tank	U, Pu, FP in HNO ₃ 2.8 g Pu/L	Volume	3	--
		Concentration	1	--
HS column	U, Pu, residual FP in organic and HNO ₃ , Pu inventory	See Footnote a	20	--
1B column	U, Pu in organic, Pu inventory	See Footnote a	20	--
1SP stream	U, Pu in organic <0.1 g Pu/L	Flow rate	5	1
		Concentration	10	2
POR stream	U, Pu in organic 0.01 g Pu/L	Flow rate	5	1
		Concentration	10	2
1BP stream	U, Pu, residual FP in HNO ₃ 400 L/h 5 g Pu/L	Flow rate	1	0.5
		Concentration	1	0.3
1BP surge tank	U, Pu, residual FP in HNO ₃ 5 g Pu/L	Volume	3	--
		Concentration	3	--
2A column	U, Pu, residual FP in aqueous, organic phases; Pu inventory	Volume Concentration	5-20	--
2AW stream	U, Pu, residual FP in HNO ₃ 500 L/h <0.1 g Pu/L	Flow meter	5	1
		Concentration	10	2
2B column	U, Pu, trace FP in aqueous, organic phases, Pu inventory	Flow meter Concentration	5-20	--
2BW stream	U, trace Pu in solvent 150 L/h Trace Pu	Flow rate	5	1
		Concentration	10	2
3A column	U, Pu, trace FP in aqueous, organic phases, Pu inventory	Flow rate Concentration	5-20	--
3AW stream	U, Pu, trace FP in HNO ₃ 215 L/h <0.1 g Pu/L	Flow rate	5	1
		Concentration	10	2
3B column	U, Pu in aqueous, organic phases; Pu inventory	Flow rate Concentration	5-20	--
3BW stream	U, trace Pu in solvent 105 L/h Trace Pu	Flow rate	5	1
		Concentration	10	2
3PS diluent-wash	Pu in aqueous phase, trace Pu in organic phase; Pu inventory	Flow rate	5-20	--
		Concentration		
3P concentrator	Concentrated plutonium nitrate 250 g Pu/L	Volume (constant)	--	--
		Concentration	1.5	--
3PD stream	Residual Pu in HNO ₃ 32 L/h <0.1 g Pu/L	Flow rate	5	1
		Concentration	10	2
3PCP stream	Plutonium-nitrate product 8 L/h 250 g Pu/L	Flow rate	1	0.5
		Concentration	1	0.3

^aInventories in the columns are estimated from process measurements of flows and concentrations in adjacent streams combined with engineering models.^{12,13}

techniques, the effects of process and measurement variations over long operating periods and for various operating modes can be studied in a short time.

Computer codes can be used to simulate the operation of the reference process using standard Monte Carlo techniques. Input data include initial values for all process variables and values of statistical parameters that describe each independent, stochastic process variable. These data are best estimates obtained from process designers and operators. Each unit process is modeled separately. When a process event occurs in a particular unit process, the values of nuclear material flows and in-process inventories associated with that unit process are computed and stored in a data matrix. These data are available for further processing and as input to computer codes that simulate accounting measurements and materials balances.

The nuclear materials flow and inventory quantities from a process model are converted to measured values by applying simulated measurements. Each measurement type is modeled separately; measurement errors are assumed to be normally distributed, and provisions are made for both additive (absolute) and multiplicative (relative) errors. Significant measurement correlations are included explicitly. The measurement models are based on the performance of similar instrumentation characterized in both laboratory and field applications to similar materials. Simulated measurements are combined to form materials balances under various strategies for materials accounting.

B. Measurement Error Models

Because the sensitivity of any MMAS is limited by intrinsic measurement errors, measurement models and error estimates for various types of instrumentation are used to predict MMAS performance. A simple measurement model is given by

$$m = M(1 + \epsilon + \eta) \quad (1)$$

where m is the measured value of a true quantity M . The measurement errors, ϵ and η , are discussed below. This model applies when error standard deviations are expressed on a relative basis and is appropriate for measurement situations in which the associated error tends to be proportional to the quantity being measured.

The measurement errors have been grouped in two categories, instrument precision ϵ and calibration η , and both are regarded as observations on random variables. The instrument precision, ϵ , represents the deviation of the measured value from the true quantity caused by the scatter or dispersion in a set of individual measurement results (for example, the uncertainty caused by counting statistics in NDA measurements). The calibration error, η , represents those errors that persist, unchanged, throughout a limited set of measurements as a result of the uncertainty in converting raw measurement results into the quantity of interest (for example, converting counts to plutonium

mass for NDA measurements). The latter errors are the most difficult to estimate because they include uncertainties in standards, calibration parameters, instrument environment, and measurement control procedures. There may be several independent η -error components, each arising from a different error source that correlates a different set of measurements. A major function of measurement control and quality assurance is to identify the sources of measurement error and to control them through appropriate calibration procedures.

The error random variables (ϵ and η) are assumed to have means of zero and variances σ_ϵ^2 and σ_η^2 , respectively. This implies that all significant measurement biases have been identified and corrected for in the measurement control program. The variance σ_m^2 of the measured value m is given by

$$\sigma_m^2 = M^2(\sigma_\epsilon^2 + \sigma_\eta^2) \quad . \quad (2)$$

To simulate a series of measurements from a given instrument, one value of ϵ is sampled from the appropriate ϵ -error distribution for each measurement, whereas a new value of η is sampled from the appropriate η -error distribution only when a calibration is performed. All measurements from the same instrument having the same η error are correlated. These correlations may dominate the materials balance uncertainty. The covariance between the i th and j th measurements is given by

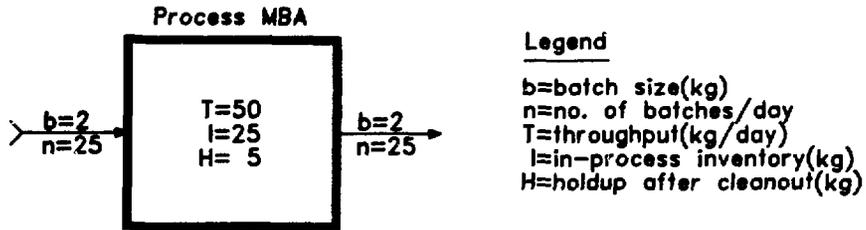
$$\sigma_{ij} = M_i M_j \sigma_\eta^2 \quad . \quad (3)$$

C. Ideal Process Example

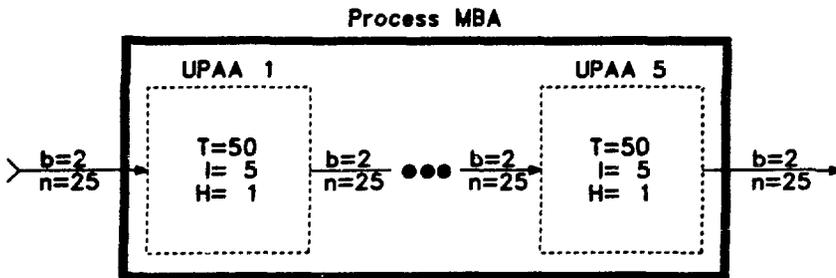
A simple example will illustrate materials accounting concepts and principles. Figure 6 represents an ideal process having a daily throughput of 50 kg of nuclear material consisting of twenty-five 2-kg batches and no process losses. The in-process inventory of nuclear material is 25 kg, and the residual holdup is 5 kg after shutdown and cleanout, which is postulated to occur once each month. The entire process is contained in a single MBA (Fig. 6a), whereas storage areas for feed and product are in separate MBAs and are not shown.

Figures 6b and 6c show two possible divisions of the process MBA into UPAAAs for dynamic accounting purposes. In Fig. 6b the MBA is divided into a series of five UPAAAs. To accomplish this division, transfers of nuclear material between adjacent UPAAAs and the in-process inventory in each UPAA must be measured. In Fig. 6c, the MBA is divided into five parallel UPAAAs. In this case the input, output, and inventory of each UPAA must be measured. In practice, the division of the MBA depends on the process configuration.

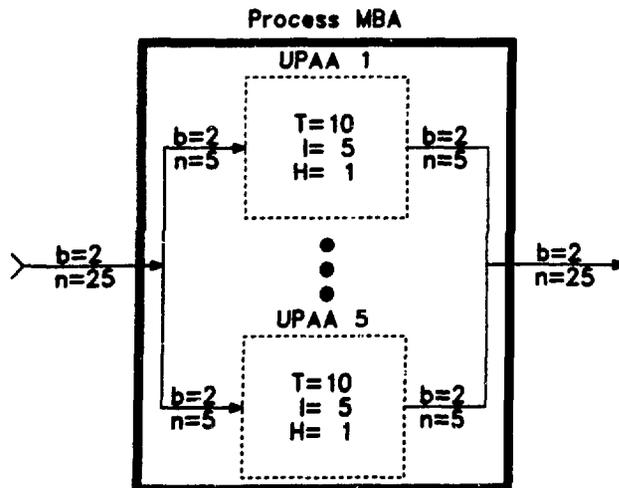
Measurement errors in dynamic materials balances applied to the ideal process can be calculated using the measurement model described in the previous section [Eqs. (1-3)]. For a given



a. Ideal process MBA.



b. MBA divided into a series of five UPAA's.



c. MBA divided into five parallel UPAA's.

Fig. 6.
 Ideal process block diagram.

accounting period during which N batches are processed, the dynamic materials balance, MB_N , for one UPAA is given by

$$MB_N = \Delta I_N + T_N \quad , \quad (4)$$

where ΔI_N is the net change in nuclear material inventory and T_N is the net transfer of nuclear material (inputs minus outputs) across the UPAA. If there were no measurement errors, MB_N would be exactly zero and, if the process were operated at steady state, ΔI_N and T_N would also be zero.

Measurement errors produce an uncertainty in MB_N having a variance σ_{MB} (assuming no correlation between transfer and inventory measurements) given by

$$\sigma_{MB}^2 = \sigma_{\Delta I}^2 + \sigma_T^2 \quad . \quad (5)$$

Understanding the behavior of the inventory-change and net-transfer variances, $\sigma_{\Delta I}^2$ and σ_T^2 , is basic to effective MMAS design.

1. Inventory-Change Variance. If the initial and final inventories, I_0 and I_N , are measured during the same calibration period (i.e., have the same η error), the variance, $\sigma_{\Delta I}^2$, of the net inventory change, ΔI , is given by

$$\sigma_{\Delta I}^2 = (I_0^2 + I_N^2)\sigma_{\epsilon I}^2 + (I_0 - I_N)^2\sigma_{\eta I}^2 \quad , \quad (6)$$

where $\sigma_{\epsilon I}^2$ and $\sigma_{\eta I}^2$ are the ϵ - and η -error variances of the inventory measurements. Note that if the initial and final inventories are equal, $I_0 = I_N$, then $\sigma_{\Delta I}^2$ has the minimum value

$$\sigma_{\Delta I}^2 = 2I_0^2\sigma_{\epsilon I}^2 \quad . \quad (7)$$

For a large class of process equipment, efficiency and economy dictate that the in-process inventory be held nearly constant during normal operation. Such near-steady-state operation benefits materials accounting by reducing the materials balance uncertainty. Furthermore, the condition $I_0 \approx I_N$ implies that the dependence of σ_{MB} on $\sigma_{\eta I}$ is weak [Eq. (6)]; hence, a well-known value for $\sigma_{\eta I}$ is not required. This result is important because standardization of in-process inventory measurements may be difficult, especially for process equipment located in high radiation fields behind heavy shielding. The ideal process is assumed to satisfy the steady-state condition so that Eq. (7) holds. The inventory measurement error ($\sigma_{\epsilon I} = 10\%$ in this example) limits the dynamic accounting sensitivity over short accounting periods.

2. Net-Transfer Variance. The variance σ_T^2 of the net material transfer T is given by

$$\sigma_T^2 = 2Nb^2(\sigma_{\epsilon b}^2 + \sigma_{\eta b}^2) + 2N(N-1)b^2\sigma_{\eta b}^2, \quad (8)$$

where b is the input and output batch size, and $\sigma_{\epsilon b}^2$ and $\sigma_{\eta b}^2$ are the ϵ - and η -error variances of the batch transfer measurements. For simplicity of presentation, the error variances of input and output batch measurements have been set equal in value (hence the factor of 2), but the two measurements are independent (i.e., uncorrelated).

The first term in Eq. (8) occurs whenever N input and N output batches are measured during the accounting period and is present even if the transfer measurements are uncorrelated. The second term in Eq. (8) accounts for pair-wise correlations among the transfer measurements [Eq. (3)]. The transfer measurements are correlated primarily because the instruments are not recalibrated during the accounting period. Note that the number of pair-wise correlations increases approximately as N^2 ; if N is sufficiently large, correlations make the dominant contribution to σ_T^2 . The second term in Eq. (8) is equal to the first term after N_0 batches have been processed, where N_0 is given by

$$N_0 = \frac{\sigma_{\epsilon b}^2 + 2\sigma_{\eta b}^2}{\sigma_{\eta b}^2}. \quad (9)$$

3. Effect of Calibration. The effect of correlations is reduced by recalibrating the transfer-measuring instruments. If the instruments are calibrated K times during the accounting period, and if n_k is the number of batches processed between the k^{th} and $(k+1)^{\text{th}}$ calibrations, then σ_T^2 is given by

$$\sigma_T^2 = 2Nb^2(\sigma_{\epsilon b}^2 + \sigma_{\eta b}^2) + 2b^2\sigma_{\eta b}^2 \sum_{k=1}^K n_k(n_k - 1), \quad (10)$$

where

$$N = \sum_{k=1}^K n_k.$$

The number of correlation terms in this case increases approximately as $\sum n_k^2$, rather than as N^2 .

The effect on σ_T of daily versus monthly recalibration of the transfer-measuring instruments is shown in Fig. 7. The relative standard deviation (RSD), σ_T divided by the throughput Nb , is plotted as a function of the number N of processed batches. Values of $\sigma_{\epsilon b}$ and $\sigma_{\eta b}$ have been taken to be 2% and 0.5%, respectively; these values correspond to $N_0 = 18$ [Eq. (9)]. The

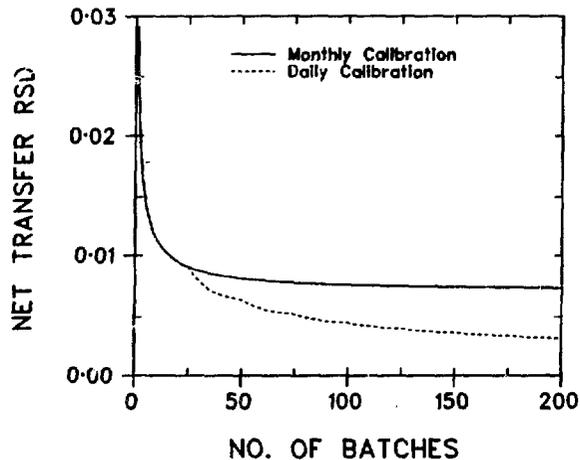


Fig. 7.

Effect of calibration on transfer measurement errors.

net-transfer RSD varies as $[(\sigma_{\epsilon b}^2 + \sigma_{\eta b}^2)/N]^{1/2}$ for small N and as $(\sigma_{\eta b}^2/K)^{1/2}$ for large N ; that is, when the transfer correlations are dominant.

Correlations between transfer measurements limit the sensitivity of materials balances over sufficiently long accounting periods. Therefore, the parameters $\sigma_{\eta b}$ and K are especially important. The value of $\sigma_{\eta b}$ depends primarily on the measurement control procedures and on the quality of available calibration standards, whereas the value of K depends on how often the transfer-measuring instruments are recalibrated. Adequate measurement controls must include well-characterized standards for the transfer measurements and must provide for recalibration of the transfer-measuring instruments.

4. Results. Table III contains values of the standard deviation σ_{MB} of materials balances calculated for the ideal process. Results are given for four accounting periods: one batch, one day, one week, and one month (30 days), and for two transfer calibration periods, one day and one month. The inventory-change and net-transfer components of σ_{MB} are given separately. Calculated values are shown for one UPAA in a series arrangement, one UPAA in a parallel arrangement, and for the entire process MBA (see Fig. 6). Note that the data for the process MBA are a synthesis of the UPAA data. In practical application the capability of combining the same accounting data in different ways to form materials balances for various accounting envelopes provides obvious safeguards advantages that can be exploited by the MMAS software.

Examination of the data in Table III supports the following conclusions. For relatively short accounting periods the materials balance standard deviation (σ_{MB}) is determined primarily by the size of the inventory (I) and the inventory instrument-precision RSD ($\sigma_{\epsilon I}$). For longer accounting periods, σ_{MB} is

TABLE III

MATERIALS ACCOUNTING IN AN IDEAL PROCESS

Accounting Period	Standard Deviation (kg)					
	Monthly Recalibration			Daily Recalibration		
	Series UPAA	Parallel UPAA	Process MBA	Series UPAA	Parallel UPAA	Process MBA
Batch						
Inventory change	0.71	0.71	1.58	0.71	0.71	1.58
Net transfer	0.06	0.06	0.06	0.06	0.06	0.06
Materials balance	0.71	0.71	1.58	0.71	0.71	1.58
Day						
Inventory change	0.71	0.71	1.58	0.71	0.71	1.58
Net transfer	0.45	0.14	0.45	0.45	0.14	0.45
Materials balance	0.84	0.72	1.64	0.84	0.72	1.64
Week						
Inventory change	0.71	0.71	1.58	0.71	0.71	1.58
Net transfer	2.59	0.60	2.59	1.20	0.38	1.20
Materials balance	2.68	0.93	3.03	1.39	0.80	1.98
Month						
Inventory change	0.14	0.14	0.32	0.14	0.14	0.32
Net transfer	10.72	2.23	10.72	2.48	0.79	2.48
Materials balance	10.72	2.24	10.72	2.48	0.81	2.50

determined by the number (N) and the size (b) of the transfers, the transfer calibration-error RSD ($\sigma_{\eta b}$), and the number (K) of transfer-instrument recalibrations.

The use of parallel process lines having reduced throughput and inventory for the same total plant throughput can markedly improve materials accounting sensitivity. Reduction of in-process inventory and accessibility of process equipment for inventory measurements are important design considerations. In this regard, large-capacity tanks present special accounting problems, and strict surveillance (process monitoring) measures should be considered in addition to materials accounting measures. Processing of relatively small batches and operation of the process near steady state generally enhance the capability of materials accounting.

From the point of view of materials measurements, rapid in-line or at-line assay techniques that provide precise inventory measurements and accurate transfer measurements, with provision for frequent recalibration of the transfer-measuring instruments, are generally favored. The period between physical inventories should be coupled to the buildup of transfer-measurement correlations; that is, after the materials-balance error standard deviation for the MBA becomes unacceptably large, a physical inventory is necessary to "rezero" the accounting system.

VI. DECISION ANALYSIS

The most promising measurement and accounting strategies are combined with statistical techniques in comparative studies of loss-detection sensitivities. Analysis of materials accounting data for indications of possible nuclear material diversion is one of the major functions of the MMAS. Diversion may occur in two basic patterns: abrupt diversion (the single theft of a relatively large amount of nuclear material), and protracted diversion (repeated thefts of nuclear material on a scale too small to be detected in a single materials balance because of measurement uncertainties).

The use of unit-process accounting and dynamic materials balances enhances the ability to detect losses, but it also means that the operator of the safeguards system will be inundated with materials accounting data. Furthermore, the significance of any isolated set of measurements is seldom readily apparent and may change from day to day, depending on plant operating conditions. Clearly, it is imperative that the safeguards system operator be assisted by a coherent, logical framework of analysis tools.

Decision analysis, which combines techniques from estimation theory, decision theory, and systems analysis, is such a framework, and is well suited for statistical treatment of the dynamic materials accounting data that become available sequentially in time. Its primary goals are detection of nuclear material losses, estimation of the amount(s), and determination of the significance of the estimates.

The detection and estimation functions of decision analysis are based on classical hypothesis testing and modern state-variable estimation techniques. The systems analysis portion attempts to set thresholds for the hypothesis tests in a rational fashion, for example, by using utility theory to determine acceptable false-alarm and detection probabilities.

The detection function is based on acceptance of the hypothesis (H_1) that some (initially unknown) amount of nuclear material is missing versus the hypothesis (H_0) that all nuclear material is present. One useful kind of decision test compares a likelihood ratio to a threshold. The likelihood ratio is defined roughly as the ratio of the probability that nuclear material is missing to the probability that it is not, with the threshold determined by the desired false-alarm and detection probabilities.

A. Sequential Decision Tests

A typical sequential decision test is illustrated by Fig 8. The curves represent possible values of a test statistic that is derived from accounting measurements in the two cases of no missing nuclear material and missing nuclear material. These two cases are represented by the curves centered at 0 and at 3, respectively. The uncertainty in the statistic is represented by the widths of the curves. Clearly, if the amount of missing material is large, the two curves will not overlap significantly, and the decision is straightforward. However, if the amount of

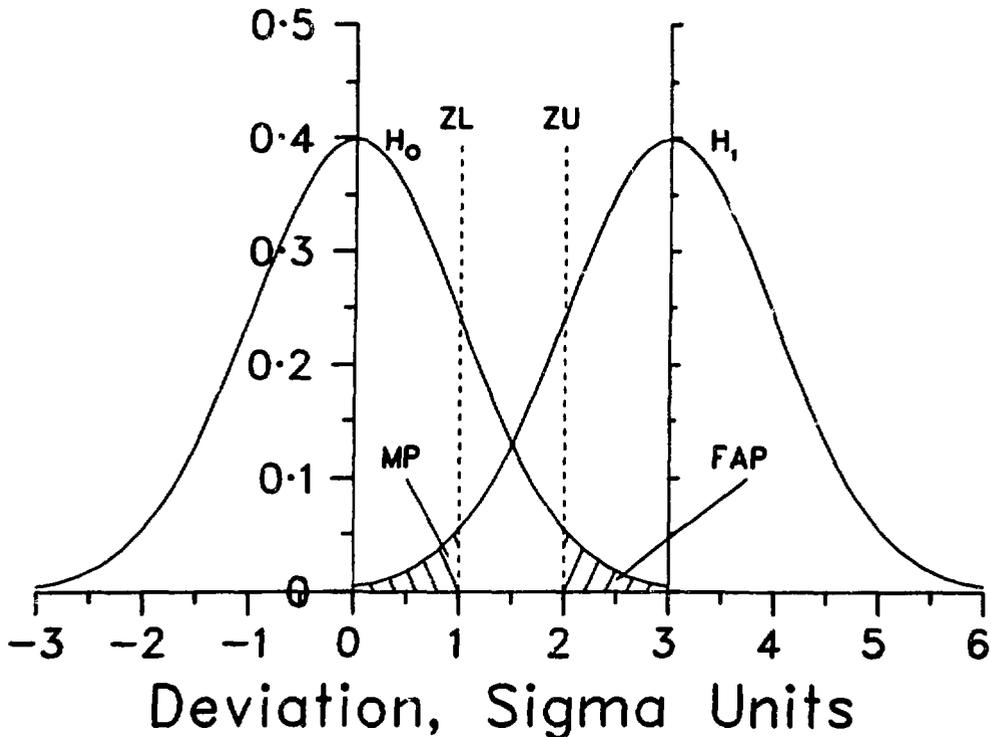


Fig. 8.

Probability density functions representing no missing nuclear material and missing nuclear material.

missing material is small, the two curves overlap and the possibility arises of making incorrect decisions. To make decisions that have the desired characteristics, two boundaries, ZU and ZL, are selected. If the statistic falls to the left of ZL, one concludes that there probably is no missing material. If the value falls to the right of ZU, one concludes that material may be missing. If the value falls between ZL and ZU, no decision is made until more data are gathered.

Note that two incorrect decisions can be made. One can conclude that there is nuclear material missing when there is none, denoted by the shaded area in Fig. 8 labeled FAP for false-alarm probability, or one can conclude that there is no missing nuclear material when in fact there is, denoted by the shaded area in Fig. 8 labeled MP for miss probability. The basic problem in detection is to minimize the probabilities of these two incorrect decisions.

B. Test Statistics

A variety of test statistics can be formed from the materials accounting data and tested sequentially for indications of diversion. Each statistic is based on a different assumption concerning the state of prior knowledge of the measurement errors

and of the diversion strategy. Three of the most useful test statistics are the Shewhart, Cusum, and Uniform Diversion statistics.

1. Shewhart. The Shewhart chart is the oldest graphical-display tool to be widely used by industry for process control. In the chart's standard form, measured data are plotted sequentially on a chart where 2σ and 3σ levels are indicated. In safeguards applications, the Shewhart chart is a sequential plot of the materials balance data with 1σ error bars. This chart is most sensitive to large, abrupt shifts in the materials balance data.

2. Cusum. The Cusum statistic is computed after each materials balance period. It is the sum of all materials balances since the beginning of the accounting interval. Cusum charts are sequentially plotted values of the Cusum statistic that are used to indicate small shifts in the materials balance data. The Cusum variance is a complex combination of the variances of individual materials balances, because these balances usually are not independent. Correlation between materials balances has two principle sources. The first is the correlation, discussed previously, between measurement results obtained by using a common instrument calibration. The magnitudes of the associated covariance terms depend on the magnitude of the calibration error and the frequency of each instrument recalibration; omission of these terms can cause gross underestimation of the Cusum variance. The second source of correlation between materials balances is the occurrence, with opposite signs, of each measured value of in-process inventory in two adjacent materials balances. As a result, only the first and last measurements of in-process inventory appear in the Cusum, and only the corresponding variances appear in the Cusum variance.

3. Uniform Diversion Test. The Kalman filter is applied widely to communications and control systems for signal processing in stochastic environments. It is a powerful tool for extracting weak signals embedded in noise. It has been applied recently to safeguards, because dynamic materials accounting systems rapidly generate large quantities of data that may contain weak signals caused by repeated, small diversions embedded in the noise produced by measurement errors.

The uniform diversion test (UDT) is designed to detect a small, constant diversion during each materials balance period. Minimum-variance, unbiased estimates of the average diversion and the inventory at each time are obtained using the Kalman filter.

The Cusum and the UDT are complementary in several respects. The Cusum estimates the total amount of missing nuclear material at each time step, and its standard deviation is the 1σ error in the estimate of the total. The UDT, on the other hand, estimates the average amount of nuclear material missing from each materials balance, and its standard deviation estimate is taken as the 1σ error in the estimate of the average. Thus, both

the Cusum and the UDT search for a persistent, positive shift of the materials balance data--the Cusum by estimating the total, the UDT by estimating the average.

C. Data Analysis Graphic Aids

1. Alarm Charts. The decision tests examine all possible sequences of the available materials balance data because, in practice, the time at which a sequence of diversions begins is never known beforehand. Furthermore, to ensure uniform application and interpretation, each test is performed at several levels of significance (false-alarm probability). Thus, it is useful to have a graphic display that indicates those alarm-causing sequences, specifying each by its length, time of occurrence, and significance. One such tool is the alarm-sequence chart, which has proven useful in summarizing the results of the various tests and in identifying trends of the materials accounting data.

To generate the alarm-sequence chart, each sequence that causes an alarm is assigned a descriptor that classifies the alarm according to its significance (false-alarm probability), and a pair of integers (r_1, r_2) that are, respectively, the indexes of the initial and final materials balances in the alarm sequence. The alarm-sequence chart is a point plot of r_1 vs r_2 for each sequence that caused an alarm, with the significance range of each point indicated by the plotting symbol. One possible correspondence of plotting symbol to significance is given in Table IV. The symbol T denotes sequences of such low significance that it would be fruitless to examine extensions of those sequences; the position of the symbol T on the chart indicates the termination point.

TABLE IV

ALARM CLASSIFICATION FOR THE ALARM-SEQUENCE CHART

<u>Classification (Plotting Symbol)</u>	<u>False-Alarm Probability</u>
A	10^{-2} to 5×10^{-3}
B	5×10^{-3} to 10^{-3}
C	10^{-3} to 5×10^{-4}
D	5×10^{-4} to 10^{-4}
E	10^{-4} to 10^{-5}
F	$< 10^{-5}$
T	~ 0.5

For example, consider a sequence of materials balance data beginning at balance number 12, and suppose that one of the tests gives an alarm with a false-alarm probability of 2×10^{-4} at balance number 19. Then on the alarm-sequence chart for that test, the letter D would appear at the point (12,19). This procedure continues for all possible sequences of the available materials balances. It is always true that $r_1 \leq r_2$, so that all symbols lie to the right of the line $r_1 = r_2$ through the origin. Persistent data trends (repeated diversions) cause long alarm sequences ($r_1 \ll r_2$), and the associated symbols on the alarm chart extend far to the right of the line $r_1 = r_2$.

2. Examples. Simulated results of diversion detection for 1 week of process operation are given in Figs. 9-11. Each figure shows results obtained with one of the decision analysis tests described above, the Shewhart, Cusum, and UDT. Each figure shows plots of the test statistic and the corresponding alarm chart for the case of no diversion (upper) and for the case of diversion (lower). In each case a strategy of low-level uniform diversion is simulated during the 51-125th materials balances. The diversion occurs during the third, fourth, and fifth days of the week. Note that significant alarms are given by the Cusum and UDT during the fourth day (the second day in the diversion scenario).

D. Systems Performance Analysis

Essential to the design of nuclear materials accounting systems is an analysis of their expected performance in detecting losses of nuclear material. Systems performance analysis, in turn, implies the definition of suitable performance measures that can be easily related to externally established criteria. Thus, there are two aspects of the performance analysis problem: first, defining performance measures, and second, relating those measures to established, quantitative performance criteria.

Performance measures for any nuclear materials accounting system embody the concepts of loss-detection sensitivity and loss-detection time. Because of the statistical nature of materials accounting, loss-detection sensitivity can be described in terms of the probability of detecting some amount of loss while accepting some probability of a false alarm. Loss-detection time is the time required by the accounting system to reach some specified level of loss-detection sensitivity. Note that the loss scenario is not specified; that is, whether the loss is abrupt or protracted, the total loss is the measure of performance. Note also that loss-detection time refers only to the internal response time of the accounting system.

1. Performance Surfaces. Intuitively, the performance of any accounting system is describable by some function

$$P[L, N, \alpha]$$

where P is the accounting system's probability of loss detection, L is the total loss over a period of N balances, and α is the

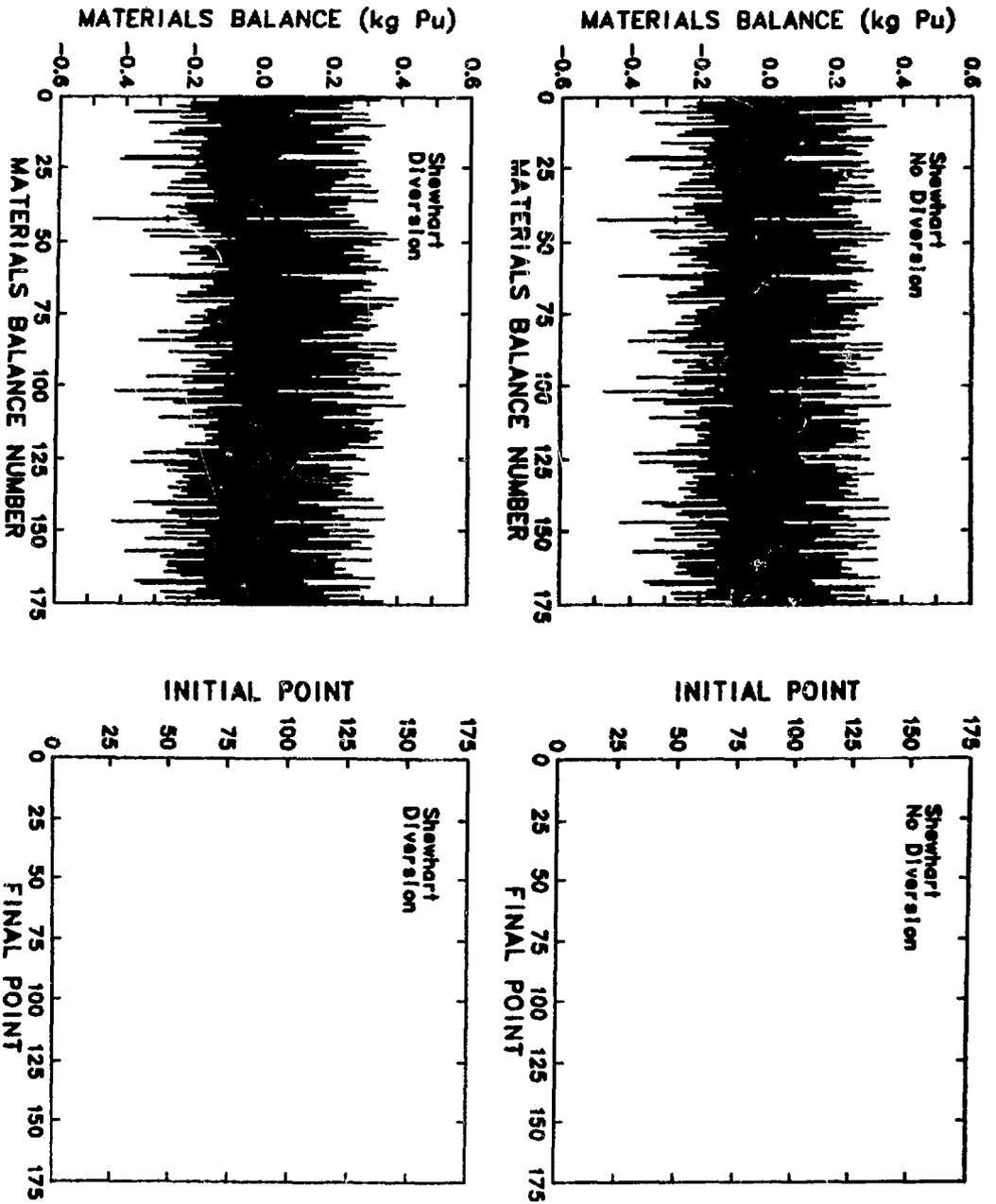


Fig. 9.
 Shewhart and alarm charts.

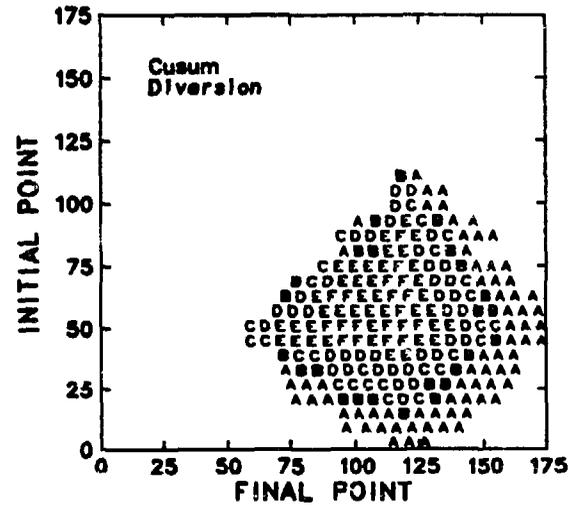
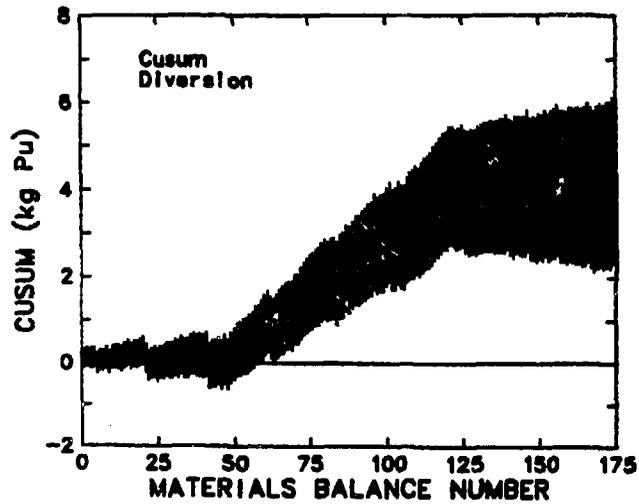
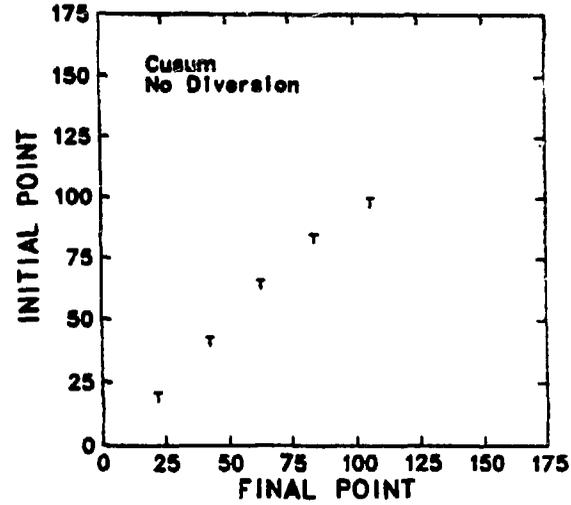
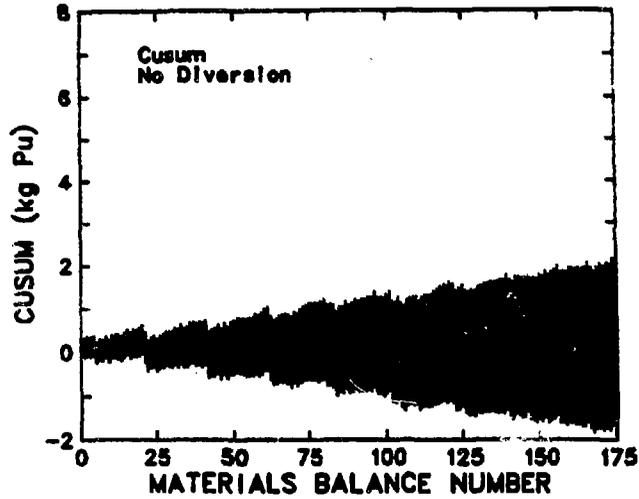


Fig. 10.
Cusum and alarm charts.

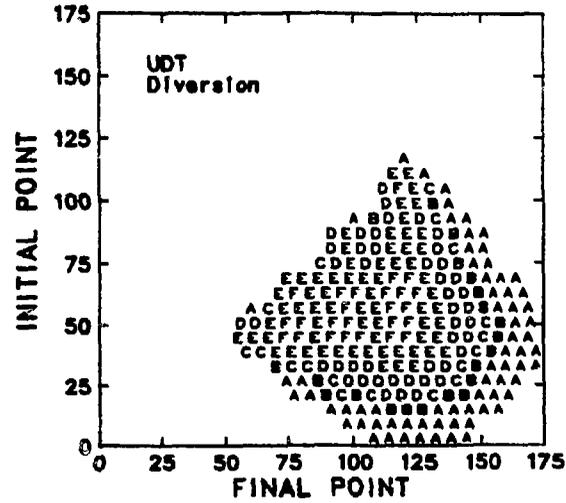
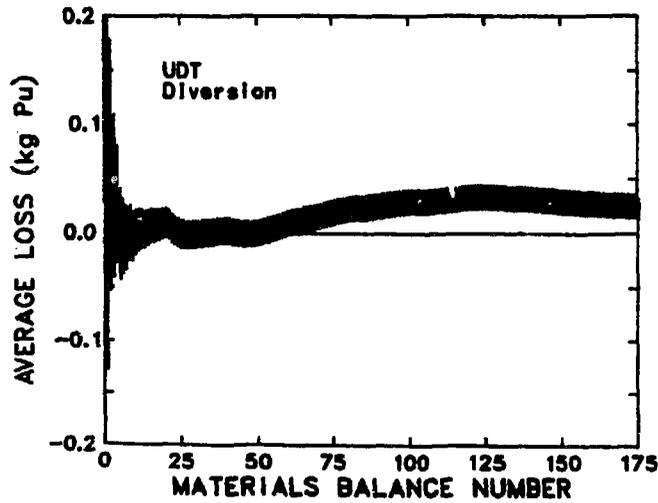
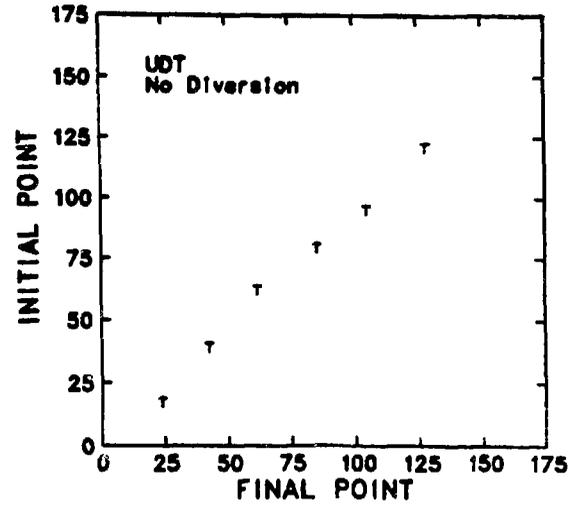
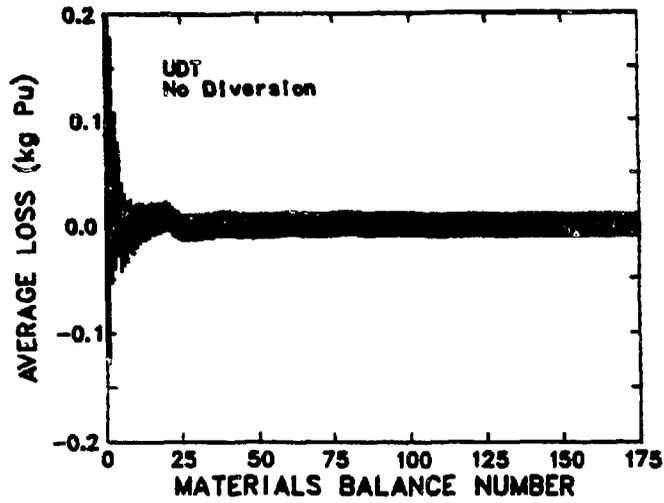


Fig. 11.
UDT and alarm charts.

false-alarm probability. Thus, a convenient way of displaying system performance is a three-dimensional graph of the surface P vs L and N for some specified value of α . We call such graphic displays performance surfaces. They are plotted in the three-dimensional space (N, L, P) illustrated in Fig. 12. They portray (correctly) the expected performance of an accounting system as a function of the three performance measures, loss, time, and detection probability, rather than as a single point.

2. Cusum Performance Surfaces. Because systems performance may depend on the details of a particular diversion strategy as well as on details of the accounting system, the overall performance is difficult to quantify. Fortunately, however, the Cusum statistic does not depend on how the material was lost, but responds only to the total loss L during any time interval N . Moreover, the Cusum test detects any loss relatively well, even though it is seldom the best test for any particular scenario.

If the Cusum test is always among the tests applied to the accounting data, the performance of the accounting system will always be at least as good as the loss-detection power of the Cusum test. Thus, the Cusum test provides a conservative, scenario-independent measure of systems performance.

Performance surfaces generated using the Cusum test (only) are referred to as Cusum performance surfaces because they are approximations to the expected performance of the system. The performance of more powerful tests for specific loss scenarios, such as the UDT, should be compared with the Cusum test performance to ensure that the Cusum approximation is not unduly pessimistic.

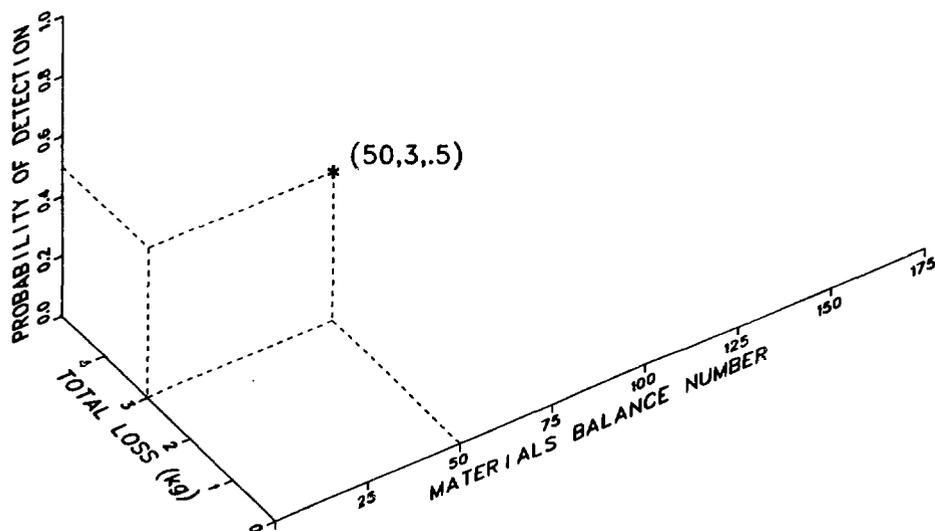


Fig. 12.
Three-dimensional space of performance surfaces.

3. Examples. Figure 13 shows two examples of Cusum performance surfaces produced using a commercially available computer graphics program (DISSPLA) that plots isometric contours of total loss L and materials balance number N. Note that contours of fixed loss-detection probability are also plotted on the Cusum performance surfaces in probability increments of 0.1.

Figure 13 illustrates the use of Cusum performance surfaces in accounting systems design and analysis. The expected performance of "worst-case" and "best-case" accounting systems are shown. The improvement in sensitivity primarily obtained by periodically recalibrating feed and product measuring devices is obvious by comparing the figures.

VII. DISCUSSION

The materials accounting systems discussed above enhance materials control and accounting by providing better information on the locations and amounts of nuclear material than is currently available by conventional methods. Advanced accounting systems must be integrated into the process and therefore should be incorporated early in the design of fuel-cycle facilities.

Dynamic accounting systems have many features in common with advanced process control systems. Improved measurements and automated data handling techniques benefit both systems. Such systems must be tailored for each process, and instrumentation must be evaluated in terms of sensitivity, reliability, and operational acceptability.

Particular process design features can have important materials accounting consequences that should be considered during process design. Based on experience, it should be expected that design alternatives can be identified that are beneficial to safeguards and benevolent to the process.

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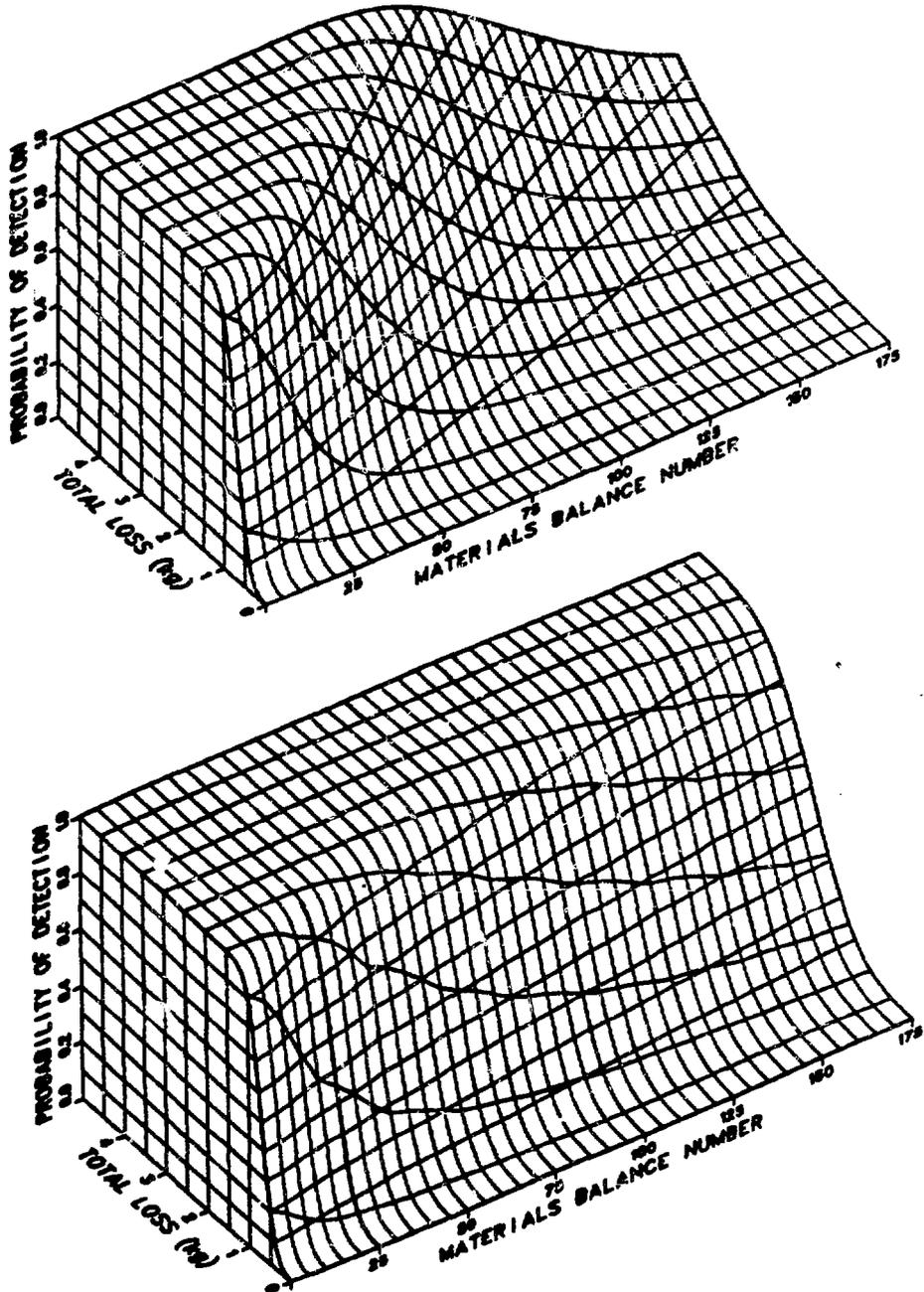


Fig. 13.
Cusum performance surfaces for two accounting cases;
worst (upper), best (lower).

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 13: SAFEGUARDING NUCLEAR POWER STATIONS

The basic features of nuclear fuel accounting and control in present-day power reactors are considered. Emphasis is placed on reactor operations and spent-fuel characteristics for Light-Water Reactors (LWRs) and Heavy-Water Reactors (HWRs)

After the session, participants will be able to:

1. Describe the basic fuel characteristics in LWRs and HWRs.
2. Describe typical fuel quantities (fresh, in-core, and spent) at LWR and HWR facilities.
3. Describe the movement of fuel and basic fuel management practices within each facility.
4. Describe the basic fuel accounting and inventory verification procedures for both LWR and HWR facilities.



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SESSION 13: SAFEGUARDING NUCLEAR POWER STATIONS

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I. INTRODUCTION

Most of the world's inventory of plutonium is contained in the spent-fuel assemblies that reside in the spent-fuel ponds of nuclear power stations. Because reprocessing of these spent-fuel assemblies is occurring at a very low rate and because away-from-reactor storage has not yet occurred to any significant extent, the world's inventory of plutonium will by necessity remain at nuclear power stations for many years. Thus, the nuclear power station is of significant nuclear safeguards interest.

The discussion in this paper focuses on the single facility--the nuclear power station with its inventories of fresh fuel, in-core fuel, and spent fuel. The focus is on the off-load refueled, light-water-cooled power reactor (LWR) because they are found in the greatest numbers in the world; however, attention is also given to the on-line refueled, heavy-water-moderated and cooled reactor (HWR).

The nuclear power station has several characteristics, which are unique to safeguards, in the nuclear fuel cycle. The nuclear material is almost always found in discrete, encapsulated units (called fuel assemblies or fuel bundles) and it remains in the same physical form during its entire residence time at the power station. It arrives at the power station in the form of fuel assemblies, it resides in the reactor core as fuel assemblies, and it is stored in the spent-fuel pond as fuel assemblies. The integrity of the assemblies is therefore maintained. Fuel assemblies are rarely disassembled at nuclear power stations; however, this could change in the future and introduce new safeguards problems. At all other facilities in the nuclear fuel cycle--except the away-from-reactor storage pond--the nuclear material can change both physical and chemical form.

The nuclear power station is the only facility in the entire fuel cycle where large quantities of fissile materials [uranium-235 (^{235}U) and plutonium-239 (^{239}Pu)] are consumed and produced. Nuclear material is not conserved. The ultimate result of this consumption and production of fissile materials is, of course, the generation of electrical energy.

Because the integrity of the fuel assemblies is maintained and because the nuclear material content of the fuel assemblies is not conserved, safeguarding at nuclear power stations is primarily done by item accountability, containment, and surveillance, which will be addressed later in detail.

II. CHARACTERISTICS OF NUCLEAR POWER STATIONS^{1,2}

A nuclear fission power reactor provides an environment in which fission reactions are initiated, sustained, and controlled; and it provides for removal of heat for power production. Shown in Fig. 1 are certain components common to all reactors: the core, coolant, control rods, and shielding. Most current power reactors also include a moderator. The coolant, either liquid or gas, flows over the fuel rods and removes the fission heat from the fuel. The control rods, usually made of materials that readily absorb neutrons, are positioned inside the fuel assembly (core) to regulate the fission chain reaction. The shielding consists of special materials that surround different portions of the reactor system to prevent harmful radiation from escaping into the local environment.

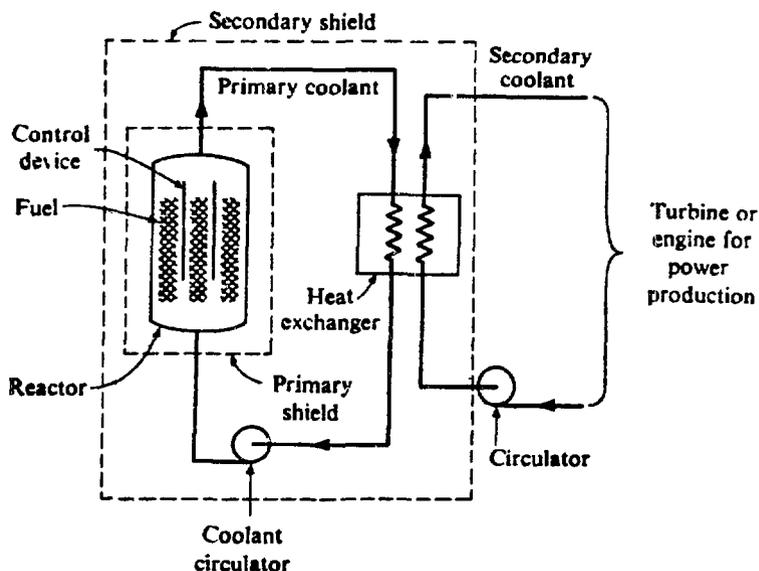


Fig. 1. Schematic of a nuclear power reactor.

The core of the nuclear reactor is that volume that contains the fission fuel. The fissile fuels used in nuclear reactors are ^{235}U , uranium-233 (^{233}U), or plutonium-239 (^{239}Pu). Uranium-238 (^{238}U) is not a fissile fuel but it is a fertile material that leads to the production of fissile ^{239}Pu . Enrichment of the fuel refers to the amount of fissionable material in the fuel. In the case of uranium it means the isotopic percentage of ^{235}U in the fuel (0.7% is contained in natural uranium). Typical water-cooled power reactors contain 2-4% ^{235}U .

The kinetic energy of the neutrons inducing fission also constitutes an important characteristic of nuclear reactors. Thus, a thermal reactor is one in which fission is induced by slow neutrons (neutrons in thermal energy equilibrium with the reactor core material). Most of today's power reactors are indeed thermal. A moderator is put into the reactor core to slow

the neutrons to thermal energies by scattering collisions. Fast reactors make no attempt to slow the high-energy neutrons produced in the fission chain reaction and thus they contain no moderator. Fast neutron fission favors breeding and opens the possibility of converting vast supplies of ^{238}U and thorium-232 (^{232}Th) to fissile nuclear fuel.

Of the many possible types of nuclear fission power reactors, only two have so far attained worldwide use in electric power systems. These are the light-water-cooled, light-water-moderated reactors developed initially in the United States and the heavy-water-cooled, heavy-water-moderated reactors developed initially in Canada. Gas-cooled, graphite-moderated, thermal reactors, developed initially by Great Britain, have seen only limited application. Although fast breeder reactors hold promise for the future, they are still under development.

As the name implies, LWRs use ordinary water (H_2O , as opposed to heavy water D_2O) as both coolant and moderator. The two common versions of LWR are the boiling-water reactor (BWR) and the pressurized-water reactor (PWR). The major difference between the PWR and the BWR is in the operating pressure. In the PWR, typical operating conditions are 2200 psia (pounds per square inch absolute--compared to 14.7 psia for normal atmospheric pressure) and 330°C , a greatly subcooled condition. At this very high pressure, the water in the reactor cannot boil, even at a 330°C temperature. The high-pressure water removes fission heat from the reactor core and is circulated through a steam generator to produce 290°C , 1000 psia steam. The steam then drives a turbine-generator to produce electrical energy.

In the BWR, the operating pressure is reduced to about 1000 psia; the cooling water at this lower pressure boils into 290°C steam directly within the reactor vessel. After passing through moisture separators and steam dryers, the steam then goes directly to the turbine. Thus, the BWR does not require an intermediate heat exchanger (steam generator).

One disadvantage in the use of LWRs for electrical power generation is the relatively low steam temperature (290°C) and resulting low thermal-conversion efficiency. An LWR generates electricity with about 32-33% efficiency as compared with 36-38% net efficiencies achieved with modern fossil-fueled plants.

The use of natural uranium, heavy-water, and on-line refueling are the basic elements in the HWR design philosophy. The most common version of HWR is the CANDU reactor manufactured and marketed worldwide by Atomic Energy of Canada Limited (AECL). CANDU systems employ D_2O as both the moderator and the coolant. The term CANDU is essentially synonymous with CANDU-PHW, the Canadian Deterium Uranium - Pressurized Heavy Water reactor.

The CANDU-600 reactor, the most common design today, can produce more than 600 MWe with a thermal efficiency in the range of 29-30%. The reactor vessel is a large, horizontally oriented cylindrical tank that contains the low-pressure heavy-water moderator. This tank is penetrated by a number of horizontal fuel channels that contain the natural-uranium fuel and the pressurized, heavy-water coolant. The coolant is pumped through the fuel channels and then through heat exchangers (steam generators)

to produce light-water steam at 400 psia and 260°C, which is then fed to the turbine.

III. "TYPICAL" FUEL CHARACTERISTICS AT NUCLEAR POWER STATIONS

The fuel assemblies for the two types of LWRs are very similar. Both use uranium dioxide as the fuel material; the uranium is enriched to 2-4% ^{235}U (Refs. 1,2). The slightly enriched uranium dioxide is fabricated into the form of cylindrical fuel pellets (~8-10 mm diam and ~10 mm long). The pellets are then loaded into long zirconium-alloy cladding tubes to produce fuel pins or fuel rods (~4 m long). A rectangular array of pins forms the final fuel assembly, or fuel bundle. The fuel assemblies are then placed in a steel pressure vessel in a right circular cylindrical array. The number of assemblies required depends on the geometrical arrangement, the reactor type, the uranium enrichment, and the operating power level of the reactor.

A shortened cutaway version of a BWR fuel assembly is shown in Fig. 2. The 8 x 8 square pin array typically contains approximately 62 fuel pins per assembly.^{1,3} The PWR pin array, 16 x 16 or 17 x 17, is larger than that of the BWR and the fuel assembly shown in Fig. 3 typically contains 236-264 fuel pins.^{1,4}

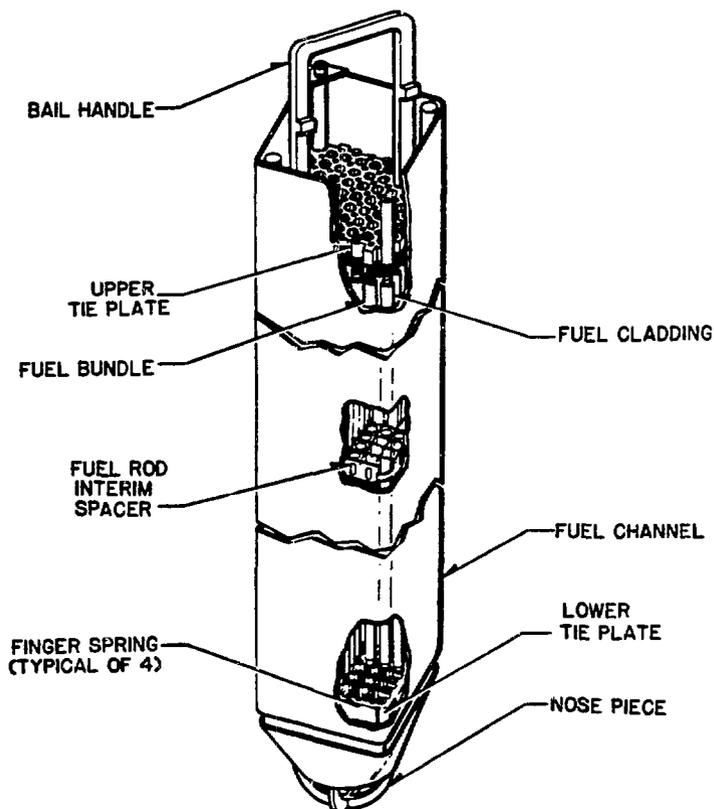


Fig. 2. BWR fuel assembly - shortened cutaway view.³

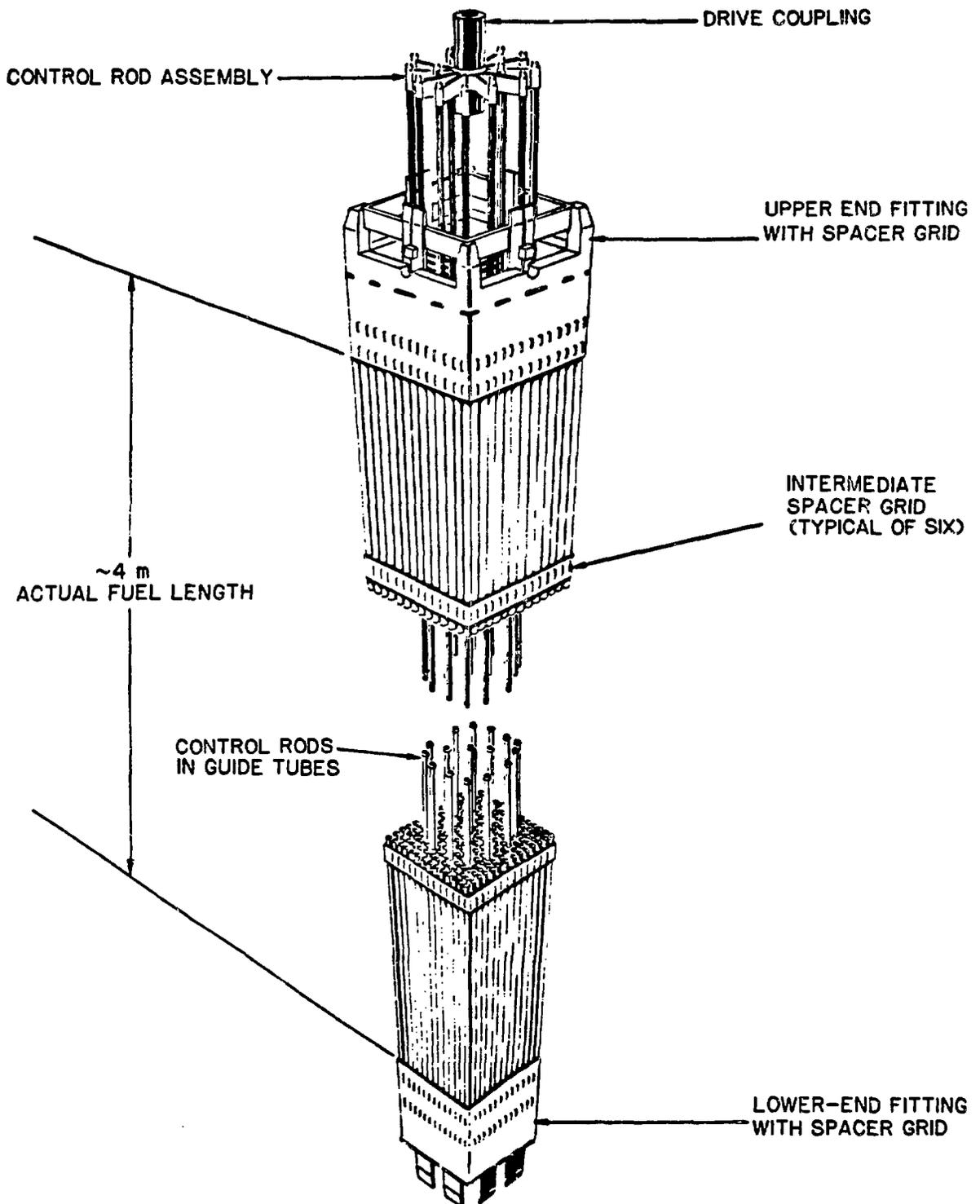


Fig. 3. PWR fuel assembly - cutaway showing partially inserted control rod assembly.⁴

Both the BWR and PWR fuel assemblies have unique serial numbers engraved on the top plate for positive identification.

In the HWR each fuel bundle (about 500 mm long and 100 mm in diameter) is made up of 37 Zircaloy-clad fuel pins containing natural UO_2 pellets (~12 mm diam and ~16 mm long), Fig. 4 (Refs. 1,5). Each fuel bundle contains 20-21 kg of natural uranium dioxide. The heavy-water moderator is contained in a horizontal reactor vessel (calandria), which is about 7.6 m in diameter by 4 m long. The vessel is penetrated by 380 calandria pressure tubes. Twelve fuel bundles are placed end-to-end in each of the pressure tubes such that the heavy-water coolant flows through the tubes and the fuel bundles simultaneously.

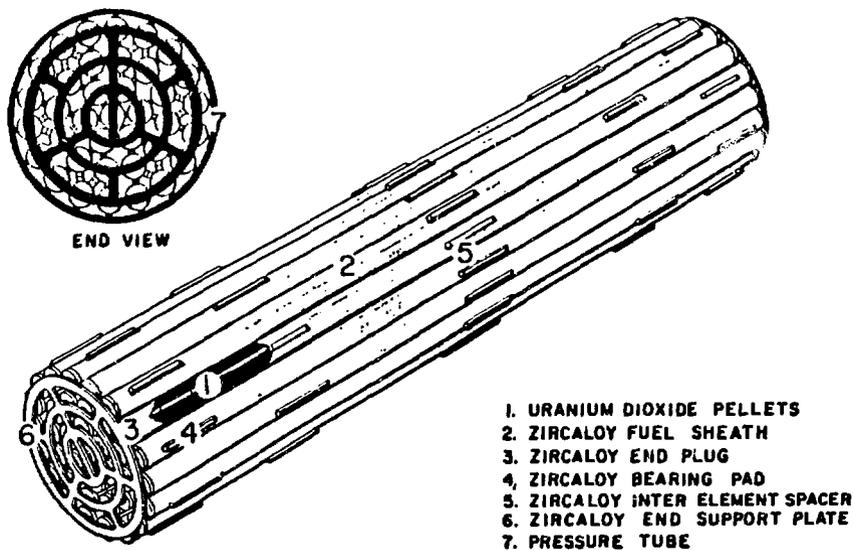


Fig. 4. CANDU fuel bundle.⁵

The characteristics of the PWR fuel listed in Table I correspond to a typical 1000-MWe station that operates on a once-through fuel cycle. The reactor is refueled off-load once a year; that is, the reactor is shut down for refueling. About one-third of the core (approximately 65 fuel assemblies) is replaced during the refueling. The uranium in the fuel is enriched to 2-4%.

The characteristics of the BWR fuel in Table I also correspond to a 1000-MWe plant operating on a once-through fuel cycle. This reactor is refueled off-load once a year during which about one-fourth of the core (or approximately 190 fuel assemblies) is replaced. The uranium in the fuel is enriched to 2-3%.

In both of these LWRs, the fuel in the reactor is inaccessible during periods of operation. The top of the reactor pressure vessel must be removed before the refueling can take place. The fuel assemblies at a LWR are therefore basically stationary during most of the year.

TABLE I

TYPICAL POWER REACTOR FUEL CHARACTERISTICS*

Typical PWR (1000 MWe)

Off-load refueling	1-year interval
Fuel enrichment	2-4%
Core inventory	~200 fuel assemblies 100 000 kg
Reload	~65 fuel assemblies
Spent fuel	~65 fuel assemblies
Pu production	~200 kg/year
Pu content spent fuel	~3 kg/assembly

Typical BWR (1000 MWe)

Off-load refueling	1 year
Fuel enrichment	2-3%
Core inventory	~750 fuel assemblies (150 000 kg)
Reload	~190 fuel assemblies
Spent fuel	~190 fuel assemblies
Pu production	~200 kg/year
Pu content spent fuel	~1 kg/assembly

Typical HWR (600 MWe)

On-line refueling	16 fuel bundles/day
Fuel enrichment	Natural uranium (0.72%)
Core inventory	4600 fuel bundles (380 pressure tubes x 12 fuel bundles per pressure tube) 98 000 kg
Reload	On-line 4500 fuel bundles/year
Pu production	~300 kg/year
Pu content spent fuel	~0.07 kg/bundle

*Adapted from Refs. 1, 2, 3, 4, 5, and 13.

The characteristics of the HWR fuel listed in Table I correspond to a 600-MWe unit, characterized by the CANDU-600.⁵ This reactor is refueled on-line; that is, refueling is done while the reactor is running. The reactor contains approximately 4600 fuel bundles. About 16 fuel bundles are replaced each day while the reactor is operating at full power.

IV. "TYPICAL" FUEL INVENTORIES AT NUCLEAR POWER STATIONS

As illustrated in Fig. 5, the inventories of nuclear material at nuclear power stations can be grouped as:

- Fresh fuel
- In-core fuel
- Spent fuel

The amount of nuclear material in the power station depends on the reactor type, the reactor power level, and the operating history of the station. Estimates of the nuclear material characteristics and flow for "typical" LWRs and HWRs were given in Table I.

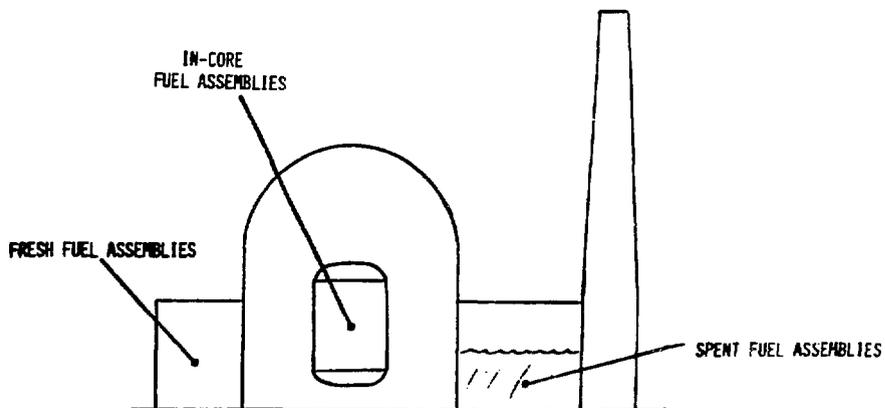


Fig. 5. Inventories of nuclear fuel at a nuclear power station.

Typical fuel assembly inventories for the three types of nuclear power stations are shown in Table II. The PWR has the smallest number of fuel assemblies in the inventory and the HWR has the largest. Spent-fuel ponds are usually designed to hold spent-fuel assemblies from several years of refueling.

Because the "back end" of the fuel cycle is developing slowly, many spent-fuel ponds throughout the world are being re-configured to hold even more spent-fuel assemblies. Thus, the number of spent-fuel assemblies remaining at the spent-fuel ponds of nuclear power stations is increasing.

The large throughput of fuel bundles in the HWR causes the number of items in the spent-fuel pond to be very large. More

TABLE II

TYPICAL FUEL INVENTORIES AT NUCLEAR POWER STATIONS¹³
(Number of Fuel Assemblies/Bundles)

<u>Reactor Type</u>	<u>Fresh-Fuel Storage</u>	<u>In Core</u>	<u>Spent-Fuel Storage</u>
PWR	75	200	Few hundred
BWR	200	750	Several hundred
HWR	3000	4600	Several thousands

than 20 000 spent-fuel bundles will accumulate at a single 600-MWe power station in 5 years.

V. SAFEGUARDING NUCLEAR POWER REACTORS⁷

Since the fuel in a nuclear power reactor is packaged in large discrete fuel assemblies or bundles, the reactor is classified as an "item facility;" that is, the nuclear fuel is contained in identifiable items, the integrity of which is usually preserved during their presence in the plant. Such items can be followed from the fuel fabrication plant, through the reactor, to reprocessing or long-term storage. Safeguards inspectors can count the fuel bundles, identify them, and verify the fuel composition by nondestructive measurements.

Safeguarding by item accountability requires that the safeguarding authorities, which are both the national authority (including EURATOM) and the international authority (IAEA), be able to verify the identity of the items. This is generally done by item counting and identification of serial numbers. Seals and surveillance cameras (both film and video) are used to complement item accountability to reduce the effort required during physical inventory verification.⁶

A. Safeguards Systems

The main emphasis for safeguarding nuclear reactors is on accounting for each individual fuel assembly, and in this way verifying the quantity of nuclear material present. The quantity of material in these units is not measured by the reactor operator, but instead is based on data supplied by the fuel fabricator and upon theoretical calculations of production and loss resulting from fuel burnup. Physical inventory is established by counting assemblies and identifying serial numbers. Seals and surveillance cameras are used to maintain continuity of safeguards knowledge during time intervals between inspections.⁷

The major components of the safeguards system can be summarized as follows:

- auditing of facility records and comparison with reports submitted to the IAEA,
- periodic closing of the materials balance by the operator (usually annually) by taking a physical inventory,
- independent verification of nuclear material by the IAEA, usually by item counting and serial number identification, and
- application of containment and surveillance measures to maintain knowledge of nuclear material.

B. MBA Structure and Key Measurement Points

Reactor facilities are usually considered as one materials balance area (MBA) subdivided into several key measurement points (KMPs) to determine material flow and inventory. Typical material flow and material inventory KMPs are shown in Table III.

TABLE III

TYPICAL KEY MEASUREMENT POINTS AT A REACTOR FACILITY

Material Flow KMPs:

KMP1	Receipt of fresh fuel
KMP2	Nuclear loss and production
KMP3	Shipment of irradiation fuel

Material Inventory KMPs:

KMPA	Fresh-fuel storage
KMPB	Fuel in reactor vessel
KMPC	Spent-fuel storage
KMPD	Other locations

Figure 6 schematically illustrates the typical KMP structure at a reactor facility.⁸ It depicts the current IAEA policy of having loss and production reported at the time of discharge from the reactor core.

C. Inspection Activities

The IAEA generally performs one physical inventory verification (PIV) per year to verify the entire fuel inventory and three to five additional interim inspections to audit records, review surveillance pictures, check seals, and service cameras. These inspections normally involve a total of 10-15 man-days/year.

The objective of the annual physical inventory verification is to establish that the station's declared inventory is correct. For LWRs, inventory verification generally occurs at the end of

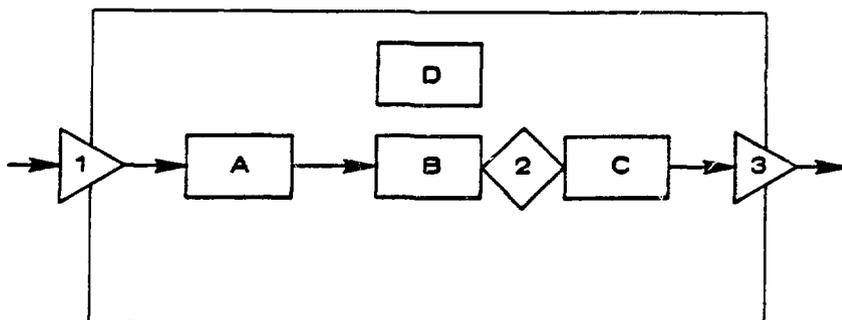


Fig. 6. Typical key measurement points in a power reactor. Inventory key measurement points are: A--fresh fuel, B--in core, C--spent fuel, D--other. Flow key measurement points are: 1--receipt, 2--production, 3--shipment.

the annual refueling, but before the top of the reactor vessel is replaced so that the inventory of items inside the reactor vessel can also be verified. For HWRs, the PIV coincides with the state's annual material balances report and physical inventory list.

1. Auditing of Records and Reports. The facility accounting records are examined to ensure that

- (a) adequate records are being kept,
- (b) they are arithmetically correct and internally consistent, and
- (c) they agree with reports submitted to the IAEA from the state safeguards authority.

Based on the records examination, the inspector is able to establish the "book" inventory of nuclear material at the facility, that is, the amount of material to be accounted for. In addition to accounting records, operating records may be examined to confirm that records of core changes and fuel movements are consistent with accounting records.

2. Inspection Reports. Since the reactor is classified as an item facility, quantitative measurements of nuclear materials are generally not performed. Inspectors' reports, therefore, are based on verification of the major components of the safeguards system described on page 10, that is, audit of records, physical inventory, and containment and surveillance (C/S) measures.

VI. SAFEGUARDING LIGHT-WATER REACTORS¹³

A. Fuel Inventory

The items (fuel assemblies) being safeguarded are located at three places in the LWR power station: fresh-fuel storage,

reactor vessel, and spent-fuel storage. Upon arrival at the reactor site, fuel assemblies are stored in a fresh-fuel storage area (usually dry, vertical racks) where they are accessible for inspection. The number of fresh-fuel assemblies in storage may range from 5-10 shortly after refueling to approximately 120-200 shortly before a scheduled refueling shutdown. The total annual flow of fresh fuel at a large LWR is ~35 000 kg of low-enriched uranium or 800 kg of ^{235}U (Refs. 1-4).

The reactor core contains 50 000-150 000 kg of uranium, depending upon reactor size. Refueling occurs annually with about one-third (PWR) or one-fourth (BWR) of the spent fuel replaced with fresh fuel. The irradiated elements remaining in the core may be shuffled to new locations to optimize power and fuel utilization. Fuel assemblies inside the core are accessible only during the refueling shutdown.

Irradiated fuel elements removed from the core are stored underwater in a storage pond. Most reactors are designed with a spent-fuel storage capacity of two to four complete cores, but safety procedures require that sufficient capacity always be available to permit a total core unloading in case of an emergency.

From a safeguards viewpoint, the irradiated fuel is strategically important because it contains roughly 1 and 3 kg of plutonium in BWR and PWR assemblies, respectively (see Table I). To ship spent fuel, a massive shielded shipping cask is lowered onto a special pad in the spent-fuel pond and loaded underwater with up to seven irradiated assemblies. Although it was initially envisioned that spent fuel be stored at reactor sites only temporarily (~1 year), the lack of reprocessing has resulted in large accumulations of irradiated fuel in reactor storage ponds.

B. Detection Targets

Based on material type and form, the technical objectives of IAEA safeguards at LWRs should be the detection of diversion of (1) 75 kg of ^{235}U contained in low-enriched fuel within 1 year or (2) 8 kg of plutonium within 1-3 months (see Appendix).¹⁰ At 3% ^{235}U , which is a typical midvalue for LWRs, 75 kg contained ^{235}U is equal to 2500 kg of uranium, which corresponds to ~6 PWR or ~13 BWR assemblies. Similarly, 8 kg plutonium is contained in ~3 PWR and ~8 BWR assemblies.

However, because of the widely accepted safeguards approach at LWRs, namely item accounting for discrete fuel assemblies, the IAEA has adopted the goal of (a) detecting the absence of one or more spent-fuel assemblies within 2-3 months and (b) the absence of one or more fresh-fuel assemblies within 1 year.¹¹

C. Diversion Possibilities

Table IV shows individual diversion possibilities, associated concealment methods, and corresponding safeguards measures.⁸ The basic diversion threats at power reactors fall into two categories: (1) removal of discrete assemblies (either fresh or irradiated, with or without the substitution of dummies) and (2) irradiation of undeclared fertile material.

TABLE IV

SUMMARY OF DIVERSION POSSIBILITIES FOR LIGHT-WATER REACTORS^{8,13}

<u>Diversion Possibilities</u>	<u>Concealment Methods</u>	<u>Safeguards Measures</u>
Removal of fuel elements from the fresh-fuel storage	Substitution with dummies	Item counting and identification Application of seals NDA measurements
Removal of fuel elements from the core	Substitution with dummies	Item counting and identification Seals Optical surveillance
Irradiation of undeclared fuel elements in the core	Undeclared shutdowns	Seals Optical surveillance
Removal of fuel elements from the spent-fuel pond	Substitution with dummies	Item counting and identification Optical surveillance NDA measurements
Removal of fuel elements from consignment when or after they leave the facility	Substitution with dummies or consignment. Understating of number of elements shipped and substitution with dummies in spent-fuel pond	Sealing of shipping container before shipment and verification of content at recipient facility, if possible

D. Inspection Activities

Typical activities that occur during inspections at an LWR are shown in Table V, which is an abbreviated version of a table in Ref. 12.¹³

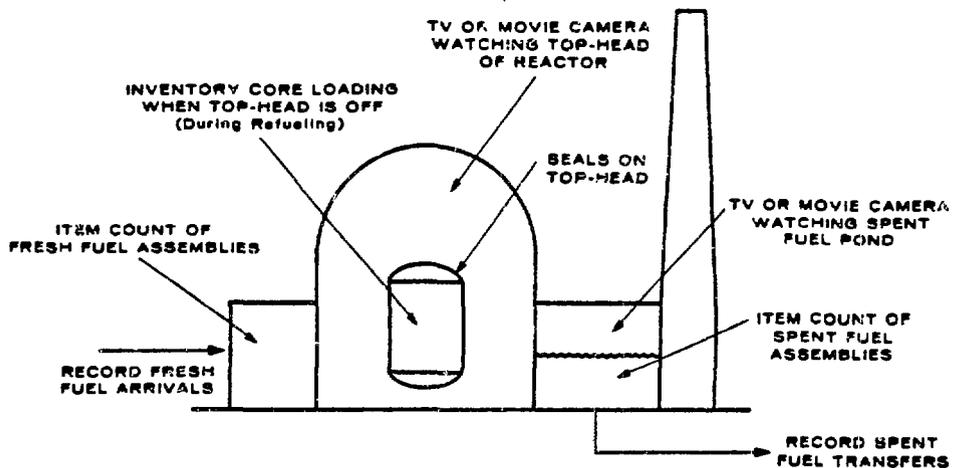
E. Verification of Nuclear Material¹³

Typical safeguards verification activities that take place at an LWR are shown in Fig. 7. The inventory of fresh-fuel assemblies is verified by identification of the serial numbers that are stamped on the top of the fuel assemblies. The fresh-fuel assemblies are either verified while they are in their storage containers (where they are dry) or in the storage pool just prior to being transferred to the reactor building for insertion into the reactor. Inspection of serial numbers of assemblies in the storage pool where they are located under several meters of water requires the use of an optical magnifier, such as binoculars.

TABLE V

SAFEGUARDING ACTIVITIES AT A LIGHT-WATER REACTORS¹³

Event	Task
After receipt of fresh fuel (one visit)	Removal of seals at assemblies and identification, records audit, check of seal at vessel, routine identification of irradiated assemblies, maintenance of camera.
After shutdown but before refueling	Removal of seal at vessel; identification and counting of fuel at reactor vessel, fresh-fuel storage and spent-fuel storage; records audit; maintenance of camera.
After refueling but before start-up	Identification and counting of fuel vessel and storages, fixing of seal to vessel, and maintenance of camera records audit.
Intermediate inspections (three visits)	Identification and counting of fuel at storages, check of seal at vessel, re-records audit, maintenance of camera.
After completion of shipment of irradiated fuel	Identification and counting of fuel at storages, check of seal at vessel, records audit, isotopic data acquisition; maintenance of camera.

Fig. 7. Safeguards verification activities at an LWR power station.¹³

During refueling when the reactor vessel is open, the in-core inventory is verified by counting and identification of serial numbers. The in-core fuel assemblies are located under about 10 m of water, and binoculars are required for the identification of the serial numbers of these fuel assemblies. After the refueling is complete and the reactor vessel is closed, seals are applied to the shielding blocks above the reactor vessel.^{14,15} Since these seals must be broken prior to the removal of the top of the reactor vessel, they provide verification that the in-core inventory was not changed during the absence of the inspector. Also, a surveillance camera is installed inside the reactor vessel as a backup to the seals. Because removal of both the shielding blocks above the reactor vessel and the head of the reactor vessel takes considerable time (days), this surveillance camera needs to take frames only infrequently; as few as 400 frames in a period of 6 months will ensure that an unreported opening of the reactor vessel will be detected.¹⁴

As spent-fuel assemblies are removed from the reactor vessel and are transferred to the storage pond, a map giving the grid location of each assembly is made. In the storage pond, as in the reactor vessel, the assemblies are located under about 10 m of water. During a physical inventory the inspector verifies with binoculars that the spent-fuel assemblies are in their proper locations. Also, surveillance cameras (film or video) are installed inside the spent-fuel bay to record the movement of the crane, fuel assemblies, spent-fuel cask, and the entrance and exit doors. The surveillance pictures are reviewed by the inspector to verify that the station's record of activities since the past inspections is correct. The surveillance cameras ensure the authenticity of the assemblies in the spent-fuel pond and reduce the effort required to complete the inspection. If the surveillance equipment fails, the integrity of the pond must be re-established by visual verification of all the assemblies.

Inspectors also collect data from the operators of the station that are related to calculated burnup, nuclear consumption and production, which will be useful for safeguards of re-processing plants.¹⁶

VII. SAFEGUARDING HEAVY-WATER REACTORS

The CANDU-600 reactor, the most common design today, will serve as the model system in this description. The CANDU-600 falls into that class of nuclear facility characterized by a continual flow of nuclear material. But since the fuel is packaged in discrete fuel bundles, this reactor is still classified as an "item facility."

The CANDU safeguards system also follows the principle of establishing item inventories and flows within the MBA, whereby measurements are made at KMPs for the determination of flow or inventory. These KMPs are the new fuel storage room, the reactor core, and the irradiated-fuel storage areas. Examples of item flows are deliveries of new fuel to the storage room, transfer

of new fuel from storage into the reactor core, and discharges of irradiated fuel from the core into the spent-fuel storage bays.

Safeguarding an HWR is characterized by keeping track of a very large number of items that are primarily inaccessible. A PIV of bundles inside the reactor is not possible because the fuel bundles are not visible inside the pressure tubes. Verification of the bundles in the spent-fuel pond is difficult because most of the bundles, stacked vertically on trays, cannot be seen. Only the fresh-fuel bundles are readily accessible.

A. Fuel Inventory

In the CANDU-600 each fuel bundle contains 20-21 kg of natural uranium dioxide, giving a total core loading of roughly 98 000 kg in 4600 fuel bundles or ~700 kg of ^{235}U (Ref. 1). Fresh-fuel assemblies are stored in dry boxes (32 bundles per box) where they can be available for inspection. The number of fresh-fuel bundles in storage may vary from a few hundred to a few thousand, but generally at least a 9-month supply is on hand. Under normal operating conditions, a CANDU-600 reactor charges 16 fresh-fuel bundles and discharges 16 irradiated-fuel bundles each day, which contributes to an annual inventory of 4000-5000 spent-fuel bundles.⁵ The basic features of the fuel-handling facilities and sequences are shown in Fig. 8.

Fresh fuel is transferred from its storage area through an equipment lock into the reactor containment building. It is then loaded into the "charge" portion of the fueling machine. The charge-machine and the accept-machine attach to opposite ends of the same pressure tube without disrupting the flow of heavy-water coolant or reactor energy production. As the charge-machine

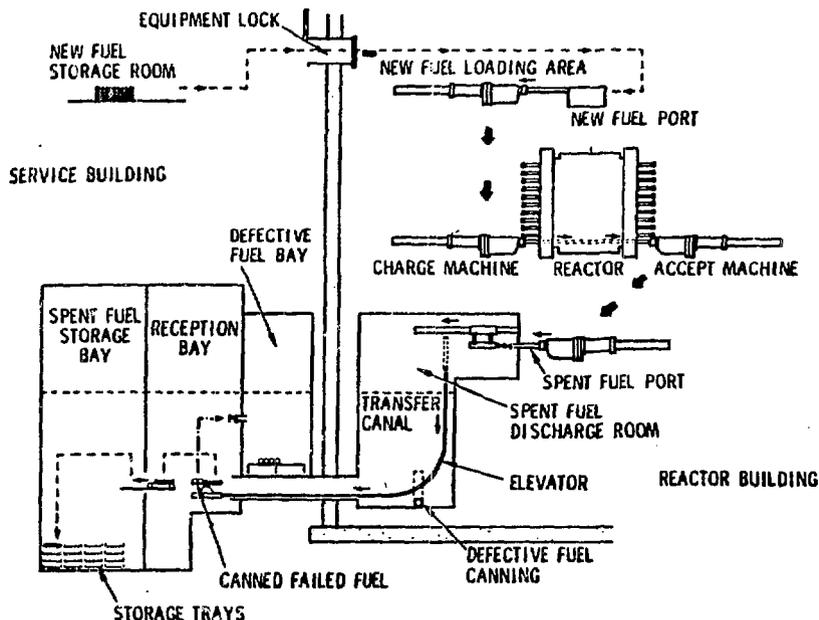


Fig. 8. CANDU fuel-handling sequence.^{1.5}

inserts a fresh-fuel bundle into the channel, a spent bundle is pushed through to the accept-machine. The accept-machine then moves to the spent-fuel discharge ports and the bundles are pushed through the containment onto the ladles of the discharge elevators, where the spent fuel travels underwater through the transfer canal to the storage pond. There the irradiated bundles are loaded onto trays, each holding 24 or more bundles, which are then stacked in modular assemblies consisting of two stacks 18-20 trays high piled on a common base.¹⁷ After 10 years of operation the spent-fuel storage pond may contain 40 000-50 000 bundles, with a total inventory of 3000-4000 kg of plutonium.

B. Detection Targets

The HWR safeguards system is designed to detect unreported removal of (1) fresh fuel from the facility, (2) irradiated fuel from the core, and (3) spent fuel from the irradiated-fuel storage bays. IAEA report STR-90 gives the following estimates of minimum removal times for one significant quantity of nuclear material from a CANDU reactor:¹⁷

Fresh fuel	1/2 day
Reactor vessel	2-30 days
Spent-fuel storage	<1 day

The design of a CANDU safeguards system is therefore based on the following detection considerations:

1. The natural-uranium fuel bundles receive minor safeguards emphasis before they are loaded into the reactor. Natural uranium has a high significant quantity (10.5 tonnes), long conversion time (10-18 months), and is considered "indirect-use" nuclear material. Indirect-use material is defined as nuclear material that must undergo enrichment or transmutation in a nuclear reactor prior to its use in a nuclear explosive device.⁹
2. A direct inventory verification of the core is avoided.¹⁸ Due to the inaccessibility of the reactor core and the on-line refueling, direct verification would be difficult and highly intrusive to the operator of the facility. Emphasis is therefore placed on safeguarding irradiated fuel.
3. Irradiated bundles are discharged at burnups in the range of 165-250 MWh/kg uranium, with an average of 196 MWh/kg uranium (~8000 MWD/tonne uranium). Since the conversion ratio of HWRs is ~0.8, somewhat higher than that of LWRs, the bundles contain typically 40-90 g of plutonium with an average of ~70 g/bundle.^{17,19} Thus, approximately 115 spent-fuel bundles contain a significant quantity of plutonium.
4. Although the absence of one or more spent-fuel bundles throws a cloud of uncertainty over the entire accounting

and inventory procedures, only the absence of a relatively large number of bundles (perhaps 10-20) within 2 or 3 months would have safeguards significance.

An instrumented CANDU detection system typically consists of the following items:¹⁸

1. Core input monitors--to count the number of unirradiated fuel bundles loaded into the core.
2. Closed-circuit television or film cameras--in areas where the unirradiated or irradiated fuel moves or is stored, to record anomalies that might indicate diversion.
3. Irradiated-fuel bundle counters--to count the number of irradiated-fuel bundles discarded from the reactor and to verify that the objects counted are highly radioactive.
4. Yes/no monitors--to indicate when irradiated fuel has been abnormally moved through penetrations or routes that do not have KMPs.
5. Irradiated fuel verifiers--to verify authenticity of irradiated fuel in the storage bay.
6. Tamper-indicating containers and seals--to hold irradiated fuel in large batches. A check of the integrity of the seal and container shows that no fuel has been removed.

C. Diversion Possibilities

Considering that the fresh-fuel bundles are indirect-use nuclear material and that the core is never really "open" to diversion, the undeclared removal of irradiated fuel from the spent-fuel storage bay is considered to be the most attractive diversion possibility for HWRs. Casks and transfer equipment are readily available. Furthermore, since the fuel in the bay has decayed significantly, it would be feasible to remove one significant quantity in one or two operations. The diversion possibilities are summarized in Table VI.

D. Inspection Activities

As with LWRs, two types of inspections are required each year: three to five routine (interim) inspections and an annual (PIV) inspection. During routine (interim) inspections, newly transferred fuel bundles must be sealed and safeguards/equipment must be serviced. The minimum activities that need to be performed at the facility are the following:

- (1) Audit operating records and reports.
- (2) Service each film camera system and complete appropriate forms. Films will be developed and reviewed off-site.

TABLE VI

SUMMARY OF DIVERSION POSSIBILITIES FOR HEAVY-WATER REACTORS

<u>Diversion Possibilities</u>	<u>Concealment Methods</u>	<u>Safeguards Measures</u>
Removal of fuel bundles from fresh-fuel storage	Substitution with dummies	Item counting and identification Container (box) counting NDA techniques (box verifier)
Removal of fuel bundles from the core	Substitution with dummies	Core input counters Irradiated-fuel bundle counters Closed-circuit TV or film cameras Yes/no monitors
Irradiation of undeclared fuel bundles in the core	Substitution with dummies	Core input counters Irradiated-fuel bundle counters Closed-circuit TV or film cameras Yes/no monitors
Removal of fuel bundles from spent-fuel pond	Substitution with dummies	Closed-circuit TV or film counters Yes/no monitors Irradiated-fuel verifiers Containers and seals
Removal of fuel elements from consignment when or after they leave the facility	Substitution with dummies or consignment. Understating of number of bundles shipped and substitution with dummies in spent-fuel pond	Sealing of shipping container before shipment and verification of content at recipient facility, if possible

- (3) Service all fuel bundle counters and fuel bundle counters/attribute verifiers.
- (4) Examine all yes/no monitors and convenience seals.
- (5) Verify that spent-fuel stacking frames to be sealed are full and verify the sealing of such stacking frames.

(6) Verify fresh-fuel boxes received (box serial numbers) if possible.

(7) Proceed with follow-up activities when required.

Review of appropriate film and bundle counter printouts for agreement with the operator's records is usually performed off-site. Verification of off-site shipments, which requires advance notification, would be in addition to the above activities. To perform these activities the inspector requires (inter alia) access to the spent-fuel bays and fresh-fuel storage and loading rooms.

The prime purpose of the annual inspection is to verify the ending physical inventory entries provided in the state's annual Material Balance Report and Physical Inventory List. Verification of physical inventory may be accomplished by direct measurement (bundle count and random attribute test), or by accepted substitute techniques such as checking sealing systems. In addition, newly transferred fuel bundles are required to be sealed and all safeguards equipment is required to be serviced. The minimum activities that need to be performed during the annual inspection are as follows:

- (1), (2), (3), (4), and (5) Same as for routine (interim) inspections.
- (6) Inspect the seals and covers of randomly selected sealed stacks in all spent-fuel bays.
- (7) Perform the fresh-fuel inventory verification activities.
- (8) Perform off-site (at IAEA Headquarters or a Field Office) inspection activities as follows:
 - (a) Review the appropriate film and compare with operations records including crane operations list and large object removal list.
 - (b) Check for discrepancies among the approximate bundle counter printouts and for discrepancies in the operator's records.
 - (c) List the verified physical inventories for all categories of nuclear material or verified book inventory.
 - (d) Compare the state's accounting report (ICR, MBR, PIL) to the facility records to ascertain that the state's report is consistent, accurate, and complete.
 - (e) Calculate material unaccounted for (MUF) based on difference between ending book inventory and ending physical inventory.

- (f) Proceed with follow-up activities when required.
- (g) Update IAEA records and prepare inspection report on the basis of the inspection activities.

E. Verification of Nuclear Material

Typical safeguards verification activities that take place at a HWR are shown in Fig. 9. Fresh-fuel inventory verification consists of a count of containers (boxes) plus a count of loose (unpackaged) bundles in combination with a random check of containers to assure that these contain the stated number of natural-uranium fuel bundles. Such testing is accomplished by NDA techniques (box verifier), which do not require opening of boxes.

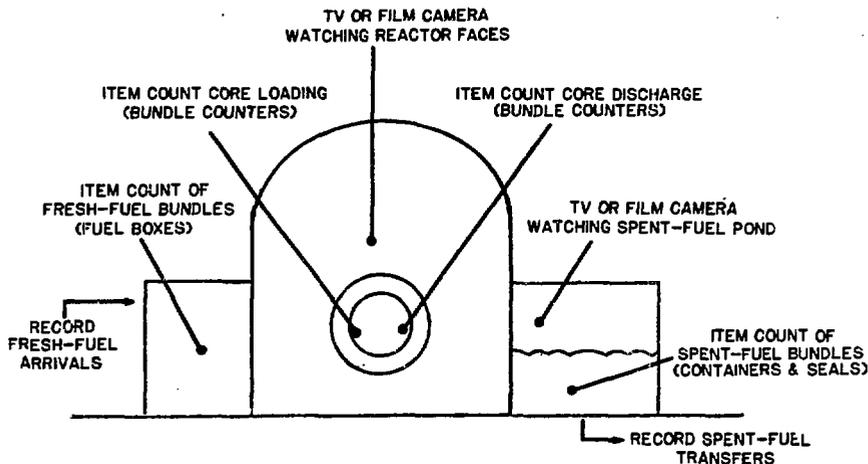


Fig. 9. Safeguards verification activities at a HWR power station.

The inspector can verify the inaccessible inventory in the core and fueling machines by the use of flow difference and C/S techniques. Flows can be independently measured by using core input counters and core discharge counters. The structural containment of the reactor building and additional C/S devices such as surveillance cameras, yes/no monitors, and seals provide a containment boundary and assure that undeclared removal of irradiated fuel by the more credible diversion routes will not occur without triggering anomalies.

Verification of the inventory in the spent-fuel bay makes use of the simplifications afforded by sealing the irradiated fuel and also uses flow difference and C/S techniques. Bundles discharged into the spent-fuel bay are counted by the core discharge counters. These counters also incorporate an attribute test (fuel verifier) to provide assurance that all bundles counted were irradiated bundles. Any bundles shipped off-site (out of the bay) can be verified by an inspector being present. The structural containment of the walls of the storage bay and the use of C/S devices such as surveillance cameras, sealing system for spent fuel, as well as the discharge counters' reverse

flow counting capability, are used to provide the containment boundary needed for the flow difference technique to be a valid means of verifying inventory. These C/S devices provide assurance that transfers other than through-flow KMPs did not occur. At each inspection the inspector would verify that stacks of irradiated fuel to be sealed are full, assuming the bundle counter and surveillance have indicated no anomalies. Verification of sealed fuel in future inspections will then consist of verifying the integrity of the sealing system.

APPENDIX⁹

SIGNIFICANT QUANTITIES

	<u>Material</u>	<u>Significant Quantity</u>	<u>Safeguards Apply To</u>
Direct-use nuclear material	Pu*	8 kg	Total element
	U-233	8 kg	Total isotope
	U(U-235 \geq 20%) - Plus rules for mixtures where appropriate -	25 kg	U-235 contained
Indirect-use nuclear material	U(U-235 < 20%)**	75 kg	U-235 contained
	Th	20 t	Total element
	- Plus rules for mixtures where appropriate -		

*For Pu containing less than 80% Pu-238.

**Including natural and depleted uranium.

ESTIMATED MATERIAL CONVERSION TO FINISHED
Pu AND U METAL COMPONENTS

<u>Beginning Material Form</u>	<u>Conversion time</u>
Pu, HEU or U-233 metal	Order of days (7-10)
PuO ₂ , Pu(NO ₃) ₄ , or other pure Pu compounds; HEU or U-233 oxide or other pure compounds; MOX or other non-irradiated pure mixtures containing Pu, U[(U-233 + U-235) \geq 20%]; Pu, HEU and/or U-233 in scrap or other miscellaneous impure compounds	Order of weeks (1-3)*
Pu, HEU or U-233 in irradiated fuel**	Order of months (1-3)
U containing <20% U-235 and U-233; Th	Order of one year

*This range is not determined by any single factor, but the pure Pu and U compounds will tend to be at the lower end of the range and the mixtures and scrap at the higher end.

**Criteria for establishing the irradiation to which this classification refers are under review.

POWER REACTOR FUEL
DETECTION TARGETS

SIGNIFICANT QUANTITIES & TIMES

<u>Material</u>	<u>Mass</u>	<u>Time</u>	<u>No. PWR Assemblies</u>	<u>No. PWR Assemblies</u>	<u>No. HWR Bundles</u>
U-235 in LEU	75 kg	1 Year	~6	~13	>500
Pu	8 kg	1-3 Months	~3	~8	>100

INSPECTION TARGETS

			1	1	~10-20**
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** Note the discussion of this number in the text, item B-4, page 13-17.

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 14: ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY

This session will provide an introduction to nondestructive assay methods and instruments as they are applied to nuclear safeguards.

After the session, participants will be able to:

1. discuss the general principles and major applications of NDA,
2. describe situations in which NDA is particularly useful for nuclear safeguards purposes,
3. distinguish between various passive and active gamma-ray and neutron NDA methods,
4. describe several NDA instruments that measure gamma rays, and identify assay situations particularly suited to gamma-ray techniques,
5. describe several NDA instruments that measure neutrons, and identify assay situations particularly suited to neutron techniques,
6. discuss the role of calorimetry in the NDA of plutonium-bearing materials,
7. compare the advantages and disadvantages of various NDA methods for different types of nuclear materials.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 14: ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY

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I. INTRODUCTION

A. History of NDA

When we speak of NDA in the context of nuclear safeguards, we are generally referring to the use of nuclear radiation to measure the quantity of fissionable material present in a given sample or container. NDA techniques have been applied to special nuclear materials in the U.S., at least to some extent, since the initiation of the Manhattan project. But it was not until 1967, when the Office of Safeguards and Material Management was established by the AEC, that effort was focused on the development of NDA techniques specifically designed for nuclear safeguards. The Los Alamos National Laboratory has been involved in this development work since its inception and is currently the DOE lead laboratory for nuclear materials measurement and accounting. Other laboratories in the U.S., including Brookhaven, Hanford, Argonne, Livermore, Idaho, Oak Ridge, Savannah River, New Brunswick, Mound, and NBS, have also contributed, as have instrument companies such as Eberline, Canberra, National Nuclear, and IRT. Significant advances in NDA technology also continue to be made by organizations in Europe, as well as in other countries such as the USSR, Canada, and Japan.

B. Uses of NDA

NDA methods are widely used throughout the nuclear fuel cycle primarily because they are able to measure the material in its existing form, and they provide rapid assay results. Applications include:

- ore location and assay
- process control
- quality control
- health and safety
- criticality
- material accounting
- containment
- waste disposal

C. Strengths and Limitations of NDA

During the past few years, NDA techniques have become established as a fundamental element of nuclear safeguards programs throughout the world. NDA is particularly well suited for safeguards applications when:

- It is difficult to obtain a representative sample for chemical analysis; for example, consider non-uniform solids, material in sealed containers, spatially distributed material, or valuable finished products.
- There is a need for many repetitive measurements, such as might be the case for receiving stations, process lines, or waste streams.
- There is a need for timely material accountability; i.e., it is desirable to close material balances in a matter of hours rather than days or weeks.

The arguments in favor of NDA are compelling, but certain limitations and consequences must also be noted:

- Adequate NDA standards are frequently not available in the particular geometry, material form, and isotopic composition that would be ideal for instrument calibration. Consequently, variations in these factors may complicate instrument calibration and data interpretation and, in many cases, may limit the accuracy of the assay result.
- Absolute calibration of NDA instruments usually depends in the final analysis on chemical methods, such as gravimetric analysis, fixed stoichiometry, titration, and mass spectrometry.
- The large quantity of data made practical through NDA can be fully utilized only if adequate computer methods are used for assisting with data analysis and interpretation.

D. Classifications of NDA Methods

Figure 1 shows, in block diagram form, a classification of NDA techniques into passive and active gamma-ray and neutron methods and calorimetry. According to Fig. 1, passive NDA methods include all techniques that derive their primary information from the natural radioactive decay of the sample, whereas, active NDA methods include techniques that derive their primary information from the interaction of an external radiation source with the sample. Similar classifications have been made by Dragnev^(1,2) and by Smith and Canada.⁽³⁾

In Fig. 1, applications are listed for each of the NDA techniques shown, along with one instrument (in parenthesis) that makes use of the principle. The information presented in Fig. 1 covers most of the widely used NDA methods, but for the sake of brevity, is not totally inclusive. In following sections, each of the techniques shown in Fig. 1 will be discussed, and the advantages and disadvantages of various NDA methods will be compared for different types of nuclear materials.

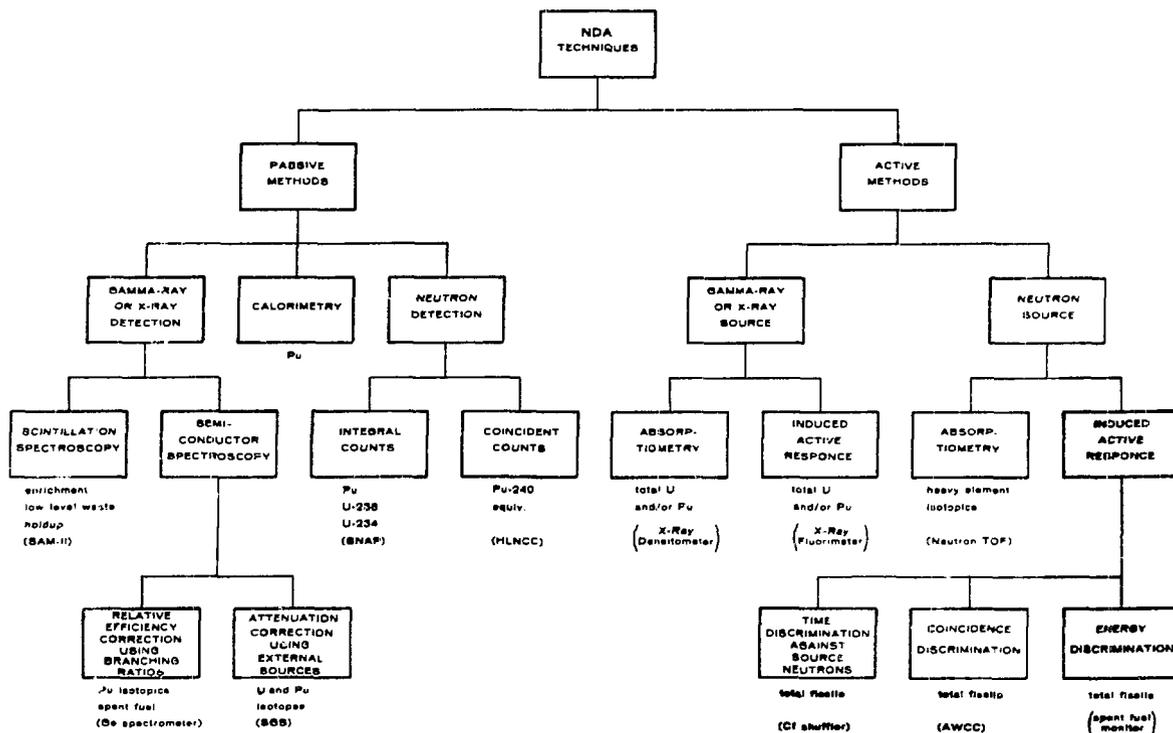


Fig. 1

Classification of nondestructive assay (NDA) techniques used for the measurement of fissionable materials.

II. PASSIVE GAMMA-RAY METHODS

A. General Information

All isotopes of uranium and plutonium are radioactive and decay by alpha emission, beta emission, or spontaneous fission. Following either alpha or beta emission, the nucleus is sometimes left in an excited energy state, which then decays by the emission of gamma rays to the ground state. Each isotope has a unique decay scheme, and when gamma rays are detected, a determination of gamma-ray energies provides a way of identifying the specific isotopes present.

Table I lists some of the gamma-ray energies and emission rates for uranium, plutonium and americium isotopes that are commonly used for the NDA of these materials.⁽⁴⁾ A more complete list of gamma-ray energies and other properties of heavy element nuclides can be found in reference 1.

Fig. 2
Arrangement for
measuring ^{235}U
enrichment of
 UO_2 powder in
cans. The
Eberline SAM-II
electronics unit
is used with a
 NaI -photomultiplier
detector mounted
vertically under
the sample can.

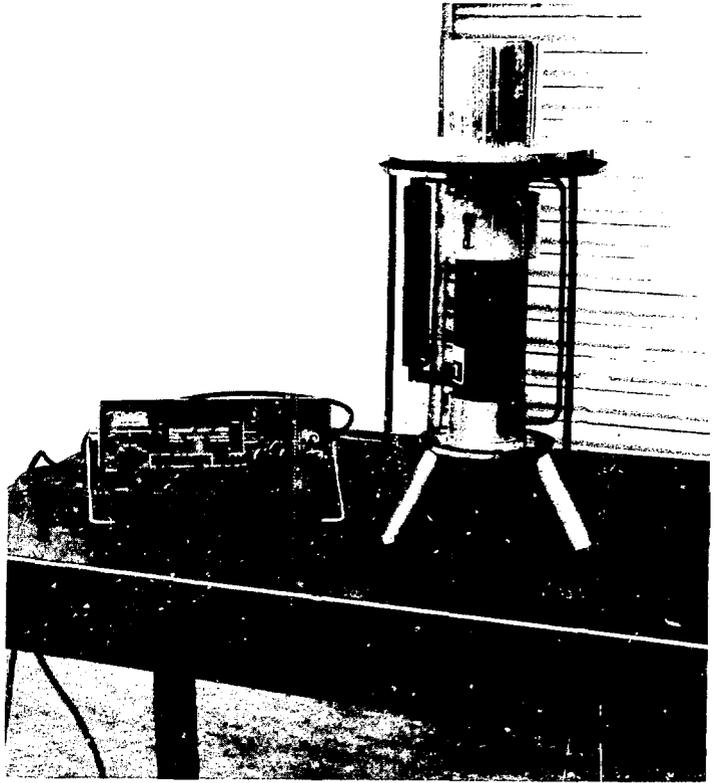


Fig. 3
Characteristic
pulse height
spectrum obtained
with a NaI
detector viewing a
 ^{235}U sample.
The curve was
obtained with a
SAM-II by varying
one of the single
channel analyzers.

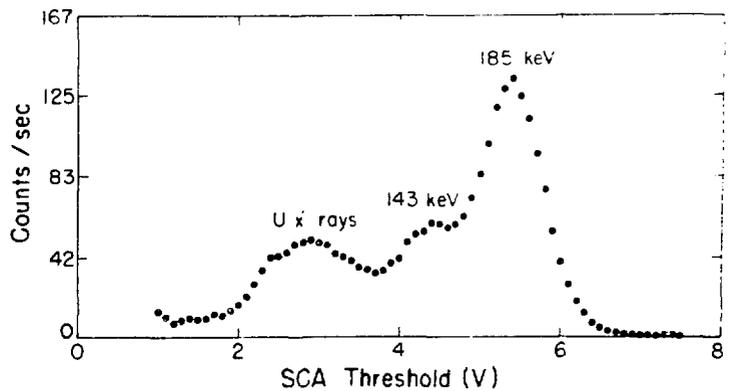


TABLE I
 URANIUM, PLUTONIUM, AND AMERICIUM
 GAMMA-RAY EMISSION RATES

Isotope	Half-life (years)	Activity Level (Ci/g)	Principal Gamma Rays (keV)	Emission Rate (gamma rays/s/g)
^{235}U	7.04×10^8		185.7	4.5×10^4
^{238}U	4.47×10^9		766.4	39
			1000.1	103
^{238}Pu	87.79	17.1	152.8	6.4×10^6
			766.4	1.5×10^5
			1000.1	8.2×10^3
^{239}Pu	24082	0.0621	129.3	1.4×10^5
			375.0	3.6×10^4
			413.7	3.5×10^4
^{240}Pu	6537	0.228	160.4	3.5×10^4
			642.3	1.2×10^3
^{241}Pu	14.35	103.4	148.6	7.3×10^6
^{242}Pu	3.79×10^5	0.0039	none	
^{241}Am	434.1	3.42	368.6	2.6×10^5
			662.4	4.4×10^5

B. Scintillation Spectroscopy

1. Enrichment Meter. Figure 2 shows the Eberline SAM-II, one of the simplest and most widely used instruments in nuclear safeguards. It consists of a NaI detector (typically 1.27 cm thick by 3.81 cm diameter), a two channel analyzer, and an up-down scaler. A typical pulse height spectrum obtained with a uranium sample using the SAM-II is shown in Fig. 3.

The SAM-II and similar types of instruments built by other manufacturers are capable of accurately measuring uranium enrichment. For samples that are thick relative to the penetrating depth of the 186 keV U-235 gamma ray and for fixed detector-sample geometry, the count rate due to 186 keV gamma rays is proportional to enrichment; this linear relationship between enrichment and count rate is referred to as the enrichment meter principle. Calibration of enrichment meters is accomplished using two or more enrichment standards having container walls similar or preferably identical to those of the unknown samples. (5)

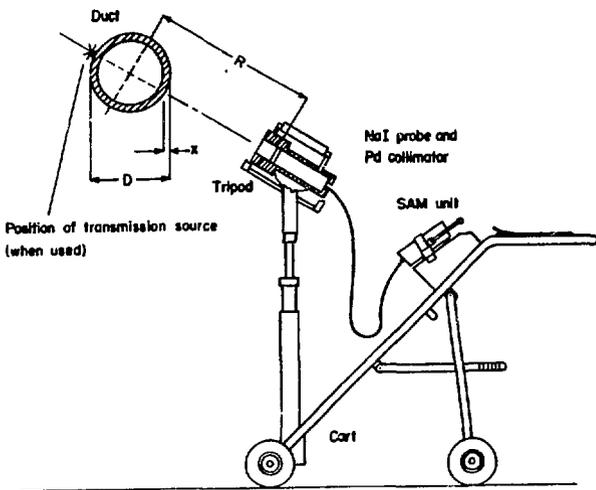


Fig. 4
Holdup of nuclear material in process lines can be measured using portable scintillation detection equipment.



Fig. 5
Scintillation detectors are used in portal monitors and in hand-held survey meters. The portable instrument shown was developed by Los Alamos Group Q-2 and manufactured by National Nuclear Corporation.

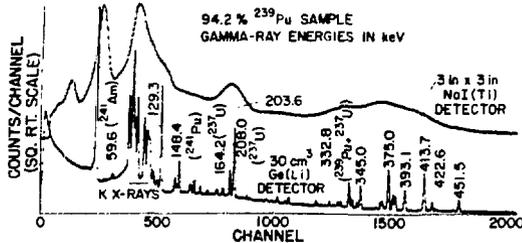


Fig. 6
Illustration of plutonium gamma-ray spectra as measured with a NaI detector (upper curve) and a Ge(Li) detector (lower curve), showing the capability of high resolution Ge spectroscopy to determine energies and relative intensities of individual gamma lines in complex spectra.



Fig. 7
The battery operated 1000 channel pulse height analyzer developed in H-Division at Los Alamos has been adapted for use by the IAEA. Small intrinsic Ge detectors, such as this 30 cm³ unit from Princeton Gamma Tech can be operated in any position.

2. Other Applications. Although the enrichment meter is perhaps the most well known, gamma-ray instruments using sodium iodide and other scintillation detectors have been used for many other applications in safeguards, such as assaying low level waste, monitoring effluents, and estimating the holdup of nuclear material in processing plants (Fig. 4). Because they are portable, simple, and reliable, instruments employing scintillation detectors are also used as portal monitors and survey meters (Fig. 5).

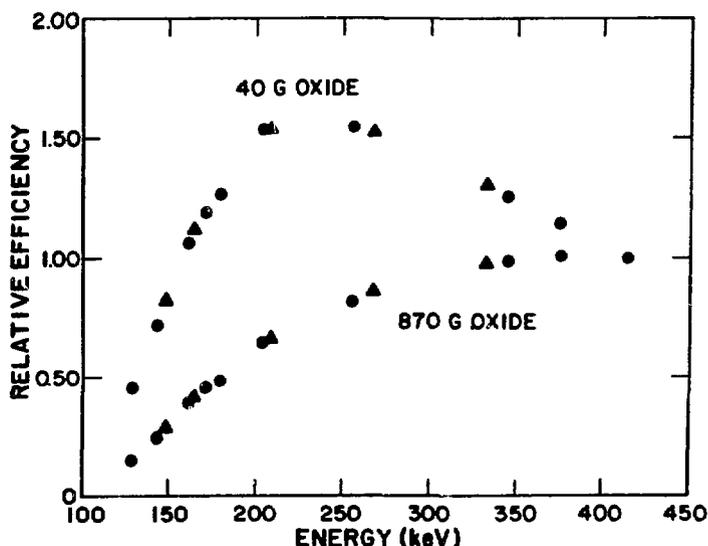
C. Semiconductor Spectroscopy

1. Methods Using Relative Efficiency Correction. High resolution gamma-ray spectroscopy (HRGS) using semiconductor detectors, such as intrinsic Ge and Ge(Li), provides significantly better energy resolution than can be achieved using scintillator detectors, as is demonstrated by the two plutonium gamma-ray spectra shown in Fig. 6. Energy resolution (FWHM) for high quality coaxial Ge detectors is on the order of 0.8 keV for 122 keV gamma-rays and 1.7 keV for 1.33 MeV gamma rays. In the last few years, portable HRGS systems have become available through the advent of intrinsic Ge detectors (that can be transported at room temperature) and smaller multichannel analyzers (Fig. 7).

If one measures the photopeak areas of gamma rays from different isotopes, it may be possible to determine isotopic ratios using a technique known as the relative efficiency correction. The relative efficiency correction factor (Fig. 8) includes effects due to attenuation in the sample, attenuation in external absorbers, and the detector sensitivity, all of which vary as a function of gamma-energy and measurement geometry.

Fig. 8

Relative efficiency curves taken with a 200 mm² x 10 mm-deep planar Ge detector, showing dependence on gamma-ray absorption in the sample. Circles are points from ²³⁹Pu; triangles are from ²⁴¹Pu and ²⁴¹Pu-²³⁷U. The circular points and triangular points for each sample are normalized at 332 keV.



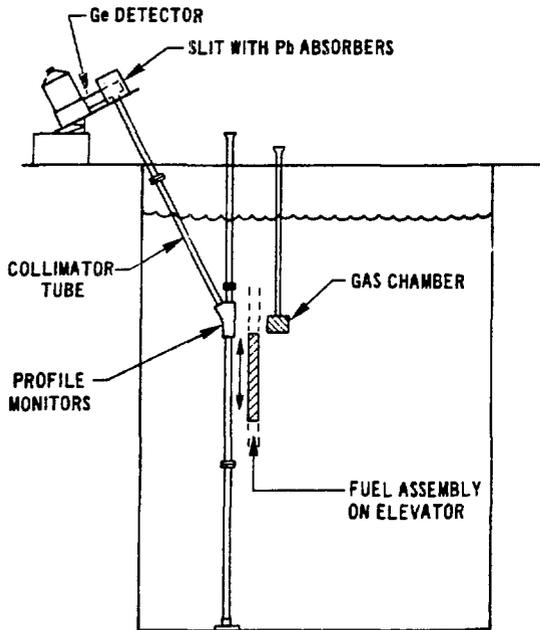


Fig. 9
Arrangement of Ge detector and slant collimator pipe for observing fission product gamma rays from spent-fuel assemblies stored underwater. Ion chambers and fission chambers are placed in the vertical pipes.

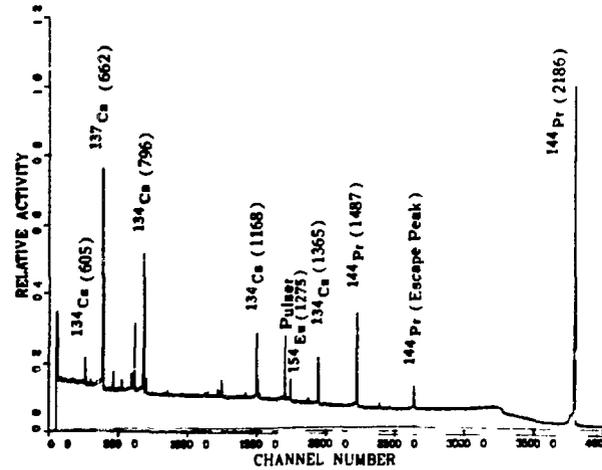


Fig. 10
Characteristic gamma-ray spectrum observed with spent fuel. From fission product isotopic ratios, it is possible to verify cooling time and burnup.

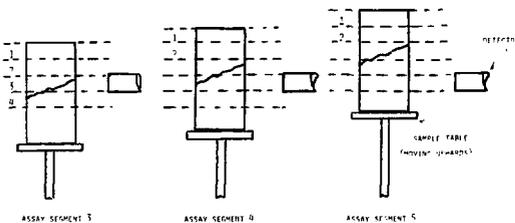


Fig. 11
In the segmented-gamma-scanner, the sample container is stepped vertically past the fixed Ge detector and transmission source. A separate gamma-ray absorption correction is made for each vertical segment.



Fig. 12
Segmented-gamma-scanner systems suitable for assaying a variety of container sizes were developed at Los Alamos and are now commercially available. The transmission source is to the right of the barrel, and the Ge detector is to the left of the barrel.

Isotopic ratios are calculated from the equation

$$\frac{I_1}{I_2} = \frac{A_1}{A_2} \frac{(BR)_2 \lambda_2}{(BR)_1 \lambda_1} \frac{\epsilon_2}{\epsilon_1}$$

where

I_1/I_2 = isotopic ratio

A_1/A_2 = ratio of photo peak areas

BR_n = branching ratio for particular gamma ray from isotope n

λ_n = decay constant of isotope n

ϵ_1/ϵ_2 = relative efficiency correction factor for two gamma rays used in calculation.

The relative efficiency correction factor can be experimentally determined from the above equation by using gamma rays of different energies from the same isotope, and setting $I_1/I_2 = 1$. This technique has been successfully applied for measuring Pu isotopic ratios and spent-fuel fission product isotopic ratios⁽⁶⁾ (see Figs. 6, 9, and 10). In these applications, a single gamma-ray spectrum contains the peak area data for both the relative efficiency correction and the determination of isotopic ratios.

The relative efficiency correction method works well when:

- a. isotopes are uniformly distributed throughout the sample,
- b. at least one isotope in the sample has two or more prominent gamma rays in the appropriate energy range, and
- c. the objective is to determine isotopic ratios in a sample, as opposed to the total amount of an isotope present in a sample.

2. Methods Using External Sources to Correct for Sample Attenuation. To deal with situations in which the three conditions listed in the previous paragraph are not met, techniques have been developed to correct for gamma-ray absorption in the sample using external radiation sources. One such instrument, the segmented-gamma-scanner (SGS),⁽⁷⁾ was designed for assaying uranium and/or plutonium waste in a variety of container sizes and matrices (see Figs. 11 and 12). The idea is to divide the sample into a series of horizontal segments and to assay each segment, one at a time, with a self-absorption correction separately determined for each segment. For assaying ^{235}U using the 186 keV gamma ray, the SGS uses a ^{168}Yb external radiation source with gamma rays at 177 and 198 keV.

Other instruments that use external radiation sources to correct passive gamma assays for absorption in the sample include the solution assay systems, PUSAS and USAS.⁽⁸⁾ All of the instruments

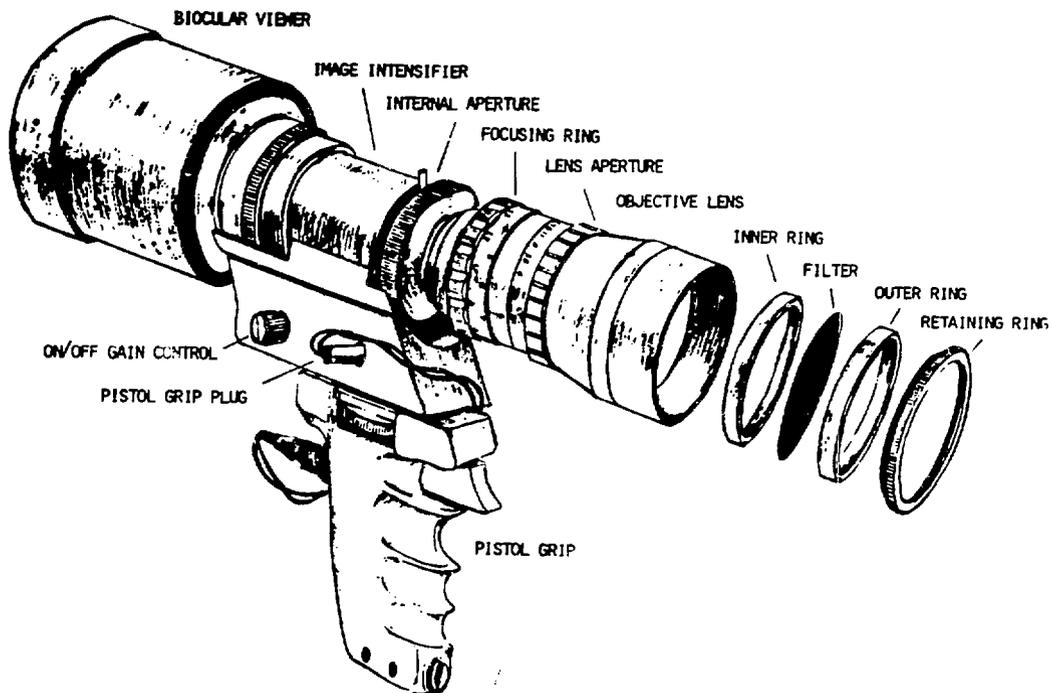


Fig. 13

The hand-held Cerenkov detector developed by Los Alamos Group Q-2 for the IAEA is used to observe light produced by irradiated fuel assemblies stored underwater. Later models permit the attachment of a film camera, so that the inspector has a permanent record.

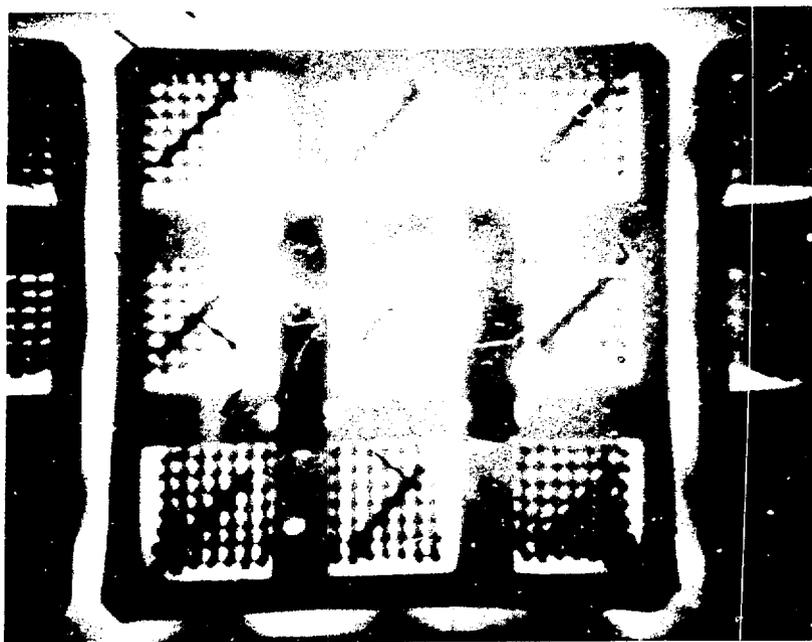


Fig. 14

Image recorded by the Cerenkov detector when observing BWR fuel assemblies, looking down into a storage pond from a bridge crane.

in this category give isotopic information. In size and complexity, they are comparable to some of the active interrogation instruments such as x-ray densitometers and active well coincidence counters.

D. Gross Gamma-Ray Techniques

A few instruments used in safeguards applications measure gross gamma-ray fields (or dose rates), rather than counting individual gamma rays. The Cerenkov detector, shown in Fig. 13, is used to obtain an image from light produced by spent-fuel assemblies stored underwater. The detector consists of a telephoto lens coupled to an image intensifier tube that amplifies the Cerenkov light intensity, so that it can be easily seen in a darkened fuel storage pond (Fig. 14). This instrument permits IAEA inspectors to verify that spent-fuel assemblies are intact and are highly radioactive, without placing any instrumentation underwater.⁽⁹⁾

Ion chambers have also been used to measure the gamma-ray fields produced by spent-fuel assemblies. In particular, ion chambers are used to determine axial gamma-ray activity profiles, which closely resemble the burnup profiles of spent-fuel assemblies.

III. PASSIVE NEUTRON METHODS

A. General Information

Neutrons originate in special nuclear materials primarily because of spontaneous fission and (α, n) reactions, see Tables II, III, and IV.⁽¹¹⁾ Passive neutron measurements can be influenced by neutron multiplication in the sample and by the presence of neutron moderators, reflectors, and absorbers in or near the sample. Compared with gamma rays, neutrons are much more penetrating in high-Z materials, and it is this characteristic that makes passive neutron techniques invaluable for assaying large heterogeneous samples of plutonium.

Whereas gamma-ray energies allow one to identify isotopic content, passive neutron energies contain no isotopic information. As a result, neutron assays involve counting rather than spectroscopy, and for this reason, passive neutron hardware is usually simpler than high resolution gamma-ray hardware. The most commonly used neutron detector for NDA instrumentation is the gas proportional counter, typically ^3He or $^{10}\text{BF}_3$. This type of detector is chosen because of its relatively high efficiency for detecting thermal neutrons, insensitivity to gamma rays, reliability, and long-term stability.

TABLE II
SPONTANEOUS FISSION OF FISSIONABLE ISOTOPES

Isotope	Half-Life (yr)	Spontaneous Fission Half-Life (yr)	$\bar{\nu}$ (Spontaneous Fission)	Spontaneous Fissions per g-s
^{232}Th	1.41×10^{10}	$\sim 10^{21}$		$\sim 10^{-8}$
^{234}U	2.47×10^5	2.0×10^{16}	~ 2	2.8×10^{-3}
^{235}U	7.04×10^8	1.9×10^{17}	~ 2	2.96×10^{-4}
^{236}U	2.40×10^7	2.0×10^{16}	~ 2	2.8×10^{-3}
^{238}U	4.47×10^9	9.86×10^{15}	1.95	5.64×10^{-3}
^{238}Pu	87.79	4.7×10^{10}	2.26	1.1×10^3
^{239}Pu	2.41×10^4	5.5×10^{15}	2.2	1.0×10^{-2}
^{240}Pu	6537	1.17×10^{11}	2.17	4.71×10^2
^{241}Pu	14.35	5.0×10^{15}	2.2	1.1×10^{-2}
^{242}Pu	3.79×10^5	6.8×10^{10}	2.16	8.0×10^2
^{241}Am	434.1	2.0×10^{14}	2.3	0.27
^{242}Cm	.4456	7.2×10^6	2.65	7.8×10^6
^{244}Cm	17.6	1.4×10^7	2.84	4×10^6
^{252}Cf	2.646	86	3.8	6.14×10^{11}

TABLE III
(α, n) YIELDS FROM OXIDES AND FLUORIDES

Material	Yield (neutrons/s/g)
$^{234}\text{UO}_2$	~ 14
$^{234}\text{UF}_6$	5.8×10^2
$^{235}\text{UF}_6$	12.2×10^{-2}
$^{238}\text{UF}_6$	12.9×10^{-3}
$^{238}\text{PuO}_2$	1.4×10^4
$^{238}\text{PuF}_4$	2.1×10^6
$^{239}\text{PuO}_2$	45
$^{239}\text{PuF}_4$	4300
$^{240}\text{PuO}_2$	170
$^{240}\text{PuF}_4$	1.6×10^4
$^{241}\text{PuO}_2$	10
$^{241}\text{AmO}_2$	3754
$^{242}\text{PuO}_2$	10

TABLE IV
NEUTRON EMISSION RATES FOR Pu METAL, PuO₂, AND PuF₄

Isotope	Wt%	Neutron Rate for 100 g of Pu (n/s)		
		Metal (Spontaneous Fission)	PuO ₂ (α, n)	PuF ₄ (α, n)
²³⁸ Pu	0.3	746	4 200	630 000
²³⁹ Pu	75.6	2	3 400	325 080
²⁴⁰ Pu	18.0	18 400	3 060	288 000
²⁴¹ Pu	5.0	0	50	5 000
²⁴² Pu	<u>1.1</u>	<u>1 900</u>	<u>10</u>	<u>1 000</u>
	Total	21 048	10 720	1 249 080

B. Passive Methods That Detect Single Neutron Counts (SNAP)

The Shielded Neutron Assay Probe (SNAP), shown in Figs. 15 and 16, can be used for assaying total plutonium when the chemical and isotopic composition are known, and suitable standards are available.⁽¹²⁾ In assaying plutonium, neutrons from both the spontaneous fission of even Pu isotopes and (α, n) reactions in the sample are measured. The SNAP detector consists of two ³He proportional tubes in a cylindrical polyethylene moderator encased in a Cd shield. To achieve directionality and reduce background, a 240° polyethylene shield can be placed around the inner cylinder.

Neutron counting has been applied to the assay of spent LWR fuel assemblies using ²³⁵U fission chamber detectors. Neutrons originate primarily from isotopes of curium and plutonium and can be correlated with burnup via a power law relationship.⁽¹⁰⁾

More specialized applications of singles neutron counting include the measurement of ²³⁴U enrichment (by observing α, n neutrons in UF₆), and the assay of total uranium in low enriched scrap (based on the spontaneous fission of ²³⁸U). These applications are considered special because, in general, passive neutron signals from uranium are too weak to give reliable assays.

C. Passive Methods That Detect Coincident Neutron Counts (HLNCC)

The purpose of using coincidence counting for passive neutrons is to discriminate against single (α, n) neutrons, while detecting coincident neutrons due to spontaneous fission. For assaying plutonium, coincidence counting is generally better than singles counting because coincidence methods are less sensitive to variations in low Z matrix materials and less sensitive to changes in neutron background.

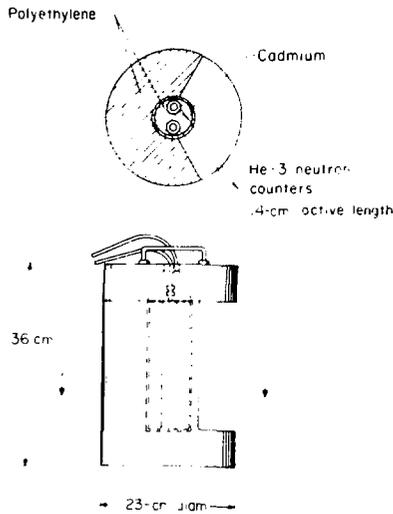


Fig. 15
 Assembly drawing of the Shielded Neutron Assay Probe (SNAP), showing two ^3He proportional tubes inside a cadmium shield.

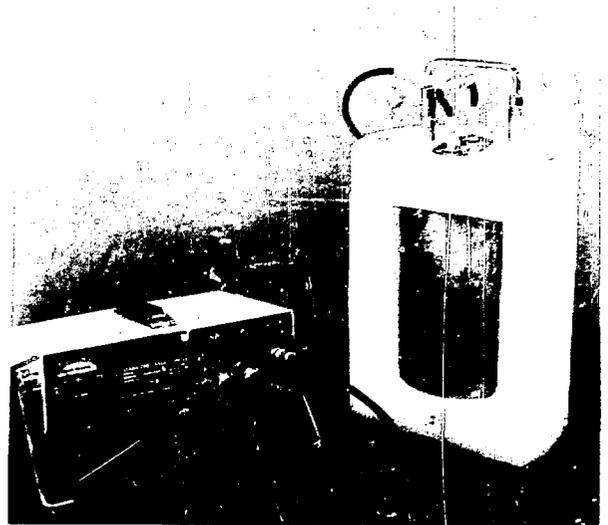


Fig. 16
 Shielded Neutron Assay Probe (SNAP) connected to the Eberline SAM-II electronics unit. The SNAP can be used to assay plutonium samples by counting both (α, n) and fission neutrons.

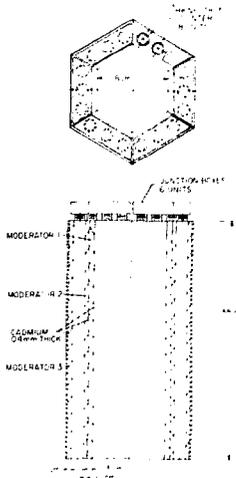


Fig. 17
 The High-Level Neutron Coincidence Counter (HLNCC) contains 18 ^3He proportional tubes in a hexagonal polyethylene moderator. Coincidence counting allows one to detect fission neutrons from ^{240}Pu and other even isotopes, while discriminating against (α, n) neutrons in the sample.

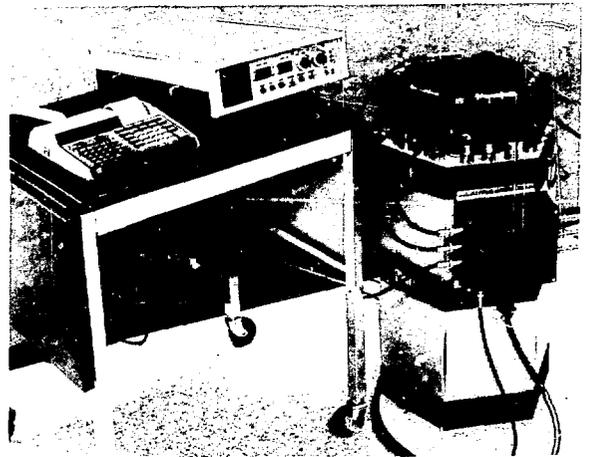


Fig. 18
 Portable assay station consisting of a High-Level Neutron Coincidence Counter (HLNCC), shift register electronics, and HP-97 calculator. Designed for use by the IAEA, this arrangement allows inspectors to make rapid assays of plutonium samples under field conditions.

Since the efficiency for detecting coincidences is approximately equal to the square of the efficiency for detecting singles, coincidence counters are designed to achieve high singles counting efficiency by using well-counter geometry, i.e., by surrounding the sample with detectors.

The High-Level Neutron Coincidence Counter (HLNCC) shown in Figs. 17 and 18 is a compromise between the highest obtainable efficiency and portability. (13) This detector, designed for use by IAEA inspectors, consists of 18 ^3He detectors in a hexagonal polyethylene shield. Larger, more efficient well counters have been designed for other applications.

Well counters are used to assay ^{240}Pu effective, a quantity defined by the equation

$$^{240}\text{Pu eff} = 2.5^{238}\text{Pu} + ^{240}\text{Pu} + 1.7^{242}\text{Pu} .$$

To obtain a complete plutonium assay, well counter measurements are frequently made in conjunction with isotopic ratio measurements using gamma spectroscopy (Fig. 19).

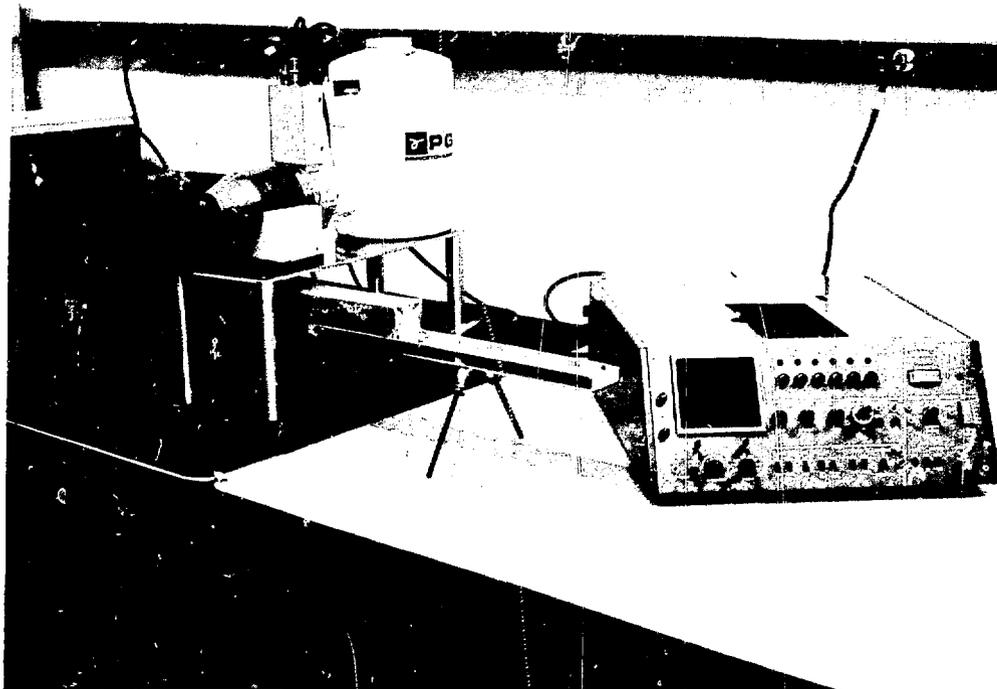


Fig. 19

Plutonium assays using the HLNCC depend on knowledge of plutonium isotopic ratios. Here, an HLNCC measurement is made on a zero power reactor fuel drawer, while isotopic ratios are being determined using an intrinsic Ge detector.

One of the more important improvements in neutron well counter technology has come about through the development of shift-register coincidence circuitry.⁽¹³⁾ This technique allows higher coincidence counting rates than is possible with conventional coincidence circuits, and as a result, can be used to assay very large Pu samples, with minimum deadtime correction.

Passive coincidence counters have also been built using plastic scintillators that detect both fast neutrons and gamma rays from spontaneous fission. Although this approach has advantages in certain applications, well counters have become more widely accepted for precise assays of plutonium, because of their insensitivity to gamma rays and their long-term stability.

IV. CALORIMETRY

The heat generated by natural radioactive decay is the basis of one of the most precise methods for assaying plutonium. Almost all of the power generated in typical Pu samples comes from alpha decay, with minor amounts coming from beta decay and spontaneous fission. Table V gives the specific power (watts/gram) for plutonium and americium isotopes of interest to calorimetry measurements.⁽¹⁴⁾ For "reactor grade" plutonium, the specific power is about 15 mW/g, which is sufficient to allow calorimetric measurements of even subgram samples.

TABLE V
SPECIFIC POWERS OF PLUTONIUM AND AMERICIUM

Isotope	Half-Life (yr)	Specific Power (W/g)	Uncertainty in Specific Power (% , 1σ)
²³⁸ Pu	87.79	5.6716×10^{-1}	0.10
²³⁹ Pu	24 082	1.9293×10^{-3}	0.27
²⁴⁰ Pu	6 537	7.098×10^{-3}	0.2
²⁴¹ Pu	14.35	3.390×10^{-3}	0.06
²⁴² Pu	379 000	1.146×10^{-4}	--
²⁴¹ Am	434.1	1.1423×10^{-1}	0.14

One of the unique advantages of calorimetry compared with other NDA methods is that absolute calibration can be performed using electrical standards; and the precision obtainable under laboratory conditions is 0.1 to 0.2%, a figure that is difficult to achieve by most other methods. On the other hand, for large samples of PuO₂, the measurement time is long, approximately two to four hours, due

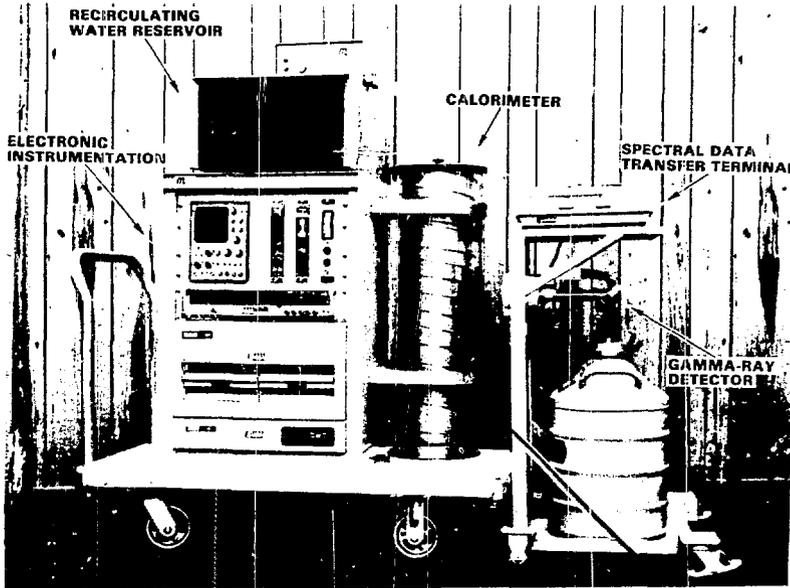


Fig. 20

Mound Laboratory instrument for assay of plutonium. The calorimeter measures power in watts, while the Ge spectrometer determines watts/gram based on Pu isotopic ratios.

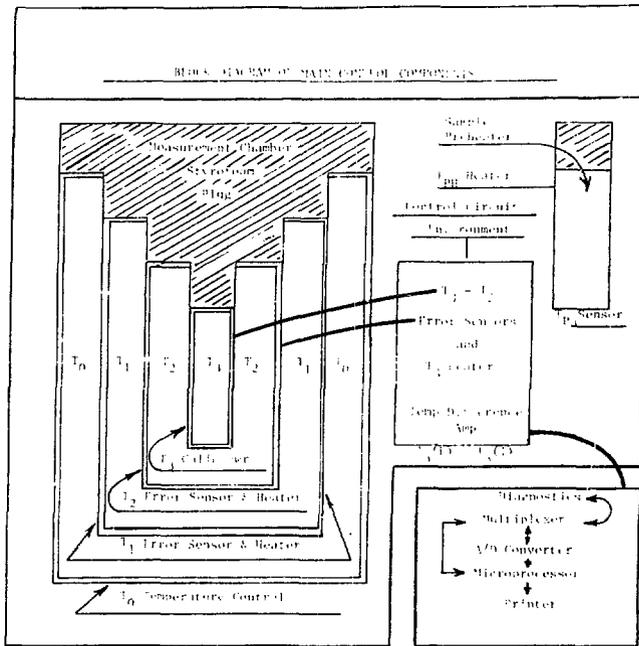


Fig. 21

Argonne design of a portable small sample calorimeter for the IAEA uses concentric aluminum cylinders, each with precise temperature control.

to the thermal properties of the sample material itself. Furthermore, calorimetry requires accurate knowledge of isotopic content, and absolute accuracy of total Pu is typically limited to about 1% because of uncertainties in determining the fraction of ^{238}Pu and ^{241}Am . Calorimeters are designed to give optimum performance (in terms of precision and measurement time) for a particular sample size, shape, and weight, and have lower precision when applied to other types of samples.

Figure 20 shows an instrument developed at Mound Labs for simultaneously measuring both plutonium isotopic ratios (using gamma-ray spectroscopy) and the power generated in the sample due to radioactive decay.⁽¹⁵⁾ The calorimeter consists of a constant temperature water bath that contains the sample well and temperature sensors. When a Pu sample is placed in the calorimeter, the sample comes to an equilibrium temperature that is measurably different from the reference temperature. Mound quotes an uncertainty in assaying grams of Pu of 1% for 11-cm-diameter containers with a measurement time of four hours.

Portable calorimeters have been developed at Argonne for use by the IAEA.⁽¹⁶⁾ The design consists of a series of concentric aluminum cylinders, each separately insulated and temperature controlled (Fig. 21). When placed in the inner-most cylinder, a plutonium sample reduces the electrical power required to maintain constant temperature. These instruments have a precision of about 1% and an equilibrium time of 20 minutes for samples of a few grams.

V. ACTIVE GAMMA-RAY AND X-RAY METHODS

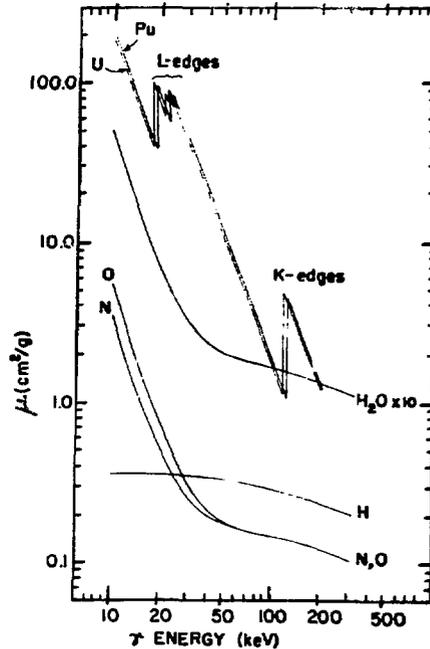
A. Absorption Spectrometry (Including X-Ray Densitometry)

Referring back to Fig. 1, active gamma-ray and x-ray methods can be further divided into absorption spectrometry (absorptiometry) and induced active response techniques.

Gamma-ray absorption measurements are not commonly used as a stand-alone assay technique in nuclear safeguards, since they are capable of little more than verifying the amount of high Z material in a sample. However, gamma-ray absorption techniques are widely used in many non-safeguards applications, such as in thickness gauges.

By contrast, x-ray absorption techniques are finding increasing application in safeguards, based largely on work at Los Alamos, where both K-edge and L-edge x-ray densitometers have been developed.⁽¹⁷⁾ X-ray densitometers are used to determine the amount of elemental uranium or plutonium in a sample by measuring the transmission of the sample at photon energies just above and below either the K or L absorption edge, see Table VI and Fig. 22. Measurements are made with a high resolution gamma-ray detector, external radiation sources, and suitable collimators for viewing the

Fig. 22
X-ray mass absorption coefficients for uranium, plutonium, and typical low Z matrix materials. X-ray densitometers have been designed that use both the K-edge and L-edge regions to determine elemental concentrations of U and Pu.



CONCEPTUAL DIAGRAM K-EDGE DENSITOMETER

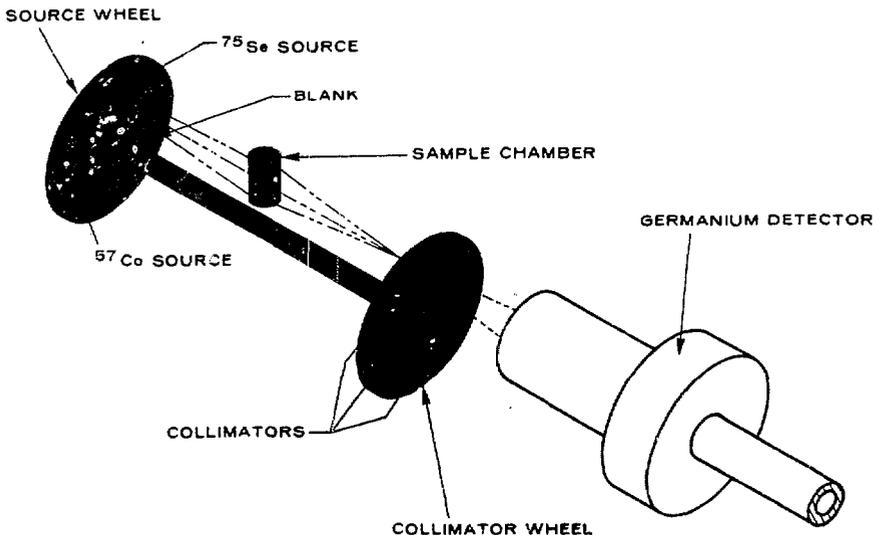


Fig. 23
In the K-edge densitometer installed at Tokai, isotopic sources and collimators are automatically rotated into position to measure x-ray attenuation of the sample just above and below the plutonium K-edge. Here a ^{75}Se source is positioned to measure the transmission at 121.1 keV.

TABLE VI
 L_{III} AND K ABSORPTION EDGE ENERGIES FOR
 URANIUM AND PLUTONIUM

<u>Absorption Edge</u>	<u>Element</u>	<u>Edge Energy (keV)</u>	<u>$\Delta\mu$ (cm²/gm)</u>
L _{III}	U	17.17	54.60
	Pu	18.05	51.90
K	U	115.60	3.65
	Pu	121.76	3.39

sample. For a K-edge assay of plutonium concentration, the sample transmission is measured at 121.1 keV (⁷⁵Se) and 122.1 keV (⁵⁷Co), see Fig. 23. Plutonium concentration (g/liter) is calculated from the equation

$$\rho = \frac{-\ln(T_2/T_1)}{\Delta\mu x}$$

where

T_2/T_1 = ratio of sample transmission at 122.1 keV and 121.1 keV

$\Delta\mu$ = difference in mass attenuation coefficient at 122.1 and 121.1 keV

x = sample thickness.

Precisions on the order of 0.5% can be obtained in a 30 minute assay.

Most of the K-edge instruments have been designed to measure discrete liquid samples of a few ml; however, an in-line instrument has been installed at the Savannah River Plant for test and evaluation (Fig. 24).

SRP DENSITOMETER
SCHEMATIC OF THE IN-LINE X-RAY ABSORPTION-EDGE DENSITOMETER
FOR THE SAVANNAH RIVER PLANT

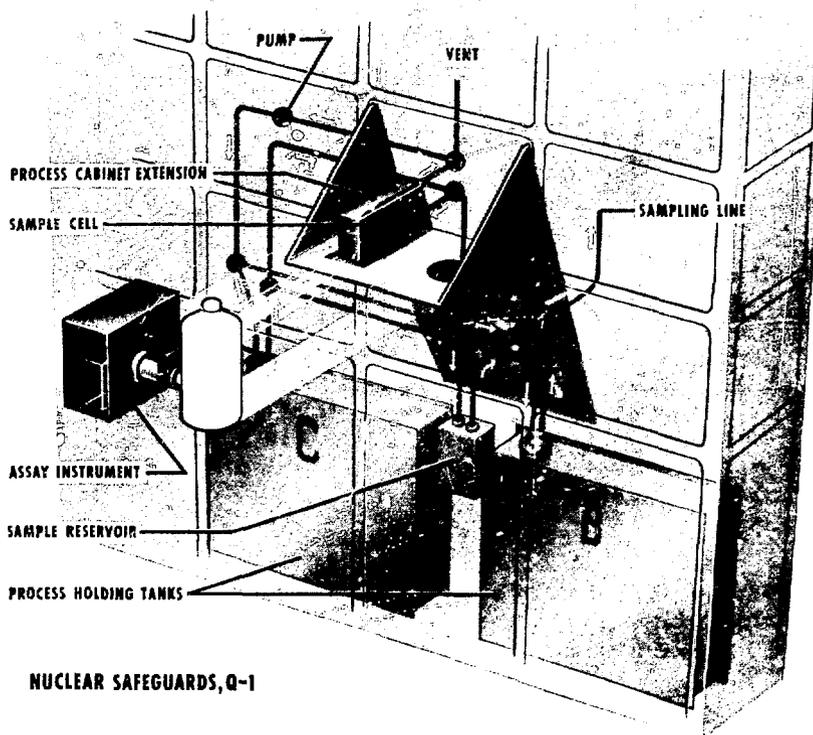


Fig. 24

The in-line K-edge densitometer installation at the Savannah River Reprocessing Plant. Plutonium product solution can be pumped from either of the process holding tanks through the sample cell, which is contained in a small extension of the process cabinet. The assay instrument sits on a shelf outside the process cabinet, allowing transmission measurements of the sample cell.

For solutions having plutonium densities below 20 g/l, the sample thickness required to perform accurate K-edge assays becomes impractically large. Table VI shows that the values of $\Delta\mu$ at the L_{III} edge are about 15 times greater than $\Delta\mu$ at the K-edge, allowing sample thicknesses to be reduced accordingly for L-edge assays.

L-edge densitometers use the bremsstrahlung from low energy x-ray generators to determine the sample transmission as a function

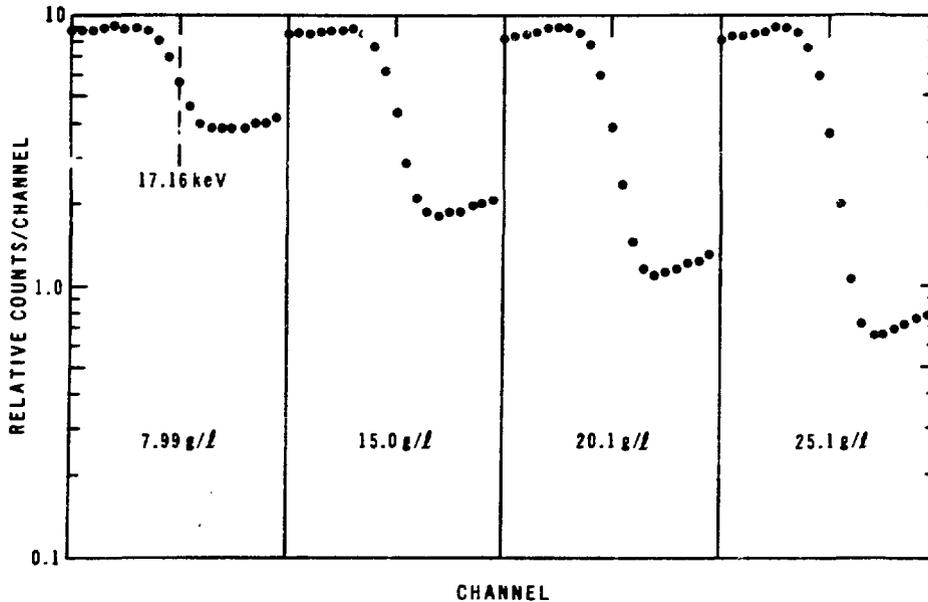


Fig. 25

X-ray transmission spectra for 2-cm-thick uranium solutions near the L_{III} absorption edge of uranium (17.16 keV), taken with the instrument shown in Figure 26.

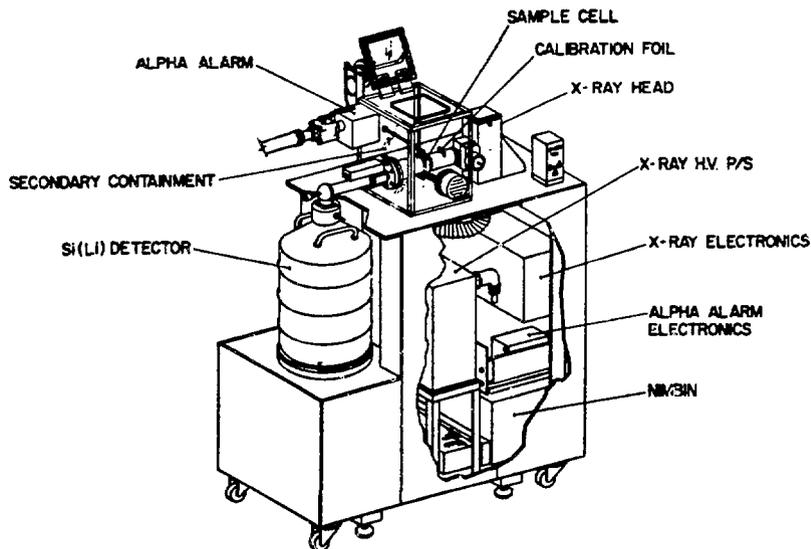


Fig. 26

L-edge densitometer designed for measuring uranium or plutonium concentrations in low density solutions. The secondary containment box which encloses the sample cell is designed to be mounted to the rear of a glovebox, and solution from the glovebox is piped into the sample cell.

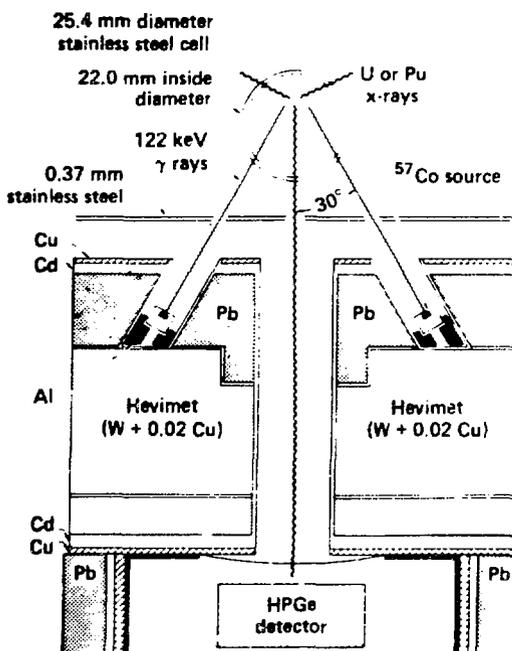
of energy across the absorption edge (Fig. 25). The use of a continuous x-ray spectrum provides a complete assay in one measurement, and the same x-ray machine can be used for assaying plutonium, uranium, and mixed U-Pu solutions (Fig. 26). Unlike K-edge assays, L-edge assays are sensitive to low Z matrix constituents because of the rapidly changing photo-electric and Compton cross-sections of low Z materials in this energy region.

B. Induced Active Response (Including X-Ray Fluorescence)

Active interrogation methods using gamma-ray or x-ray sources are not widely used in safeguards today, although one method was utilized in the past and another method looks promising for the future. In the early 1970s, IRT developed a barrel scanner using bremsstrahlung from a 10 MeV electron linac to cause photo-fission in ^{235}U , ^{238}U , and ^{239}Pu .⁽¹⁸⁾ Between each linac pulse, neutrons from the sample were moderated and counted with BF_3 counters. Although this technique gives fairly accurate assays of scrap materials, it has largely been replaced by active neutron methods.

A method that holds promise for future safeguards applications is x-ray fluorescence. For many years x-ray fluorescence has been used as a laboratory tool for chemical analysis based on the fact that characteristic x-ray energies depend on atomic number. Most previous applications used electron bombardment to produce the characteristic K or L x-rays; hence, careful sample preparation was required, much as is the case for alpha counting. More recently, low energy gamma-rays from isotopic sources have been used as the excitation source,⁽¹⁹⁾ allowing measurement of plutonium and uranium in their existing containers (Fig. 27).

Fig. 27
Arrangement of ^{57}Co excitation sources and Ge detector used by Camp and Ruhter⁽¹⁹⁾ for x-ray fluorescence measurement of uranium and plutonium solutions contained in a cylindrical (pipe) geometry.



X-ray fluorescence has been shown to have high precision over a wide dynamic range of uranium and plutonium concentrations. In mixed uranium-plutonium solutions, the method is capable of giving an accurate determination of the Pu/U ratio. However, to give accurate assays of individual concentrations of uranium and plutonium, techniques must be developed to correct for absorption in the sample of both the excitation gamma rays and the fluorescent x-rays.

VI. ACTIVE NEUTRON METHODS

A. General Information

Active neutron methods constitute one of the most powerful techniques for the assay of fissionable materials, and the number of active neutron instruments used in safeguards grew rapidly during the 1970s. Initially, active neutron assays were performed using reactors and positive ion accelerators as the source of neutrons, and these methods are still used when the ultimate in sensitivity is needed for small sample assay. However, for most safeguards applications, instruments that use isotopic neutron sources are preferred because of improved size, cost and reliability. Characteristics of the most commonly used isotopic neutron sources are shown in Table VII.(1)

TABLE VII

COMMON ISOTOPIC NEUTRON SOURCES

<u>Source</u>	<u>Approximate Average Energy</u>	<u>Half-Life</u>	<u>Maximum Typical Strength n/s</u>
^{252}Cf	Fission (2 MeV)	2.6 yr	5×10^9
$^{238}\text{Pu-Li}(\alpha, n)$	0.5 MeV	88 yr	2×10^6
$^{238}\text{Pu-Be}(\alpha, n)$	5 MeV	88 yr	10^6
$^{241}\text{Am-Li}(\alpha, n)$	0.5 MeV	458 yr	5×10^5
$^{124}\text{Sb-Be}(\gamma, n)$	23 keV	60 days	5×10^8

The primary instrument design problem in active neutron interrogation is in discriminating against source neutrons, while detecting neutrons produced by induced fissions in the sample. As shown in Fig. 1, the three methods used for discriminating against source neutrons are:

- coincidence discrimination,
- time discrimination, and
- energy discrimination.

In the following sections, instruments will be discussed that employ each of the above techniques.

B. Coincidence Discrimination (Random Driver, AWCC)

The random driver (Fig. 28) was one of the first active neutron assay instruments developed specifically for safeguards. The Los Alamos design⁽²⁰⁾ uses an AmLi neutron interrogation source of about 5×10^5 neutrons/s and large plastic scintillator neutron detectors, shielded from the sample with lead to reduce gamma-ray sensitivity. By demanding that two neutrons be counted with a 50 ns

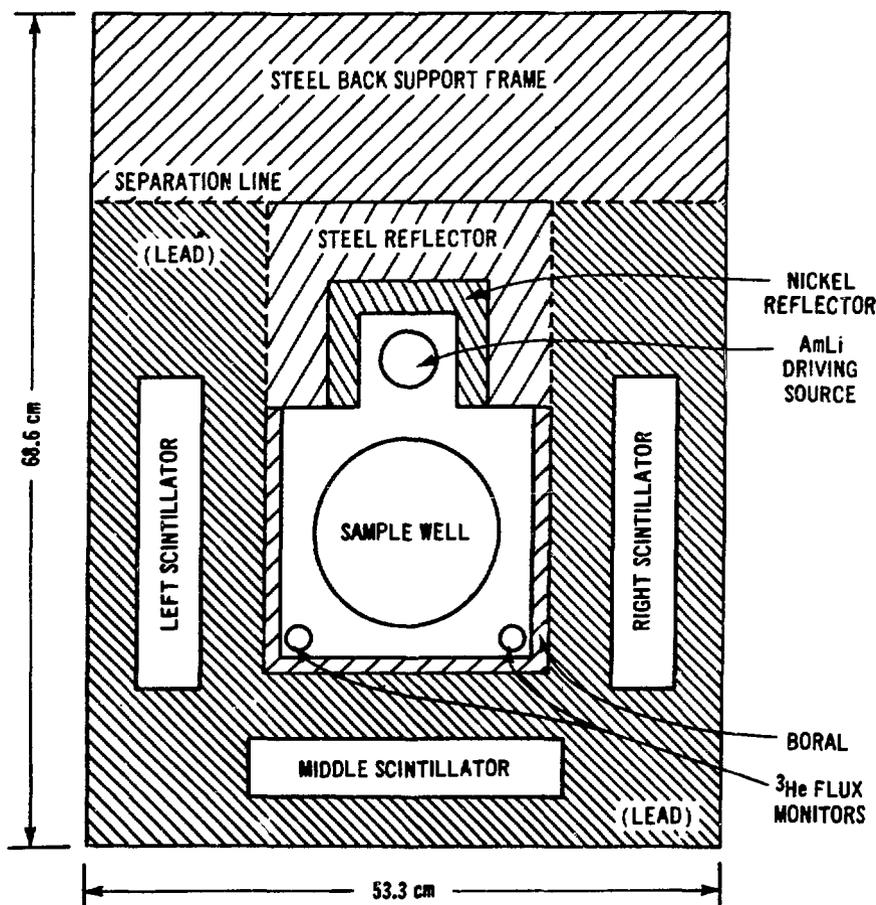


Fig. 28

Random driver of recent design used by Los Alamos for assay of plutonium samples. One of the first active neutron instruments designed for safeguards applications, random drivers have been widely used for the assay of uranium scrap materials in fuel fabrication facilities.

coincidence resolving time, single neutrons from the AmLi source are discriminated against, while multiple neutrons from induced fission in the sample are detected. Other random driver designs that omit the lead shielding are able to assay samples of approximately 0.1 gram of ^{235}U , but are also sensitive to gamma-ray attenuation in the sample. Random drivers have been widely used for assaying uranium scrap and waste materials, and have been designed to accommodate a variety of container sizes, ranging from a few liters to 200-liter waste barrels.

Most random drivers have incorporated into their design ^3He detectors used to correct the assay for hydrogenous moderating material in the sample and a means of rotating the sample in order to provide more uniform neutron irradiation. Some random drivers have also used temperature sensors to correct for detector temperature dependence. Although the smaller random drivers are suitable for van installations, their basic design using large scintillator detectors and lead shielding does not lend itself to portability.

The Active Well Coincidence Counter (AWCC) was designed as a simpler, more easily transported replacement for the random driver (Figs. 29, 30). The design of the AWCC is very similar to passive neutron well coincidence counters (Section III.C), except that two small AmLi neutron sources (approximately 5×10^4 n/s) are placed in end plugs above and below the sample well.⁽²¹⁾ A shift register coincidence unit effectively discriminates against single neutrons from the AmLi sources while detecting coincident neutrons from fissions in the sample. Compared with the random driver, the AWCC is less accurate for small samples, and it is slightly more expensive; but it is far more portable, rugged, and reliable; and, for these reasons, more suitable for IAEA applications.

An instrument based on the same principles as the AWCC was designed to assay fresh LWR fuel assemblies (Fig. 31). All of the instruments in this class can be used in the passive mode (by removing the AmLi neutron sources) to assay plutonium.

C. Time Discrimination (Cf Shuffler)

One of the oldest techniques for assaying fissionable materials involves irradiating samples with neutrons from reactors or particle accelerators and then counting either delayed neutrons or gamma rays from the sample. Delayed neutrons are emitted by neutron unstable fission products with half-lives ranging from 0.25 to 56 s. For ^{235}U , the ratio of delayed neutrons to prompt neutrons is about 1/120, and for ^{239}Pu , about 1/335. Delayed gamma rays are emitted by many different fission products with half-lives ranging from seconds to years.

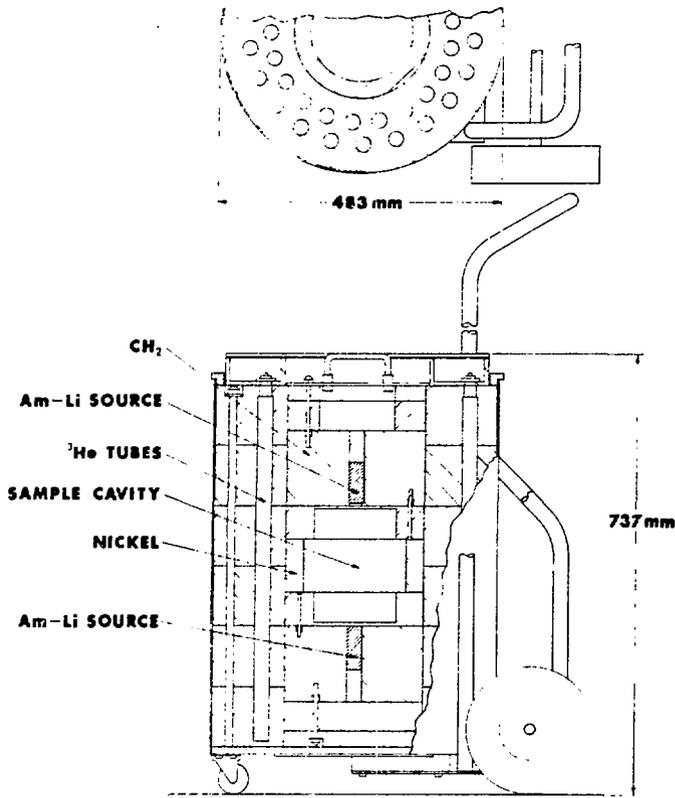
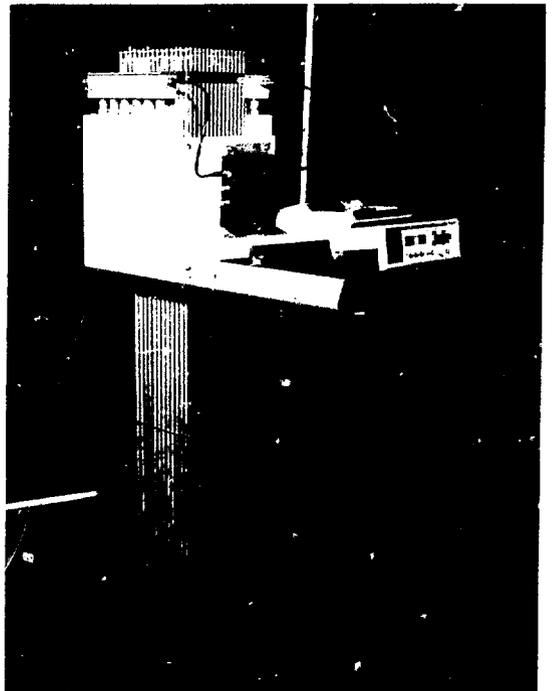


Fig. 29
Cross-section of Active Well Coincidence Counter, showing location of neutron sources in end plugs above and below the sample well.

Fig. 31
Active neutron instrument for the assay of fresh fuel assemblies. It uses a single AmLi neutron source on one side of the fuel assembly and six ³He detectors in polyethylene slabs on the other three sides of the assembly. The electronics package is the same for this instrument, the Active Well Coincidence Counter, and the High-Level Neutron Coincidence Counter.



Fig. 30
The Active Well Coincidence Counter was designed as a transportable instrument for IAEA use in assaying uranium samples.



With the production of large ^{252}Cf sources in the late 1960s, it became possible to use isotopic sources in delayed neutron and gamma-ray assay instruments. The Cf shuffler (Figs. 32, 33) uses a 1 mg ^{252}Cf source (approximately 2.5×10^9 n/s), a U-shaped source transfer tube, and ^3He proportional counters around the sample well.⁽²²⁾ A motor-driven cable moves the source into position where it irradiates the sample for a few seconds, then quickly withdraws the source to a shielded position. With the source removed, the ^3He detectors are gated on to count delayed neutrons, and the whole cycle is then repeated many times for an assay. Typical irradiation and counting cycles are about 10 seconds each, although optimum times may vary depending on sample characteristics.

Cf shufflers are among the most sensitive assay instruments, capable of measuring 1 mg of ^{235}U in small containers, with an assay time of approximately 30 minutes. Using source-tailoring techniques such as Ni reflectors and CH_2 moderators, one can adjust the energy spectrum of the interrogating neutrons to obtain either a thermal or a fast neutron assay. Shufflers have been designed for a wide range of material types, including ^{235}U scrap from fuel fabrication facilities, hot waste barrels containing uranium and plutonium, and highly enriched spent-fuel elements and waste canisters (Fig. 34). For measuring spent fuel, the Cf source must be large enough to overcome neutron background in the sample due to plutonium and curium isotopes.⁽²³⁾

Another type of instrument using ^{252}Cf neutron irradiation was developed for assaying fast breeder reactor fuel rods (Fig. 35). Here the technique was to continuously move a fuel rod through a shielded neutron irradiator, past a NaI detector where delayed gamma rays are counted. Individual fuel pellets can be scanned and total fissile accurately measured for both materials accounting and quality control.⁽²⁴⁾

D. Energy Discrimination (Spent-Fuel Assay System)

Several active neutron instruments have been designed that discriminate against source neutrons on the basis of neutron energy. One fairly recent example⁽²⁵⁾ is an instrument designed at Oak Ridge for the assay of spent breeder reactor fuel subassemblies. It uses four large ^{124}Sb -Be photo-neutron sources, each of which produce about 10^9 neutrons/s. Detectors are methane-filled, proton-recoil proportional counters, capable of discriminating against the 23 keV neutrons from the sources, while detecting the more energetic neutrons from induced fissions in the spent fuel. Developed for performing assays at the head end of a reprocessing plant, the system is capable of 5% precision in a 20-minute measurement time.

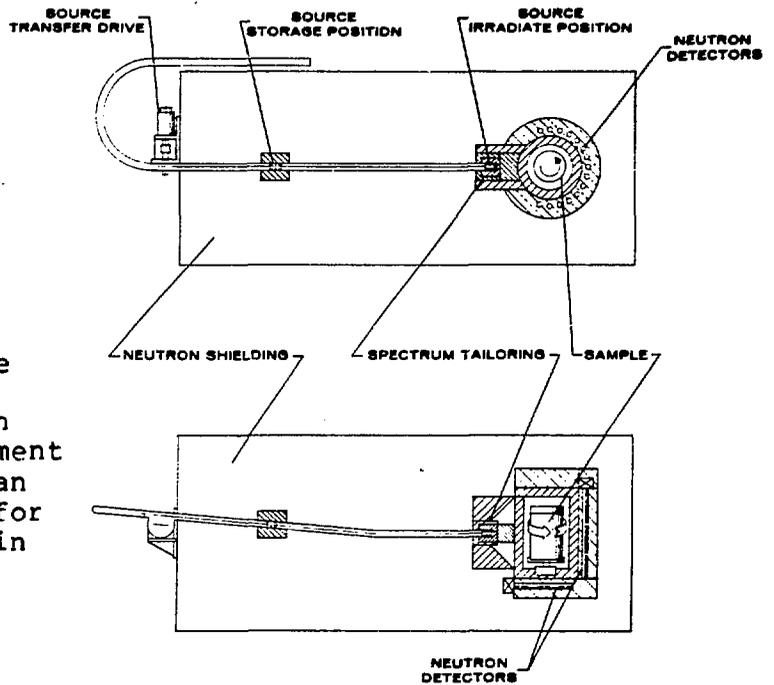


Fig. 32
 Top and side views of the californium shuffler installed at the Savannah River Plant. The instrument was designed to provide an assay precision of 0.3% for uranium scrap and waste in 18 cm x 30 cm cans.



Fig. 33
 Complete Savannah River Cf shuffler showing terminals, electronics rack, and hoist for lowering samples into the measurement well.

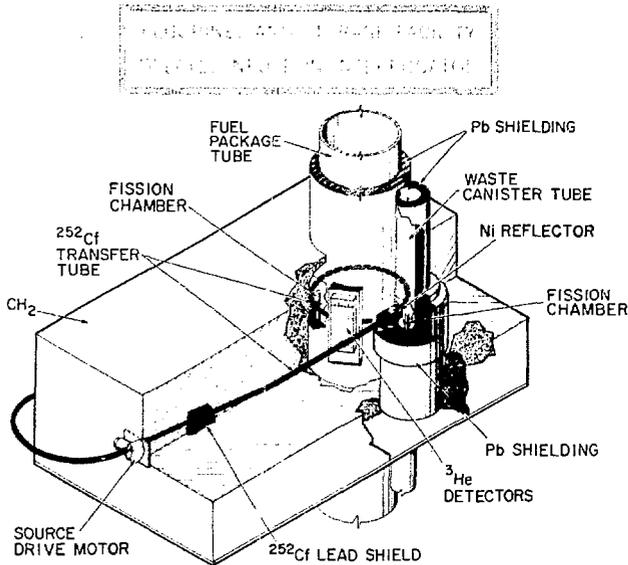


Fig. 34
Large Cf shuffler system for the assay of either spent-fuel assemblies or waste canisters. To achieve a more uniform assay of assemblies, the Cf source tube moves around the irradiation cycle. This instrument is to be installed in the Florinel and Storage (FAST) Facility at the Idaho Chemical Processing Plant.

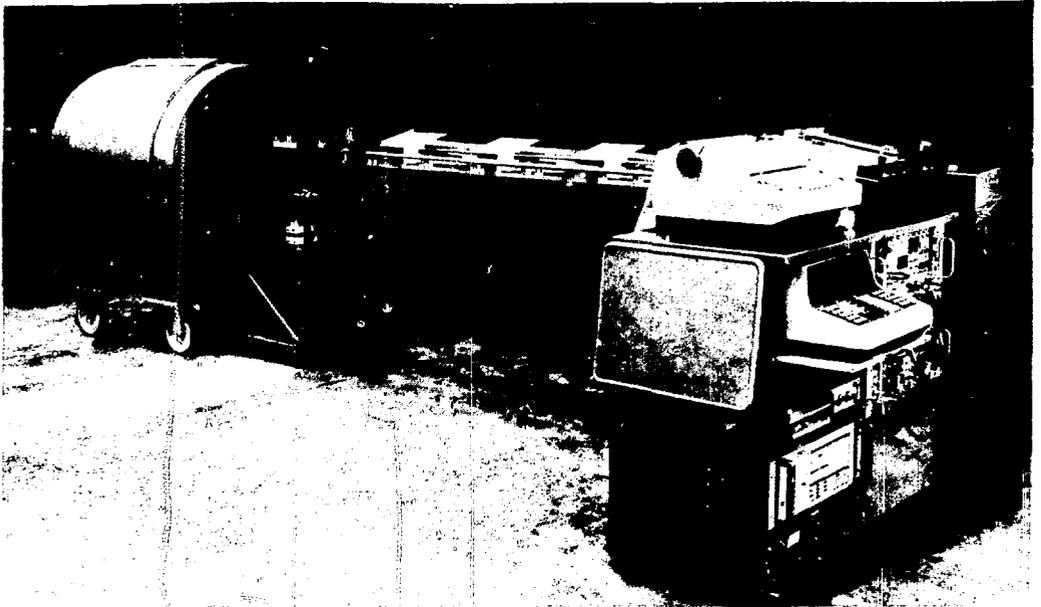


Fig. 35
Fuel rod scanner developed for the Fast Flux Test Facility (FFTF) at Hanford, Washington. The hybrid assay instrument uses a Cf source for fast neutron interrogation and measures delayed gamma rays with two large NaI detectors. The system determines plutonium fissile content in a fuel rod to better than 0.5% accuracy and has been used to assay many thousands of rods.

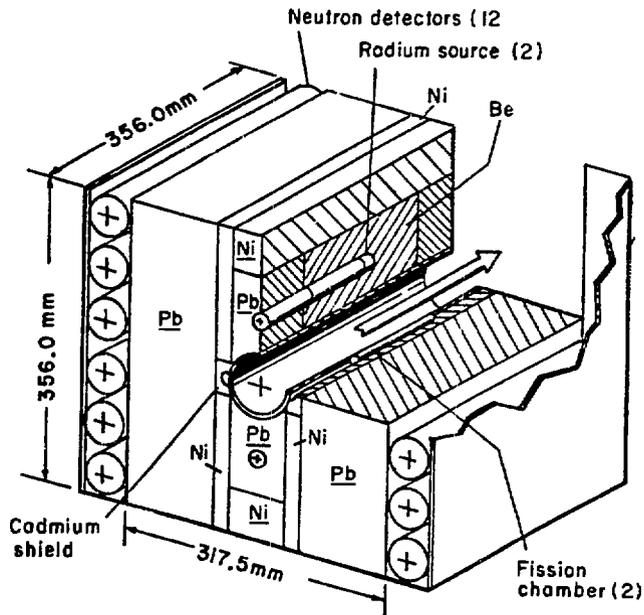


Fig. 36

^{226}Ra -Be neutron source and ^4He detector arrangement used by Los Alamos (26) for assay of ^{235}U content of irradiated Rover (nuclear rocket) fuel. The ^4He proportional counters detect fission neutrons while discriminating against the less energetic source neutrons.

An earlier system designed at Los Alamos for assaying irradiated nuclear rocket fuel worked on the same principle, but was physically much smaller (Fig. 36). It used two small ^{226}Ra -Be(γ ,n) sources and twelve ^4He gas proportional counters. (26) The technique of energy discrimination against source neutrons has also been applied by Los Alamos in instruments for assaying fresh LWR fuel assemblies and for well logging of uranium ore formations.

VII. CONCLUSIONS

The interpretation of essentially all assays depends on having information about the sample, other than the quantity being measured. Usually, the more well characterized a sample is from a physical and chemical standpoint, the more accurately it can be assayed, either destructively or nondestructively.

The selection of one NDA technique over another commonly depends on what one knows and does not know about the characteristics of the sample material. From the standpoint of NDA, the most important characteristics of a sample are its spatial properties (size, shape, uniformity, etc.), its isotopic properties (ratios of fissionable isotopes), and its matrix properties (atomic numbers, density, unusual non-fissioning isotopes, etc.).

If a sample to be assayed has well determined isotopic properties but poorly defined spatial properties, then a neutron method or calorimetry is likely to provide the best assay. Consider, as examples, the dependence of passive neutron and calorimetric assays on precise knowledge of plutonium isotopic content, but their relative independence of sample uniformity.

When neither spatial nor isotopic properties are well known, a combination of gamma-ray spectroscopy and active neutron methods is likely to provide the most accurate assay and greatest level of confidence.

Variations in high Z or high density matrix materials (that are not properly corrected for) increase the uncertainty in gamma-ray assays more than in neutron assays. Variations in low density matrix materials, such as water, oxygen, and fluorine, increase the uncertainty in neutron assays more than in gamma-ray assays. Thus, a high density matrix tends to favor neutron assay, while a low density matrix tends to favor gamma-ray assay.

The relationship between gamma-ray assay, neutron assay, and calorimetry is complementary in nature. When the characteristics of a sample (spatial, isotopic, or matrix) limit the accuracy of one NDA approach, another approach can generally be used with a high degree of confidence.

A large number of NDA instruments have been developed over the past decade and many are now commercially available. Future development work is expected to produce a new generation of NDA equipment that will be easier for inspectors to independently calibrate, operate, and maintain, and also to lead to new approaches for potential problem areas, such as large bulk processing facilities.

Table VIII graphically summarizes points discussed above. For Case I, gamma-ray scattering and absorption parameters are measurable or known, but isotopic composition of fissionable and matrix materials is unknown. In this case several different gamma-ray techniques can be applied to give the typical assay results indicated. For Case II, isotopic composition of fissionable and matrix materials is known, but gamma-ray scattering parameters of the sample are not known. In this case passive or active neutron techniques and calorimetry are applicable. For Case III, neither gamma-ray scattering parameters nor isotopic composition of the sample are known. In this case, high resolution gamma-ray spectroscopy can be used to detect the presence of certain isotopes, and active neutron methods may be able to give an estimate of effective 'fissile content.

TABLE VIII

CONDITIONS UNDER WHICH VARIOUS NDA METHODS ARE USEFUL

	<u>Measurable or Known Sample Characteristics</u>	<u>Useful NDA Methods</u>	<u>Typical Assay Results</u>
Case I	Key gamma-ray scattering/absorption characteristics	Passive gamma	Enrichment Isotopic ratios, Iso- topic content
		X-ray	Pu, U concen- tration
		Passive gamma and Passive neutron	Pu mass
		Passive gamma and Calorimetry	Pu mass
Case II	Isotopic composition	Passive neutron	Pu mass
		Calorimetry	Pu mass
		Active neutron	U-235 mass Pu mass
Case III	Nil	Passive gamma	Presence of certain iso- topes
		Active neutron	Effective fissile

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 15: NDA MEASUREMENTS FOR LWR FUEL
FABRICATION FACILITIES

This session reviews the principal NDA techniques used for measurement of low-enriched uranium (LEU) and describes how these techniques can be applied to different material balance areas in an LEU fuel fabrication plant.

After the session, the participants will understand how passive gamma-ray, passive neutron, and induced fission NDA techniques are used by LEU fuel fabrication plant operators and safeguards inspectors in applications, such as production control and inventory verification.



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October 17-November 4, 1983

SESSION 15: NDA MEASUREMENTS FOR LEU
FUEL FABRICATION FACILITIES

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Los Alamos National Laboratory

I. INTRODUCTION

Nondestructive assay (NDA) techniques and instrumentation can be a valuable component of a fuel fabrication facility's overall nuclear materials accountability system. This paper describes the application of NDA at each key measurement point (KMP) following the material flow from receipt of the feed material to shipment of the finished fuel assemblies. At each KMP, measurements are made by the facility operator and the inspection agencies, both national and international. The methods used by the two organizations differ.

We begin with a brief review of the relevant NDA techniques and then discuss their application at each KMP, distinguishing between facility measurements and inspection agency verification measurements.

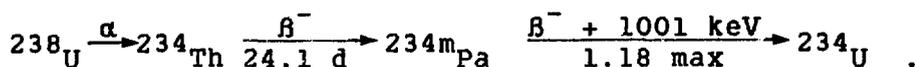
II. NDA TECHNIQUES USED FOR THE MEASUREMENT OF LOW-ENRICHED URANIUM

Radiation signatures that can be used include those of gamma rays, neutrons, and induced-fission radiations.

A. Gamma-Ray Signatures (Fig. 1)

The most widely used gamma ray for uranium measurements is that of the 185.7-keV line emitted during the natural decay of ^{235}U . It has an intensity of 4.3×10^4 $\gamma/\text{g/s}$ and can be easily separated from other lines. Because of its relatively low energy, it has a limited range in UO_2 or UF_6 . For example, the mean free path is 2 mm in UF_6 and approximately 5 mm in UO_2 powder. However, the limited penetrability can be turned to an advantage. It can be shown that for uranium materials (for example, UO_2 or UF_6) in quantities large enough so that the 186-keV gamma rays from the center of the material cannot reach the surface, the number of gamma rays counted at the surface per surface area is proportional to the ^{235}U enrichment ($^{235}\text{U}/\text{U}_{\text{total}}$).¹ The enrichment is a key quantity in fabrication plant quality control and accountability. Thus this type of gamma measurement is quite useful.

The isotope ^{238}U also emits a useful gamma ray at 1001 keV but through a two-step decay process:



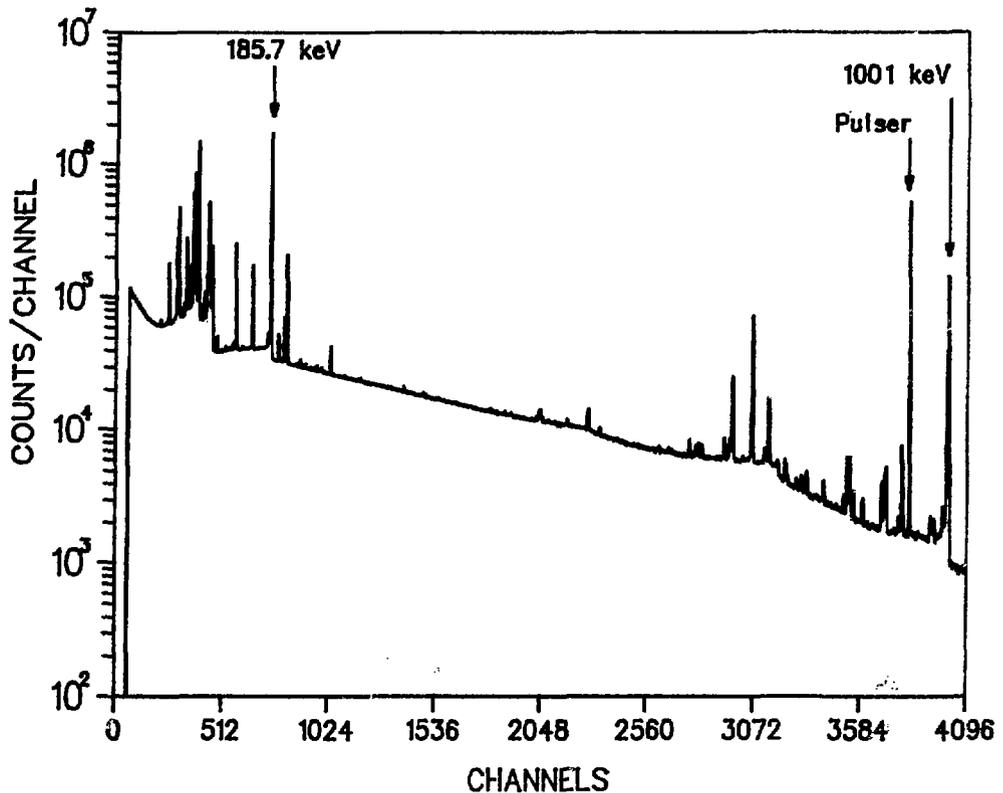


Fig. 1.

High-resolution gamma spectrum of 3%-enriched uranium.

The implication of the two-step process is that any time thorium is separated from uranium the 1001-keV activity will change until an equilibrium can be reached, approximately 4×24.1 days after separation. Processes such as UF_6 enrichment, melting or vaporization of UF_6 , and oxide conversion can result in separation of the two elements. The intensity of the ^{238}U 1001-keV line when at equilibrium is 1.0×10^2 $\gamma/\text{g}/\text{s}$, 400 times less intense than the ^{235}U 186-keV gamma-ray line. However, its penetrability is about 15 times greater. Thus, for some situations, this high-energy ^{238}U signature is used to measure the quantity of uranium present.

B. Neutrons

Uranium naturally emits two sources of neutrons: those from (α, n) reactions and those from decay by spontaneous fission (SF).

The (α, n) reaction proceeds in two steps. First, a uranium isotope (for example, ^{234}U) emits an alpha particle, which in turn reacts with a light element (for example, fluorine or oxygen), and this latter reaction emits a single neutron. Thus the number of neutrons depends on the number of alpha particles, the isotopic composition of the uranium, and the chemical form (that

is. UO_2 , UF_6 , etc.). Table I illustrates this point and emphasizes the role of the ^{234}U isotope with its high alpha-particle emission rate. Uranium-234 is usually present in only small percentages. However, as is indicated in Table II, ^{234}U can dominate the (α, n) neutron emission. Usually this neutron signature is used only for large quantities of UF_6 with well-known ^{234}U isotopic information.

Uranium isotopes can also decay by the process of SF, with the resulting emission of two or more neutrons per fission event.

TABLE I

ALPHA-DECAY AND UF_6 NEUTRON YIELDS FOR URANIUM ISOTOPES

<u>Isotope</u>	<u>$T_{1/2}$ (yr)</u>	<u>Alpha Activity (α/g)</u>	<u>Neutrons/g-s</u>
^{234}U	2.48×10^5	2.27×10^8	$5.8 \times 10^{2^a}$
^{235}U	7.13×10^8	7.90×10^4	12.2×10^{-2}
^{236}U	2.39×10^7	2.35×10^6	3.95
^{238}U	4.51×10^9	1.23×10^4	12.9×10^{-3}

^aBy comparison, $^{234}\text{UO}_2$ yields only 14 neutrons/g-s.

TABLE II

 UF_6 NEUTRON YIELDS OF
NORMAL URANIUM

<u>Isotope</u>	<u>Neutrons/s per gram U</u>	<u>Relative Yield (%)</u>
^{234}U	3.3×10^{-2}	53.5
^{235}U	8.7×10^{-4}	1.4
^{238}U	12.8×10^{-3}	21.0
^{238}U SF ^a	<u>1.5×10^{-2}</u>	24.1
Total:	6.2×10^{-2}	

^aSpontaneous fission.

Table III lists the SF rates and shows that the ^{238}U isotope is the predominant SF neutron emitter for low-enriched uranium (LEU). It is possible to separate SF neutrons from (α, n) events using neutron coincidence counting instrumentation. Thus, this technique can measure the quantity of ^{238}U present in an item. However, the count rate is low. This technique therefore is used only for items containing kilograms of uranium.

C. Induced-Fission Radiation

In measurement cases in which the natural signatures do not give good results, it is possible to induce the fission process using an external neutron source. This is called active neutron interrogation. Active neutron instruments are usually designed to preferentially measure the total ^{235}U content in an item. As mentioned earlier, it is difficult to measure the ^{235}U quantity in larger samples, either because of small penetrability (186-keV gamma ray) or the absence of neutrons. Uranium-235 can be separated from ^{238}U by designing the active neutron energy spectrum to be below the fission threshold of ^{238}U . This approach has been used to measure cans of UO_2 powder, fuel rods, and fuel assemblies.

TABLE III
SPONTANEOUS FISSION OF FISSIONABLE ISOTOPES

<u>Isotope</u>	<u>SF Half-Life (yr)</u>	$\bar{\nu}$ <u>(SF)</u>	<u>SF/g-s</u>
^{232}Th	1.4×10^{18}		4.1×10^{-5}
^{234}U	2.0×10^{16}	~2	2.8×10^{-3}
^{235}U	1.9×10^{17}	~2	2.96×10^{-4}
^{236}U	2×10^{16}	~2	2.8×10^{-3}
^{238}U	9.86×10^{15}	1.95	5.64×10^{-3}
^{238}Pu	4.9×10^{10}	2.26	1.1×10^3
^{239}Pu	5.5×10^{15}	2.2	1.0×10^{-2}
^{240}Pu	1.17×10^{11}	2.17	4.71×10^2
^{241}Pu	5.0×10^{15}	2.2	1.1×10^{-2}
^{242}Pu	6.8×10^{10}	2.16	8.0×10^2
^{241}Am	2×10^{14}	2.3	0.27
^{252}Cf	86	3.8	6.14×10^{11}

III. APPLICATION OF NDA TECHNIQUES AT KMPs

We now discuss the techniques used to measure LEU flowing through a fabrication facility.

A. Receiving MBA

Low-enriched feed material is received in one of two chemical forms: UF_6 from an enrichment facility or UO_2 powder from an oxide conversion facility.

UF_6 typically arrives in cylinders containing 1-2 metric tons of solid UF_6 . These cylinders are less than one-half full when the UF_6 is solid. The quantity of material is determined by weighing the cylinder and determining its isotopic and chemical composition.

The facility maintains and calibrates scales for accurately weighing full or empty cylinders. International Atomic Energy Agency (IAEA) inspectors can check the scales by bringing in a portable load-cell weighing system that can weigh full cylinders with an accuracy of 1 kg out of 2000 kg.²

The facility operator determines the ^{235}U isotopic composition, that is, enrichment, by drawing a UF_6 sample for laboratory mass spectroscopy analysis. Inspectors can also obtain a sample to be sent away to a laboratory, but long delays usually occur before the results are available. Three alternatives have been suggested to provide more rapid analyses for inspection purposes. Two involve obtaining a sample and the third is an enrichment measurement performed on the UF_6 cylinder itself.

The first alternative is to utilize a transportable quadrupole mass spectrometer.³ Essentially this means that the inspector hand-carries the "laboratory" during inspections.

The second alternative is to measure the UF_6 sample using gamma-ray spectroscopy.⁴ The sample is fed into the counting chamber in the gaseous phase. By measuring the 186-keV line for ^{235}U content and the gamma-ray transmission using an external gamma source for total uranium, the ^{235}U enrichment is determined. Two such instruments are currently being tested for use by IAEA inspectors. They are not portable instruments but are intended to be transported to a facility under inspection. Results indicate that accuracies of 1-2% relative can be achieved in counting times of 10-15 min.

The third alternative is to use the gamma-ray enrichment principle, making the measurements of the 186-keV line through the wall of the large cylinders with portable instrumentation. Figure 2 shows the detector-cylinder geometry. A portable high-resolution gamma detector (HRGS) is used because experience has shown that low-resolution NaI measurements are unreliable. The buildup of uranium decay products on the cylinder walls produces gamma rays that interfere within the NaI spectra. The HRGS spectrum separates the 186-keV line from the interferences. The thick cylinder walls attenuate the 186-keV gamma-ray line quite strongly, by about a factor of 5. If all cylinder walls had exactly the same thickness, the effect of the attenuation would cancel out in the enrichment measurement. But the wall thicknesses do vary slightly and therefore each cylinder wall must be

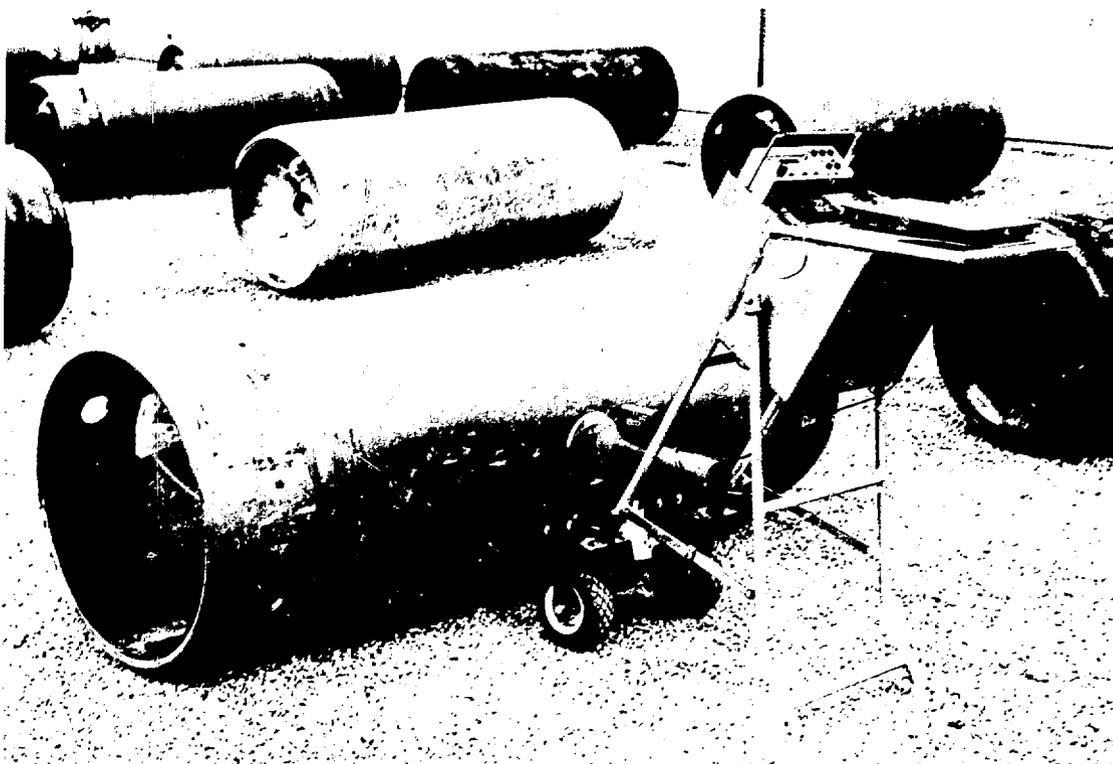


Fig. 2.

Detector-cylinder geometry for enrichment measurement. Although a NaI detector is shown in the photograph, a high-purity germanium detector is preferred.

measured; this is done using a commercially available ultrasonic thickness gauge. Thus, the final determination of enrichment combines a gamma-ray measurement with a wall-thickness correction.

The advantage of this third approach is that the measurement is performed on the cylinders in their storage locations, that is, with no cylinder movement or sample taking. However, the accuracy obtained is much poorer than with sample-taking methods. At present, accuracies of 10% relative have been achieved. Ongoing development work hopes to reduce this accuracy figure to 5% relative in the near future.

If the feed material is UO_2 powder, it is usually packaged in containers of a few tens of kilograms each. Again the facility accountability values are determined by weighing and sampling. The gamma-ray enrichment technique works quite well for cans of UO_2 powder because the walls of the containers are thin, the geometry is more suitable, and a daughter product interference is low. Facility operators have reported accuracies of 1-2% using NaI detectors and commercially available electronics packages.⁵ IAEA inspectors carry portable versions of this equipment to make similar independent measurements. The operator uses these enrichment measurements for quality assurance.

whereas the inspection agency considers this procedure a verification measurement.

B. Processing MBA

For fabrication or processing material balance areas (MBAs), the items requiring measurement include pellets, rods, and process waste. Pellets are weighed and a few pellets are sent to the analytical laboratory for total dissolution. For process control purposes, some facilities count gamma rays in a single pellet, using a well-type NaI detector. The pellet is essentially surrounded by the detector, resulting in a high counting efficiency. The type of measurement is somewhere between an enrichment determination (requiring infinite thickness and constant surface area) and a measure of the total ^{235}U contained in the pellet. The results may be difficult to interpret for accountability purposes.

For inventory verification of cans containing greater than a kilogram of pellets, IAEA inspectors can use an instrument based on active neutron interrogation: the thermal-neutron active well coincidence counter (AWCC) (Fig. 3).⁶ This instrument uses two moderated AmLi neutron sources to induce fissions in the ^{235}U . Fission neutrons are counted in detector tubes that surround the sample well. An important part of the AWCC is the coincidence logic circuitry that distinguishes between single neutron events (AmLi neutrons) and coincidence neutron events (fission neutrons). Counting times of 5 min yield measurements with precisions of less than 1%. The accuracies depend on the can size and the quantity of material. For items containing larger quantities of LEU, the AWCC or a similar active interrogation device provides the only practical way to measure total ^{235}U content.

The active interrogation technique is also used to measure fabricated fuel rods (pins), primarily because of the short measurement times required. The throughput of rods can be very high in a commercial facility, and the measurement method must keep up with it. Rod scanners for LEU fuel rods typically use a moderated neutron source (usually ^{252}Cf) to induce fissions in ^{235}U . The source is located inside a large moderator-biological shield. Rods are pushed through a channel in this shield at speeds of 5-6 m/min. (Many scanners have more than one channel and can measure a number of rods simultaneously.) Following irradiation, the rod passes through neutron and/or gamma detectors that measure the delayed products of fission. These delayed neutrons and gamma rays are emitted for up to a few minutes after the fission event. Different scanners are designed to use the fission signatures in different ways. One way is to use the delayed gammas to measure pellet-to-pellet variation on a relative basis and the integrated delayed neutron count as a measure of the total ^{235}U content in a rod. The commercially available rod scanners have proven themselves to be extremely valuable for quality control and, in some cases, are used for accountability values. Inspection agencies have also used facility-owned scanners for inventory verification. When the inspectors use facility equipment, they first independently authenticate^{7,8} that the instrument is performing correctly.



Fig. 3.
An active well coincidence counter.

It is particularly important to use NDA equipment to measure finished products because of the expense associated with destroying items in order to destructively analyze them.

Process waste includes items such as wet grinder sludge, solid wastes, and HEPA filters. Because of the small quantities of materials involved per batch, high measurement accuracy is unnecessary. For much of the waste, NDA is the most practical measurement approach. Gamma-ray counting of the 186-keV line is used for the low-density items; for the heavier items, use of either an active instrument or gamma-ray counting of the high-energy 1000-keV line usually gives the required accuracy.⁹

C. Fuel Assembly Storage/Shipping MBA

The fuel assembly storage/shipping MBA offers the challenging problem of measuring the finished product, namely, full fuel assemblies. The facility will have already established the accountability values of the assemblies based on the quantities in each individual rod. It is the task of the inspector to verify these values using portable NDA instruments. Figure 4 shows one such instrument developed for the IAEA that is called the active neutron coincidence collar (ANCC).¹⁰ As the name implies, it is based on active neutron interrogation. An AmLi neutron source is located on one of the sides, with neutron detectors on the other three sides. Induced-fission events are detected using the

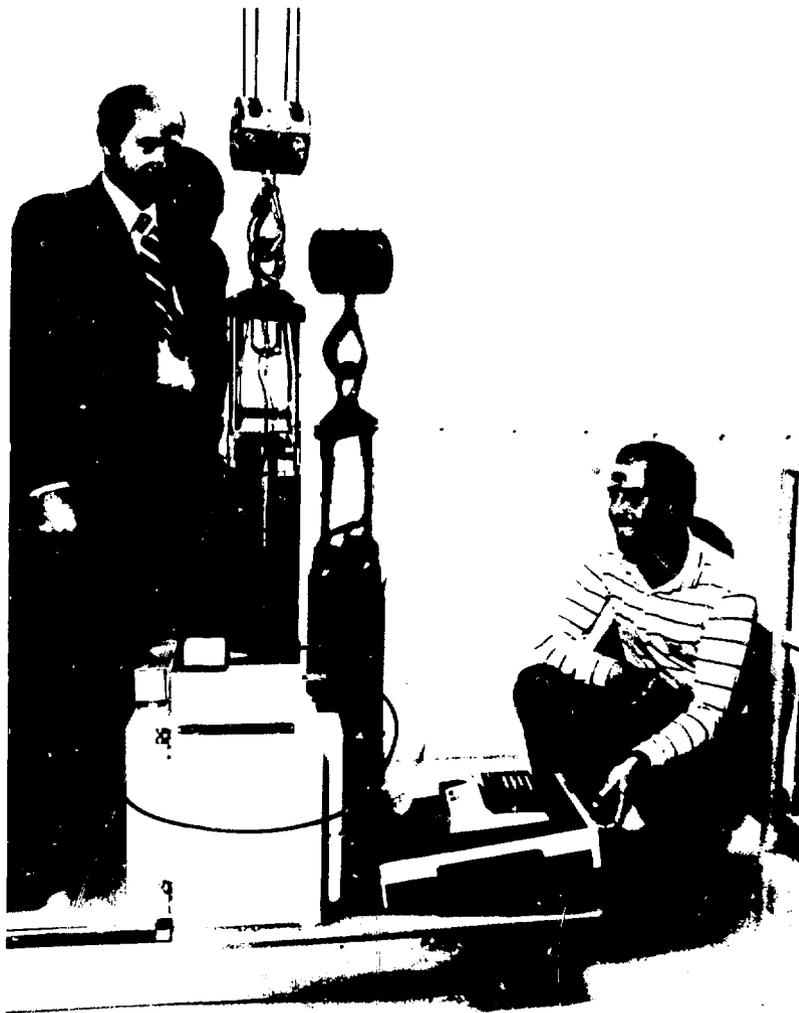


Fig. 4.
An active neutron coincidence collar measuring
LEU fuel element.

coincidence logic electronics. Because the ANCC is much shorter than the fuel assembly, it measures the ^{235}U content per unit length. To calculate the total ^{235}U content, the length of the fuel region must be determined, for example, with a NaI detector or known from rod scanner measurements. Even without length information, ANCC measurements can be used to verify average enrichment, presence or absence of neutron poisons, and the total number of fuel rods. Additional information can be obtained by removing the neutron source and counting the ^{238}U SF neutrons. This measures the ^{238}U per unit length. Thus, an inspector has an NDA tool that can be used to independently verify fuel assemblies.

IV. CONCLUSION

For any measurement system to give long-term reliable results, its performance should be monitored by a measurement control program. A measurement control program¹¹ involves making a series of instrument checks on a regular basis (for example, daily) and recording the results for the purpose of determining precision, accuracy, and drifts in the system. As an example of the kinds of checks made for a typical NDA instrument, a series of replicate run (for example, 15) will determine precision (reproducibility) and the measurement of a known standard will yield accuracy. By measuring accuracy over a long period of time (for example, months) long-term drifts can be watched. A well-designed measurement control program is a necessary part of this overall system.

Another necessary and often expensive component of the measurement system is the availability of well-known and representative physical standards. The ultimate limitation on measurement accuracy is determined by the uncertainty in the instrument calibration and the physical standards used to produce the calibration.

In conclusion, NDA instrumentation does play an important role in the measurement of LEU as it moves through the fabrication facility.

In addition to providing necessary information for inspection agencies, the NDA results can be used by facility operators for process and quality control.

REFERENCES

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2. E. Dermendjiev, W. Lauppe, and F. Schinzer, "Mass Verification of UF_6 Stored in 30-Inch Cylinders," IAEA-SM-260/4, International Symposium on Recent Advances in Nuclear Materials Safeguards, Vienna, Austria, November 8-12, 1982.

3. G. Guzzi and A. Federico, "Use of Transportable Quadrupole Mass Spectrometer for Isotope Analysis of Uranium Hexafluoride," IAEA-SM-260/51, International Symposium on Recent Advances in Nuclear Materials, Vienna, Austria, November 8-12, 1982.
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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 16: TOUR OF LOS ALAMOS SAFEGUARDS R & D
LABORATORIES: DEMONSTRATION AND USE OF NDA
INSTRUMENTS AND MATERIALS CONTROL AND
ACCOUNTING SIMULATION

The group will visit the Los Alamos National Laboratory and tour the nuclear safeguards R & D facilities. Many of the instruments described in sessions 14 and 15 will be available for the participants' examination and "hands-on" use. These will include:

- Portable single channel and multichannel pulse height analyzers for field measurement of uranium enrichment,
- Laboratory gamma-ray spectroscopy system for assay of waste samples,
- Active well neutron coincidence counter for measurement of uranium samples,
- Neutron coincidence collar for measurement of unirradiated uranium fuel assemblies.

These NDA instruments will be set up to perform simple nuclear fuel measurement experiments. After a brief introduction participants will have access to the various instruments and, following instructions, will be able to perform the indicated nondestructive assay. Attendants will be at all instruments to answer questions and guide the measurements.

In addition to the NDA instruments, the participants will have an opportunity to experience an interactive simulation of materials diversion scenarios and their monitoring and detection through the Los Alamos Real-Time Materials Accounting System Simulator (RTMASS). Attendants will guide the participants through the exercise and discuss MC&A questions.

At the end of this session participants will:

- be aware of the range of nondestructive assay instrumentation available to the facility operator or safeguards inspector,
- know the typical range of accuracy and precision attainable using NDA techniques,
- have gained some "hands-on" experience with the various instruments and measurement procedures,
- be more familiar with the mechanics of material diversion in a facility and its detection through real-time materials accounting.



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SESSION 16: TOUR OF LOS ALAMOS SAFEGUARDS R & D
LABORATORIES: DEMONSTRATION AND USE OF
NDA INSTRUMENTS AND MATERIAL CONTROL AND
ACCOUNTING SIMULATION

Los Alamos Safeguards Staff

I. INTRODUCTION

This session will be devoted to a "hands on" tour of non-destructive assay techniques and instrumentation which can be used to measure the fissile content of unirradiated nuclear fuel assemblies and fuel components. In addition, time will be allocated for all students to experience a computer simulation of a materials accounting exercise during attempted diversions of material in a nuclear process. There are stations set up on the tour to allow the exploration of five different exercises:

<u>Station</u>	<u>Title</u>
1	Measurement of Uranium Enrichment: The portable, intelligent multichannel analyzer and stabilized assay meters.
2	Measurement of LWR Fuel Assemblies in the Field: The neutron coincidence collar.
3	Active Neutron Coincidence Assay of Uranium-Bearing Fuel: The active-well coincidence counter (AWCC).
4	Passive, Transmission-Corrected Gamma-Ray Assay of Uranium Waste Containers: The segmented gamma scanner.
5	Real Time Materials Accounting Systems Simulator (RTMASS).

At each station, there will be approximately one hour available during which members of the Los Alamos National Laboratory Safeguards Assay Group and Safeguards Systems Group will explain the exercises and encourage the course participants to take part in the activities themselves. There should be ample time for all participants to sample the measurements and simulator and to discuss their uses and significance with the staff.

The tour participants will be divided into five groups, and the groups will circulate among the five demonstration stations according to the following schedule:

	Station 1	Station 2	Station 3	Station 4	Station 5
9:00 AM	Introductory Lecture and Coffee Break				
10:00 AM	Group 1	Group 2	Group 3	Group 4	Group 5
11:00 AM	Group 2	Group 3	Group 4	Group 5	Group 1
12:00 N	----- Lunch at LANL Cafeteria -----				
1:30 PM	Group 3	Group 4	Group 5	Group 1	Group 2
2:30 PM	Group 4	Group 5	Group 1	Group 2	Group 3
3:30 PM	----- Coffee Break -----				
4:00 PM	Group 5	Group 1	Group 2	Group 3	Group 4
5:00 PM					

Stations 1-3 are located in the Safeguards Assay Group Instructional center (building 110); station 4 is in the gamma-ray laboratory in building 2; and station 5 is in the conference room of building 27. Participants will be guided to the stations outside building 110.

II. STATION 1: MEASUREMENT OF URANIUM ENRICHMENT: THE PORTABLE, INTELLIGENT MULTICHANNEL ANALYZER

A. Description

The goal of this exercise is to measure the ^{235}U enrichment of uranium oxide. The measurement is based on the fact that the emission rate of the 185.7-keV gamma ray from an infinitely thick sample (4.0 g/cm^2 or 4mm of sintered oxide) is directly proportional to the atom fraction of ^{235}U in the sample. The equipment used for this measurement is a 1.9-cm x 1.9-cm NaI detector and a battery-powered, 1024-channel analyzer. The detector has an ^{241}Am alpha source which provides a reference peak in the output spectrum that is used to stabilize the instrument. A two-window peak area determination is made using one window set over the 185.7-keV peak and another set just above this to sample the Compton background produced in the detector by higher energy gamma rays from ^{238}U and its daughter products. The ^{235}U enrichment is determined from the equation:

$$\%^{235}\text{U} = A * C_1 + B * C_2$$

where C_1 and C_2 are the measured activities in the two windows and A and B are calibration constants. The calibration constants are determined by measuring two samples of known enrichment. The MCA has a software function ENRH which guides the user through the calibration and subsequent measurement of unknown samples.

B. Procedure

1. Turn PWR switch on (up).
2. Press SHFT STAT and set MCA parameters as follows:
 - CT = 100
 - DETECTOR = 1 (NAI)
 - INPUT POL = 0 (-)
 - GAIN = 16
 - LLD = 15
 - ULD = 255
 - MEMORY GROUP = 4 of 4
3. Place the 10% uranium oxide can on the detector and collect a 100-s spectrum, press STOP/START/1/ENTR. The MCA will collect the spectrum and stop after 100 s. Observe the spectrum and identify the 185.7-keV peak from ^{235}U .
4. Press SHFT ENRH and follow instructions:
 - set CT = 300 s
 - use PRESET WINDOWS

5. Place 17.5% can on detector, enter 17.5 as enrichment for standard 1 and press start.* At end of the 300-s measurement of first standard record C_1 and C_2 at the top of the attached data sheet.
6. Place 1.96% can on detector, enter 1.96 as enrichment for standard 2 and press start. Record C_1 and C_2 and the calibration constants A and B on the data sheet.
7. The system is now calibrated and ready to measure unknown samples. Measure other cans as time allows and record the results on the lower part of the data sheet. During the assay the system displays a running estimate of the enrichment based on the accumulated counts.
8. The SAM-2 uses a similar NaI detector and two single-channel analyzers (SCA) to make the same enrichment measurement. This instrument is much more limited in application than the portable MCA but can be used for enrichment measurements. Several SAM-2 instruments have been calibrated and should give the same value for the unknown sample enrichments as the MCA. Take a sample can and place it on the SAM detector. Press RESET/START. At the end of two minutes, the enrichment will be displayed on the front panel; this is a cumulative measurement so the intermediate readings have no meaning.

C. References

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*The enrichment, 17.5%, is entered as "1", "7", "ENTER", "5", "ENTER".

DATA SHEET FOR ENRICHMENT MEASUREMENT WITH NAI AND PORTABLE MCA

CALIBRATION:

<u>%²³⁵U</u>	<u>C₁</u>	<u>C₂</u>	<u>TIME</u>
17.5			300 s
1.96			300 s

A = _____

B = _____

MEASUREMENT OF UNKNOWN CANS:

<u>CAN NO.</u>	<u>%²³⁵U</u>	<u>+</u>	<u>ERROR</u>	<u>KNOWN %²³⁵U</u>
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The Los Alamos Portable Multichannel Analyzer, along with the NaI detector in the configuration appropriate for enrichment measurements. The analyzer is battery powered and contains sufficient measurement and analysis software to direct and carry out a complete enrichment measurement.

V. STATION 4: PASSIVE, TRANSMISSION-CORRECTED GAMMA-RAY ASSAY
OF URANIUM WASTE CONTAINERS: THE SEGMENTED GAMMA
SCANNER (SGS)

A. Description

The goal of this exercise is to measure the ^{235}U content of 30-gallon barrels of low-density, uranium-bearing waste materials. To overcome the variability typical of waste samples, a powerful method for making such measurements is the segmented gamma scan. In this procedure, individual horizontal segments of the sample are assayed for ^{235}U content. In the assay of each segment, a transmission correction is measured and applied, using a ^{169}Yb gamma-ray source external to the sample and mounted on the instrument. As was discussed in the session on NDA fundamentals, such a correction allows the assay to take into account the absorption of gamma rays by the sample material.

The measurement instrument is fully automated, with the motion of the sample table, data acquisition, and data analysis being performed under computer control. As a result, required operator interactions are minimized. The measurement result is a geometric profile of the SNM in the container and the total ^{235}U content. These results are printed out by the computer as the measurement concludes.

The SGS in this exercise is designed to handle large barrels of material, and the assay procedure used is a so-called "one-pass" assay. In this procedure, both the sample and the transmission source gamma ray intensities are measured simultaneously. The portion of the gamma-ray spectrum of interest is shown in Figure 1. The sample transmissions at the ^{169}Yb gamma-ray energies (177 and 198 keV) are interpolated to give the transmission at the assay energy

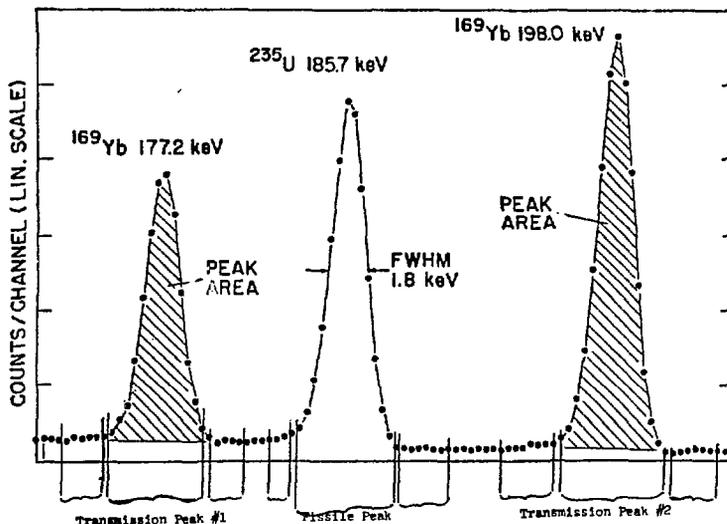


Figure 1. High-resolution gamma-ray spectrum for SGS assay in the energy region 165-205 keV.

(185 keV). The measured assay peak intensity is corrected accordingly, and the assay proceeds. If the ^{235}U loading of the sample is very low, then the 185-keV peak will be very weak and may be seriously distorted by the strong ^{169}Yb peaks on either side of it. In such a case, a so-called "two-pass" assay is performed, where the 185-keV gamma-ray intensity is first measured with the ^{169}Yb source shielded; then the Yb transmission gamma rays are counted in a second measurement.

Other designs of the SGS exist which facilitate the measurement of smaller samples, such as small process cans or even smaller laboratory samples in bottles or vials. Examples of these other SGS designs will be shown during the exercise.

B. Procedure

The SGS is calibrated by measurement of samples of known composition and loading. To save time, we have performed this calibration measurement in advance of the laboratory exercise. The SNM profile of the calibration sample will be displayed near the instrument. Sample measurements will be performed by removing arbitrary amounts of material from the calibration sample and remeasuring the barrel.

The segmentation configuration for the measurements is chosen at the beginning of the assay procedure, and this choice has also been made in advance. The segmentation chosen for this exercise is shown in Figure 2. The sample barrel contains several sealed plastic bags of cleaning tissues which have been dusted with uranium oxide powder. As a result, material can be removed from, added to, and repositioned in the sample barrel with little effort.

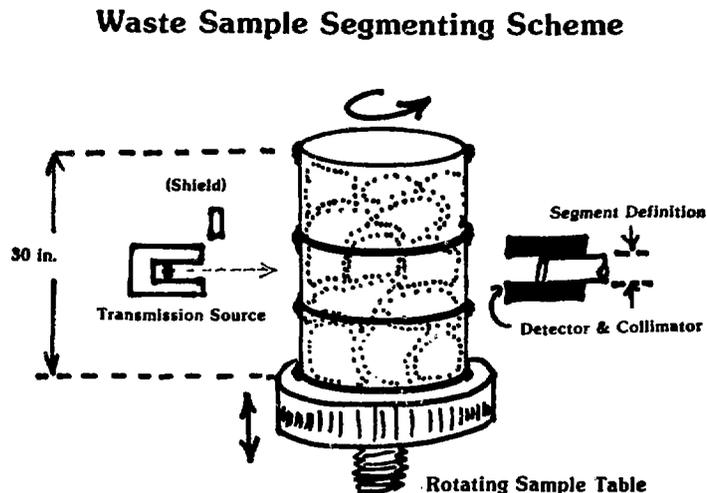


Figure 2. The sample barrel is 30 inches high and is divided into ten 3-inch segments, as defined by the detector collimator. As each segment is assayed, the barrel is rotated to smooth out any inhomogeneities in material placement.

The measurement has been set up in advance to involve the one-pass assay with the segmentation shown in Figure 2. The assay is begun by choosing the total count time for the 10 segments, which determines the assay precision for that measurement. As the measurement proceeds, the instructor will discuss the gamma scanning technique in more detail and also show the other SGS instruments in the laboratory. Measurement results for each exercise will be duplicated so that each student can have a personal copy.

The students should be aware of the precision obtained in each measurement as a function of total counting time. Record the measurement results in the table below for later reference.

C. Reference

1. "Gamma-Ray Measurements with the Segmented Gamma Scan," E. Martin, D. Jones, and J. Parker, Los Alamos Report LA-7059-M (1977).

DATA TABLE FOR SGS MEASUREMENT RESULTS:

Calibration data: _____ Corrected counts/gram Uranium
 [Supplied by instructor from previous measurements]

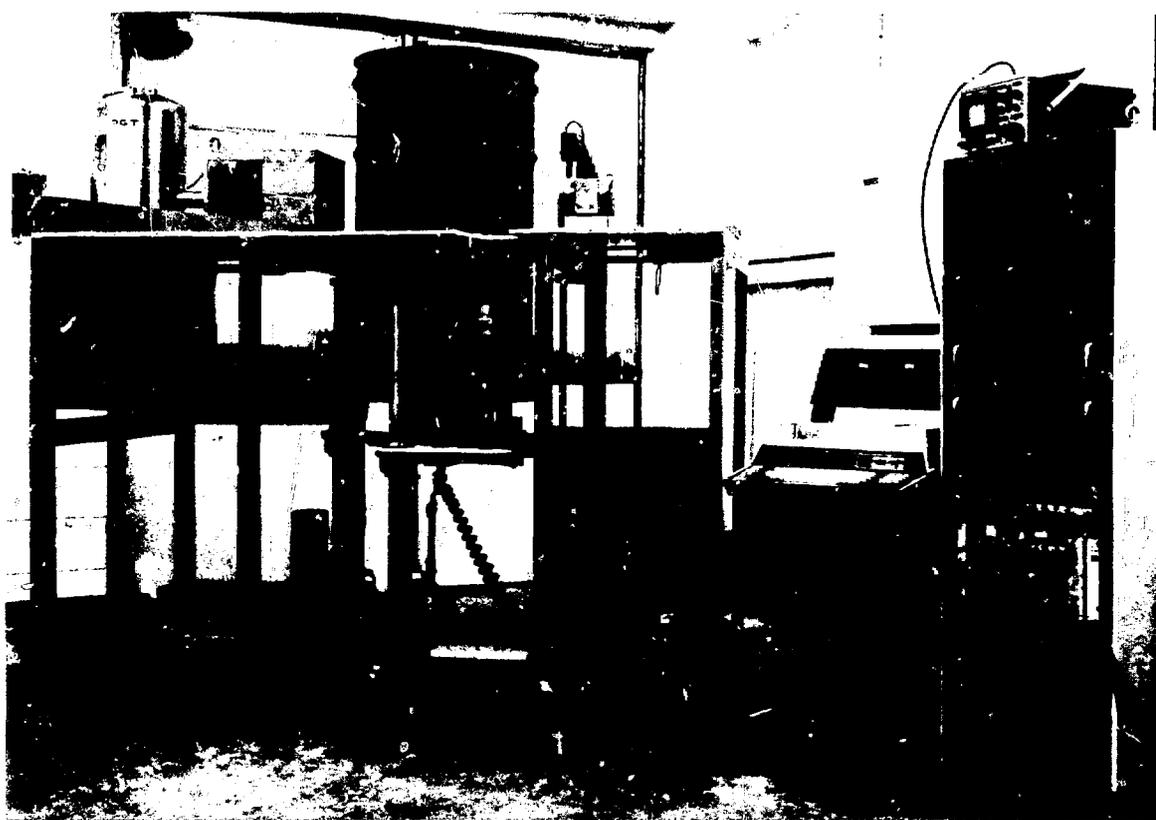
Segmentation: 10 3-inch segments, one-pass assay

Measurement #	Count time/segment [T]	Total U(g) [M _U]	$\sigma(M_U)$	$\sigma^r(M_U)$
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Note: The quantity $\sigma(M_U)$ is the statistical uncertainty of the assay result, in grams. The quantity $\sigma^r(M_U)$ is the relative or fractional uncertainty in M_U , defined by:

$$\sigma^r(M_U) = \sigma(M_U)/M_U$$

It is the quantity $\sigma^r(M_U)$ that will improve (decrease) as the counting time is increased.



The Segmented Gamma Scanner (SGS) for transmission-corrected passive gamma-ray assay of large containers of low-density uranium-bearing materials. The measurement of the container is divided into discrete segments; each segment is individually assayed for U-235, with transmission correction. From these data, the total U-235 content and an SNM profile are obtained for that container. The sample is automatically rotated during the assay in order to smooth out any inhomogeneities. The entire apparatus and the measurement procedure are computer controlled for added ease of operation.

Similar gamma-scanners exist on smaller scales, to measure typical uranium oxide cans and even smaller samples in bottles and vials.

VI. STATION 5: REAL TIME MATERIALS ACCOUNTING SYSTEMS SIMULATOR

A. Introduction

The Real Time Materials Accounting Systems Simulator (RTMASS) has been developed primarily as an educational tool to simulate in real time the operation of a nuclear materials accounting system. In essence the RTMASS is a computer game with two principal players, the Diverter and the Nuclear Material Control Officer (NMCO). The Diverter attempts to steal a goal quantity of nuclear material while the NMCO tries to detect the missing material. Each of the players has his or her own computer terminal for interfacing with the RTMASS.

The RTMASS encompasses the three major codes, MODEL, MEASIM, and DECANAL, that have been developed primarily for Safeguards Systems Studies at Los Alamos. The MODEL code is used for the simulation modeling of the process. This code consists of the SLAM II¹ Simulation Language along with some auxiliary input and output subroutines. The MEASIM² code simulates the process measurements and computes the measurement error variances. DECANAL³, the DECision ANALysis code, consists of a series of detection algorithms that can be used to determine the presence of a diversion.

A block diagram showing the flow of information in the simulator is shown in Fig. 1. The Process Model block simulates the process. Output from this block consists of the arrays of process variables that serve as the input to the Measurement Model. The measured values of the process variables are computed by the Measurement Model. These measured values are then input to the Decision Analysis block where calculations are made to determine if a diversion has taken place. As can be seen in Fig. 1, the Diverter interfaces with the process model in the theft of material, while the NMCO monitors the outputs from the decision analysis algorithms. After this analysis the NMCO makes a decision of either "diversion" or "no diversion." If the decision is "diversion," the simulation is terminated, whereas if the decision is "no diversion," the simulation continues. In addition to modeling the process, SLAM II is also used to control the flow of information for the complete RTMASS system as represented in Fig. 1.

B. Model Description

The RTMASS has been designed to allow for flexibility with regard to the particular process being simulated. For purposes of education on the simulator, however, a simple process serves just as well as a more complicated process and also improves the response time because of the reduced computational requirements. A simple tank with a single input and single output as shown in Fig. 2 is used for the process in this exercise. The tank has an inventory of 100 kg with daily batch input and output transfers of 10 kg each. Materials balances are drawn around the process at a frequency of once per day. The process measured values are assumed to behave according to the following equations.

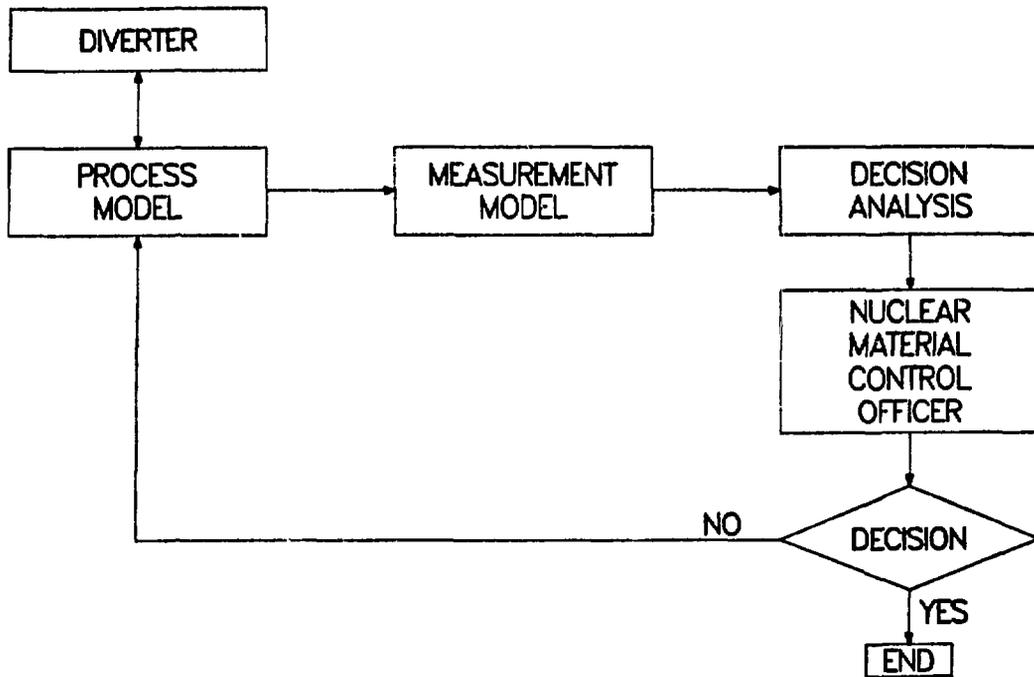


Fig. 1. Information flow diagram for the RTMASS.

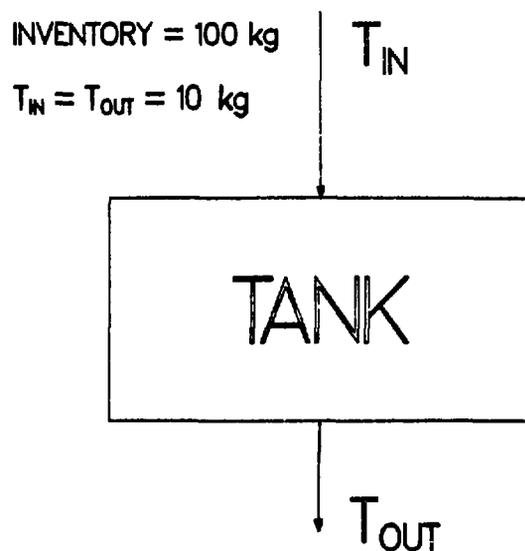


Fig. 2. Process model for the RTMASS.

$$I_m = I(1 + \epsilon_I) \quad (1)$$

$$T_m = T(1 + \epsilon_T + \eta_T) \quad (2)$$

where

I_m = measured value of the inventory,
 I = actual true value of the inventory,
 ϵ_I = inventory random error,
 T_m = measured value of the transfer,
 T = actual true value of the transfer,
 ϵ_T = transfer random error, and
 η_T = transfer systematic (correlated) error.

Both the input and output transfer measurements are assumed to behave according to the same equation. All the measurement errors are assumed to have a standard deviation of 0.006868 kg, that is,

$$\sigma_{\epsilon_I} = \sigma_{\epsilon_T} = \sigma_{\eta_T} = 0.006868 \quad (3)$$

C. Detection Algorithms

As indicated above, the game is played by the Diverter trying to steal material and the NMCO attempting to detect this loss of material. If there were no measurement errors, the NMCO would be able to detect the loss of material without fail. With measurement errors present, however, the NMCO cannot be sure if the signals he observes from the decision analysis tests are due to a real diversion or to measurement errors. The NMCO has at his disposal a number of tests that he can use to detect a diversion. These include the Shewart, CUSUM, Uniform Divergence (UDT), CUMUF, and Residual MUF tests. Alarm charts are employed in the first three of these tests, Shewart, CUSUM and UDT, to assist in making the decision regarding diversion or no diversion. The alarms on the chart consist of color-shaded squares ranging from a dark blue for a very weak alarm to dark red for a very strong alarm. The CUMUF and Residual MUF tests employ threshold boundary crossings to indicate the presence of a diversion.

D. Diversion Sensitivity

The simulation is designed to run for a maximum of 50 days with a materials balance taken once per day. The goal quantity of material to be taken by the diverter over this time period is calculated for this exercise from the "diversion sensitivity."

"Diversion sensitivity" is an important consideration for this system from a safeguards standpoint. For the purposes of this discussion "diversion sensitivity" is that quantity of material diverted over a given period of time that can be detected

as missing by the NMCO with some reasonable probability of success and with a relatively small false-alarm probability. One way of calculating "diversion sensitivity" is via the standard deviation for the CUSUM over the time interval being considered. If N is equal to the number of balances and σ is the CUSUM standard deviation for N balances, then a uniform diversion of $2\sigma/N$ over these N balances can be detected via the sequential CUMUF test 60% of the time with a false-alarm probability of 5%. Hence, the 2σ value is one way of measuring "diversion sensitivity." In this simulator exercise the 2σ value will be used to define the goal quantity of material to be diverted.

For the simple process of Fig. 2 and the measurement error models of Eq. (1) and (2), it can easily be shown that the CUSUM variance for N balances is given by

$$\sigma^2 = 2I^2\sigma_{\epsilon_I}^2 + 2NT^2(\sigma_{\epsilon_T}^2 + N\sigma_{\eta_T}^2) \quad , \quad (4)$$

where

- σ^2 = CUSUM variance for N balances,
- N = number of balances,
- σ_{ϵ}^2 = variance of the inventory random error,
- σ_{ϵ}^2 = variance of the transfer random error, and
- σ_{η}^2 = variance of the transfer systematic error.

From Eq. 3 and with $N = 50$ it follows that

$$\sigma = 5.0 \quad .$$

Hence, the "diversion sensitivity," or 2σ as it has been defined for the purposes of this exercise, is equal to 10 kg. This is the amount of material that the Diverter will attempt to steal over N balances without being detected by the NMCO.

E. Operational Procedures

As indicated above, the RTMASS is designed to simulate 50 days of the process with materials balances drawn once per day. Control of the system alternates between the Diverter and the NMCO. For the first 10 days of the simulation, the Diverter can divert material but the NMCO cannot observe any of the data. At the end of 10 days the NMCO enters the game to observe the outputs from the decision analysis tests. He now has the opportunity to observe the results from the following decision analysis tests:

1. Shewart,
2. CUSUM,
3. Uniform Diversion Test (Kalman Filter),
4. CUMUF and Residual MUF test.

The CUMUF and Residual MUF tests are separate tests, but the results are presented simultaneously on the same screen. The NMCO enters a carriage return to bring up another test on the screen. After viewing the resultant graphical output from the decision analysis tests, the NMCO makes the decision "diversion" or "no diversion." If he concludes that a diversion has taken place, he terminates the simulation by entering a "0" at the terminal. If he is uncertain at this point about "diversion," he continues the simulation by entering a "1" and then enters the number of days to which he would like the simulation to continue before he analyzes more data. The Diverter is then given another chance to divert material, and the cycle repeats itself. If the simulation continues for 50 days without the NMCO detecting a diversion, then by default the decision is "no diversion."

F. References

1. A. A. B. Pritsker and C. D. Pegden, Introduction to Simulation and SLAM (Halstead Press, New York, 1979)
2. E. A. Kern, "User's Manual for a Measurement Simulation Code," Los Alamos National Laboratory report LA-9246-M (July 1982).
3. J. T. Markin, A. L. Baker, and J. P. Shipley, "DECANAL User's Manual," Los Alamos National Laboratory report LA-9043-M (April 1982).

DIVERSION TABLE
REAL TIME MATERIALS ACCOUNTING SYSTEMS SIMULATOR

DIVERTER _____

DATE _____

<u>DAY</u>	<u>DIVERSION</u>	<u>DAY</u>	<u>DIVERSION</u>	<u>DAY</u>	<u>DIVERSION</u>
1	_____	21	_____	41	_____
2	_____	22	_____	42	_____
3	_____	23	_____	43	_____
4	_____	24	_____	44	_____
5	_____	25	_____	45	_____
6	_____	26	_____	46	_____
7	_____	27	_____	47	_____
8	_____	28	_____	48	_____
9	_____	29	_____	49	_____
10	_____	30	_____	50	_____
11	_____	31	_____		
12	_____	32	_____		
13	_____	33	_____		
14	_____	34	_____		
15	_____	35	_____		
16	_____	36	_____		
17	_____	37	_____		
18	_____	38	_____		
19	_____	39	_____		
20	_____	40	_____		

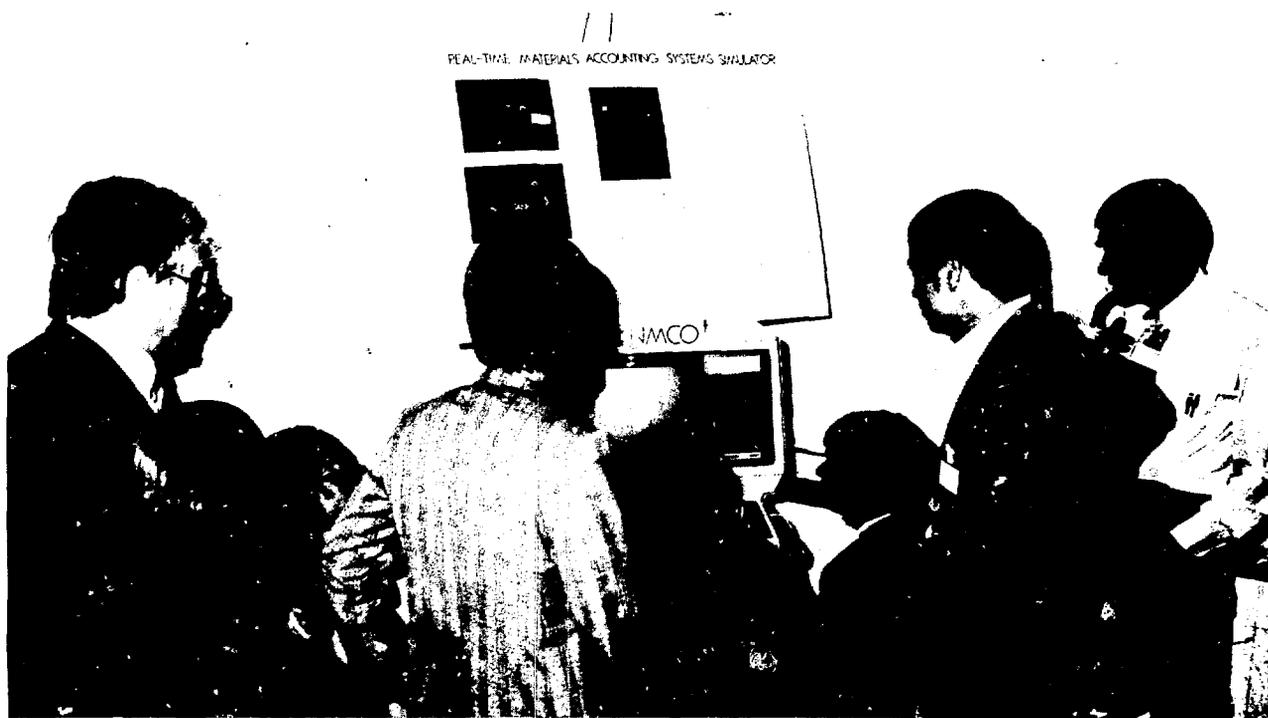
TOTAL DIVERTED _____

WIN _____

LOSE _____



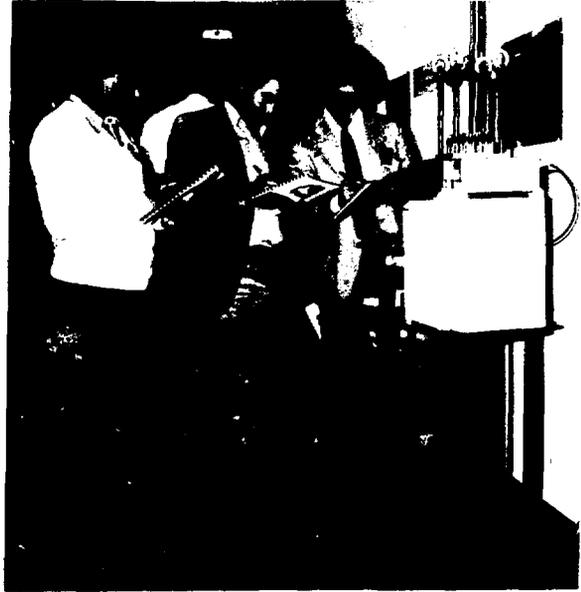
The instructor, Jim Halbig, explains the operation of the portable multichannel analyzer for uranium enrichment measurements.



Students used a computer terminal to verify nuclear materials balances, using the Real-Time Materials Accounting Systems Simulator (RTMASS).



A uranium oxide sample is inserted into the Active Well Coincidence Counter by the assayist and his "assistants."



Data acquisition with the Neutron Coincidence Collar on a model LWR fuel assembly.



The instructor, Dick Siebelist, describes the operation of the Segmented Gamma Scanner.

VII. PARALLEL SESSIONS:

NDA WORKSHOP
MC&A WORKSHOP

In the morning wrap-up session on the second day, the participants will divide into 5 subgroups to discuss NDA or MC&A problems of their choice. The five subgroup topics will be as follows:

NDA

1. Measurement of UF_6 Cylinders (full cylinders, heels)
2. Measurement of Bulk Uranium Oxide (U_3O_8 powder, UO_2 pellets)
3. Measurement of Finished Fuel Materials (loaded rods, fuel assemblies)
4. Measurement of Scrap and Waste (recoverable scrap, low-level waste)

MC&A

5. General Materials Accounting Analysis

The MC&A Workshop will begin with a discussion of some practical considerations in establishing a materials accounting system: setting boundaries for material balance areas, locating key measurement points, measurement errors, and frequency of materials balance closure. The participants will then discuss the calculation of MUF and $\sigma(MUF)$ and study (through worked examples) the relationship of these quantities to plant throughput, measurement errors, and detection goal quantities.

In the NDA exercises, the participants will address one of the measurement tasks listed above and establish which NDA technique(s) are the most suitable for the goals of the measurement. Further consideration will be given to other NDA techniques, pointing out their shortcomings for the measurement task or possible complementary information other NDA techniques might provide.

At the end of approximately one hour, each of the subgroups will select a rapporteur who will report to all of the participants on the conclusions of his group.

NDA Workshop

DISCUSSION OUTLINE

In considering your measurement task, recall the instruments with which you worked yesterday:

- o The Active-Well Neutron Coincidence Counter
- o The Neutron Coincidence Collar
- o The Segmented Gamma Scanner
- o The Mini-multichannel Analyzer and NaI Detector

[Consider also such options as Rod Scanning and weighing]

FOR THE REPORT FROM YOUR GROUP, ADDRESS THE FOLLOWING QUESTIONS:

1. What measurements are possible on this material?
 - a. Uranium enrichment?
 - b. Total U-235 mass?
 - c. Total Uranium Mass
 - d. Verification of some other measurement?
 - e. Weight of the sample
2. Is this measurement a candidate for materials accounting or for process control and verification? Would an inspector wish to measure this type of sample?
3. What radiations are emitted by this material? Can they be used for NDA?
4. What radiations can be induced in this material for assay purposes?
5. Which of the NDA instruments would best achieve your measurement goals?
6. For the instrument you have chosen, what are the limitations on the measurement as to:
 - a. sample size
 - b. density of material; matrix material
 - c. container type
 - d. count times
 - e. attainable precisions
7. Discuss the disadvantages or shortcomings of the other NDA instruments you rejected for this particular measurement task.
8. Given the instrument you have chosen, discuss the measurement itself:
 - a. What sample preparation is required, if any?
 - b. Can you measure all or only part of the sample?
 - c. What information will you obtain about the material in the sample?
9. Can some other measurement and/or measurement instrument be combined with your optimum choice to give more precise or more complete assay results on this sample?

Participants should prepare a set of answers and comments pertaining to these questions and organize them into a short oral report, lasting approximately 10 minutes. Each subgroup should select a rapporteur, who will report to all the participants on the conclusions of the subgroup's discussions.

Prepared viewgraphs, blank transparency sheets, and marking pens will be provided for each group, so that the rapporteur can use visual aids, if desired.

Time for subgroup discussion: Approximately one hour.

Time for subgroup reports: Approximately ten minutes per group.

MEASUREMENT TASKS:

1. MEASUREMENT OF UF₆ CYLINDERS:

Full Cylinders arrive at the plant receiving dock with shipper declaration of total UF₆ weight and U-235 enrichment. Plant personnel require some verification of these data for economic and materials control reasons. Plant inspectors are usually interested in verification of enrichment and traceable data on total U-235 arriving at the plant.

Cylinder heels are residual contents in cylinders that have been emptied. They constitute a small amount of SNM which should be accounted for.

2. MEASUREMENT OF BULK URANIUM OXIDE:

U₃O₈ powder is the immediate result of fluoride-to-oxide conversion. The powder contains some moisture and may be in the form of bulk powder or green pellets. The powder is relatively high-density material.

UO₂ pellets are produced when the green U₃O₈ pellets are sintered. They are found in open containers before loading into fuel rods.

3. MEASUREMENT OF FINISHED FUEL MATERIALS:

Loaded rods are sealed zircalloy tubes containing UO₂ pellets. The amount of SNM in the rods can be determined by tracing accounting records (ledger entries). The rods must be checked for pellet-to-pellet uniformity, nominal enrichment, and active length.

Fuel assemblies need to be checked for fissile content and verified as to enrichment. Total SNM content is also available from ledger records.

4. MEASUREMENT OF WASTE MATERIALS:

Recoverable scrap may be in the form of bulk oxide powder or broken pellets, resulting from the sintering, pelletizing, grinding, and loading steps in the process. This material should be accounted for and returned to the process.

Low-level waste contains very small amounts of SNM in the form of trace contamination on gloves, rags, and other low-density items. The material is usually stored in barrels for disposal, after SNM content is verified to be below allowed values.

M C & A Workshop

DISCUSSION OUTLINE

DISCUSSION: SOME PRACTICAL CONSIDERATIONS IN ESTABLISHING A MATERIALS ACCOUNTING SYSTEM

1. System designer must know
 - Process flowsheet.
 - Operating scheme - days and hours of operation, timing of process steps, batch operation versus continuous processing.
 - Physical layout.
 - Process control measurements.
2. Setting boundaries of materials balance areas
 - Do on basis of flowsheet and layout.
 - Consider ability to make good transfer measurements.
 - Quantity of in-process inventory.
3. Locating measurement points
 - What materials should be measured?
 - What measurement techniques are available?
 - Process control measurements that can be used to provide materials accounting information.
 - Additional measurements that may be required.
4. Random and systematic errors and their propagation.
5. Frequency of materials balance closure
 - Process logic.
 - Schedule closure to avoid difficult measurement or estimation problems.
 - Timeliness of detection of anomalies.
6. How can materials accounting aid process operator?
 - Provide additional information useful for process control.
 - Timely warning of process anomalies.

MUF = MATERIAL UNACCOUNTED FOR

- $MUF = \text{Beginning Inventory} + \text{Receipts} - \text{Removals} - \text{Ending Inventory}$
- $\text{Book Inventory} = (\text{Beginning Inventory} + \text{Receipts} - \text{Removals})$
= "What Should Be"
- $\text{Physical Inventory} = \text{Ending Inventory} = \text{"What Is"}$
- $MUF = \text{Book} - \text{Physical} = (\text{"What Should Be"}) - (\text{"What Is"})$
- If there were no losses and measurements were perfect: $MUF = 0$
- However, $MUF \neq 0$. Measurement Uncertainties, Process Losses (Buildup), Diversion.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 17: BASIS FOR MODEL FUEL FABRICATION PLANT ACCOUNTING
AND CONTROL SYSTEM

Session 17 describes the criteria and principles upon which the accounting systems used in the model plant are based.

After the session, participants will be able to:

1. understand how the accounting system is designed to meet safeguards criteria for both IAEA and State Systems, and
2. understand the principles of materials accounting used to account for element and isotope in the model plant.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 17a: BASIS OF PLANT ACCOUNTING SYSTEM

R. A. Schneider
Exxon Nuclear

I. INTRODUCTION

This presentation describes in an introductory manner the accountability design approach which is used for the Model Plant in order to meet U.S. safeguards requirements. The general requirements for the U.S. national system are first presented. Next, the approach taken to meet each general requirement is described. This presentation introduces the general concepts and principles of the accountability system. Individual topics will be covered in more detail in the remainder of the course.

II. GENERAL REQUIREMENTS FOR MATERIALS ACCOUNTING

The general requirements for materials accounting for the U.S. national safeguards system are given below for bulk handling facilities.

1. Measure all quantities of nuclear material received, shipped, discarded, and on inventory;
2. Maintain a formal accounting system for recording all internal and external transactions and measurements;
3. Conduct physical inventories;
4. Maintain material control areas;
5. Provide to the safeguards authorities reports of all external transfers, material status reports, and all usual events or discrepancies;
6. Maintain a measurement control program for estimating and controlling measurement errors; and
7. Provide for audits, verification activities, and performance evaluation by safeguards inspectors.

The above general requirements are also common to Euratom and IAEA safeguards.

However, since a main objective of the course is to illustrate how national system requirements are met, the general requirements of the U.S. system are used for purposes of illustration. The detailed accountability requirements for U.S. plants are given in

Title 10, Part 70 of the Code of Federal Regulations. The training course will illustrate only the more universal features of those detailed requirements.

The implications of general requirements and the approaches taken in the design of the Model Plant accountability system are discussed for each general requirement in the next section. It should be again noted that each of the topics covered in this introductory presentation will be covered in more detail in the remainder of the course.

III. ACCOUNTABILITY DESIGN CONSIDERATIONS

A. Measurements.

1. Completely Measured Material Balance. The requirement that all quantities of nuclear material received, shipped, discarded, and on inventory be measured has a number of important implications. First, it requires a completely measured material balance. This, in turn, requires a measurement process for each type of item comprising the material balance. It also requires of bulk handling facilities that the engineering design be such to ensure that all quantities be included in the material balance, e.g. that there are no unmeasured effluents and that all of the hold-up inventory can be measured.

In addition, the U.S. and IAEA safeguards systems require that the measured material balance be of a certain minimum quality in regard to measurement uncertainty.

a. Receipts and Shipments. For the Model Plant, receipts are cylinders of essentially pure UF_6 and product shipments are fuel assemblies of also essentially pure UO_2 . For these items, extremely high quality measurements (weight and assay of pure compounds) can be made.

b. Waste Discards. The measurement of waste discards present a more difficult problem. Waste materials are typically difficult-to-measure material forms. Further, serious consideration must be given to the process and facility design to ensure that all discards are included in the measurement system.

For the model plant, liquid wastes transferred to the solar evaporation lagoons are measured by the volume and concentration of each batch volume transferred. Solid wastes transferred to burial or retained waste are measured for U-235 content by passive gamma counting using calibration standards that simulate the waste materials.

The completeness of the measurement system is established in the following manner:

1. All discharges to the atmosphere are monitored for uranium,
2. There are only two transfer lines to the lagoons, one for the quarantine tanks and one for the grinder water tanks,

3. There are no floor drains in the process building,
4. All liquid vessels have double containment and all liquid effluents are monitored for low level uranium concentrations.
5. All potential liquid discharges to the ground are monitored by a system of wells,
6. Potential tracking losses on shoe covers and protective clothing are monitored at the laundry, and
7. All equipment which is removed for burial is checked for uranium by radiation measurements and wiping tests.

c. Inventory. As was noted earlier in the Course, each inventory item for the Model Plant is a discrete measureable item. The bulk of the inventory is based on measurements made in advance of the inventory. The inventory cleanout items represent the quantities of ADU, dirty powder, filters, etc., which are removed in the cleanout of process equipment and associated plenums and ducts. Each item such as bucket of ADU or dirty powder is weighed and assayed for inclusion in the inventory. The small quantities of material which are not removed by rigorous cleanouts are not included in the inventory, but are treated as material unaccounted for (MUF).

The problem of system completeness also applies to the inventory of material held up in equipment and duct work. To assure the completeness of cleanouts, each piece of process equipment is inspected after cleanout. Duct work and plenums are also examined to ensure that material has been removed for inclusion in the inventory and to ensure that there are no buildups of material downstream of the cleanout points.

2. Quality of the Measured Material Balance.

a. Sigma MUF Criteria. For U.S. bulk handling facilities, quantitative criteria for material balance accounting are expressed in terms of materials unaccounted for or MUF. By way of review, MUF is illustrated in Figure 1. As shown in Figure 1, if there are no unmeasured losses and no unmeasured inventory (hold up) and if there are no measurement uncertainties, MUF would be zero. However, measurement uncertainties are inherent to measurement processes, thus even under ideal conditions of no unmeasured losses and no unmeasured inventory MUF will not be exactly zero. Although measurement uncertainties are inherent, they can be minimized by employing high quality measurements.

In the U.S., the need for a certain minimum measurement quality is specified by numerical values for the limit of error of MUF or LEMUF.

This is illustrated in Figure 2. For a low enriched uranium fabrication plant, the U-235 LEMUF is required to be less than 0.5 percent of throughput for the six month plant material balance. This compares to an IAEA suggested standard of accountability of 0.6 percent of throughput for LEMUF ($2\sigma_{MUF}$). The alarm level for MUF is

LEMUF, that is, the observed MUF should be less than LEMUF or an investigation of the cause of MUF exceeding the LEMUF is required.

b. Evaluation of Sigma MUF. In theory, to design the measurement and accounting system to achieve an acceptable LEMUF is a complex problem involving a number of factors. These include measurement processes, measurement errors, number of measurements, accounting practices, process aspects, and error propagation considerations.

In practice, the problem is more commonly one of establishing a measurement system to meet both manufacturing and accountability needs and then evaluating the LEMUF of that system versus safeguards numerical criteria for LEMUF.

MUF = MATERIAL UNACCOUNTED FOR

Material Balance Area

- $MUF = \text{Beg. Inv} + \text{Receipts} - \text{Removals} - \text{End. Inv.}$
- $\text{Book Inventory} = (\text{Beg. Inv} + \text{Receipts} - \text{Removals})$
= "What Should Be"
- $\text{Physical Inventory} = \text{Ending Inventory} = \text{"What is"}$
- $MUF = \text{Book} - \text{Physical or}$
= ("What Should Be") - ("What Is")
- If No Losses, Perfect Measurements: $MUF = 0$
- $MUF \neq 0$; Could Be Losses (Build Up), Measurement Uncertainty or Theft

Figure 1. MUF

LIMIT OF ERROR OF MUF (LEMUF)

- $LEMUF = 2 \sigma_{MUF}$
- Limits of MUF Due Solely To Measurement Uncertainties
- $\sigma^2_{MUF} = \sigma^2_{B1} + \sigma^2_{Rec} + \sigma^2_{Rem} + \sigma^2_{E1}$
Propagation Of All Measurement Errors For All Items
(Quantities) In the Material Balance Equation
- $LEMUF < 0.5\%$ Of Throughput For Uranium Fabrication
- Alarm Point: $MUF > LEMUF$

Figure 2. LEMUF

As noted earlier, the exact evaluation of LEMUF is a complex problem involving the preparation of detailed models for the plant material balance, the measurement system, error parameters, and error propagation. These aspects are covered in the sessions on Statistics and in the session on the Example Design Information Questionnaire.

To illustrate some of the system design considerations applicable to a low-enriched uranium fabrication plant, a summary example is developed and shown in Table I.

The first two columns in Table I represent a simplified material balance for the plant expressed in strata of like items and quantities expressed as a percentage input (or throughput). The third column shows the measurement methods for determining the quantities of uranium element in each item. The fourth column shows the expected relative error for the entire stratum, that is the combined random and systematic error of the stratum expressed as a relative standard deviation. The fourth column shows the relative measurement uncertainty as a percentage of plant input. The last column shows the percentage contribution of each stratum to the variance of MUF (σ^2_{MUF}). The propagated relative σ_{MUF} of 0.182% is the root mean square of the values in column 5, e.g.

$$\% \sigma_{MUF} = \sqrt{(0.04)^2 + (0.04)^2 + (0.06)^2 + (0.06)^2 + \dots}$$

The example σ_{MUF} evaluation in Table I illustrates several concepts important to the design of the accountability system. The first is the concept of identifying the individual contributors to σ_{MUF} and evaluating the relative impact of each stratum or measurement process on σ_{MUF} . The second is the concept of the relationship between the process and σ_{MUF} . This latter point is illustrated by the contribution to σ_{MUF} from waste and scrap measurements. (Note: The large waste errors are chosen for illustration only.) Measurement errors of those items comprise about 90 percent of the variance of MUF. It is seen from column 2 that their impact is directly related to the percentage of waste and difficult-to-measure scrap generated by the process. The adverse effect of those items on σ_{MUF} could be reduced by process improvements which reduce the waste losses and amount of difficult-to-measure scrap. For example, conversion of the difficult-to-measure scrap to a more measurable form such as U_3O_8 would significantly reduce the σ_{MUF} .

c. U σ_{MUF} and U-235 σ_{MUF}

In the course, the uranium element MUF and σ_{MUF} are emphasized. This is not to imply that enrichment measurements and enrichment control are not important, but rather to emphasize that the basic measurements and accounting features for fuel fabrication deal first with uranium element and secondly with the enrichment.

The U.S. criterion for LEMUF is for the U-235 LEMUF not the U element LEMUF. However, whether the enrichment measurement errors actually enter into the U-235 LEMUF is highly dependent on processing and accounting booking practices. Since fuel fabrication does not change the enrichment but only blends enrichments, U-235 measurement

TABLE I. Example Uranium LEMUF Evaluation

<u>Component</u>	<u>% Input</u>	<u>Measurement</u>	<u>Combined Error, % σ</u>	<u>σ, % Input</u>	<u>% Variance of MUF</u>
<u>Receipts</u>					
UF ₆	100	Weight-Assay	0.04	0.04	4.8
<u>Removals</u>					
1. UO ₂ Rods	99.5	Weight-Assay	0.04	0.04	4.8
2. Liquid Waste	0.3	Volume-Concentration	20	0.06	10.9
3. Solid Waste	0.2	NDA	30	0.06	10.9
<u>Inventory (Beginning and Ending)</u>					
1. UO ₂ Pellets	10	Weight-Factor	0.06	0.006	0.1
2. UO _x Powders	10	Weight-Factor	0.1	0.01	0.3
3. Difficult-To Measure Scrap	5	Weight-Assay	3	0.15	68.1

$$U, \sigma_{MUF} = 0.182\%$$

$$U, LEMUF = 0.364\%$$

errors generally affect U-235 MUF accounting only when enrichment blending takes place. Thus, if the enrichment of the feed UF_6 is maintained throughout the process such that the accounting records can be based validly on the enrichment of the starting UF_6 , then the U-235 measurement errors do not contribute to the U-235 LEMUF. In this case, the relative U-235 LEMUF is the same as the relative U element LEMUF. However, if the measured enrichments of feed product, and inventory are booked into the accounting records, even though no enrichment blending has taken place, then those enrichment measurement errors will contribute to the U-235 LEMUF. In this case, the relative U-235 LEMUF will be larger than the relative U element LEMUF.

In the Model Plant arrangement selected for this course, the isotopic integrity of about 85% of plant input is maintained at the starting feed enrichment and only about 15 percent of throughput is affected by enrichment measurement errors. To assure that the isotopic integrity is maintained, mass spectrometric measurements are made on each lot of UO_2 powder and pellets. Those measurements are treated as verification measurements and are not booked into the accounting records unless a statically significant difference is noted (e.g. evidence that blending took place). The 15 percent of throughput processed through scrap recovery where blending takes place is also measured for enrichment. Those measurements are booked into the accounting records and those enrichment measurement errors contribute to the U-235 LEMUF.

B. ACCOUNTING REQUIREMENTS

The U.S. national system requires that a formal accounting system be maintained for recording all receipts, shipments, waste dis-cards, and inventory quantities. This subject is discussed in detail in the next two sessions following this introductory presentation.

C. PHYSICAL INVENTORIES

For low enriched uranium, a physical inventory is required at six month intervals. A completely measured physical inventory is required. For the required inventory, process cleanouts are carried out and all such materials removed and converted to measured items. Only tamper-safe (sealed) items may be included in the physical inventory on the basis of previous measurements. Items which are not sealed or items with broken seals even though previously measured must be verified by remeasurement to be included in the physical inventory. Other U.S. requirements for physical inventories include:

1. Written instructions for each inventory,
2. Reconciliation of the book and physical inventory,
3. Documentation of inventory findings, and
4. Calculation of MUF and LEMUF within 30 days after the start of physical inventory and reporting of planned actions if MUF exceeds LEMUF or if LEMUF exceeds LEMUF limits ($>0.5\%$).

The subject of physical inventories is covered in more detail in the Session entitled, "Procedure for Taking Physical Inventories".

D. MATERIAL CONTROL AREAS

The U.S. national system requires that internal material control areas be established for physical and administrative control of nuclear materials. The material control areas for the Model Plant are shown in Figure 3.

The material control areas for the Model Plant were selected on the basis of process, administrative, accounting, and physical considerations. The operation of each MBA is the responsibility of one of the Plant supervisors. Each MBA has defined physical boundaries and each MBA represents a natural grouping of like processing and handling operations. Lastly, the natural flow of material between MBAs involves the transfer of discrete measureable items so that flows into and out of the MBA can be accurately accounted for.

The item control area structure is designed to provide maximum inventory and administrative control over all materials not in an immediate processing status and over all items amenable to item control. ICA-1 (Shipping and Receiving) is established so that all materials entering and leaving the plant are under item control upon receipt and prior to shipment. The storage ICAs are established to place all bulk materials not in an immediate processing status under time control.

The Rod and Bundle ICA represents the ideal case for item control since each rod and bundle can be treated as previously measured sealed quantities.

The computer based accounting system maintains a running book inventory of each MBA and an individual item listing of each item in each ICA. The computer data base is updated daily and an item listing is printed out daily for all ICAs except Rod and Bundle assembly which is printed out at inventory time. The concept of having most of the inventory present as discrete previously measured items, each of which is identified by location, quantity, and serial number on the time listing, greatly facilitates inventory taking.

The combination of the item control area arrangement and measurement of items at the time of creation and the subsequent inclusion of items placed in item control on the perpetual inventory listing represents, in a sense, a form of advance inventory taking.

E. SAFEGUARDS REPORTS

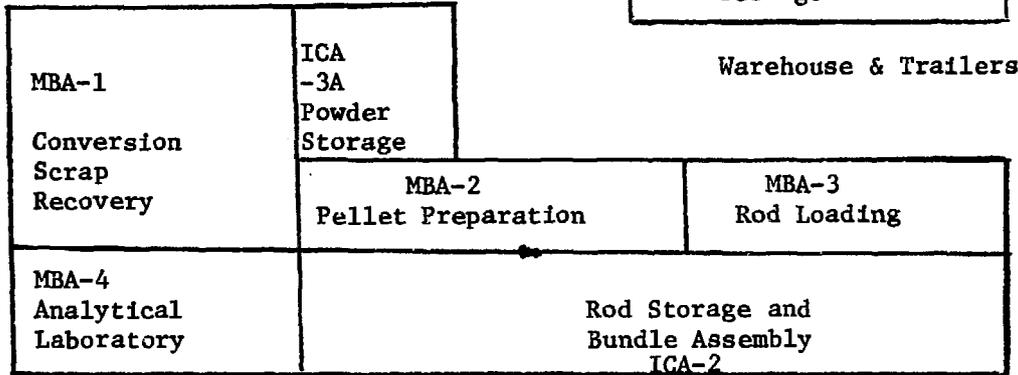
U.S. safeguards regulations require several routine reports and several types of special reports of discrepancies. The routine reports are the Nuclear Material Transaction Reports (NRC Forms-741) and the Material Status Reports (NRC Forms-742). See references 1 and 2.

SOLAR EVAPORATION PONDS
MBA-1

ICA-1
Shipping-Receiving

ICA-3K
Waste
Barrel
Storage

ICA-3B-H
Storage



UO₂ PLANT

ICA-1
Shipping-Receiving

Warehouse

17a-9

Figure 3. Model Plant Material Control Areas

The Material Status Reports (Forms-742) are submitted every six months (March 31 and September 30) and state the quantities of nuclear materials received, produced, possessed, transferred, disposed of or lost.

Special reports are required of any material accounting discrepancies. Any loss of nuclear materials such as loss of a discrete item or an accidental loss or theft or attempted theft must be reported immediately to the U.S. Nuclear Regulation Commission. Material balance discrepancies such as in the event that the observed MUF exceeds the LEMUF on other action limits of the U.S. national system must also be reported to NRC and appropriate actions taken to resolve the discrepancy.

For the Model Plant used in the course, routine reports are also submitted to the Region V Inspection Office (San Francisco) of NRC. That Office conducts the routine inspections of the plant for the U.S. national system. Waste discards are reported monthly, and MUF reports are submitted following the required six-month inventory and for the three-month inventories which are taken by the Model Plant for its own purposes. The LEMUF and a MUF measurement bias report is also submitted after the six-month inventories.

The details of the various reports submitted to the U.S. national system will be covered the MC&A System Design Workshop.

F. MEASUREMENT CONTROL PROGRAM

The U.S. national system requires that a formal measurement control program be established and implemented to control, estimate, and document measurement errors. The measurement control program for the Model Plant will be presented in detail in the session entitled "Measurement Control Program".

G. SAFEGUARDS INSPECTIONS

Under U.S. national system requirements, the Model Plant is inspected several times a year by inspectors from the Region V Office (San Francisco). The inspections are unannounced and are conducted usually by three inspectors. The inspections are to assure compliance with the Regulations and License Conditions for the facility. The detailed requirements are incorporated in the Fundamental Material Control Plan for the Model Plant. The Fundamental Material Control Plan is a procedures description document which describes the safeguards accountability procedures used by the Model Plant. The inspectors also obtain samples for verification of certain key measurements. Those samples are sent to the New Brunswick Laboratory which is a U.S. government laboratory.

At the end of each inspection, the inspectors conduct an exit interview with plant personnel to discuss the results of their inspections. A formal inspection report is also prepared and a copy sent to Plant Management.

To accommodate the unannounced inspections, picture badges are kept at the main Badge House and those badges are issued to the inspectors upon presentation of their credentials and recognition by Plant Security personnel. The inspectors have access to all parts of the plant and all key personnel are made available for discussions with the inspectors. Usually, the inspectors are accompanied by plant safeguards personnel in inspections of plant areas.

H. BACKGROUND MATERIAL

For technical background material on U.S. materials accounting requirements and for guidance in developing materials accounting procedures and techniques, the student is referred to the Division 5 Regulatory Guides Materials and Plant Protection. The table of contents and copies of those guides are available as follows:

Requests for single copies of the latest revision of a regulatory guide, the only version currently in print, should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Director, Division of Technical Information and Document Control. Earlier revisions may be examined at the Commission's Public Document Room, 1717 H Street NW., Washington, D.C. Regulatory guides are not copyrighted, and Commission approval is not required to reproduce them.

I. REFERENCES

1. NUREG/BR-006, Instructions for Completing Nuclear Material Transaction Reports (Form DOE/NRC 741, 741A and 740M).
2. NUREG/BR-0007, Instructions For Completing Material Balance Report, Physical Inventory Listing, and Concise Notes (Forms DOE/NRC 742, 742C, and 740M).



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 17b: MODEL PLANT ACCOUNTING SYSTEM

M. F. Schnaible
Exxon Nuclear

I. INTRODUCTION

This presentation describes some basic concepts and techniques used in the model plant accounting system and relates them to U.S. safeguards requirements. The specifics and mechanics of the model plant accounting system will be presented in Session 21.

II. ACCOUNTING DEFINITION

"Accounting is the system of recording and summarizing ... transactions in books and analyzing, verifying, and reporting the results".
Webster's New Collegiate Dictionary, G. & G. Merriam Co., 1979.

Note that the key words in the definition are recording, summarizing, analyzing, verifying, and reporting. Each of these functions or activities is necessary to achieve the desired result. It is important to the design of a cost-effective system that each of these functions is properly considered.

The recording function must be completed on a timely basis with a high degree of accuracy. A basic source of recording error results from long elapsed times between the event or activity and its recording, or the transfer of data from one record form to another. The development of real time computer systems has greatly improved timeliness, and reduced the need to transcribe data. Accuracy in recording must also be concerned with completeness. Once an event is recorded, accuracy can be checked in various ways, but the assurance that all events or activities have been recorded is much more difficult. Diagnostic or editing techniques should be used to ensure the integrity and completeness of the data record.

The analyzing function must be done in such a manner as to show the proper result.

The reporting function must also be accurate and complete. Report titles should describe the data presented and the time or period covered. Timeliness in reporting is very important. The distribution and use of a report should also be understood before it is prepared.

III. INTERNAL CONTROL

Internal control is one of the most important features of any accounting system. It is the organization plan which, along with proper procedures, assures that the accounting record is accurate and complete. The emphasis of an internal control system should be on the prevention of errors rather than the later detection of them.

The following are features of a good internal control system which should be followed in any accounting system, whether it is computerized or manual:

- a. Duties should be separated so that persons responsible for the physical protection and handling of the material do not also maintain the records of the material.
- b. Responsibility should be fixed by company directive so that a specified individual is held accountable. A manual of policies and procedures should be written and available for use.
- c. The personnel involved should be responsible individuals who have received proper training in the procedures to be followed.
- d. There should be a periodic rotation of duties.
- e. Transactions should be recorded promptly in the system of accounts.
- f. All source transactions should be accounted for.
- g. Accounting records and procedures should be periodically checked by an independent auditor.

IV. GENERAL REQUIREMENTS FOR AN ACCOUNTING SYSTEM

The following are general requirements for an accounting system as required under the U.S. national safeguards system:

A system of records and reports shall be established, maintained, and followed which will provide information sufficient to locate special nuclear material and to close a measured material balance around each material balance area and the total plant.

The system shall include.

1. A centralized accounting system employing double-entry book-keeping;

2. Subsidiary accounts for each material balance area and item control area;
3. Records showing the measurement of all special nuclear material received, produced, transferred between MBAs, transferred from MBAs to ICAs, on inventory, or shipped, discarded, or otherwise removed from inventory and for the determination of the limit of error associated with each measured quantity . . . except for samples which have been determined by other means to contain less than 10 grams U-235 The system shall provide for sufficient measurements to substantiate the quantities of element and isotope measured and the associated limits of error;
4. Procedures for the reconciliation of subsidiary accounts to control accounts at the end of each accounting period; and
5. Procedures for reconciliation of control and subsidiary accounts to the result of physical inventories.

A Company requirement is to maintain accounts of ownership for material belonging to others as well as provide the quantity records in support of the Company assets. The model plant accounting system also provides data to satisfy this requirement, but the specifics are not covered in this course.

V. SYSTEM DESIGN CONSIDERATIONS

The model plant accounting system is designed as a cost-effective tool to meet the national systems requirements, as well as maintain effective internal control. Special features are incorporated in the design of the model system for maintaining adequate internal control, establishing a comprehensive data record, assuring data accuracy, maintaining a system of accounts, and providing useful reports. Many of these features are interrelated. For example, useful reports depend on maintaining a good system of accounts, which in turn depend on data accuracy, etc.

The following is a brief discussion of these system design considerations:

A. Internal Control

1. MBA and ICA Custodians from Shop Operations are responsible for handling the material and recording the appropriate transactions. Accountants and clerks are responsible for processing

the transactions and maintaining the books of account. Physical inventories are taken by two person teams - one member is independent from operations.

2. Responsibilities are outlined in the Nuclear Materials Safeguards Procedure Manual. All plant receipts and shipments are made through one internal ICA - Shipping/Receiving. Internal MBA's and ICA's are set up to correspond to the logical plant functions.
3. Training sessions are held periodically to assure that all individuals properly understand the current procedures.
4. Duties are rotated periodically as a part of the overall Company operations.
5. Transactions are picked up and processed on a daily basis.
6. Source transactions are accounted for by the custodians who approved them.
7. The accounting records and procedures are checked periodically through unannounced audits by outside inspectors and internal auditors.

B. Data Record

The following general principles are followed in establishing a comprehensive data record:

1. The coding schemes use terms already in common use.
2. All transactions are readily identified with physical containers by use of Material Record Cards.
3. The record is compatible with present or future automated data collection systems.
4. The record is compatible with automated record processing systems, i.e., computers.
5. Common element and isotope factors are applied from a table to the extent possible.
6. ICA items are maintained on a perpetual basis, whereas MBA items are identified only at physical inventory.

The following data elements are maintained in the accounting record:

Transaction Date:

Year, Month, Day, Time of Day

Transaction Codes:

B	Beginning Inventory	T	Location Transfer
R	Receipt	P	Project/Enrichment Transfer
S	Shipment	I	Physical Inventory
D	Measured Discard	N	Memo Transaction
M	Material Unaccounted For		
E	Ending Inventory		

Source Document Reference Name and Number:

Self-explanatory.

Ownership Code:

Denotes owner of material.

Material Type:

Depleted, enriched, and natural uranium.

Material Composition:

UF₆, Powder, Pellets, Rods, Bundles, etc.

Project Designation

This denotes the specific reload associated with a transaction.

Nominal Enrichment:

This is a subset of the enriched uranium material type used to denote enrichment level. This is not an isotope factor.

Plant Location:

This denotes a specific MBA or ICA.

Container Number:

Self-explanatory

Tamper-Indicating Seal Number:

Self-explanatory.

Item Gross Weight

To tenth of a gram

Item Tare Weight

To tenth of a gram

Element Weight

To hundredth of a gram

Isotope Weight

To hundredth of a gram

C. Data Accuracy

Double-entry bookkeeping is the technique required by national regulations to ensure the accuracy and reliability of the accounting record. This technique requires that each transaction be recorded twice, once as a positive number, and again as a negative number in separate accounts so that when summed, the result is zero. This technique has been used in financial accounting for many years.

Modern data processing by computers has resulted in the development of additional techniques to ensure accuracy and reliability. Some of these techniques include:

- o Table Comparisons--This is usually used to check the validity of codes. An example is to set up codes, D, E, and N in a table to represent uranium material type for depleted, enriched and natural. Each time a material type code is entered, it is checked against the valid codes of D, E, and N. If another code is used, an edit message would indicate the error. However, if a D were used instead of an N, no error would be detected by this technique.
- o Check Digit--This is usually used to check the validity of a series of digits as is used in an item number. The check digit is usually the last in a series and results from an algorithm involving the other digits. A transposition of any of the digits would be detected by this technique.

- o Duplication Checking--This is used to check for duplicates in a data element which is supposed to only contain unique items, i.e., container number. Often there are two containers with the same identification, as opposed to one container recorded twice.
- o Batch Balance--This is used to check quantity amounts for accuracy. Several quantity amounts are summed and the total also entered into the data collection machine. If the machine calculation does not match the inputted sum, an error is detected.
- o Key Verification--After the initial keying of data, the data is keyed again, usually by another person. The probability of making a keying error twice is very small. This is one of the best techniques available because it checks both alphabetical and numerical data.

The model plant accounting system uses double-entry accounting, table comparisons, duplicate checking, and key verification techniques to assure the accuracy and reliability of the accounting record.

D. System of Accounts

A system of accounts is set up to facilitate timely retrieval of the data and permit flexible reporting. In the model accounting system, two computer systems are set up to process the data:

- o The Nuclear Material Reporting System (NMRS) maintains a perpetual inventory balance for the plant as a whole. All transaction records since inception are maintained in the current data files.
- o The Nuclear Inventory Control System (NICS) maintains a perpetual inventory balance for internal plant MBA's and item listings for internal plant ICA's. Transaction records are purged following a physical inventory.

Both computer systems are set up on a data base concept rather than an "account basis" as is often used in financial accounting. The data can be sorted by using various reference keys to obtain a particular account balance. Summarization of data can be handled at any desired level. Transactions can be grouped around any given criteria to achieve the desired result. The accuracy of the overall plant ledger is maintained through zero balancing. The data record schemes for the two systems are similar.

E. Reporting

Examples of specific reports, or computer printouts, will be covered in a later session. A general principle that is followed is to print out the entire data record whenever possible. The printouts also tend to follow the format of the input source documents.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

SESSION 18: DESCRIPTION OF MODEL PLANT MEASUREMENT AND CONTROL SYSTEM

The plant layout will be described in relation to the key measurement points and material control areas. The measurements made at each key measurement point are described.

After the session, participants will be able to:

1. understand the relationships between plant layout, material flows, and key measurement points, and
2. more fully understand later presentations on details of the measurement and accounting systems.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 18a: BRIEF PLANT DESCRIPTION

D. G. McAlees
Exxon Nuclear

The plant layout is described in relation to the measurement points, material flow, and main process steps.

UF₆ feed enters the plant via truck through the main West Gate and proceeds to the UF₆ storage area for weighing on the UF₆ scale and temporary storage. The storage area and UF₆ scale are located near the northeast corner of the UO₂ Building. The UF₆ cylinders are next taken to the conversion area of the UO₂ Building which is adjacent to the cylinder storage area. In the conversion area, UF₆ is converted to UO₂ powder. Also located in the conversion area are 1) the liquid waste tanks where the liquid wastes are measured for volume and sampled for uranium concentration, 2) the recycle process, and 3) the solid waste assay unit. The UO₂ powder from the conversion process is loaded into five gallon buckets and weighed and sampled. After measurement, the powder is sent to temporary storage and then to the pellet preparation area located in the middle portion of the UO₂ Building. After pellet pressing, sintering, grinding, and inspection are complete, the pellets are weighed on trays and sampled for accountability.

Accountability samples of UO₂ powder, pellets, scrap, liquid waste, etc., are measured in the Analytical Laboratory located in the northwest corner of the UO₂ Building.

Finished pellets are transferred to the rod loading area where the pellet columns are weighed into fuel rods. After rod finishing, the rods are assembled into bundles and temporarily stored on hangers. They are then packaged in shipping containers and taken out through the south door of the UO₂ Building to the Shipping and Receiving Warehouse for shipping to light water reactors. The warehouse is located on the southwest area of the site.

Other areas of safeguards interest include the scrap storage warehouse on the east side of the UO₂ Building, the waste barrel storage area on the south side of the site, the storage ponds on the east side, and the Specialty Fuels Building on the west side of the site. The mass spectrometer and quantometer laboratories are located in the Specialty Fuels Building.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 18b: MODEL PLANT KEY MEASUREMENT POINTS

R. A. Schneider
Exxon Nuclear

I. INTRODUCTION

FOR IAEA safeguards a "Key Measurement Point" is defined as a location where nuclear material appears in such a form that it may be measured to determine material flow or inventory. This presentation describes in an introductory manner the key measurement points and associated measurements for the model plant used in this training course. During the remainder of the course, key measurement points will be covered in more detail.

II. MODEL PLANT KEY MEASUREMENT POINTS

A. General

The feed to the model low enriched uranium fuel fabrication plant is UF_6 and the product is finished light water reactor fuel assemblies. The waste discards are solid and liquid wastes. The plant inventory consists of unopened UF_6 cylinders, UF_6 heels, fuel assemblies, fuel rods, fuel pellets, UO_2 powder, U_3O_8 powder, and various scrap materials.

At the key measurement points the total plant material balance (flow and inventory) is measured. The two types of key measurement points—flow and inventory are described next.

B. Flow Key Measurement Points

The flow key measurement points (KMPs) for the model plant are those locations where plant receipts and shipments (removals) are made. Normally, flow measurements points are those locations where nuclear materials which enter and exit the plant site boundary are made. However, for the model plant, transfers of solid and liquid wastes to on-site retained waste are also considered as flows since those materials are effectively removed from the plant material balance.

The key measurement points for flow for the model plant are shown below:

Key Flow Measurement Points

<u>Material Flow</u>	<u>Location</u>
UF ₆ Receipts	UF ₆ Scale Area and Diffusion Plant Load Out Area
UF ₆ Heel Returns	UF ₆ Scale Area
Product Removals	Rod Loading Hoods
Solid Wastes (Barrels and Filters)	Waste Assay Counter
ADU Process Centrate	Quarantine Tank Area
Grinder Water Centrate	Grinder Area

1. UF₆ Flow. UF₆ feed cylinders are weighed on the UF₆ scale which is located by the UF₆ cylinder storage area. UF₆ cylinder heels are also weighed at that location. The sampling of UF₆ is done at the diffusion plant load out area under the surveillance of an agent of the company who witnesses the sampling and also does the percent uranium analysis to verify the shipper's assay. Samples obtained by the company agent are sent to the plant laboratory for verification of the shippers isotopic analysis (U-235).

2. Product Flow. The basic measurements for product removals from the plant of finished fuel assemblies are made at the rod loading hoods where the weights of UO₂ pellets loaded into each rod are measured. Samples are also taken at that point for percent uranium and for isotopic. These measurements of the quantities of uranium element and U-235 isotope contained in each fuel rod provide the accounting basis for the weight of element and isotope in the finished fuel assemblies when the rods are assembled into bundles.

3. Solid Waste Flows. Solid wastes (Barrels and Filters) are measured for grams of U-235 at the Waste Assay Counter. Although some of solid wastes are retained on site for possible future recovery, the measurement point is considered a flow point, since the waste containers no longer enter into the plant processing material balance.

C. Liquid Wastes

1. ADU Process Centrate. The liquid waste from the ammonium diuranate precipitation process is collected in connected banks of "quarantine" tanks. A bank of connected tanks consists of 5 identical tanks of about 100-gallons volume each. When a bank becomes full, the bank is sampled and a calibrated volume is transferred to the lagoons. Each process line, including scrap recovery, has twin banks of quarantine tanks where the volume of centrifuged process effluent is measured and the solution sampled prior to transfer to the lagoons.

2. Centrifuged Grinder Water. Periodically small volumes of centrifuged grinder water are transferred to the lagoons. Prior to transfer, the volume of the small hold tank (12-14 gallons) is measured, a sample taken, and the entire contents of the tank are transferred to the lagoons.

D. Inventory Key Measurement Points

For the model plant, the physical inventory consists entirely of measured items. The great majority of those items are measured at the time they are created and in advance of the physical inventory. The remainder and small fraction of the inventory consists of items created from the cleanout of process equipment. Those items are created and measured just prior to the physical count and are considered an integral part of inventory taking.

The plant accountability system is designed to measure each item as it is created and to have the measurement data recorded on a material record card. Items going to temporary storage are tamper safed at the time of measurement and placed under item control. Items moving through the production process are measured when material changes take place so that the material record card always represents the current state of the material. At inventory time, those untamper-safed items are inventoried by verifying the original measurements.

As a result of the above accountability design features, the inventory key measurement points are those locations where the items are measured at the time of creation. Those locations and associated measurements are shown in Table I. The physical count of the inventory covers nearly the entire area of the UO₂ Plant and all outside item control areas. The areas covered by the inventory teams in the physical count of the inventory are shown in Figure 1.

TABLE I. Inventory Key Measurement Points

<u>Inventory Item</u>	<u>Measurement and Location</u>
UF ₆ full Cylinders and Heels	Weighing, UF ₆ scale area,
Green Powder	Powder weighing and sampling at powder bucket loading areas of the two conversion lines and the scrap recovery line.
Green Pellets in Boats	Weighing on Scales adjacent to press on each line.
Sintered Pellets in Boats	Weighing on scales adjacent to sintering furnaces on each line.
Pellets on Trays	Weighing on scales at pellet inspection (after grinding) on each line.
Fuel Rods	Fuel Rod inventory is based on weights of UO ₂ weighed into each Rod at the Rod Loading Hoods and assay of samples taken at that point.
Fuel Assemblies	Accountability is based on individual Fuel Rod data.

TABLE I. (contd)

<u>Inventory Item</u>	<u>Measurement and Location</u>
ADU	Sampled at clean out location and weighed on powder scales on each conversion line and scrap recovery.
Grinder Sludge	Sampled and weighed on each line near the grinders.
Dirty Powder	Sampled and weighed near the powder bucket loading area.
Hard Scrap	Weighed on powder bucket scales on each line.
U ₃ O ₈	Sampled and weighed in the U ₃ O ₈ Room.
Equipment Holdup	Inventory cleanouts are carried out to remove material held up in process equipment and associated plenums and ducts. All clean out materials such as ADU, dirty powder, solid wastes and filters are measured for inclusion in the inventory. The ADU and dirty powder are measured at locations given before for those materials. Solid wastes and filters are measured at the Waste Assay Counter.
Analytical Laboratory Holdings	Inventory items within Analytical Laboratory are measured at inventory time in the same manner as production items e.g., weight and assay or weight and measured factor.

It should be noted that some of the key measurement points for flows are also key measurement points for inventory, since measurements made at flow points provide the accounting basis for many inventory items, e.g. fuel rods, fuel assemblies, UF₆ cylinders and UF₆ heels.

The inventory locations where the physical count of the inventory is taken (Figure 1) include the four-material balance areas in the UO₂ Building and all of the item control areas both inside and outside of the UO₂ Building.

SOLAR EVAPORATION PONDS
MBA-1

ICA-1
Shipping-Receiving

ICA-3K
Waste
Barrel
Storage

ICA-3B-H
Storage

MBA-1 Conversion Scrap Recovery	ICA -3A Powder Storage	Warehouse & Trailers	
	MBA-2 Pellet Preparation	MBA-3 Rod Loading	
MBA-4 Analytical Laboratory	Rod Storage and Bundle Assembly ICA-2		

UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

Figure 1. Inventory Locations



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 19: GENERAL PLANT TOUR

Following the plant description of Session 18, a plant tour will be given to solidify the features of this description.

After the session, the participants will be able to:

1. understand the relationships between plant layout, material flows, and key measurement points,
2. understand more fully the later presentations on details of measurement and accounting systems.



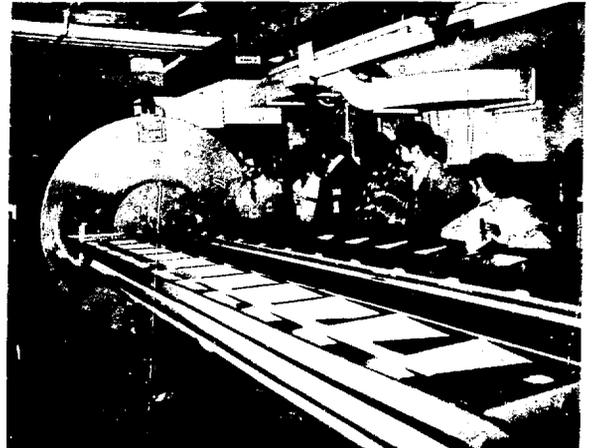
Cylinder Loading Area



UO₂ Powder Bulk Storage



Pellet Loading Station



Dual Fuel Rod Scanner



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 19: GENERAL PLANT TOUR

D. G. McAlees and R. A. Schneider
Exxon Nuclear

A tour of the plant is conducted to show the students the general plant arrangement, the various measurement points and measuring equipment, and the various material containers and material forms.

The tour includes the UF_6 cylinder storage, handling and weighing area; the UF_6 to UO_2 conversion process; the pellet preparation, rod loading and bundle assembly areas; and the fuel bundle shipping area and the solar evaporation ponds.

The participants are shown the UF_6 scale, the UF_6 cylinder handling equipment, and where the UF_6 cylinders enter the process building.

The visitors wear protective clothing and eye protection to enter the conversion area where UF_6 is converted to UO_2 and the UO_2 powder is homogenized and stored. The liquid waste measuring tanks and the Waste Assay Counter used to measure solid wastes are also shown during the tour of the conversion area. The adjacent pellet preparation area where pellet pressing, sintering, grinding, inspection, and weighing operations are carried out is also shown.

The tour of the UO_2 Building also shows where fuel pellet columns are weighed and loaded into fuel rods. The bundle assembly area and fuel rod and bundle handling equipment and storage locations are also seen.

The tour of the outside areas shows the solar evaporation ponds, the waste barrel storage area, fuel shipping containers, and the fuel shipping staging area.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 20: DISCUSSION OF PLANT TOUR AND MODEL PLANT ACCOUNTING
SYSTEM

Subgroups will discuss the plant layout, process steps, equipment, and material forms seen during the plant tour and how they relate to safeguards materials accounting. A series of questions will be considered by the subgroups and answers provided by the instructors.

After the session, participants will better understand the relationships between the plant processes, physical layout, material containers and handling equipment, and the safeguards measurements and accounting system.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 20

QUESTIONS FOR SUBGROUP
DISCUSSIONS OF PLANT TOUR

1. Describe the locations where three flow measurements and three inventory measurements are made.
2. Show in diagram form below the main process steps in going from UF_6 feed to finished fuel pellets.
3. Which of the areas seen during the tour would you expect to contain the largest fraction of the plant inventory?
4. Name two NDA instruments that are used as safeguards overcheck instruments.
5. If you were establishing internal material control areas within the UO_2 Building (see Figure 1, page 19b-5), where would you measure the inputs and outputs to each area? What measurements would you have carried out at each location?



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 21: NUCLEAR INVENTORY CONTROL SYSTEM

Session 21 describes the basis and operation of the computer-based accounting systems used in the model plant.

After the session, participants will be able to understand how the computer-based accounting system operates to meet the safeguards objectives described in Session 17.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 21: NUCLEAR INVENTORY CONTROL SYSTEM

A. Kraft
Exxon Nuclear

I. INTRODUCTION

This presentation describes the design used in accounting for nuclear material in the Model Plant. Many of the design philosophies are in response to the Nuclear Regulatory Commission regulations. More detailed coverage of the system components are described later in the course.

II. GENERAL DESCRIPTION

The computer based accounting system of the Model Plant is designed to account for low enriched uranium by project (reactor reload), enrichment, and plant location. The separate accounting by project account or reactor reload is for commercial reasons and is not a U.S. national system requirement. A given reload can consist of as many as four enrichments. The account for that reload would consist of four separate project/enrichment accounts.

In concept, the system maintains two plant material balances. One part, the Nuclear Material Reporting System (NMRS) maintains a material balance for the plant as a whole. The other part, the Nuclear Inventory Control System (NICS) maintains an internal material balance by individual material control areas. The NICS keeps two types of inventories. For material balance areas (MBA's), running book inventories are kept for the quantities of U-element and isotope for each project/enrichment account. For the material in item control areas (ICA's), a current inventory file is maintained of each item and its associated identification and quantity.

At the completion of a physical inventory, the NICS calculates a MUF for each material balance area and for each project/enrichment account.

Both the external and internal accounting systems are activated by the movement of material. The external system is activated by plant receipts and shipment. The internal system is activated by material transfers among the internal material control areas. For the internal material movements, a transfer document is completed and processed by the computer based system. The system makes the appropriate transactions, for example, the additions or removal of quantities for an MBA or the creation or deletion of an item in an ICA. The system processes many such transactions daily.

For most of the items comprising the material balance, the individual item weights are used. As an example for kilograms of UO₂ in a bucket, the measured weights are converted by the computer based system to weights of uranium element by applying a specific element factor based on the uranium assay of the item or lot or by supplying a U-element factor. Conversion to quantities of U-235 is done by application of an enrichment factor.

To facilitate the application of the U-element and isotope factors, tables are maintained in the computer based system. Entry to the U-element factor table is by the material composition code and to the isotope factor table by the project/enrichment account code.

Experimental data for the U-element factors are accumulated in separate records, evaluated statistically, and updated as appropriate from the statistical analysis. The project/enrichment accounts are identified using the nominal enrichment. This is the factor used in the isotope table until all isotopic measurements are completed, at which time a weighted average isotopic composition is computed and the table updated.

The key features of the individual parts of the systems are described next. The details of the application will be covered in the next session where the day to day operation of the accounting system will be illustrated.

III. COMPUTER BASED SYSTEMS

A. Nuclear Material Reporting System (NMRS)

The Nuclear Material Reporting System represents the official records of nuclear material for the Model Plant. This system maintains all plant receipts and shipments, physical inventory and MUF by project and enrichment. Entries are made by means of the NRC 741 reports and physical inventory cards from the associated NICS system.

The system generates all reports used for plant accounting, and for the NRC and customers.

B. Nuclear Inventory Control System (NICS)

The Nuclear Inventory Control System is a computer based system which maintains internal control of all nuclear material within the Model Plant; material moving into the plant and then into each Material Control Area (MCA). The system also handles all processing for physical inventories reconciliations and inventory summarizations. Inventory data files are communicated to the NMRS system.

C. Material Control Area Structure

The plant is divided into two types of material control areas.

1. Item Control Area (ICA). Item control areas are designed to maintain control of uniquely identified, usually sealed containers. These areas are generally long-term storage areas. The unique items can be easily located within the areas.

2. Material Balance Area (MBA). Material balance areas are designed to maintain control of nuclear material in process areas. The material is not necessarily in final-stage containers and is generally in the area for a short time. The NICS system maintains mass balances for material in MBA's by project and enrichment. At time of inventory, the items located in MBA's are manually recorded on inventory forms, i.e., they are not pre-listed as are the items in ICA's. The MBA's are designed to isolate MUF within the plant.

IV. NICS PROCESSING

A. NICS Transactions

1. Material Movement Within the Plant. Several material transfer forms are used to record movement of material from area to area. These forms are collected daily and keypunched. The daily material transfers are entered into the processing program designed to edit the transactions and update material balances and inventories.

2. Receipts and Shipments. All external receipts and shipments (to and from the plant) are recorded on this form. The receipt contains the container identification, project, nominal enrichment, material composition, element factor and weight and the isotope factor and weight. The element and isotope weights are recorded to the nearest gram. The individual items on this form are entered into shipper-receiver ICA-1. The container number identification is recorded for shipments and the container is deleted from ICA-1 when shipped.

3. Location Transfers. Transfers of all material among the MCA's are made on this form. This form contains the date, shipper MCA, receiver MCA, container, project, enrichment, material composition, gross and tare weights.

If the transfer is from an MBA, all pertinent information must be included on the form. However, if the transfer is from an ICA, only the container need be listed since the container already exists on the inventory file.

These transfers are again collected for keypunching and entered into the main processing program of the NICS system.

a. Material Record Card and Conversion Factors. Two basic data records are used in conjunction with the location transfer forms. As each item of material is generated, the applicable weight data, material composition, item identification number, project and nominal enrichment are recorded on a material record card. The material record card is attached to the container. When a container (or other similar item) is transferred, the data on the record card are entered on the location transfer form which is processed into the computer based system via key punching of the data and submittal of key punch cards. The corresponding data for the U-factor are selected from the memory for each appropriate material composition such as green UO₂ or sintered UO₂. For items such as ADU and grinder sludge, which require a U-assay for each item, the laboratory result is entered into the system along with the location transfer form. The isotopic

factors are also stored in the memory for each project-enrichment. The use of element and isotopic factors tables is described later.

4. Project Transfers. Frequently, material is classified under a particular project and needed for another project with like enrichment. In this case, the material transfer to the new project is made on this form. Similarly, a project transfer is made of any material going into the scrap processing plant.

5. MUF Transactions. At the end of a material balance period, the MUF is calculated and entered into the system. The MUF is calculated by comparing the MBA book balance with the MBA physical inventory. Those MUF's are consolidated by project and enrichment and passed to the NMRS system.

B. Factor Tables

Only the gross and tare weights are required on the material transfer documents. In order to calculate the element and isotopic weight on the transfer, assignments of uranium and U-235 factors are made from the element and isotopic factor tables. The element factor table is keyed by the material composition code. This is a three-character code which describes the form the material is in; powder, pellets, rods, hard scrap, etc. The first character is U.

1. Element Factor Table. An example portion of the element factor table follows:

PD	0	.8760
SP	0	.8810
RD	1	.8810
UF	1	.6760

The first column shows the last two characters of the material composition code. The second column is a flag to indicate to the program whether or not the material composition code in question requires a unique or standard factor. If the flag is 0, then the table value is used to calculate uranium. If the flag is 1, then a unique uranium factor must be recorded on the transfer document.

2. Isotopic Factor Table. An example portion of the isotopic factor table follows:

0000	E200	.02000
0100	E310	.03095
0222	E278	.02782

Column 1 is a project code. Column 2 is the nominal enrichment. Column 3 is the specific U-235 factor used to convert uranium weight to U-235 weight. The U-235 factor is used for all material compositions of the same project and enrichment.

3. % U and U-235 Factor Log. The factor log is a record of all %U and U-235 analyses made for each lot of material for a given project and nominal enrichment. The data in the factor log are used to

compute weighted average isotopic factors and to compute pellet lot U-element factors for pellets loaded into fuel rods.

C. Data Base Files

The system data base files consist of an inventory and transaction sequential tape file.

1. Inventory File. The inventory file contains all MBA balances by project and enrichment, as well as the entire file of items in the ICA's. Each item in ICA has associated with it the following information:

Project
Enrichment
Material composition
Shipper MCA
Document report number
Seal number
Date of transaction
Gross and tare weights
U and U-235 factor

2. Transaction File. The transaction file contains all location transfers for a given period of production, usually a month. Also on this file are the project transfers and MUF entries for a given material balance period.

3. Factor Tables. The element and isotopic factor tables are maintained on a direct access device accessible to all programs in the system.

D. Bundle Assembly

Summarizing the nuclear material in assemblies is accomplished by use of the pre-punched rod card. When the rod is created and recorded on a location transfer, the uranium factor for the lot from which the rod came is read from the factor log record and recorded on the location transfer. During computer processing of these transfers, rod cards are punched. These cards are organized at the rod storage ICA.

During bundle assembly the rod cards are pulled from storage and assembled into bundle decks according to the rod loading bundle map. The bundle identification is punched into these cards in preparation for input to the bundle composition program.

The bundle composition program produces a summary of the nuclear material content of the bundle. It also produces reports to assist in Quality Control audits and bundle shipments. A copy of the summary accompanies the shipment to the customer.

Location transfer cards are punched by the bundle composition program to create an item listing of the bundles. The rod card decks are also used to create location transfer cards to delete the rods from the rod inventory listing.

E. NICS Processing

Following is a summary of the processing which takes place in the NICS system.

1. Process all location transfers, maintaining MBA balances and ICA inventory.
2. Produce ICA physical inventory listings.
3. Process rod physical inventory data.
4. Process MBA physical inventory records.
5. Calculate MBA MUF.
6. Produce complete transaction file listing.
7. Process all physical inventory reconciliation transactions and produce ending inventory summaries.
8. Program interface with NMRS to supply ending inventory, MUF and project transfers.

V. COMPUTER OPERATION

Material and inventory control is maintained by one primary program in the system. All material movement transactions are processed by this program. The MBA balances and ICA items are maintained on a sequential tape file. The program reads the daily material movement transactions, merges them with the current MBA balances and ICA file, then creates the newly updated tape. The necessary factor tables are maintained on a permanent drum file. The transactions created from the input cards are appended to the current transaction file and a new tape created.

This program makes a cursory edit of the input before processing fully. The edited transactions in error are listed and processing aborted for error correction. When no errors are detected, the new tapes are created and reports generated.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

**SESSION 22: DESCRIPTION AND EXAMPLE OF ACCOUNTING FORMS AND
REPORTS**

Session 22 describes the accounting forms and reports which are used in the accounting systems of the model plant. Examples showing quantities and material compositions are given.

After the session, the participants will be able to understand how the accounting forms are used and how accounting reports are generated by the computer-based systems. They will understand how the data elements appear on the forms and how the accounting system is activated by material movement.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 22 DESCRIPTION AND EXAMPLE OF RECORDS,
REPORTS AND FORMS

D. L. Noss
Exxon Nuclear

I. PRACTICAL APPLICATIONS OF NUCLEAR MATERIALS ACCOUNTING

This training lesson is intended to describe pertinent aspects of the nuclear material accounting routines used by Exxon Nuclear utilizing the two computer systems described previously by Tony Kraft.

A. Account Structure

As with any accounting system, it is necessary to have prepared a chart of accounts that aid in consistent control of operations and proper classification of data. Since we have two computer systems, each of which functions differently, we likewise have an account structure (or data base) for each system.

Charts 1 and 2 show in detail the account structures applicable to each system. The one for NICS has five basic categories while the one for NMRS has seven. Each account structure has four common categories consisting of: material type, project, enrichment and material composition. As to differences in the structures, NICS provides for accounting for material control areas--NMRS does not. NMRS provides for accounting by type activity, ownership and reporting categories--NICS does not.

Changes to the account structures are accomplished by means of completing data base forms designed for each computer system. These forms are reproduced and included in Appendix A.

B. Accounting Forms

Again, in conjunction with any accounting system appropriate records and forms are essential so as to accomplish a logical flow of record keeping and approved procedures thereby providing a degree of internal control.

Chart 3 lists five basic forms used for documenting internal and external movements of nuclear material. Other miscellaneous forms, although not listed on the chart, are also used for varying reasons. As we progress through the training lesson each form utilized will be discussed. A sample copy of forms has been reproduced and is included in Appendix A.

The first form listed is a regulatory form utilized in accordance with the instructions provided by the U.S. Nuclear Regulatory Commission (NRC). Form 741 is completed and distributed for each inventory change of any special nuclear material, including shipments, receipts, burnup, production, onsite losses, onsite gains, inventory differences, or any other inventory adjustment, involving one gram or more of contained uranium-235, uranium-233, or plutonium. In addition, any inventory change involving one kilogram or more of source material would require a Form 741.

For shipments, the shipper must send the form no later than the close of business the day after the shipment. For receipts, the receiver must acknowledge receipt of shipments within ten days of receipt of material. If delayed measurements are to be made, Form 741 must be completed within ten days. Following this action, Form 741 must be completed within thirty days after receipt of the shipment, with proper measurement results.

The Exxon Nuclear designed forms are printed in three parts consisting of an original and two copies (pink and yellow). After each transaction is documented and signed by both the shipping and receiving custodian it is serially numbered by Nuclear Materials Accounting. The original copy is retained by NMA for permanent filing and the respective custodians are provided with their copies.

C. Accounting Reports

Chart 4 shows principal reports which are generated for both management and regulatory requirements. Reports generated as a result of a physical inventory will be discussed during a later session related to physical inventories. Sample copies of reports listed are reproduced and included in Appendix B. The so-called TRAP report is not included because it is similar, except for content, as the one included in the MIMS set. All the figures shown in the sample reports represent those for the model plant on which this training course is based.

D. Material Control Areas

Chart 5 portrays the material control areas established for operating the model fuel fabrication facility. Transfers of materials in and out of identified boundaries are based on measured values. All transfers are recorded on a source document signed by a designated custodian.

Material Balance Area - an area in which material changes form or composition, i.e., UF_6 to UO_2 powder, UO_2 powder to pellets.

Item Control Area - an area where there is no change in form or composition; all material is in encapsulated form such as rods or tamper-safed containers.

E. Data Processing

Documents used to record movement of nuclear materials are picked up daily from custodians by Nuclear Materials Accounting. Processing routines that take place are listed as follows:

1. Documents

1. Audited for authorized signatures
2. Audited for completion in conformance with established procedures
3. Serially numbered for control purposes
4. Keypunched
5. Filed permanently

2. Edit Report (MIMS)

1. Analyzed to determine reason for errors listed
2. Correct errors as necessary

3. Final Report (MIMS)

1. Provide copies to respective custodians
2. Make cursor review of "transaction file" for unusual items
3. Investigate and arrange for correction of unusual items.

The charts that follow depict the flow of documentation in relation to the movement of material and highlight other pertinent steps involved in the accounting and reporting processes.

The last Chart 24 shows the overall flow of documents in relation to the movement of process material from time of receipt on plant to time of shipment off plant, i.e. steps 1 through 8. Steps 9 through 13 track the flow of scrap material and a cylinder heel, while steps 14 and 15 show the flow of samples sent to the Analytical Lab.

IAEA TRAINING COURSE
ACCOUNTING, RECORDS, AND REPORTS

APPENDIX A - FORMS

- A-1. Request for Changes in NICS and NMRS Data Base
- A-2. Corporate Data Base Input Form
- *A-3. DOE/NRC Form 741 - Nuclear Material Transaction Report
- A-4. Form Deleted 1981
- *A-5. Receipt/Shipment
- *A-6. Location Transfer
- *A-7. Project/Enrichment Transfer
- A-8. UF₆ Inventory Record Card
- A-9. UF₆ Cylinder Weigh Ticket
- *A-10. Nuclear Materials Reporting System Data Input
- A-11. Analytical Request and Report Form (with label)
- A-12. Material Record
- A-13. Tamper-Indicating Seal Log Book
- A-14. Rod Fabrication Follower Card
- A-15. Lagoon Inventory Log

*See Appendix B-6 for example of completed forms.

IAEA TRAINING COURSE
ACCOUNTING, RECORDS, AND REPORTS

APPENDIX B - REPORTS

- | | |
|--------------|---|
| B-1. (a-s) * | Material Inventory Maintenance System (MIMS) |
| B-2. | Material Balance Ledger (NMRS) |
| B-3. | MUF and Measured Discard Summary |
| B-4. | Possession Limits |
| B-5. | DOE/NRC Form 742 - Material Status Report |
| B-6. | Example of Transaction Flow
- UF ₆ to Fuel Assembly |

* Material Inventory Maintenance System listings (B-1) will be distributed to course participants during session 22.

REQUEST FOR CHANGES IN NICS & NMRS FACTOR DATA BASE

PROJ #	FACTOR			NICS SYSTEM									NMRS SYSTEM								
	NOMINAL	AVERAGE	XN-50	DELETED		PROGRAM CHANGED						DONE BY	FACTOR TABLE			ACTION		DONE BY			
				ACTION A/D	FACTOR DATE	ENCDS	JAWE PUMP	PUPT	ENCDS	YUDE PUMP	PUPT		NO	N5	N6	A/D	DATE				
1.																					
2.																					
3.																					
4.																					
5.																					
6.																					
7.																					
8.																					
9.																					
10.																					
11.																					
12.																					
13.																					
14.																					
15.																					
16.																					
17.																					
18.																					
19.																					
20.																					

22-6

Reason for change _____

Requested by _____ on _____ Approved by _____ on _____

DOE/NRC FORM 741A

(7-88) Previous editions are obsolete.
 MANDATORY DATA COLLECTION
 AUTHORIZED BY 10 CFR 30, 40, 50, 70,
 75, 150, Public Laws 83-703, 93-438, 96-51

U.S. DEPARTMENT OF ENERGY AND U.S. NUCLEAR REGULATORY COMMISSION
 NUCLEAR MATERIAL TRANSACTION REPORT

(Continuation Page)

Approved by OMB
 038-R047E
 Approved by GAO
 B-180225 (R004G)
 Expires 6-30-83

TRANSFER SERIES			
SHIPPER'S NO. (1-4)	RECEIVER'S NO. (5-8)	TRANSACTION NO. (9-14)	FORM NO. (15)

PAGE	OF	PAGES
------	----	-------

LINE NO. (1-2)	TYPE OF TRANSFER (3-4)	IDENTIFICATION (BATCH NAME) (5-8)	NO. OF ITEMS (9-10)	PROJECT NUMBER (11-14)	DATE (15-16)	SHIPPER'S FACILITY CODE (17-18)	SHIPPER'S CODE (19-20)	COUNTRY CONTRACT NUMBER (21-24)	KEY NEAS POINT (25-26)	NEAS IDENT			GROSS WEIGHT (27-30)	NET WEIGHT (31-34)	ELEMENT WEIGHT (35-38)	ELEMENT LIMIT OF ERROR (39-42)	WEIGHT % ISOTOPE (43-46)	ISOTOPE WEIGHT (47-50)	ISOTOPE LIMIT OF ERROR (51-54)
										1 (27)	2 (28)	3 (29)							
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	
24. SHIPPER'S DATA										25. RECEIVER'S DATA									
SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED (See instructions for provisions regarding confidentiality)										SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED (See instructions for provisions regarding confidentiality)									

A-3a

22-9

R RECEIPT S SHIPMENT

NUCLEAR MATERIAL TRANSACTION

Not Required For Shipments

CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP	ELEMENT WT.	ISOTOPE WT.	ELEMENT FACTOR	ISOTOPE FACTOR
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									

FORM 741 REFERENCE		FROM / TO LOCATION			NOTES				
DATE (mo/da/yr)	TIME (24 hr. clock)	MCA	S/R ICA CUSTODIAN		NM ACCOUNTING			REPORT NO.	
		101							

DISTRIBUTION: WHITE & CANARY - NM Accounting PINK - S/R ICA

A-5

22-10

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
--------------------	---------------------	----------	--------------------	--------	---------------------

CONTAINER NO.	SEAL NO.	MATL. TYPE	NOMINAL ENRICHMT.	PROJECT NO.	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR	
1						.	.		1
2						.	.		2
3						.	.		3
4						.	.		4
5						.	.		5
6						.	.		6
7						.	.		7
8						.	.		8
9						.	.		9
10						.	.		10
11						.	.		11
12						.	.		12
13						.	.		13
14						.	.		14
15						.	.		15
16						.	.		16
17						.	.		17
18						.	.		18
19						.	.		19
20						.	.		20

DISTRIBUTION:
 WHITE - NM Accounting
 CANARY - Receiver
 PINK - Shipper

NOTES:

REPORT NO.

P PROJECT/ENRICHMENT TRANSFER

NUCLEAR MATERIAL TRANSACTION

FROM			CONTAINER NO.	MATL.COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR		
PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.							
1									1
2									2
3									3
4									4
5									5
6									6
7									7
8									8
9									9
10									10
11									11
12									12
13									13
14									14
15									15
16									16
17									17
18									18
19									19
20									20
TO		PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.	NOTES:				
LOT NO.		BLEND NO.							
DATE (mo/da/yr)	TIME (24 hr. clock)	MBA	MBA CUSTODIAN		NM ACCOUNTING		REPORT NO.		

DISTRIBUTION: WHITE: NM Accounting PINK: MBA Custodian

A-7

22-12

UF₆
INVENTORY RECORD

No. _____

Item I. D. _____

Material Form _____

Enrichment _____

Gross Weight Lb. _____

Tare Weight Lb. _____

Net Weight Gm U _____

Inventory Date _____ By _____

UF₈ CYLINDER WEIGH TICKET

DATE _____

CYLINDER NO. _____

WEIGHED BY _____

_____ ▶ **KGS. GROSS**

_____ ▶ **KGS. ZERO**

REMARKS _____

WEIGHED ON MURPHY - CARDINAL DIGITAL SCALE

NUCLEAR MATERIALS REPORTING SYSTEM DATA INPUT

DATE		TC	741 REFERENCE				REF NO	OWN	RPT CAT	M T	ENRICHMENT	MAT'L COMP	PROJECT	COMMENTS	AMOUNT (GRAMS)	
MO	DAY		YR	FROM RIS	TO RIS	#									c	ELEMENT WT
1	7	9	12	15	19	20	24	27	31	35	41	44	48	52	72	80
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																

NOTES:

PREPARED BY	APPROVED BY	DATE	REPORT NO
-------------	-------------	------	-----------

A-10

22-15

ANALYTICAL REQUEST & REPORT FORM

SERIAL NO.	TYPE SAMPLE	ENRICHMENT	LOT NO.	CAN NO.	PROJECT	APPROVAL
<input type="radio"/> BET	<input type="radio"/> H ⁺	<input type="radio"/> Pu LOW LEVEL	<input type="radio"/> U. TITR	<input type="radio"/> UO ₂ POWDER REL		
<input type="radio"/> C	<input type="radio"/> H ₂ O	<input type="radio"/> Pu TITR	<input type="radio"/> GAS REL	<input type="radio"/> UO ₂ PELLET REL		
<input type="radio"/> CL	<input type="radio"/> M. SPEC	<input type="radio"/> RARE E	<input type="radio"/> H ₂			
<input type="radio"/> E. SPEC	<input type="radio"/> N ₂	<input type="radio"/> SO ₄	<input type="radio"/> O ₂			
<input type="radio"/> EBC	<input type="radio"/> O/U	<input type="radio"/> SPG	<input type="radio"/> TOT. SOL.			
<input type="radio"/> F	<input type="radio"/> pH	<input type="radio"/> U. GRAV	<input type="radio"/> S			
<input type="radio"/> Fe	<input type="radio"/> PS	<input type="radio"/> U. LOW LEVEL				
GRAMS SAMPLE IN			RECEIVED BY	DATE	TIME	

Sample Container Label:

LOT _____ **60282**
 ENR _____ PROJ. _____
 CAN _____
 G _____
 T _____
 N _____

MATERIAL RECORD

Project _____

Enrichment _____

Material _____

BT No: _____

Lot No. _____

WB No: _____

Bucket No. _____

TY No: _____

Gross Wt. _____

Tare Wt. _____

Net Wt. _____

Grams

Operator Initials _____

Date _____

FUEL FABRICATION COMPANY, INC.
MRS MASTER FILE DETAIL LISTING

FROM 07/01/79 TO 07/30/79

MATERIAL CAT T/C COMP. DATE MAT NRC-DDE ELEMENT ISOTOPE									

MATERIAL CAT T/C COMP. DATE MAT NRC-DDE Y81 REF. REF. OWNER WT(GM) WT(GM)									

JOB 0001 REACTOR RELOAD 1									
E-03.000	N	NC	000	7/25/79	BMA=YUD=1=0	0001	FNC	2,000	60
	N	NV	UUF	7/25/79	BMA=YUD=1=0	0001	RPC	1,398,000	41,940
E-03.000	N							1,400,000	42,000
	B	SP	UUD	7/25/79	YUD=XYZ=1=0	0001	RPC	-499,967	-14,999
E-03.000	B							-499,967	-14,999
	P	PT	UMR	7/25/79	000=000=0=0	0000	ENC	60,007	1,803
E-03.000	P							60,007	1,803
	M	MM	UMR	9/30/79	000=000=0=0	0000	ENC	-67,421	-2,025
	M	MM	UMR	9/30/79	000=000=0=0	0001	FNC	=1	1
E-03.000	M							-67,422	-2,024
	E	EE	UMS	9/30/79	000=000=0=0	0000	000	-529	-16
	E	EE	UDU	9/30/79	000=000=0=0	0000	000	-55	-2
	E	EE	UPD	9/30/79	000=000=0=0	0000	000	-365,296	-10,459
	E	EE	URD	9/30/79	000=000=0=0	0000	000	-14,999	-450
	E	EE	USP	9/30/79	000=000=0=0	0000	000	-9,744	-293
	E	EE	UUD	9/30/79	000=000=0=0	0000	000	-499,967	-14,999
	E	EE	UUM	9/30/79	000=000=0=0	0000	000	-2,026	-61
E-03.000	E							-892,618	-26,780
TOTAL	E-03.000								

MUF AND MEASURED DISCARD SUMMARYFOR THE PERIOD 7/1/79 - 9/30/79

(In Kilograms)

	<u>DOE Owned</u>		<u>Non DOE Owned</u>		<u>TOTAL</u>	
	<u>Kgs U</u>	<u>Kgs U235</u>	<u>Kgs U</u>	<u>Kgs U235</u>	<u>KgsU</u>	<u>Kgs U235</u>
Beginning Inventory					-0-	-0-
Receipts					1,400.00	42.000
Shipments					(499.967)	(14.999)
Measured Discards					-0-	-0-
Ending Inventory					898.818	26.966
MUF (Loss) Gain					(1.215)	(.035)

WEEKLY INVENTORY AND POSSESSION LIMIT REPORT

AS OF _____

(Quantities in Kilograms)

	<u>Depleted</u>	<u>Natural</u>	<u>Thorium</u>	<u>Enriched</u>		<u>Plutonium</u>	
				<u>U</u>	<u>U-235</u>	<u>Element</u>	<u>Fissile</u>
Balance Prior Week	_____	_____	_____	_____	_____	_____	_____
Adjustments Prior Period	_____	_____	_____	_____	_____	_____	_____
Current Week Activity:							
Project Transfers	_____	_____	_____	_____	_____	_____	_____
Receipts	_____	_____	_____	_____	_____	_____	_____
Shipments	(_____)	(_____)	(_____)	(_____)	(_____)	(_____)	(_____)
Discards	(_____)	(_____)	(_____)	(_____)	(_____)	(_____)	(_____)
Decay						(_____)	(_____)
Balance	=====	=====	=====	=====	=====	=====	=====
License Possession Limit	40,000.00*	20,000.00*	5,000.000*		10,000.000**	100.000**	

*Per Washington State License # WN-1052-1

**Per Federal License # SNM-1227, Amendment # 14, Dated 10/26/78

Distribution:

Prepared By: _____

Date:

B-4

22-23

DOE/NRC FORM 742 (7-80) MANDATORY DATA COLLECTION AUTHORIZED BY 10 CFR 30, 40, 50, 70, 75, 150, Public Laws 83-703, 93-438, 95-91.

U.S. DEPARTMENT OF ENERGY AND U.S. NUCLEAR REGULATORY COMMISSION

APPROVED BY OMB 038-R0479 APPROVED BY GAO B-180225 (R0841) Expires 6-30-83

MATERIAL BALANCE REPORT

Form with sections: SECTION A MATERIAL ACCOUNTABILITY (lines 7-40), SECTION B COUNTRY CONTROL NUMBER DATA (lines 41-81), SECTION C CERTIFICATION (lines 82-83). Includes fields for name, license number, report period, inventory, receipts, removals, and total weight.

R RECEIPT **S** SHIPMENT

NUCLEAR MATERIAL TRANSACTION

	CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP	ELEMENT WT.	ISOTOPE WT.	ELEMENT FACTOR	ISOTOPE FACTOR
1	EX 800	509999	E	300	0001	UUF	1400.000	42.000	67600	03000
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										

FORM 741 REFERENCE		FROM TO LOCATION			NOTES	
BWA YUD 1		Enrichment Plant			Receipt of full UF ₂ Cylinder	
DATE (mo/day/yr)	TIME (24 hr. clock)	MCA	S/R ICA CUSTODIAN	NM ACCOUNTING	REPORT NO.	
7/25/79	1400	101	Signature Required	Signature Required	00001	

B-6a

22-25

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo., da./yr.) 7/25/79	TIME (24 hr. clock) 1415	FROM MCA ICA-1	SHIPPING CUSTODIAN Signature Required	TO MCA MBA-1	RECEIVING CUSTODIAN Signature Required
--------------------------------	-----------------------------	-------------------	--	-----------------	---

CONTAINER NO.	SEAL NO.	MATL. TYPE	NOMINAL ENRICHMT	PROJECT NO	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR
EX 800	S09999	E	300	0001	UUF	2,707,000.0	636,000.0	67600
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

B-6c

22-27

DISTRIBUTION:
 WHITE - NM Accounting
 CANARY - Receiver
 PINK - Shipper

NOTE:

Transfer of full UF_6 cylinder from cylinder storage to conversion area.

REPORT NO.
00002

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1430	MBA-1	Signature Required	ICA-3A	Signature Required

CONTAINER NO.	SEAL NO.	MATL. TYPE	NOMINAL ENRICHMT.	PROJECT NO	MATL COMP	GROSS WT.	TARE WT.	URANIUM FACTOR
1 PD 00001	E00001	E	300	0001	UPD	21905.0	2500.0	87600
2 PD 00002	E00005	E	300	0001	UPD	21905.0	2500.0	87600
3 PD 00007	E00011	E	300	0001	UPD	21905.0	2500.0	87600
4 PD 00008	E00012	E	300	0001	UPD	21905.0	2500.0	87600
5 PD 00009	E00013	E	300	0001	UPD	21905.0	2500.0	87600
6 PD 00010	E00014	E	300	0001	UPD	21905.0	2500.0	87600
7 PD 00011	E00015	E	300	0001	UPD	21905.0	2500.0	87600
8 PD 00012	E00016	E	300	0001	UPD	21905.0	2500.0	87600
9 PD 00013	E00017	E	300	0001	UPD	21905.0	2500.0	87600
10 PD 00014	E00018	E	300	0001	UPD	21905.0	2500.0	87600
11 PD 00015	E00019	E	300	0001	UPD	21905.0	2500.0	87600
12 PD 00016	E00020	E	300	0001	UPD	21905.0	2500.0	87600
13 PD 00017	E00021	E	300	0001	UPD	21905.0	2500.0	87600
14 PD 00018	E00022	E	300	0001	UPD	21905.0	2500.0	87600
15 PD 00019	E00023	E	300	0001	UPD	21905.0	2500.0	87600
16 PD 00020	E00024	E	300	0001	UPD	21905.0	2500.0	87600
17 PD 00021	E00025	E	300	0001	UPD	21905.0	2500.0	87600
18 PD 00022	E00026	E	300	0001	UPD	21905.0	2500.0	87600
19 PD 00023	F00027	E	300	0001	UPD	21905.0	2500.0	87600
20								

DISTRIBUTION:
 WHITE - NRC Accounting
 CANARY - Receiver
 PINK - Shipper

NOTE:

Transfer of green powder buckets from
 conversion area to powder storage area

REPORT NO
 00003

B-6A

22-28

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo., da./yr.) 7/25/79	TIME (24 hr. clock) 1445	FROM MCA ICA-3A	SHIPPING CUSTODIAN Signature Required	TO MCA MBA-2	RECEIVING CUSTODIAN Signature Required
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CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR
PD 00001	E 00001	E	300	0001	UPD	21905.0	2500.0	87600
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

B-6e

22-29

DISTRIBUTION:
 WHITE - NM Accounting
 CANARY - Receiver
 PINK - Shipper

NOTE:
 transfer of green powder bucket from powder storage area to pellet preparation area.

REPORT NO.
 00001

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1500	MBA-2	Signature Required	MBA-3	Signature Required

CONTAINER NO.	SEAL NO.	MATL. TYPE	NOMINAL ENRICHMT.	PROJECT NO.	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR
1 TRAY 0001		E	300	0001	USP	9310.0	2500.0	88100
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
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13						.	.	
14						.	.	
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17						.	.	
18						.	.	
19						.	.	
20						.	.	

B-6F

22-30

DISTRIBUTION:
 WHITE - NM Accounting
 CANARY - Receiver
 PINK - Shipper

NOTES:

transfer of sintered pellet tray from pellet preparation area to rod loading area

REPORT NO.
 00005

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1515	MBA-3	Signature Required	ICA-2	Signature Required

CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR
1	ROD 00001	E	300	0001	URD	2837.5	0.0	88100
2	ROD 00002	E	300	0001	URD	2837.5	0.0	88100
3	ROD 00003	E	300	0001	URD	2837.5	0.0	88100
4	ROD 00004	E	300	0001	URD	2837.5	0.0	88100
5	ROD 00005	E	300	0001	URD	2837.5	0.0	88100
6	ROD 00006	E	300	0001	URD	2837.5	0.0	88100
7	ROD 00007	E	300	0001	URD	2837.5	0.0	88100
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

DISTRIBUTION:
 WHITE - No Accounting
 CANARY - receive
 PINK - Shipper

NOTE: transfer of loaded rods from rod loading area to rod/bundle storage area

REPORT NO.
 00036

B-6g

22-31

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1530	ICA-2	Signature Required	ICA-1	Signature Required

CONTAINER NO.	SEAL NO	MATL. TYPE	NOMINAL ENRICHMT.	PROJECT NO	MATL COMP	GROSS WT.	TARE WT.	URIANIUM FACTOR
BUNDLE 01	E00002	E	300	0001	UUD	567,500.0	0.0	88100
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

DISTRIBUTION:
 WHITE - NRC Accounting
 CANARY - Receiver
 PINK - Shipper

NOTE

transfer of finished bundle from rod/bundle storage area to shipping/receiving area

REPORT NO.
 00007

B-6h

22-32

RECEIPT SHIPMENT

NUCLEAR MATERIAL TRANSACTION

CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP	ELEMENT WT.	ISOTOPE WT.	ELEMENT FACTOR	ISOTOPE FACTOR
1 BUNDLE 01	E00002	E	300	0001	UUD	499,968	14,999	88100	03000
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									

B-61

22-33

FORM 741 REFERENCE	FROM LOCATION	NOTES			
YUO XYZ 1	Reactor Power Co.	Shipment of finished bundle			
DATE (mo/d/yr)	TIME (24 hr. clock)	MCA	S/R ICA CUSTODIAN	NM ACCOUNTING	REPORT NO.
7/25/79	1600	I01	Signature Required	Signature Required	00008

DISTRIBUTION WHITE & CANER

DOE/NRC FORM 741
REV. (10-78) CP
10 CFR 30.40, 50, 70, 150
Previous editions are obsolete

U.S. DEPARTMENT OF ENERGY AND U.S. NUCLEAR REGULATORY COMMISSION
NUCLEAR MATERIAL TRANSACTION REPORT

Approved by GAO
E-190225 (10/548)
Expires: 12-31-81

1. SHIPPER'S USE	2. RECEIVER'S USE	3. TRANSACTION NO.	4. CORRECTION NO.	5. PROCESSING CODE	6. RECEIVED	7. ACTION CODE	8. DATA CODE	DOCUMENTATION ID (by document classification)	
YUD	XVZ	1			SHIPPER	RECEIVER		PAGE 1 OF 1 PAGES COPY 1 OF 5 COPIES BEING	
9. NAME AND ADDRESS OF SHIPPER Fuel Fabrication Plant Richland, Washington		10. NAME AND ADDRESS OF RECEIVER Reactor Power Company Jackson, Michigan		11. NO. OF DATA LINES (120-211)		12. NATURE OF TRANSACTION (122)		13. DISTRIBUTION OF COPIES	
C. ATTENTION D. TELEPHONE		C. ATTENTION D. TELEPHONE		13. A. SHIPPED FOR ACCOUNT OF		13. B. R15 (123-26)		13. C. SHIPPED TO ACCOUNT OF	
14. TRANSFER AUTHORITY: CONTRACT, DRAWING, OR ORDER NUMBER (133-89)				15. EXPORT OR IMPORT TRANSFER: A. LICENSE NO. (22-311) B. U.S. PORT EXIT/IMPORT (32-33)				16. ACTION DATE	
17. MATERIAL TYPE AND DESCRIPTION: Enriched Fuel Assembly				18. TRANSPORTATION PROFILE				19. PACKAGE IDENTIFICATION	
20. ACTION DATE				21. MONTH				21. DAY	
21. YEAR				22. TOTAL GROSS WEIGHT (402-06)				22. TOTAL VOLUME (409-04) (461-73)	
				6800 Lbs.					

24. SHIPPER'S DATA											A SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED				26. REMARKS	
LINE NO. (124-211)	DOE PRODUCT NUMBER AND IDENTIFICATION (124-212)	MATERIAL TYPE (124-213)	COMPO SITION CODE (124-214)	OWNER CODE (124-215)	USE CODE (124-216)	NUMBER OF ELEMENTS (124-217)	COUNTRY CONTROL NUMBER (124-218)	GROSS WEIGHT (124-219)	NET WEIGHT (124-220)	ELEMENT WEIGHT (124-221)	WEIGHT % ISOTOPE (124-222)	ISOTOPE WEIGHT (124-223)	LIMITS OF ERROR			
B	C	D	E	F	G	H	I	J lbs.	K lbs.	L	M	N	O	P		
01		20	309	J		1	USUS0000	6,800	1,251	499,967	3.0000	14,999	560	132		

25. RECEIVER'S DATA											A SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED					
LINE NO. (125-211)	DOE PRODUCT NUMBER AND IDENTIFICATION (125-212)	MATERIAL TYPE (125-213)	COMPO SITION CODE (125-214)	OWNER CODE (125-215)	USE CODE (125-216)	NUMBER OF ELEMENTS (125-217)	COUNTRY CONTROL NUMBER (125-218)	GROSS WEIGHT (125-219)	NET WEIGHT (125-220)	ELEMENT WEIGHT (125-221)	WEIGHT % ISOTOPE (125-222)	ISOTOPE WEIGHT (125-223)	LIMITS OF ERROR			
B	C	D	E	F	G	H	I	J	K	L	M	N	O	P		

18. U.S.C. SECTION 1001; ACT OF JUNE 25, 1948, 52 STAT. 749; MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./day/yr.) 7/25/79	TIME (24 hr. clock) 1445	FROM MCA MBA-1	SHIPPING CUSTODIAN Signature Required	TO MCA ICA-3K	RECEIVING CUSTODIAN Signature Required
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CONTAINER NO.	SEAL NO.	MATL. TYPE	NOMINAL ENRICHMT	PROJECT NO	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR
1 DRUM 0001	E00004	E	300	0000	UDW	400.0	0.0	99999
2 FILT 0001	P00001	E	300	0000	UFW	200.0	0.0	99999
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
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13						.	.	
14						.	.	
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16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

B6-k

22-35

DEFINITIONS:
 WHITE - NIP - accounting
 CANARY - receive
 BLUE - Shipper

NOTE:

transfer of one barrel and one filter from
 Conversion area to scrap storage area

REPORT NO.
 00009

P PROJECT/ENRICHMENT TRANSFER

NUCLEAR MATERIAL TRANSACTION

FROM									
PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.	CONTAINER NO.	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR		
1 0006	E	298	LAGOON	ULW	2000.0	0.0	99999		1
2 0007	E	303	LAGOON	ULW	1700.0	0.0	99999		2
3 0008	E	301	LAGOON	ULW	1900.0	0.0	99999		3
4									4
5									5
6									6
7									7
8									8
9									9
10									10
11									11
12									12
13									13
14									14
15									15
16									16
17									17
18									18
19									19
20									20

TO	PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.	NOTES:
	0000	E	300	
LOT NO.	BLEND NO.			
—	—			

DATE (mo/ds/yr)	TIME (24 hr. clock)	MBA	MBA CUSTODIAN	NM ACCOUNTING	REPORT NO.
7/25/79	1430	MBA-1	Signature Required	Signature Required	00010

DISTRIBUTION: WHITE: NM Accounting PINK: MBA Custodian

B-61

22-36

P PROJECT/ENRICHMENT TRANSFER

NUCLEAR MATERIAL TRANSACTION

FROM			CONTAINER NO.	MATL.COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR		
PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.							
1	0002	E	296	HS 0001	UHS	26340.0	2500.0	88100	1
2	0003	E	299	AD 0001	UAD	17670.0	1000.0	60000	2
3	0004	E	310	GS 0001	USL	16000.0	1000.0	80000	3
4	0005	E	300	DP 0001	UDP	22270.0	2500.0	86000	4
5						.	.		5
6						.	.		6
7						.	.		7
8						.	.		8
9						.	.		9
10						.	.		10
11						.	.		11
12						.	.		12
13						.	.		13
14						.	.		14
15						.	.		15
16						.	.		16
17						.	.		17
18						.	.		18
19						.	.		19
20						.	.		20

TO	PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT.	NOTES:
	0001	E	300	
LOT NO.	BLEND NO.			
1-A	1			

DATE (mo/da/yr)	TIME (24 hr. clock)	MBA	MBA CUSTODIAN	NM ACCOUNTING	REPORT NO.
7/25/79	1430	MBA-1	Signature Required	Signature Required	00011

DISTRIBUTION: WHITE: NM Accounting PINK: MBA Custodian

B-6m

22-37

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (MM/DD/YY) 7/25/79	TIME (24 hr clock) 1500	FROM MCA NBA-1	SHIPPING CUSTODIAN Signature Required	TO MCA ICA-1	RECEIVING CUSTODIAN Signature Required
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CONTAINER NO	SEAL NO	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO	MATL COMP	GROSS WT	TARE WT	URANIUM FACTOR
EX800		E	300	0001	UuH	639000.0	636000.0	67600
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
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17						.	.	
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19						.	.	
20						.	.	

B-60

22-39

DISTRIBUTION:
 WHITE - NMA - counting
 CANARY - H. J. ...
 ... Shipping

NOTE:
 Transfer of empty U₆ cylinder (heel) from
 Conversion Area to Cylinder Storage Area

REPORT NO.
00013

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./y): 5/25/79	TIME (24 hr. clock): 1520	FROM MCA: ICA-2	SHIPPING CUSTODIAN: Signature Required	TO MCA: MBA-3	RECEIVING CUSTODIAN: Signature Required
------------------------------	------------------------------	--------------------	---	------------------	--

CONTAINER NO	SEAL NO	MATL TYPE	NOMINAL ENRICHMENT	PROJECT NO	MATL COMP	GROSS WT	TARE WT	URANIUM FACTOR
ROD00001		E	300	0001	URD	2837.5	0.0	88/00
2						.	.	
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

DISTRIBUTION:
 WHITE - NOT RECORDED
 CANARY - IN USE
 BLACK - STORED

NOTES:

Transfer of rods from rod/bundle storage area to rod loading area (Bundle transfer program)

REPORT NO.

00014

B-6p

22-40



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

SESSION 23: ASSIGNMENT OF ELEMENT AND ISOTOPE FACTORS

Session 23 describes the use of uranium element and U-235 isotope factors in the model plant materials accounting system.

After the session, participants will be able to understand the basis for the use of element and isotope factors and how they are used in the computer-based accounting system.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 23: ASSIGNMENT OF ELEMENT AND ISOTOPE FACTORS

R. A. Schneider
Exxon Nuclear

I. INTRODUCTION

As discussed previously by Tony Kraft and Dan Noss, element and isotope factors are assigned in the NICS internal accounting system on the basis of coded information included on the material transfer documents. This section will explain more fully the manner in which NICS assigns these factors.

A. Factor Tables

Chart 1 shows a sample NICS element and isotope factor table relating to the model plant. The isotope factor table consists of three columns. The first column is a listing of numerical project accounts. Each project account corresponds to a nuclear reactor reload. The second column lists the nominal enrichments associated with each project account. As explained previously, nuclear materials accounting is based on a project enrichment account, or an account with a given project code and nominal enrichment. For each such account, a specific isotope factor (third column) is used by NICS to assign all isotope weights.

The element factor table also consists of three columns. The first column is a listing of the last two letters of all the material composition codes used in the plant. As an example, for full cylinders of UF_6 gas, the material composition code is UUF, but only the letters UF appear in the factor table. The second column consists of a binary valued factor flag, whose purpose will be discussed in the next subsection. The last column contains the numerical element factor value, which is used by NICS to assign all uranium element weights.

The information in both the element and isotope factor tables is used by NICS to convert net weights of material to weights of uranium element and U-235 isotope. Both tables are edited using the FACT program based on the factor request form discussed earlier by Dan Noss.

B. Element Factors

Chart 2 shows the procedure used by NICS to assign element factors. After a material transfer document has been keypunched and submitted to the computer, NICS keys on the last two letters of the material composition code of each item. NICS then searches the element factor table for that two letter code and checks the value of the factor flag in the table. If the flag is zero, the numerical value from the third column is assigned to that item. If the flag is one, NICS assigns the value

CHART 1. Sample NICS Factor Tables

NICS - NUCLEAR INVENTORY CONTROL SYSTEM

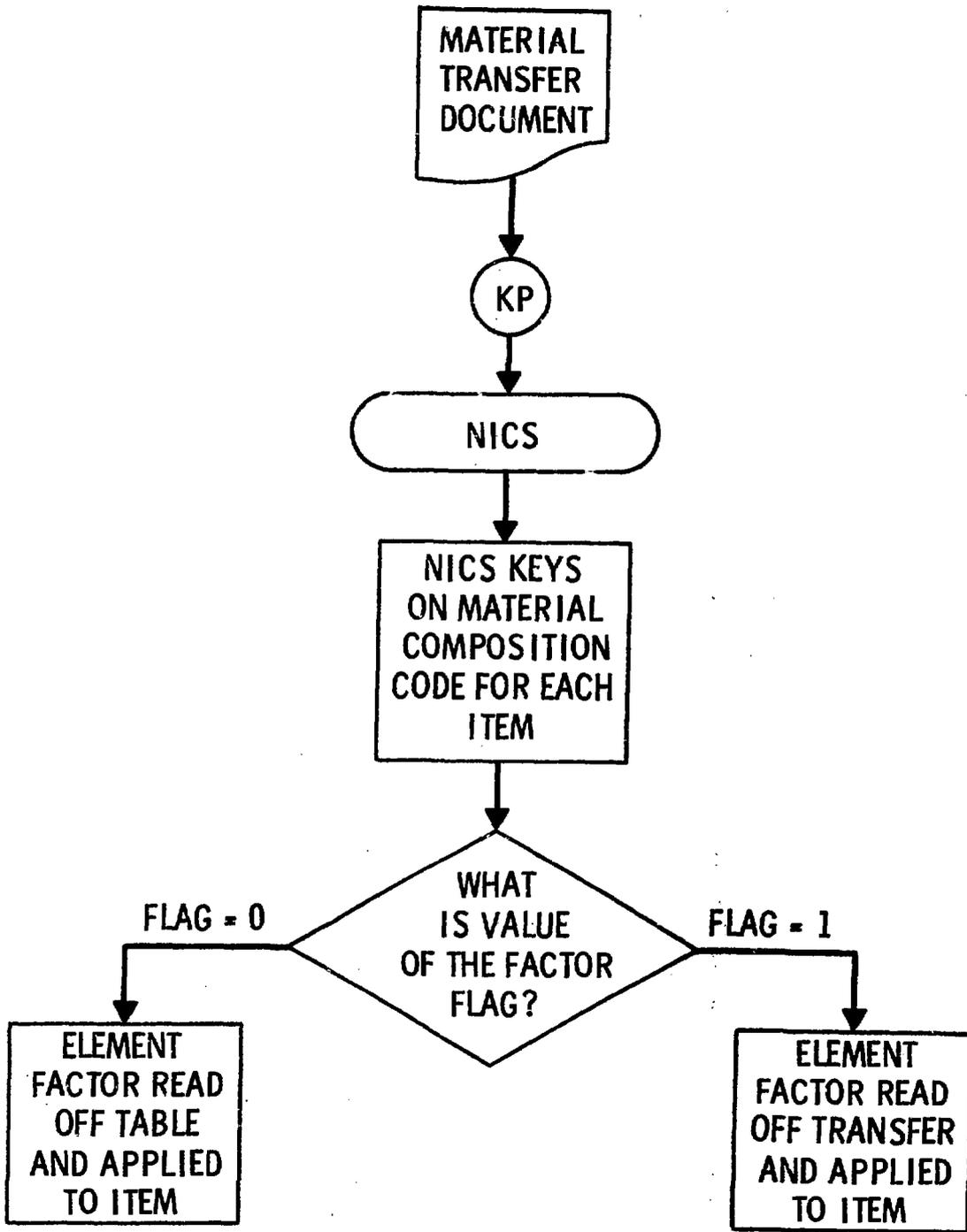
ISOTOPIC FACTOR TABLE

<u>PROJECT CODE</u>	<u>ENR</u>	<u>ISOTOPIC FACTOR</u>
0	E300	0.030000
1	E300	0.030000
2	E296	0.029600
3	E299	0.029900
4	E310	0.031000
5	E300	0.030000
6	E298	0.029800
7	E303	0.030300
8	E301	0.030100

U-FACTOR TABLE

<u>MATL COMP</u>	<u>UNIQUE FACTOR FLAG</u>	<u>U-FACTOR</u>
UF	1	0.67600
UH	1	0.67600
PD	0	0.87600
GP	0	0.87600
OU	0	0.84500
SP	0	0.88100
RD	1	0.88100
UD	1	0.88100
HS	0	0.88100
AD	1	0.60000
DP	1	0.86000
SL	1	0.80000
DW	0	0.99999
FW	0	0.99999
LW	0	0.99999

CHART 2. Assignment of Element Factors



which was recorded on the transfer document. A schematic diagram of this process is shown on Chart 8.

From Chart 1, there are seven material composition codes for which the factor flag is one. The source of the element factor for these seven material composition codes varies. For full and empty UF₆ cylinders (codes UUF and UUH), the verified enrichment plant value is used. For ammonium diuranate, dirty powder, and grinder sludge (codes UAD, UDP, and USL), each item is sampled and analyzed by the Analytical Lab for percent uranium. This value is then applied by NICS to the item. For rods (code URD), the specific lot uranium factor, as determined by the Analytical Lab, is applied to each item. For bundles (code UUD), the value is determined by the bundle transfer program (BUNCO). This is accomplished by assembling the component rod IBM cards in a deck, and running them through BUNCO, which produces a summary like that shown in Chart 3. This summary lists the uranium content of each rod, and the total for the bundle. The bundle element factor is determined by dividing the bundle element weight by the bundle net weight. This procedure is equivalent to a weighted average of all component rods.

C. Isotope Factors

Charts 4 and 5 show how isotopic values are assigned to a project enrichment account. Uranium for a new account is received into ICA-1 based on the receivers measured weights, and the verified enrichment are added to the factor table, and the associated specific isotope factor is assigned a composite value of all uranium received. When material is subsequently transferred throughout the plant, NICS keys on the project and nominal enrichment codes recorded for each item on the material transfer documents. NICS then searches the isotope factor table for the same project and nominal enrichment, and assigns the associated isotope factor to that item. A schematic diagram of this process is shown in Chart 8.

When all the uranium has been processed, and the finished fuel bundles are ready for shipment, the project average enrichment is calculated. The procedure involved will be discussed in the next subsection. This value then replaces the initial value in the factor table, and is applied to all fuel bundles. The project average enrichment is also applied to all residual material, at the time of a physical inventory, using the INSUM program.

D. Project Average Enrichment

Charts 6 and 7 show the steps involved in determining the project average enrichment. For each lot of material produced, the plant measured isotope values are averaged and tested statistically against the enrichment plant (UF₆ cylinder) isotopic value from which the lot was derived. All lots within the project enrichment are then divided into two groups; those which pass the test, and those which fail it. In either case, the net weight of the lot is multiplied by the plant measured element factor for that lot to yield the lot element weight. That result is then multiplied by the appropriate isotope factor, based on the results of the test, to give the lot isotope weight. Lots passing the test use the enrichment plant isotope

CHART 3. Sample "BUNCO" Summary

***** B U N C O *****

BUNDLE TRANSFER PROGRAM

PROJECT = REACTOR POWER RELOAD 1

R PROJECT LETTER
0001 PROJECT CODE

NOMINAL U-235
ENR FACTOR

300 .030000

BUNDLE = BUNDLE03 PROJECT = REACTOR POWER RELOAD 1

ROD	NOM ENR	U-235 FACTOR	U FACTOR	NET WEIGHT	ELEMENT WEIGHT	ISOTOPE WEIGHT
---	---	-----	-----	-----	-----	-----
ROD00010	300	.030000	.88090	2837.50	2899.55	74.99
ROD00011	300	.030000	.88095	2837.00	2899.26	74.98
ROD00012	300	.030000	.88100	2838.00	2500.28	75.01
ROD00013	300	.030000	.88105	2838.00	2500.42	75.01
ROD00014	300	.030000	.88098	2837.50	2899.78	74.99
			TOTAL	14188.00	12449.29	374.98

BUNDLE = BUNDLE03 701 REPORT SUMMARY

NOM ENR	U-235 FACTOR	ELEMENT FACTOR	NET WEIGHT	ELEMENT WEIGHT	ISOTOPE WEIGHT
---	-----	-----	-----	-----	-----
300	.030000	.88098	14188.00	12449.29	374.98

CHART 4. Assignment of Isotope Factors

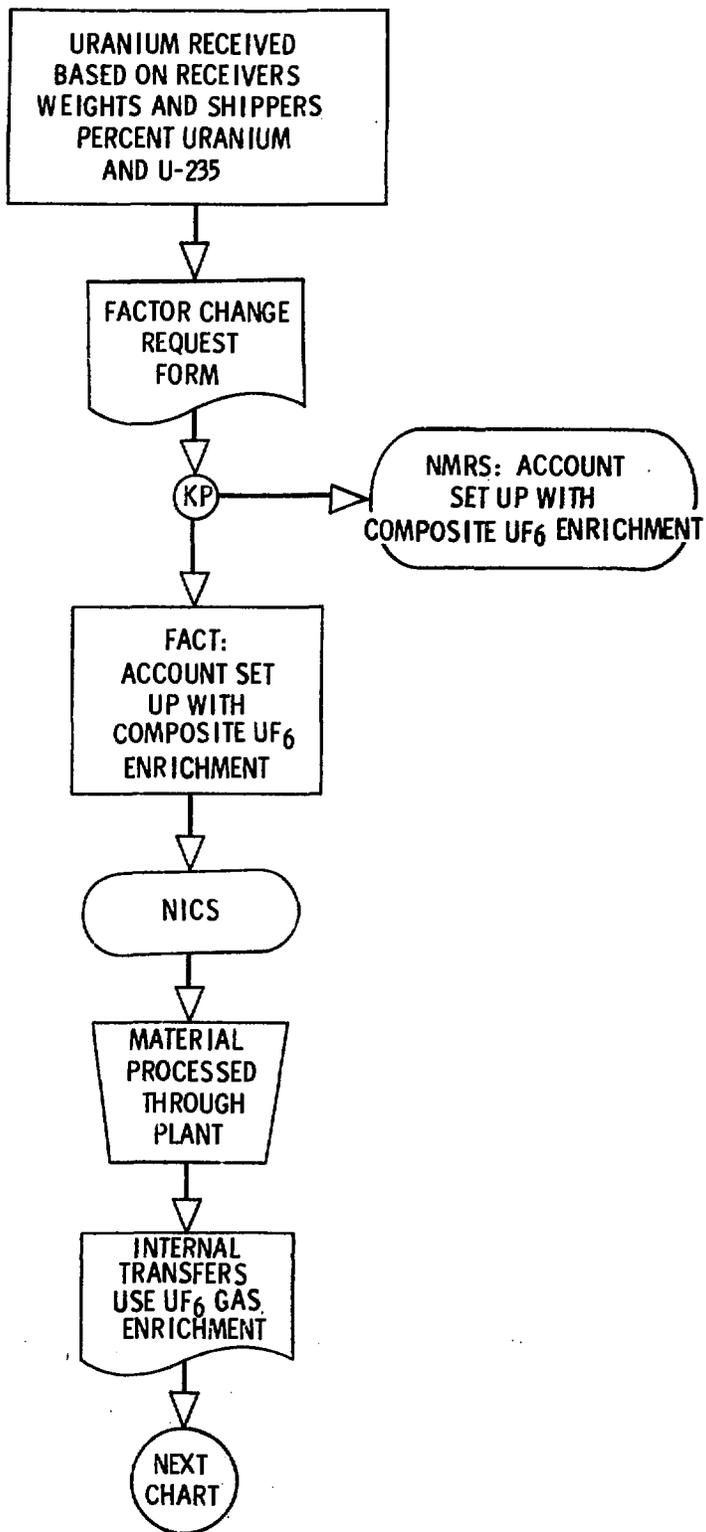


CHART 5. Assignment of Isotope Factors

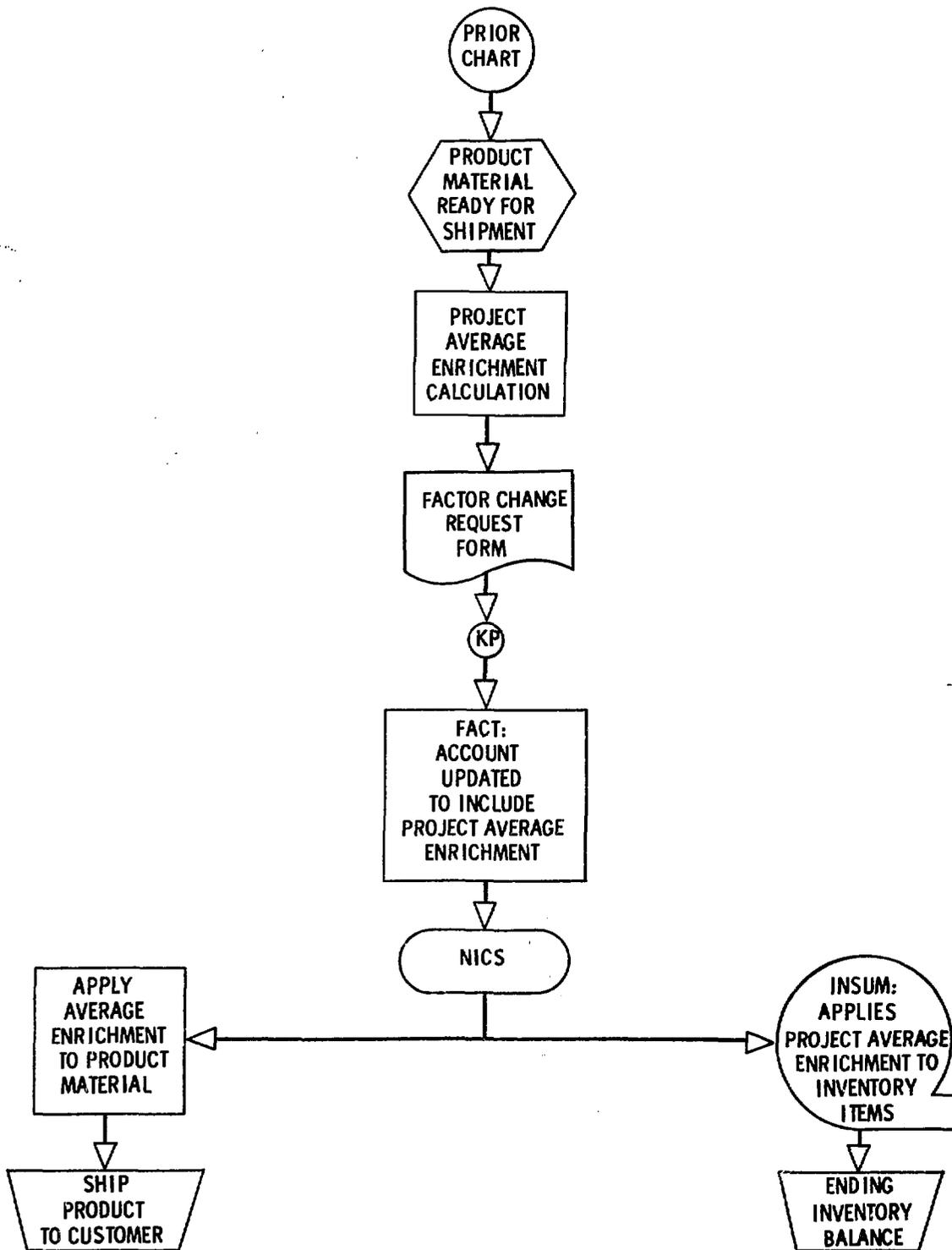


CHART 6. Project Average Enrichment

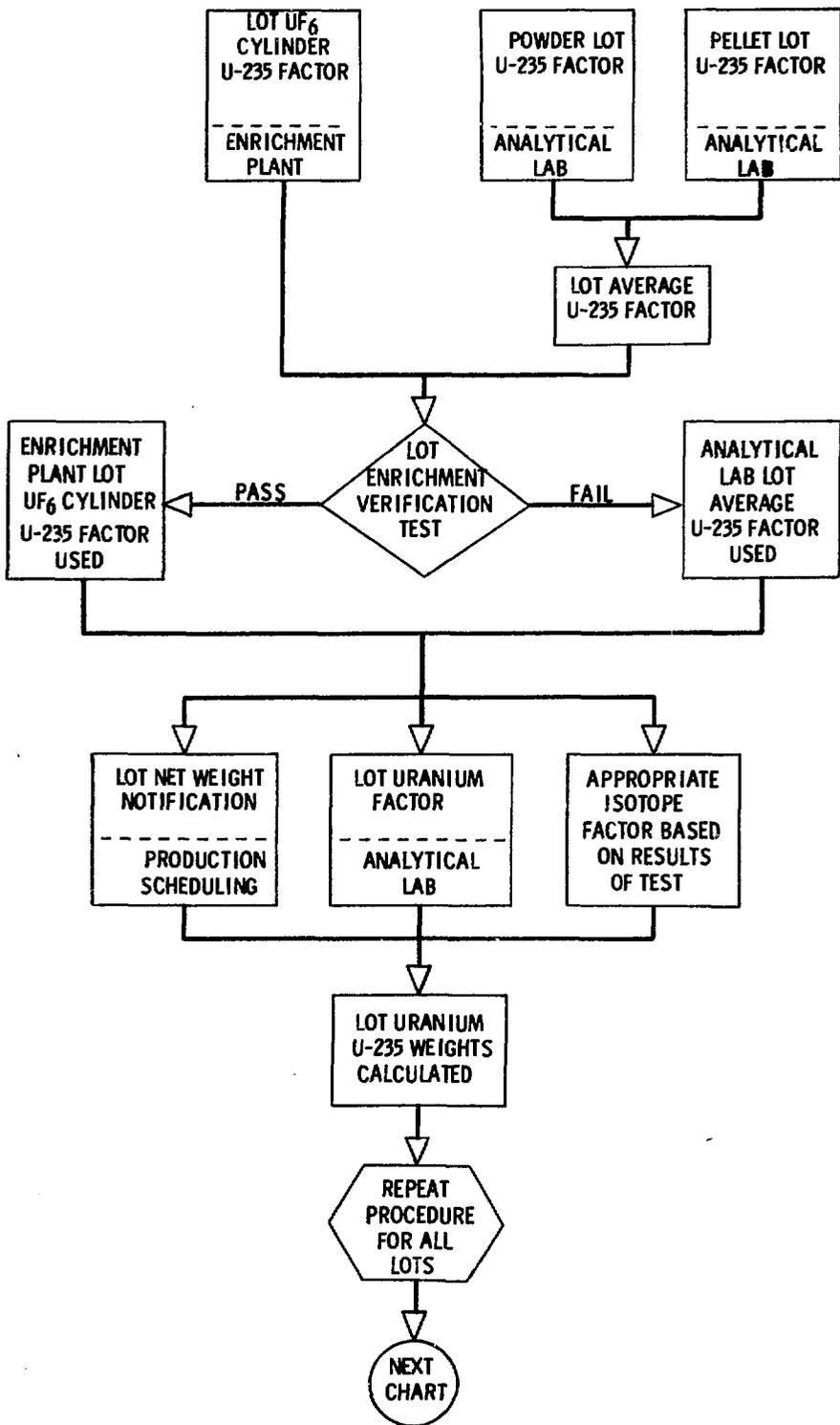


CHART 7. Project Average Enrichment

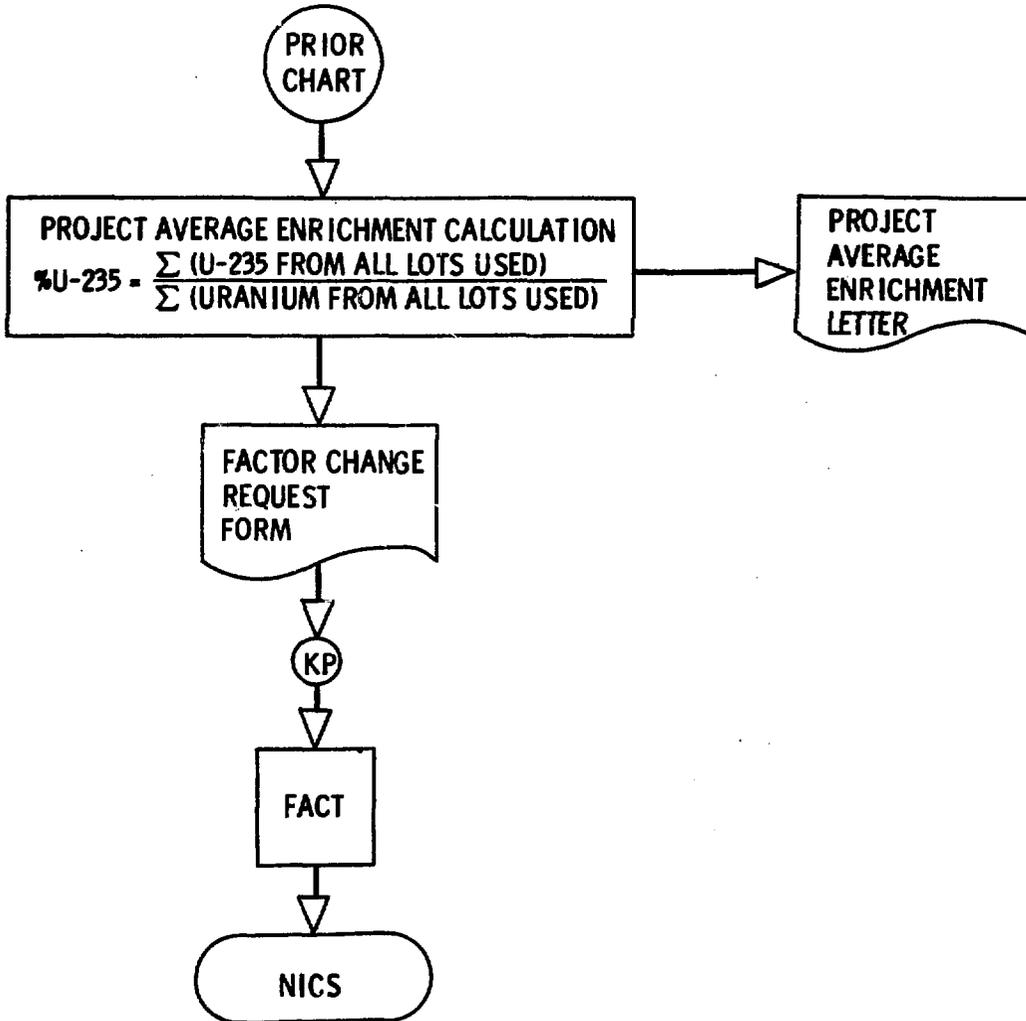
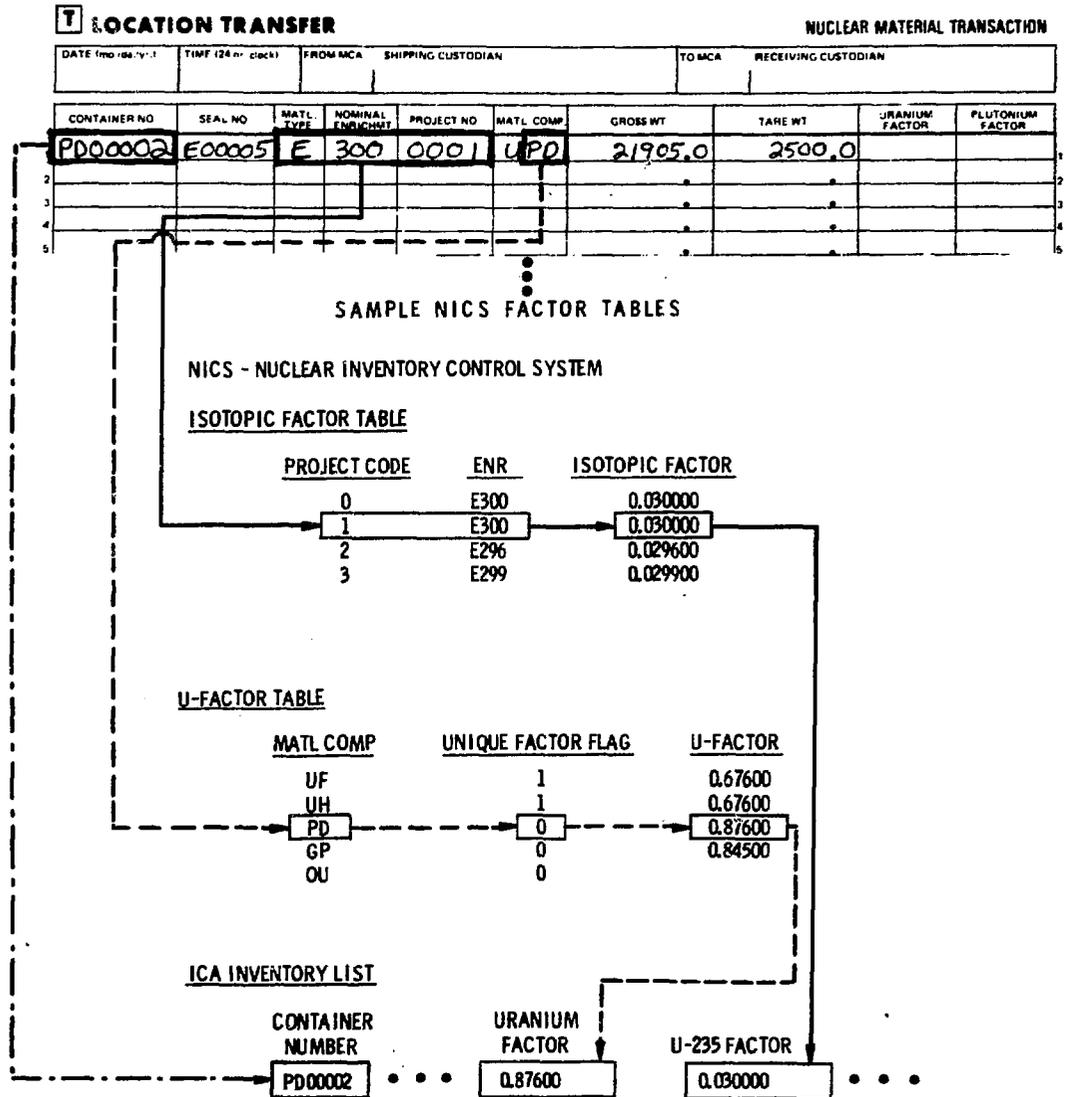


CHART 8. Step-by-Step Process for Assigning Element and Isotope Factors



factor, while those lots failing the test use the plant measured average lot isotope factor. The isotope and element weights for all lots used in the reload are summed, and the project average enrichment is determined by dividing the isotope weight sum by the element weight sum.

A summary of the assignment of element and isotope factors is provided in Chart 9.

E. Data Treatment

The uranium element factors for UO_2 powder and sintered pellets are based on the measured averages of powder and pellet lots. The values for those factors are monitored using cusum plots. The average values for percent uranium of each pellet and powder lot produced are plotted on a cusum graph. Typically five gravimetric analyses are done on each pellet lot and three on each powder lot. If a shift in the process average is detected by the cusum technique, a new factor which is based on the new process average is computed and entered into the factor table.

The uranium element factor data are examined for correctness by the Analytical Laboratory. The data are also evaluated statistically for internal consistency using a chi-square test before being included in the cusum plots.

The isotopic factor data used in determining the weighted average enrichment of a given project-enrichment are based on the average of the mass spectrometer measurements of samples taken from each powder-pellet lot produced. Typically two or more U-235 analyses are made on each pellet lot and one or more on the corresponding parent powder lot. The U-235 data are also evaluated for correctness and internal consistency before being used for accounting purposes.

The general subject of data treatment is discussed in more detail in the session on the Measurement Control Program.

CHART 9. Summary of Assignment of Factors by NICS

ELEMENT FACTORS

1. UF₆ GAS RECEIVED USING VERIFIED ENRICHMENT PLANT VALUES
2. FACTOR IN TABLE IS USED FOR INTERNAL TRANSFERS IF FLAG - 0
3. FACTOR ON TRANSFER IS USED FOR INTERNAL TRANSFERS IF FLAG - 1
 - a) FOR CYLINDERS VERIFIED ENRICHMENT PLANT VALUE IS USED
 - b) FOR SCRAP UO₂, ANALYTICAL LAB VALUE IS USED
 - c) FOR RODS, LOT VALUE IS USED
 - d) FOR BUNDLES, WEIGHTED AVERAGE OF COMPONENT ROD VALUES USED

ISOTOPE FACTORS

1. UF₆ GAS RECEIVED USING VERIFIED ENRICHMENT PLANT VALUES
2. PROJECT ENRICHMENT ACCOUNT SET UP USING COMPOSITE UF₆ GAS ENRICHMENT
3. INTERNAL TRANSFERS USE ENRICHMENT IN ISOTOPE FACTOR TABLE
4. PROJECT AVERAGE ENRICHMENT DETERMINED WHEN ALL MATERIAL HAS BEEN PROCESSED
 - a) THIS VALUE IS APPLIED TO ALL BUNDLES PRIOR TO SHIPMENT
 - b) THIS VALUE IS APPLIED TO INVENTORY ITEMS, VIA INSUM, FOR PHYSICAL INVENTORIES



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
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October 17-November 4, 1983

Session Objectives

SESSION 24: PROCEDURE FOR TAKING PHYSICAL INVENTORIES

This session describes how plant physical inventories are planned and taken. The description includes the planning and preparation for taking the inventory, the clean-out procedures for converting in-process material to measurable items, the administrative procedures for establishing independent inventory teams and for inventorying each inventory area, the verification procedures used to include previously measured tamper-safed items in the inventory, and lastly, procedures used to reconcile the inventory and calculate MUF (materials unaccounted for).

After the session, participants will be able to:

1. understand the planning and pre-inventory procedures and their importance,
2. understand the need for and the required intensity of clean-out procedures,
3. understand how inventory teams are formed, and how the inventory is conducted,
4. understand the distinction between inventory previously measured tamper-safed items and other materials not so characterized,
5. understand the reconciliation procedures,
6. calculate a MUF given the book and inventory results.



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October 17-November 4, 1983

SESSION 24: PROCEDURE FOR TAKING PHYSICAL INVENTORIES

R. A. Boston
Exxon Nuclear

I. INTRODUCTION

Physical inventories are taken periodically to meet Company, State and IAEA requirements. Those physical inventories may be verified by IAEA and/or State inspectors. This presentation describes in an introductory but detailed manner the approaches and procedures used in planning, preparing, conducting, reconciling and reporting physical inventories for the Model Plant.

Physical inventories are taken for plant accounting purposes to provide an accurate basis for starting and closing the plant material balance. Physical inventories are also taken for safeguards purposes to provide positive assurance that the nuclear materials of concern are indeed present and accounted for.

II. GENERAL

The plant inventory is taken over a two-three day period by inventory teams. The inventory is taken by material control area (MBA or ICA) with one or more teams assigned to a material control area. The inventory teams are two-person teams. One person on each team is from the custodial organization (e.g., Operations or Shipping & Receiving) and one from an independent organization.

Physical inventory taking is a major undertaking in terms of manpower and lost production costs. It is important that it is carefully planned and that preparations are made well in advance.

At the Model Plant, a detailed action plan is followed for each inventory. This plan is in the form of a checklist which is arranged in the chronological order in which the tasks are to be completed. As each task is completed, the date of completion is noted on the checklist and the name of the person carrying out the task is also noted on the list by the person's signature.

Because of the number of tasks and organizational components involved in taking a physical inventory, overall responsibility for inventory taking is assigned to an inventory coordinator. It is the responsibility of the coordinator to oversee all preparations, provide necessary training to the inventory teams, and lead the effort of inventory taking, reconciliation, and assembling the results into a reportable form.

The overall inventory program is illustrated in Table I, and a detailed description follows.

TABLE I
NUCLEAR MATERIALS PHYSICAL INVENTORY PROGRAM

RULES AND REGULATIONS

FEDERAL REGULATIONS (IAEA)
LICENSING REQUIREMENTS
COMPANY REQUIREMENTS

RESPONSIBILITY

INVENTORY COORDINATOR
MATERIAL CUSTODIANS
INVENTORY TEAMS

PLANNING

PRE-INVENTORY REVIEW MATERIAL LOCATIONS
TIME SCHEDULE
MANPOWER ASSIGNMENTS (TWO MAN TEAMS)
WRITTEN INVENTORY PROCEDURES
INVENTORY LISTINGS, SHEETS AND TAGS
DETAILED CHECKLISTS
TRAINING

PHYSICAL INVENTORY PROCESS

RECORDING AND VERIFYING DATA
SEAL INTEGRITY
OBSERVING ACTIVITIES
PROBLEM SOLVING

RECONCILIATION

ACCOUNTABILITY PHYSICAL INVENTORY STICKERS
AUDITING INVENTORY DATA
MAKING APPROPRIATE CORRECTIONS
FINALIZING INVENTORY RESULTS

REPORTS

NRC (IAEA)
MANAGEMENT

III. PHYSICAL INVENTORY PROGRAM

A. Planning and Preparation

1. Selection of an Inventory Coordinator. The inventory coordinator should be designated several months before the time of the inventory.

2. Schedule. The physical inventories for the Model Plant are taken near the end of March and near the end of September. The inventories are scheduled just before a normal production break, e.g., a weekend, to minimize material movement for the reconciliation process.

3. Announcement of Inventory Date. When the exact date of the inventory has been determined, the inventory coordinator formally announces the date to all affected organizational components. The announcement specifies any State and/or IAEA requirements that must be met (e.g., two person inventory teams or sealing requirements, etc.). Additionally, internal procedures for equipment cleanout, measurements, sealing procedures, and general inventory counting instructions are given.

4. Preparation of Inventory Taking Material

a. Inventory Packages. Prior to the inventory, the inventory coordinator prepares a package for each inventory team to use in taking the inventory. The packages for teams doing the inventory of an MBA contain a set of inventory stickers and a set of physical inventory sheets. The packages for teams doing ICA's contain inventory stickers, a current computer listing of the ICA holdings, and an ICA Physical Inventory Write-In Form.

b. Inventory Stickers. In taking the inventory each inventory item (container, bin, stack) is physically tagged with an adhesive sticker which is uniquely numbered in a sequential order. For the Model Plant, an inventory is typically composed of between 20,000 and 25,000 items so the series of 0 through 25,000 is used in numbering the tags, allowing for some overage. In addition to the unique numbering, the stickers (also referred to as inventory tags) are color coded. One color is used for an inventory, the color is then changed for the succeeding inventory. For example, if a monthly physical inventory frequency is used, then yellow could be used in January, blue in February, orange in March, green in April, etc. This color coding provides traceability from one inventory to the next and helps avoid confusion when trying to determine if all containers have been inventoried at the time of counting.

The approximate number of items expected to be present in each control area is estimated before the inventory so that the proper sequence of inventory sticker numbers can be assigned to each area.

c. Physical Inventory Record Sheets. The packages for teams inventorying MBA's are supplied with a set of Physical Inventory Record Sheets (shown in Table II). The inventory sheets are prenumbered to correspond to the inventory sticker numbers assigned to that MBA. Thus, for each inventory sticker number in the inventory package there is a correspondingly numbered line on the inventory sheet.

d. ICA Physical Inventory Write-In Sheet. The inventory packages for teams inventorying ICA's are supplied with a set of ICA Physical Inventory Write-In Sheets (shown in Table III). These are not numbered and are used to record any containers which are not listed on the latest computer list of items in the ICA.

e. ICA Inventory Tag Reconciliation Form. Also placed into the ICA packages is one ICA Inventory Tag Reconciliation form. This form is completed at the time of inventory by the inventory team members and is used to reconcile the number of tags used to the number of container inventoried on the day of the count. The form is shown in Table IV.

5. Waste and Scrap Container Preparations. At the Model Plant, contaminated HEPA filters and barrels (drums) of solid waste are accumulated and stored in designated areas after they have been measured for uranium content and sealed. These containers have been entered into the accounting system as items for material accounting purposes. Because of the large number of these items, a subsystem of the primary accounting system has been developed which lists the filters and barrels in the row and sequential order in which they are stored. The row lists help to expedite the inventory of these items. It is necessary to update the sequential row lists by entering adjustments into the computer for additions to the inventory or possible shipments or rearrangements of the containers. The changes made to row lists are verified by pre-inventory checks of the area prior to the formal inventory.

The lists are separated by row and placed in marked packages together with the exact number of inventory stickers needed, an ICA Inventory Tag Reconciliation form, and ICA Physical Inventory Write-In Sheets. One miscellaneous package is prepared with tags and sheets to be used to inventory those containers not yet appearing on row lists but already entered into the accounting records. The computer listing for these recently added items will be printed and inserted into the package when the final computer lists of the ICA's are printed.

6. Fuel Rod Preparations. At the Model Plant, fuel rods are inventoried by location and in groups rather than as unique items. There are a number of storage locations for rods in fixed arrays with assigned compartment identifications. There are also designated in-process storage locations. The I02 Rod Inventory

TABLE II

I **PHYSICAL INVENTORY RECORD** **EXXON NUCLEAR COMPANY, Inc.** **NUCLEAR MATERIAL TRANSACTION**

INVENTORY TAG NO.	CONTAINER NO.	SEAL NO.	M T	NOMINAL ENRICHMT	PROJ. NO.	MATL. COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR	LOT NO.
1							.	.		
2							.	.		
3							.	.		
4							.	.		
5							.	.		
6							.	.		
7							.	.		
8							.	.		
9							.	.		
10							.	.		
11							.	.		
12							.	.		
13							.	.		
14							.	.		
15							.	.		
16							.	.		
17							.	.		
18							.	.		
19							.	.		
20							.	.		
DATE (mo/day/yr)	LOCATION	INVENTORIED BY				VERIFIED BY				

24-5

TABLE III

ICA PHYSICAL INVENTORY WRITE-IN SHEET

CONTAINER NO.	SEAL NO.	TAG NO.	PROD. NO.	NOMINAL ENRICHMENT	PAYL. COMP.	GROSS WT.	TARE WT.	NET COUNT	REPORT NO.	DATE	
1										1	
2										2	
3										3	
4										4	
5										5	
6										6	
7										7	
8										8	
9										9	
10										10	
11										11	
12										12	
13										13	
14										14	
15										15	
16										16	
17										17	
18										18	
19										19	
20										20	
DATE (mo/da/yr)		ICA CODE	INVENTORIED BY				VERIFIED BY				

TABLE IV

ICA _____ INVENTORY TAG RECONCILIATION
_____ PHYSICAL INVENTORY

NUMBERS OF CONTAINERS

- 1. Listed on computer printout (PHIL) _____
- 2. Listed on Write-in sheet _____
- 3. Subtotal _____
- 4. Deduct containers listed but not tagged (_____)
- 5. Total Containers _____

INVENTORY TAGS

- 6. Numbers assigned (from _____ thru _____) _____
- 7. Deduct numbers not used (from _____ thru _____) (_____)
- 8. Deduct voided tags (#'s _____, _____, _____) (_____)
- 9. Net tags assigned _____
- 10. Variance (Line 5 minus Line 9) _____

ANALYSIS OF VARIANCE

Prepared By _____ Date _____

Physical Count Sheet is used to record the rod inventory (Table V). In preparing for the inventory, the rod inventory count sheets are numbered to coincide with the appropriate sticker assignments for the rod inventory and where possible the bin number or storage location identification is pre-inserted on the form. The count sheets, stickers and tag reconciliation form are included in the inventory package. The I02 Rod Inventory Physical Count Sheet is shown in Table V.

7. Inventory Tag Control Log. As sticker assignments are made to the various MBA's and ICA's, the sequence of numbered tags designated for use is listed on the Inventory Tag Control Log (shown in Table VI). This log serves as the master control for reconciling tag use in the inventory.

8. Cleanouts, Measurements, and Tamper-Safing. Progress of the pre-inventory cleanouts, MBA container weight and enrichment verifications and tamper-safing of containers is monitored as the inventory date approaches. Additionally, sampling with analytical determination of uranium element and isotope content is required for all items which were not previously measured.

For the Model Plant, a full cleanout of process equipment, vessels, plenums, and ductwork is required to achieve a "completely measured" material balance. Material removed during the cleanout is placed in containers and sampled, weighed, and sealed. Also, any filters removed during the cleanout and any solid waste drums resulting from cleanout must also be measured to be included in the inventory.

Many of the items present at inventory time were measured at the time they were created. Those which could be sealed at time of measurement were sealed so that they could be included in the inventory at the previously measured values. The contents of the items which could not be sealed at the time of the original measurement, such as pellets in open sintering boats, are verified at time of inventory by remeasurement of one or more properties to be included in the inventory. Similarly, items with broken seals must be verified by remeasurement. Also, in preparing areas for the inventory, previously measured items which were not tamper-safed are verified by remeasurement and either tamper-safed or placed in tamper-safed containers. Pellets on trays are verified by reweighing and placed in sealed bins prior to the inventory. Fuel rods are item identified, counted and placed in sealed storage bins. These activities facilitate the efficiency and safeguards effectiveness of inventory taking.

9. Personnel Assignments and Training. Personnel assignments are made by the inventory coordinator from lists of available personnel provided by management. An inventory team is made up of two people. One normally from the custodial organization and one from a separate (independent) organization.

TABLE V

I-02 ROD INVENTORY
PHYSICAL COUNT SHEET

	Tag No.	Bin No.	Seal No.	Type	No.								
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													

INVENTORIED BY: _____ DATE _____

VERIFIED BY: _____ DATE _____

TABLE VI

<u>AREA</u>	<u>MCA</u>	<u>CAPA- CITY</u>	<u>ASSIGNMENT TAG SEQUENCE</u>			<u>TOTAL</u>	<u>ACCOUNTED TAGS</u>			<u>TOTAL</u>	<u>VARIANCE FROM ASSIGNMENT</u>	<u>COMMENT</u>	<u>TO AUDITORS</u>
			<u>FROM</u>	<u>TO</u>	<u>ADDS</u>		<u>USED</u>	<u>RETURNED</u>	<u>VOID</u>				
Conversion Scrap Recovery													
Pellet Preparation													
Ceramic Operations													
Rod Loading													
Analytical Labs													
Shipping/Receiving													
Rod/Bunble Assembly													
Powder Storage Room													
Radioactive Warehouse & Trailers													
Solid Waste Storage													
Tag Reconciliation													

24-10

It is desirable for at least one team member to be familiar with the assigned inventory area, including the materials, container types, measurements, and container locations.

The second member of the inventory team is not from the custodial group and it is his function to provide independence in the inventory. Accounting personnel have worked well in this role because of their recording accuracy and organizational independence.

After the inventory teams have been determined, the team members are notified of their assignments by letter. The letter identifies the schedule for conducting the inventory by inventory location and the date and time of the start of each inventory. Included in the notification letter are instructions to attend a pre-inventory meeting and the detailed procedures to be followed in taking the inventory.

Personnel not previously experienced in taking inventory may be given training in advance to familiarize them with recording procedures, assigned location of responsibility, as well as safety or radiation work procedures.

More than one team may be assigned to an inventory area to expedite its completion. In this case, a lead team is designated to assume responsibility for the area and supervision of other area teams. The lead team is responsible for the thorough taking of the inventory and for the collection of the inventory materials and completed inventory sheets.

10. Notification of Inventory Schedule to Computer Services. Computer Operations and keypunch personnel are notified by letter of the final inventory schedule and are given estimated work loads and required processing schedules as far in advance as possible so that they may plan personnel coverage. To handle the data processing workload, evening and weekend operations are scheduled for data processing personnel.

11. Final Computer Updates and Inventory List Preparations. Accounting collects all completed transaction, bundle assembly, and shipment/receipt documents late on the day before the physical inventory from the material custodians. These documents are processed into the accountability system to update the ICA computer lists in the Material Inventory Maintenance System (MIMS). ICA inventory listings are then printed from the PHIL program. The lists are separated by ICA and inserted into the inventory packages, along with the inventory stickers, write-in and tag reconciliation forms.

The part of the waste barrel and filter inventory computer report (WBILE) which shows the miscellaneous barrels and filters which are not in a row sequence is separated from a current (WBILE) report and placed in the inventory package.

The various computer programs used in conjunction with the taking, reconciling and booking of the inventory are shown in Table VII.

B. Taking the Physical Inventory

1. General. The Model Plant typically conducts the physical inventory by material control area (MCA) during a 2-3 day period. The order of inventorying MCA's is staggered to maximize the efficiency of the inventory and minimize the production outage. Frequently, the first day inventory includes some outside storage locations such as the waste barrels and filters, shipping and receiving, and some scrap storage locations. The UF₆ to UO₂ conversion area may also be inventoried on the first day, provided cleanout and inventory preparations have been completed. The remainder of the plant including the pelletizing, rod loading and storage areas are inventoried the second day to complete the inventory.

Inventory hold periods for material movements are strictly enforced once the inventory begins in a material control area. Movements of material may continue in and between areas which are to be inventoried on the second day so long as they do not interfere with the inventory and, of course, must be properly recorded.

After the inventorying of a material control area is completed to the satisfaction of the coordinator, it is released to a semi-hold status which allows limited internal material movements within the area but not between areas. These movements are minimized to aid in reconciliation.

2. Pre-Inventory/Final Instruction Meeting to Inventory Teams.

Inventory team members are assembled just prior to the start of the physical inventory. A check is made to assure all members are present and replacements are assigned if necessary.

The coordinator distributes the inventory packages to the assigned teams and explains their contents. Instructions are given emphasizing the importance of achieving a thorough and accurate inventory and the need to use a methodical and systematic approach. Requirements for verifying and sealing untamper-safed items are also reviewed.

Area closeout procedures are also explained, including the need to 1) do a post inventory search for untagged containers, and 2) consolidate multiple inventory listings if more than one team is used in the area.

3. MBA Physical Inventory Procedure. Following the instructions to systematically inventory the area, a team may first walk through the area and plan the inventory approach or divide the area into subareas if more than one team is to be used.

To record the inventory, one member of the team becomes the reader (normally the operations member who is familiar with the

TABLE VII
COMPUTER PROGRAMS AND REPORTS USED
FOR PHYSICAL INVENTORY

<u>PROGRAM/ REPORT</u>	<u>TITLE</u>	<u>DESCRIPTION</u>	<u>DATA BASE</u>
MIMS	Material Inventory Maintenance System	Primary material inventory maintenance system. Keeps element and isotope MBA material balances by area, by material type, project, and nominal enrichment accounts. Shows ICA inventories of individual containers with element and isotope quantities in project/enrichment sequence for each ICA. Lists daily transactions which update MBA totals and ICA listings.	Recorded material transfer documents and FACT.
PHIL	ICA Physical Inventory List	List of all items by ICA in a format conducive to verifying the ICA physical inventory. The items on the lists are sorted by container number.	MIMS
MPIS	MBA Physical Inventory List	MBA detailed summary and listings of items and quantities recorded by MBA physical inventory.	Recorded MBA Physical inventory record data and FACT.
INSUM	Inventory Summary	Consolidated summary of ending inventory (MBA and ICA) in quantities of element and isotope by material type, project, enrichment, and material composition.	MIMS and MPIS

TABLE VII
(continued)

<u>PROGRAM/ REPORT</u>	<u>TITLE</u>	<u>DESCRIPTION</u>	<u>DATA BASE</u>
EIS	Ending Inventory Summary	Detailed summary and item listing of ending inventory in quantities of element and isotope by material type, composition, project and enrichment.	MIMS and MPIS
RODIN	ICA-2 Rod Inventory	Comparison of fuel rod book inventory to physical inventory by rod identification prefix.	I02 rod inventory physical count sheets and MIMS.
FACT	Element and Isotope Factor Table	Table of specific element and isotope factors by project.	Measurement data.
WEIT	Duplicate Container List	Lists containers with duplicate identifications listed on ending inventory records.	MIMS and MPIS
MBMUF	MBA MUF Calculation	Compares MBA book inventory to physical inventory and show the difference by MBA, project and enrichment.	MIMS-MBA book quantities and MPIS
TRAP	Transaction File List	Complete listing of all transactions effecting the NICS material balances and inventory listings. Includes shipments, receipts, project/enrichment changes, and MUF's. Sorts by MCA, project, enrichment, material type, and container ID. The material balance period produces several of these files.	Recorded material transfer documents

TABLE VII
(continued)

<u>PROGRAM/ REPORT</u>	<u>TITLE</u>	<u>DESCRIPTION</u>	<u>DATA BASE</u>
SCRAP	Scrap Container Inventory Report	Summarizes scrap items by material composition.	MIMS and MPIS
WFILE	Waste Barrel/Filter Inventory Listing	Row sequence listings of waste barrels and HEPA filters. Also shows miscellaneous barrels and filters not in rows.	MIMS

area) and the other (independent or accounting staff member) becomes the recorder. The reader takes the inventory stickers provided, locates the first container to be inventoried and reads aloud to the recorder all the information on the container and on the material record card (attached to or by the container). The second team member records the data, including the container number, seal number, material type, nominal enrichment, project number, material composition, and gross and tare weights. The team will not know the uranium factor but should list the lot number when available. As the reader reports the seal number, he should check its integrity being careful not to break a paper seal. Lastly, the reader reports the adhesive inventory sticker number and affixes it to the container in a conspicuous location such as the lid or on the material record card. The recorder acknowledges his completion of the data line and indicates that the sticker number is the same as the number on the data sheet. The team then moves on to the next item, etc., until the inventory is complete.

If the team encounters an unsealed item or an item with a broken seal, the contents are verified by remeasurement following established verification procedures for each type of item, e.g., reweigh, SAM-2 enrichment check, or sample and assay.

When the inventory of the area has been completed, the team(s) goes through the area again to assure that no containers have been omitted or overlooked. Both team members sign and date each page of the inventory record sheets. All unused record sheets, inventory stickers, and completed inventory record sheets are returned to the coordinator. The team is released to return to regular work when the coordinator has satisfied himself of the completeness and accuracy of the inventory.

4. ICA Physical Inventory Procedure. Teams inventorying the ICA's use the same systematic approach as is used in the MBA's with the exception that they are verifying data already listed on the computer printout rather than recording the inventory data.

The team first completes items 1 and 6 on the Inventory Tag Reconciliation form (Table IV); identifying the number of items listed on the computer printout and the sequence and total number of inventory stickers assigned to the team.

They begin the inventory with the reader, stickers in hand, first identifying only the container number. The recorder finds and acknowledges the existence of that container number on the listing. The reader then proceeds to call out the inventory data exactly as it appears on the container and the attached material record card while the recorder checks that the data are the same as on the computer listing. The data include seal numbers, project number, material type, nominal enrichment, gross and tare weights.

If any of the listed data on the computer printout differs from the recorded information on the container, the data on the computer report is circled and the information shown on the container is written in next to it. The seal on the item is tested for integrity, and if broken or missing, the seal number on the computer printout is circled and the words "broken" or "missing" noted on the list. This identifies the item for verification by remeasurement.

After checking that all inventory data on the container are the same as on the computer list, the reader then calls out the first inventory sticker number and attaches it in a conspicuous location on the container. The recorder writes the reported sticker number in the space provided on the computer printout on the same data line as the container is listed. The team then proceeds to the next item and so on until the inventory is completed.

If the team encounters a container not listed on the computer printout, it is recorded on the ICA Physical Inventory Write-In Sheet (Table III) along with all the inventory data.

When the physical inventory has been completed in the area, the team goes through the area to assure that all containers have been tagged, and signs and dates the computer listing and write-in sheet. If multiple teams are inventorying the area, the inventory should be consolidated onto one of the computer printouts and this listing identified as the master list.

The ICA Inventory Tag (sticker) Reconciliation form (Table IV) is then completed by the teams. The inventory sticker variance (line 10) must equal zero or the discrepancy resolved before the inventory is complete.

The coordinator is notified that the inventory is complete and the teams return to their regular work. The teams turn in their unused inventory forms and stickers and completed inventory sheets and forms to the coordinator.

5. Waste Barrel and Filter Inventory Procedure. Inventory of the waste barrels and filters is identical to the other ICA's except that containers are row listed in the sequential order in which they are stored. The only data to be verified are the container and the seal number. If a container is found out of sequence, it is noted on the computer list for later correction but not as an inventory error.

As in other ICA's, the Write-In Sheet and Tag Reconciliation form must be completed to record the inventory.

6. Fuel Rod Inventory Procedure. At the Model Plant, the inventory of fuel rods is based on verifying by physical inventory that the total number of rods for each project, rod type, and enrichment agree with the computer-based book inventory. Once the physical presence of the rods has been proven by actual inventory, then the quantities of element and isotope are calculated by the computer by summing up the previously measured values for the element and isotope content of each fuel rod.

Each fuel rod is inscribed with a unique eight-character identification. The first three characters identify the project, rod type, and enrichment. The fuel rod inventory is taken by counting the total number of rods for each three-character prefix and comparing the count to the computer-based book inventory. Any discrepancies must be resolved by full identification and reconciliation of individual rods.

For the inventory, the teams count the number of rods with a given prefix at one location and record it on the IO2 Rod Inventory Physical Count Sheet (Table V). If the location is sealed, the count is taken from the material record card attached to the storage bin. For additional accuracy, both members of the inventory team count the rods to avoid error. More than one type of prefix may be found at one location. The inventory form provides for recording multiple prefixes and quantities counted for each type.

The inventory sticker is placed in a conspicuous location at the storage location. Care is taken to match the sticker to the correct inventory location recorded on the inventory sheet because some preassignment of stickers to storage bins is made in advance. All designated storage bins are inventoried. If a bin is empty, it is noted on the inventory sheet.

When completed, the teams date and sign all inventory sheets. The teams are released to return to regular work by the coordinator when he is satisfied that the inventory is complete and correct.

1. Reconciliation of ICA Inventories. Inventory materials are returned to the coordinator. He records the number of inventory stickers used or returned on the Inventory Tag Control Log (Table VI). Necessary reconciliations are made to the inventory based upon collected transactions which were recorded between the last computer system updating of the ICA book inventories which was used to produce the inventory lists and the start of physical inventory.

Lists are prepared for each ICA showing containers, 1) listed on the computer printout but not found by physical inventory, 2) found during the inventory but not on the computer listing, 3) with broken or missing seals, and 4) for which the information on the material record card and container does not agree with the information on the computer listing. A description of the data variance is noted on the list.

Missing inventory items must be located or evidence of their disposition found. Transaction documents are recorded and processed reflecting the results of these reconciliations. Write-ins are also recorded as transfers into the ICA. Seal and other inventory data variances are resolved by the ICA custodian and the necessary transaction documents recorded and processed to update the computer data base (MIMS). The ICA reconciliation is judged to be complete when there are no missing containers, unresolved write-ins, or seal, project, enrichment and weight variances from the recorded physical inventory.

2. Reconciliation of the Fuel Rod Inventory. Data recorded on the IO2 Rod Inventory Physical Count Sheets are processed and submitted into the computer program RODIN. The report from this program identifies the differences, by prefix, between the book and physical inventories.

These differences, together with a full listing of all rods, are returned to the rod custodian for resolution of the variances. Reinventory of some rod locations may be necessary to reconcile the counts. If differences remain, a complete reinventory may be required or a rod-by-rod verification to resolve variances using the full rod listing from the book inventory. Reported differences for a rod prefix must be resolved before finalizing the inventory. A difference in one rod prefix cannot be used to offset a difference in another prefix.

3. Reconciliation of the MBA Inventories. Collected MBA Physical Inventory Record sheets are inspected by the coordinator for recording errors then processed into data entry format. They are entered into the MPIS program which makes edits for mistakes in projects and enrichments and in gross and tare weights. After correction, the program produces a report listing and summarizing the MBA inventory items. The report is examined by the coordinator and suspected errors in weights or enrichments are checked by comparison to the inventory record or by remeasurement of the item. Unsealed items are listed and it is the responsibility of the area custodian to see that verification measurements have been made and the data reported to the coordinator.

4. Other Reconciliation Activities. As a part of the reconciliation the computer reports WEIT and SCRAP are printed. WEIT lists any container identifications duplicated in the inventory. All duplications are resolved before closing the inventory. The SCRAP report lists all containers identified as scrap by material composition. The uranium element factors for all items requiring unique analysis (certain scrap items) are checked to assure they have been sampled and element factors applied. Items requiring unique determination of uranium content cannot be included in the ending inventory at a temporary or average factor.

Before finalizing the inventory, specific enrichment factors are calculated for each project-enrichment (as needed) and applied to inventory items by the computer.

5. Calculation of Inventory Difference. After reconciliations of the ICA and MBA inventories, the ending physical inventory for the entire plant is summarized by the computer on the report EIS. This report shows the element and isotope quantities for each item in the inventory and summarizes the quantities by material type.

The ending physical inventory for the plant is then compared to the ending book inventory to determine the MUF for the Model Plant.

6. Reporting Inventory Results. Reports are prepared and distributed as required to meet State and IAEA requirements. Management type reports are prepared to inform company management of the inventory quantities and the results of the inventory.

All source documents and ending inventory reports are retained as prescribed in the accounting procedures.

Inventory notes or comments are preserved for future reference and revisions to the Inventory Progress Checklist are noted to assist in taking the succeeding physical inventory.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

SESSION 25: USE OF TAMPER-INDICATING SEALS AT MODEL FACILITY

This session describes the program used to procure and control access to tamper-safing seals. It illustrates the actual physical application of paper and metal seals to process containers.

After this session, participants will be able to:

1. understand how tamper-safing seals are processed and controlled to prohibit unauthorized use,
2. understand how the two types of seals are actually applied to process items,



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 25 (Part 1): USE OF TAMPER-INDICATING SEALS AT MODEL FACILITY

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I. INTRODUCTION

Tamper-indicating seals, when applied to containers of nuclear material, serve a vital safeguards function. Because of the importance of the seal in safeguards, it is essential that their acquisition, storage, and distribution be controlled effectively.

1. Seal Types

There are two basic types of tamper-indicating seals: metal and paper. Their description and method of application to containers will be discussed in Part 2 of this session. Metal seals are generally used to seal metallic containers and fuel shipments; paper seals are used for plastic containers, boxes, hoods, cabinets, cans, shelves, and other container and storage types for which metal seals cannot be used. Both types of seals are serially numbered to provide a unique identification for ease of control.

2. Acquisition

Metal and paper seals which have been accepted for use by the NRC are purchased from commercial vendors by the plant seal custodian. They are ordered sufficiently in advance so that the current supply will not run out before the new seals arrive. When a supply of seals is received, the seal inventory form, shown in charts 1 and 2, is updated by the seal custodian. The date of receipt is recorded, along with the serial number of the first and last seal received in sequence, and the total number of seals on hand. The records of metal and paper seals are maintained by the seal custodian, and are kept separate from each other.

3. Storage

Seals and their associated records are stored under lock by the seal custodian, except when they are received from the vendor, or distributed to material control area (MCA) custodians.

4. Distribution

When seals are distributed to a MCA custodian, the seal inventory form is reduced by the number of seals issued, as shown in Charts 1 and 2. The MCA custodian signs the seal inventory form to indicate his receipt of the seals, and the seal custodian initials

CHART 1
METAL SEAL INVENTORY

DATE	SEAL INVENTORY			SEAL DISTRIBUTION					SEAL CUSTODIAN INITIALS
	SERIAL NUMBERS			SEALS ISSUED TO					
	FROM	TO	BALANCE	FROM	TO	NAME	MCA	SIGNATURE	
7-24-79	00001	01000	1000						
7-25-79	00021	02000	980	00001	00020	FILL IN NAME	MBA-1	SIGNATURE	INITIALS

CHART 2
PAPER SEAL INVENTORY

DATE	SEAL INVENTORY			SEAL DISTRIBUTION					SEAL CUSTODIAN INITIALS
	SERIAL NUMBERS			SEALS ISSUED TO					
	FROM	TO	BALANCE	FROM	TO	NAME	MCA	SIGNATURE	
7-24-79	00001	01000	1000						
7-25-79	00021	01000	980	00001	00020	FILL IN NAME	MBA-1	SIGNATURE	INITIALS

the form to verify issuance of the seals. In addition to obtaining the seals, the MCA custodian also receives seal log sheets, such as shown in charts 3 and 4, which are serially stamped to correspond to the seal numbers. These sheets are used by the MCA custodian to maintain control over the seals credited to him, and to record the eventual disposition of each seal. Two employees witness each seal application and complete the seal log sheet. At frequent intervals, the MCA custodian reviews the entries made and initials the sheet. When not in use, all seals and seal log sheets are maintained under lock. Periodically, seal audits are performed to check compliance of the seal control program.

CHART 3

TAMPER INDICATING SEAL LOG BOOK

P TYPE PAPER SEAL

E TYPE METAL SEAL

SEAL NUMBER	CONTAINER NUMBER	DATE SEALED	NOMINAL ENRICHMENT	VERIFIED GROSS WEIGHT	MEASUREMENTS VERIFIED AND SEALED BY: SIGNATURES (2 EMPLOYEES REQUIRED)		CUSTODIAN INITIALS
					Signature	Signature	
00001	PD00001	7/25/79	3.00	21905	Signature	Signature	Initials
00002							
00003							
00004							
00005							
00006							
00007							
00008							
00009							
00010							
00011							
00012							
00013							
00014							
00015							
00016							
00017							
00018							
00019							
00020							

CHART 4

TAMPER INDICATING SEAL LOG BOOK

P TYPE PAPER SEAL

E TYPE METAL SEAL

SEAL NUMBER	CONTAINER NUMBER	DATE SEALED	NOMINAL ENRICHMENT	VERIFIED GROSS WEIGHT	MEASUREMENTS VERIFIED AND SEALED BY: SIGNATURES (2 EMPLOYEES REQUIRED)		CUSTODIAN INITIALS
					Signature	Signature	
00001	FILT0001	7/25/79	3.00	200	Signature	Signature	Initials
00002							
00003							
00004							
00005							
00006							
00007							
00008							
00009							
00010							
00011							
00012							
00013							
00014							
00015							
00016							
00017							
00018							
00019							
00020							

CHART 5

IMPORTANCE OF SEALS

- **A SEAL PROTECTS THE INTEGRITY OF THE PRIOR MEASUREMENT**
- **SEALS PERMIT THE USE OF ITEM ACCOUNTING FOR BULK MATERIAL CONTAINERS**
- **SEALS FACILITATE INVENTORY TAKING BY PERMITTING ACCEPTANCE OF PREVIOUS MEASUREMENTS**



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 26: ANALYTICAL METHODS USED AT MODEL FACILITY

After this session, the participants will be able to understand the principles and the practical aspects of the wet chemistry analytical methods used in an LEU fuel fabrication facility.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 26: ANALYTICAL METHODS USED AT MODEL FACILITY

N. S. Wing
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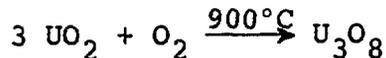
I. GRAVIMETRIC URANIUM ANALYSIS

A. Basis

The determination of uranium by the gravimetric technique is widely used in the industry. In our experience, it is the most precise and easiest to use method for the determination of uranium.

B. Theory

Pre-weighed uranium dioxide samples are oxidized to U_3O_8 in air at $900^\circ \pm 25^\circ C$. The method is not specific for uranium and corrections must be made for impurities. Differences in atomic weights also require corrections. The basic chemical reaction that takes place is



U_3O_8 is a stoichiometric compound and the percent uranium can be calculated by using the appropriate gravimetric factors and corrections.

1. Procedure. Figure 1 lists the basic analytical steps in this technique. The figure is self-explanatory and utilizes basic good laboratory practices, as required by any accurate gravimetric technique.

2. Calculations. Figure 2 shows the basic calculations used in these analysis. The calculation is self-explanatory. You will

1. WEIGH SAMPLE INTO FIRED CRUCIBLES WHICH HAVE BEEN COOLED AND STORED IN A DESICCATOR. FIVE TO TEN GRAMS ARE OPTIMUM.
2. IGNITE SAMPLE IN A MUFFLE FURNACE AT $900 \pm 25^\circ$ FOR A MINIMUM OF FOUR HOURS (CONSTANT WEIGHT)
3. COOL IN A DESICCATOR AND RE-WEIGH
4. U_3O_8 IS A STOICHIOMETRIC COMPOUND AND CAN BE USED TO CALCULATE THE PERCENT URANIUM. THE METHOD IS VERY ACCURATE IF APPROPRIATE CORRECTIONS ARE MADE.

Figure 1. Basic Analytical Steps (similar to ASTM C696 Paragraphs 14-22)

$$\% U = \frac{F [W_2 - (W_2 \times I_m \times 10^{-6})]}{W_1} 100$$

WHERE

$$F = \frac{3 \text{ ATOMIC WT URANIUM}}{(3 \text{ ATOMIC WT URANIUM}) + (8 \times 15.9994)}$$

W_2 = WEIGHT U_3O_8 AFTER IGNITION

W_1 = WEIGHT OF SAMPLE TAKEN

I_m = NON-VOLATILE IMPURITY OXIDES EXPRESSED AS PARTS OXIDE PER MILLION PARTS U_3O_8

Figure 2. Calculations

note that the weight of ignited sample is corrected for the weight of non-volatile impurity oxides to give the "true" weight of U_3O_8 .

3. Corrections. As noted earlier, corrections must be made for impurity and isotopic content. These are discussed in the following.

a. Impurity Corrections. Non-volatile impurities in the UO_2 will be converted to higher oxides during the ignition step. The impurity content of each element is determined, usually by Emission Spectroscopy. Appropriate factors are applied to convert the weight of the element's oxide to the weight of the ignited sample, U_3O_8 . This is an important step for accurate work.

The effect of not correcting for impurities is shown in Figure 3. For the sake of this discussion, assume a UO_2 sample has only iron as an impurity, at the concentration shown. During reduction to UO_2 , the iron is present as FeO . During oxidation, it is converted to Fe_2O_3 . If no corrections are made for this impurity, the error will be as shown, with the results being reported high. It is obvious that at higher levels, the bias becomes significant.

b. Isotopic Corrections. A smaller bias can be introduced if corrections are not made for differences in atomic weight caused by differences in enrichment or ^{235}U content.

Figure 4 shows the errors that will be introduced if the gravimetric factor is based upon the atomic weight of "natural" uranium--commonly called a reference book factor.

In this figure, it is assumed there is no ^{236}U and the ^{234}U remains constant over the range of ^{235}U contents shown. In actual practice, this would not be the case; however, for the sake of illustration, it is acceptable.

ASSUME A SAMPLE OF UO_2 WITH ONLY IRON AS AN IMPURITY. ERRORS INTRODUCED BY NOT CORRECTING FOR IRON CONTENT ARE AS SHOWN.

ppm Fe	"TRUE" URANIUM CONTENT	"INDICATED" URANIUM CONTENT	% ERROR
50	88.143	88.150	0.008
100	88.138	88.150	0.014
200	88.126	88.151	0.028
500	88.092	88.153	0.069
1000	88.036	88.157	0.137
2000	87.922	88.165	0.276

Figure 3. Effect of Not Correcting Gravimetric Uranium Analysis for Impurities

WEIGHT PERCENT ISOTOPE			ATOMIC WEIGHT	GRAVIMETRIC FACTOR	% FROM "NATURAL"*
^{235}U	^{234}U	^{238}U			
0.200	0.0053	99.7947	238.044	0.848010	0.0011
0.711	0.0053	99.2837	238.029	0.848001	0
1.000	0.0053	98.0047	238.020	0.847997	-0.0005
5.000	0.0053	94.9947	237.898	0.847931	-0.0083
10.000	0.0053	89.9947	237.746	0.847848	-0.0180
20.000	0.0053	79.9947	237.443	0.847683	-0.0374
30.000	0.0053	69.9947	237.140	0.847519	-0.0569
40.000	0.0053	59.9947	236.839	0.847354	-0.0763
50.000	0.0053	49.9947	236.538	0.847190	-0.0957
75.000	0.0053	24.9947	235.788	0.846778	-0.1442
90.000	0.0053	9.9947	235.341	0.846532	-0.1732
95.000	0.0053	4.9947	235.192	0.846450	-0.1829

*NOTE: ASSUME A SAMPLE WITH A ^{235}U CONTENT, I, IS CALCULATED USING A REFERENCE BOOK OR "NATURAL URANIUM" GRAVIMETRIC FACTOR. THE ABOVE ERRORS WOULD APPLY WITH NEGATIVE VALUES, GIVING A POSITIVE BIAS, AND CONVERSELY.

Figure 4. Gravimetric Factor as a Function of ^{235}U Content

Note that the errors are listed as percent from natural, and almost all are negative values. The negative value will result in a positive bias. Positive values will result in a negative bias.

C. Equipment Needed

The following equipment is required for the analysis. Note that except for the crucibles being a specified type, the equipment is that normally found in a laboratory.

1. Analytical balance (0.1 mg sensitivity)
2. Platner mortar
3. Muffle furnace
4. Crucibles
 - a. Quartz or Vicor
 - b. Platinum
5. Desiccator

II. ISOTOPIC ANALYSIS

A. Introduction

Isotopic analysis is a very important part of a safeguards program. Weights and percent uranium analysis are both essentially "blind" to isotopic content. That is, a substitution of low enriched uranium for a high enriched material can only be detected by isotopic analysis. There are three techniques used to determine the isotopic content. These are:

1. Emission Spectrometry. Isotopes have a slightly different emission spectra than the principal element. By going to high orders of refraction there is sufficient resolution of the spectral lines so that the spectra can be evaluated. The intensities of the spectral lines are related to standards and can be used to measure the ^{235}U content.

2. Gamma Counting. Gamma counting can be done by a passive system counting the gamma emitted by the ^{235}U . In some cases an active system, in which the ^{235}U is activated with neutrons and the more energetic daughters are counted, is also used. The best results are obtained when the weight of uranium in the samples and standards is carefully controlled.

3. Mass Spectrometry. We use mass spectrometry to perform isotopic analyses. In my experience, this is the most accurate method of analysis. It is also the most expensive. The remainder of this discussion will be directed to this type of analysis.

B. Instrumentation

There are two types of mass spectrometers routinely used in the industry. One is commonly called a Gas Instrument and is used for analysis of UF_6 . The second is a Thermal (or Surface) Ionization Instrument. A brief discussion of these instruments will illustrate the differences.

1. Gas Instrument. This instrument is designed to analyze UF_6 gas only. The sample is introduced as UF_6 gas. The rate of gas flow

is regulated by a "leak" and vapor pressure from a frozen sample. A typical technique uses double standards, one lower than the enrichment being measured and one higher. With double standards, the analyses are very precise and accurate.

As a rule, only ^{235}U and ^{238}U are measured. Minor isotopes are not. Analyses are restricted to gaseous samples. Plutonium and most other elements cannot be analyzed. These instruments have a potential memory problem. That is, there can be interferences from previously analyzed samples. Because of the instrument design, a larger sample size is required than for a thermal instrument.

2. Thermal Ionization. A thermal instrument is much more versatile than a gas one. Typically a sample is dissolved and dried on the instrument's filaments. This makes it possible to perform whatever chemical purification steps are necessary to have the sample in the optimum form. Sample form is, therefore, not an important consideration provided it can be dissolved.

In addition, the instrument can be used for analyses of other materials. We have analyzed boron and gadolinium with our instrument. In the past, I have analyzed plutonium with similar instruments.

Memory problems are minimal with these instruments and minor isotopes can be analyzed with the major ones. Very small samples are analyzed which reduces the requirement for radiological control.

A mass spectrometer measures masses only. It cannot differentiate between elements with the same mass. For example, the hexapotasium--39 polymer has a mass of 234 and can interfere with ^{234}U measurements. In some cases, chemical purification is required to eliminate interferences.

C. Theory

Figure 5 is the mathematical formula that describes the flight of an ion through a magnetic field. The equation is commonly called the focusing equation for mass spectrometry. Note that if the radius of curvature and accelerating voltage are held constant and the magnetic strength varied, a different mass to charge is brought into focus. This phenomena is used to "scan" a sample. Masses 238 through 234 and then 234 through 238 are routinely scanned by changing the magnetic strength. (Any mass range can be scanned.)

Figure 6 is a schematic drawing of a mass spectrometer. An ion is accelerated through a magnetic field where it is bent proportional to its mass, acceleration, and the strength of the magnet. This is illustrated in the right hand section of the figure. Mass 238 is focused to enter the defining slit. As the magnet strength is decreased, masses 236, 235, and 234 will enter the defining slit and be recorded.

Figure 7 is a typical down-mass/up-mass scan. The headings over each peak identify the mass and the attenuator setting. For example, mass 238 indicates an attenuator setting of 30 volts full scale. The peak is approximately 63% of full scale, so the voltage being measured is 0.63×30 , or 18.9 volts.

$$\frac{M}{e} = K \frac{R^2 B^2}{V}$$

WHERE:

M = MASS (AMU)

e = CHARGE ON ION, EG. 1, 2, ETC

K = PROPORTIONALITY CONSTANT, 3.113×10^{-4}

R = RADIUS OF CURVATURE (INCHES)

B = MAGNETIC STRENGTH (GAUSS)

V = ACCELERATING VOLTAGE

Figure 5. Mass Spectrometer Focusing Equation

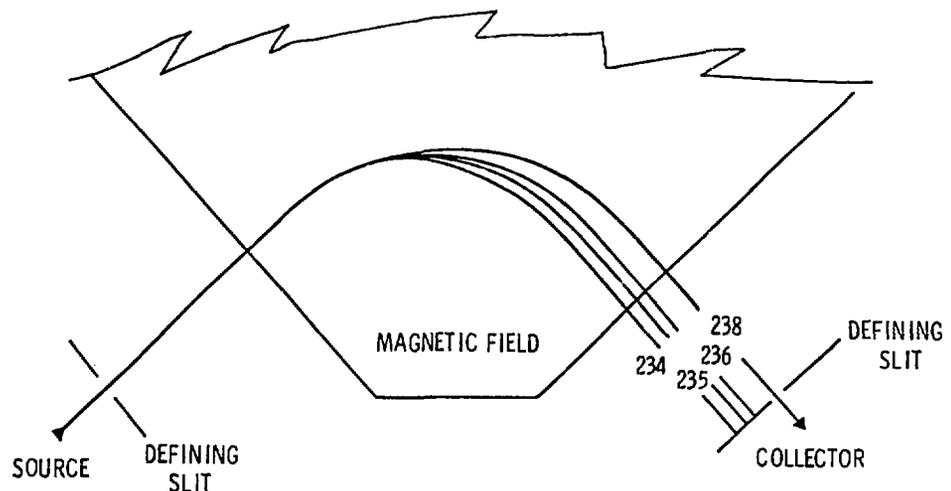


Figure 6. Mass Spectrometer Schematic

The scans in this figure are made on a U^+ ion beam. Note that there is no peak indicated at mass 237. This is because ^{237}U has a halflife of 6.75 days. In about two months, any ^{237}U would be decayed to essentially nothing.

Figure 8 is a mass spectrometer scan that shows a peak at mass 237. This arises because the scan was made on a UO^+ ion beam. The peak at the mass 238 is really at mass 254 and is a combination of ^{238}U and ^{16}O . The following table illustrates various combinations of isotopes that can occur if the oxide peak is used. If not carefully controlled, apparent masses from UO^+ ions can result in erroneous conclusions.

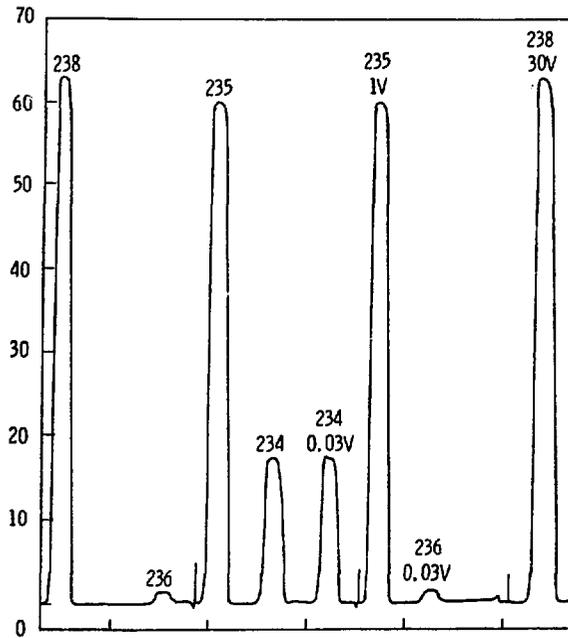


Figure 7. Typical Mass Spectrometer Scan

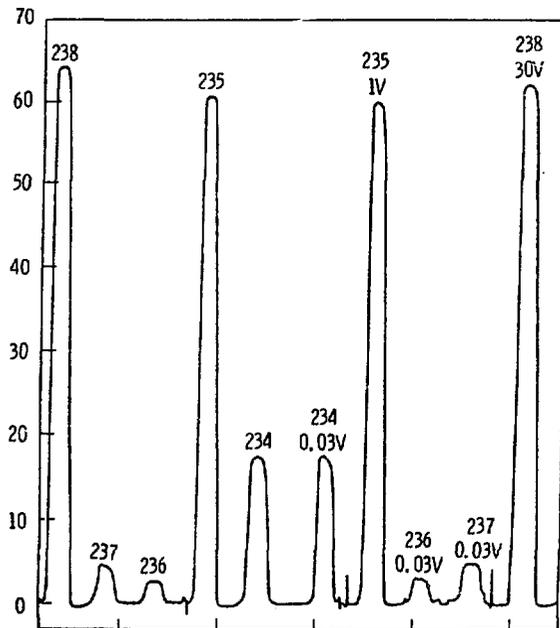


Figure 8. Scan Made Using UO^+ Ion (note 237II)

Effect of Oxygen Isotopes

	Percent Oxygen Isotope	^{234}U	^{235}U	^{236}U	^{238}U
^{16}O	99.758	250	251	252	254
^{17}O	0.038	251	252	253	255
^{18}O	0.204	252	253	254	256

The apparent peak at mass 237 is really a combination of $^{235}\text{U} + ^{18}\text{O}$, and to a much lesser degree, $^{236}\text{U} + ^{17}\text{O}$. This illustrates the reason most spectroscopists favor using the U^+ ion beam. Calculations are significantly simplified, and some uncertainty is removed from the analysis. This problem is not encountered with a UF_6 instrument because fluorine has only one stable isotope.

D. Instrument Description

Figure 9 lists the basic description of our instrument. Some specific points in this description are discussed in the following:

1. Typical Instrument. The instrument has a 15-in. (38.1-cm) radius. A typical instrument uses a 12-in. (30.4-cm radius). In the focusing equation the radius is a squared term, so by going to a larger radius, an improvement in resolution is obtained.

2. Triple Filament Mount. Figure 10 is a photograph of the sample and ionizing filaments mounted on a sample "hat." The sample is mounted on the side filaments and dried. The center or bottom filament is used for ionizing the sample. The sample filaments can be operated at a lower temperature than the ionizing filament to prolong sample life.

NUCLIDE SU INSTRUMENT
 90° SECTOR MAGNET
 15 INCH (38.1 CM) RADIUS OF CURVATURE
 20 STAGE ELECTRON MULTIPLIER
 10⁸, 10⁹, 10¹¹ OHM INPUT RESISTORS
 VIBRATING REED ELECTROMETER
 STRIP CHART RECORDER
 MAGNETIC SCANNING
 TRIPLE FILAMENT MOUNT - RHENIUM OR
 TANTALUM
 VACUUM LOCK
 VACUUM ION PUMPS

Figure 9. Mass Spectrometer Description

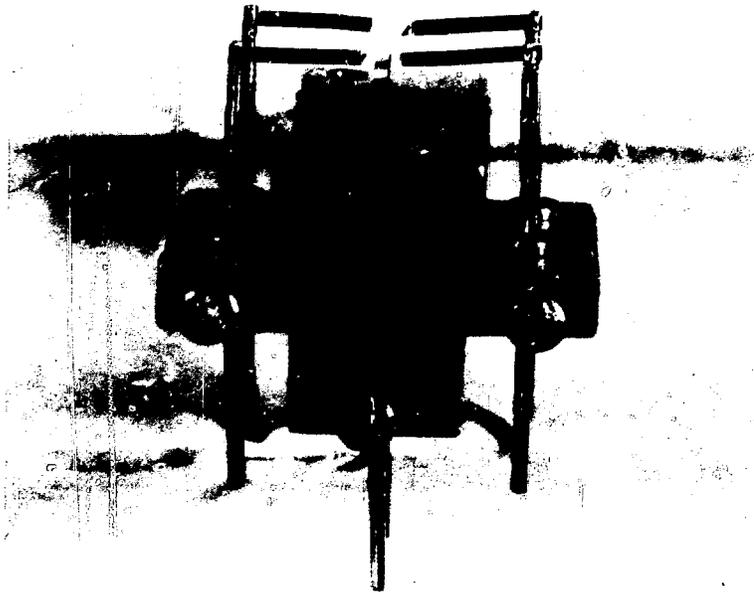


Figure 10. Mass Spectrometer Filaments

The uranium ion that is produced is a function of the ionization filament temperature. Up to a point, the higher the temperature, the more predominant the U^+ ion. In round numbers, we operate the ionization filaments at approximately $2000^{\circ}C$ and the sample filaments at approximately $1500^{\circ}C$.

3. Source. The "hat" and sample filaments are attached to the source which is shown in Figure 11. The filaments and "hat" attach to the plate identified as J-1. This operates at the accelerating voltage (approximately 9 KV).

Plate J-2 is called the draw out plate. It can be at the same potential as J-1 or slightly negative to "pull out" the U^+ ions.

Plate J-3 is a de-focus plate. This limits ionization to that from the ionization filament. Any ionization from the sample filament is eliminated.

Plates J-4 and J-5 are in reality a split plate. The potential on the plates can be equal or positive or negative in relation to each other. The variable potential is used to steer the ion beam to the most optimum signal. With this source we get a very clean ion beam.

4. Electron Multiplier. Figure 12 is a schematic drawing of our electron multiplier. It is a twenty-stage multiplier, and we get approximately a 10^6 gain in signal by using it. Its use makes it possible to analyze small samples.

E. Calibration

The mass spectrometer is calibrated against National Bureau of Standards isotopic special reference materials. This calibration is commonly called a mass discrimination, or multiplier discrimination

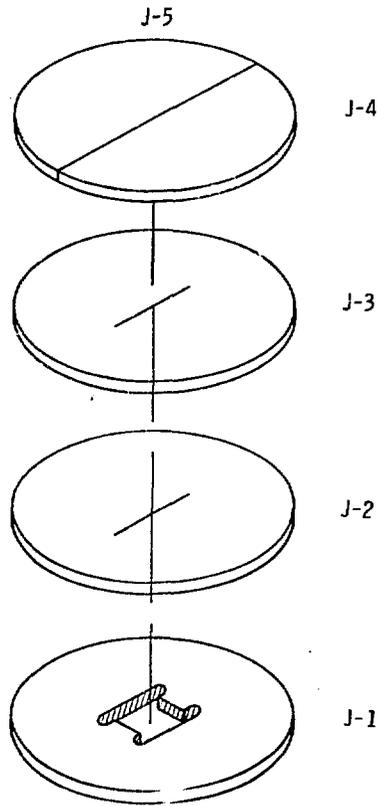


Figure 11. Source (exploded view)

factor (MDF). It is needed when an electron multiplier is used. This is because different masses have a different effect upon the multiplier. If you imagine the different masses have different kinetic energy ($K_e = 1/2 MV^2$) you can see how a lighter mass has less effect on producing secondary electrons than a heavier one. The MDF corrects for this, as well as other effects.

F. Calculations

Figure 13 is an illustration of how data are recorded. Each horizontal line represents an up-mass/down-mass scan. Voltage ratios of each isotope to the ^{238}U voltage are calculated for each scan. The average ratios of these are identified as R 48, R 58, R 68, for the 234, 235, and 236 voltage ratio to the 238.

The final isotopic ratios are corrected for mass discrimination as follows:

$$\bar{R}' = \frac{\bar{R}}{1 + \frac{\Delta M}{M} (\text{MDF})}$$

where \bar{R} = Average ratio for each isotope/238
 ΔM = Differences in mass, e.g., 238 - 235
 M = 238
 MDF = Multiplier Discrimination Factor.

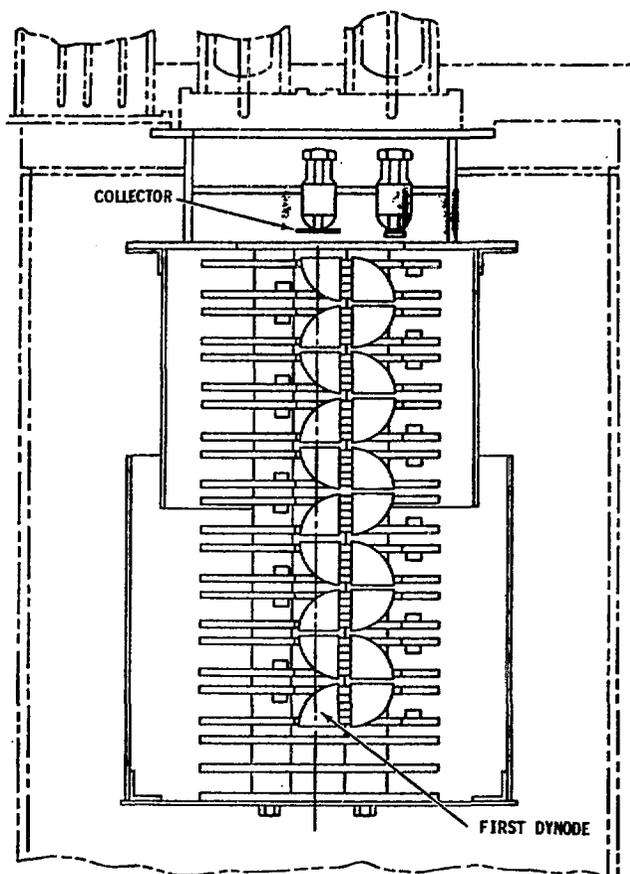


Figure 12. Electron Multiplier

Calculate the relative atom and mass percent for all isotopes as follows:

$$A = 100 \bar{R}' / [1 + \bar{R}'_{48} + \bar{R}'_{58} + \bar{R}'_{68}]$$

$$B = 100 M \bar{R}' / [238.05 + 234.04 \bar{R}'_{48} + 235.04 \bar{R}'_{58} + 236.05 \bar{R}'_{68}]$$

where: A = Atom percent of a given isotope
 B = Mass percent of a given isotope
 M = Nuclidic mass of a given isotope

III. FLUORIMETRIC ANALYSIS

A. Introduction

The observation of the phenomena of fluorescence dates back to the 16th century, but was first seriously studied by Herschel in 1845 and Sir David Brewster in 1846. About 1852, Sir J. J. Stokes established the general law that fluorescent radiations are always of longer wavelength than those exciting them. He also gave the phenomena its present name.

C. Specificity. Foreign substances that produce a measureable luminescence at 5550 Å limit the specificity of the method. As yet, no element other than uranium has been found to give a detectable luminescence^(a) in high sodium fluoride fluxes (>90% NaF) under the same conditions of excitation (3550 Å) that are optimum for uranium fluorescence.^(b)

D. Quenching. Serious interference is caused by other compounds that decrease the fluorescence of uranium. This effect is called quenching and substances causing quenching are called quenchers. Quenching is believed to be due mainly to the absorption of light by the quenching material. Substances that cause quenching include Fe, Ca, Cr, Co, Cu, Mg, Mn, Ni, Pb, Pt, Pu, Si, Zn, and HNO₃. Freedom from quenching is expressed as ϕ , which is defined as the ratio of fluorescence found in a particular case to the fluorescence given by the same amount of uranium in some arbitrarily chosen standard conditions in which quenching is low. Values of ϕ for various quenchers, quencher concentrations, fluxes, and uranium concentrations are given in Figures 14 and 15.

As demonstrated by the data, ϕ is proportional to the quantity of quencher present and is independent of the amount of uranium

QUENCHER	AMOUNT (μg) ⁽¹⁾	ϕ
Cr	10	0.33
HNO ₃	25,000	0.69
HNO ₃	15,000	0.54
Th	2,000	0.42
Mn	2,000	0.20
Fe	2,200	0.15

(1) THE QUANTITY OF QUENCHER PRESENT WHICH REDUCES THE FLOURESCENCE OF 0.4 μg OF URANIUM TO THE GIVEN ϕ VALUES IN A PURE SODIUM FLUORIDE FLUX WITH A TOTAL WEIGHT OF $0.4 \pm 0.05 \mu\text{g}$.

$$\phi = \frac{\text{FLUORESCENT READING OF } 0.4 \mu\text{g U} + \text{QUENCHER}}{\text{FLUORESCENT READING OF } 0.4 \mu\text{g U ALONE}}$$

PRICE, G., R. FERRETTI, AND S. SCHWARTZ. "THE FLUORIMETRIC DETERMINATION OF URANIUM," ANAL. CHEM. 25: 322. 1953.

Figure 14. Quenching of Uranium Fluorescence in Pure Sodium Fluoride Flux

- (a) Luminescence, used in the sense of photoluminescence, is the property of emitting light as a result of the absorption of light energy, either during absorption (fluorescence) or an appreciable time after (phosphorescence).
- (b) Fluorescence is the property of emitting radiation as a result of, and only during, the absorption of radiation from some other source.

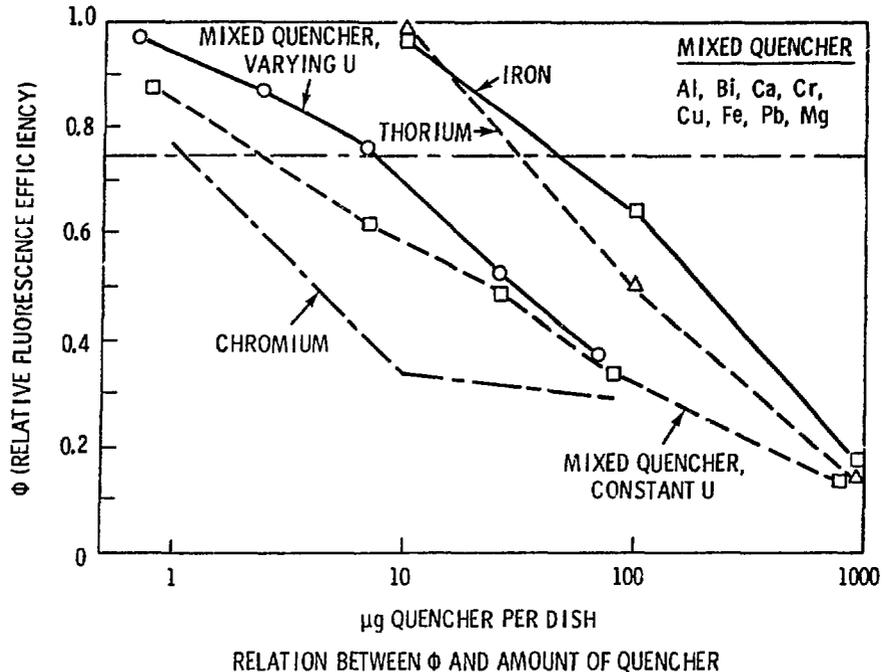


Figure 15. Quenching in Pure NaF

present. Because of these properties, there are two methods of correcting the quenching effect without the necessity of a chemical separation. The first is by diluting the sample to a point where the amount of quencher is negligible. This technique is generally used only for moderately concentrated uranium solutions to avoid blank effects at near the uranium detection limit. The second technique, which has more general application, consists of "spiking" or adding a known amount of uranium as an internal standard. Since the "spike" is quenched to the same degree as the sample, the quenching effect can be accurately corrected.

E. Flux, Fusion, and Fusion Vessels. To achieve the greatest intensification of the fluorescence of uranyl salts, sodium fluoride-lithium fluoride fluxes are employed. Sodium fluoride fluxes are characterized by high melting points ($\sim 1000^{\circ}\text{C}$) and the formation of transparent melts.

Fusion of the flux and uranium mixture is accomplished by melting the mixture in a platinum dish with a specially designed multiple Merker Burner assembly. This unit is programmed to fuse and anneal the melts. With this method of melt preparation, reproducible results are obtained. Figure 16 is a photograph of the fusion unit.

The composition of the atmosphere to which the flux is exposed while molten greatly affects the reproducibility. Pure sodium fluoride-uranium melts fused in carbon dioxide are non-fluorescent. Fusion in an inert atmosphere such as nitrogen, helium, or argon produces normal fluorescence. Sodium fluoride fluxes attack platinum when fused in high oxygen ($\geq 90\%$ by volume) atmospheres. Ordinary air atmosphere fusions produce normal fluorescence and are used for control laboratory application.

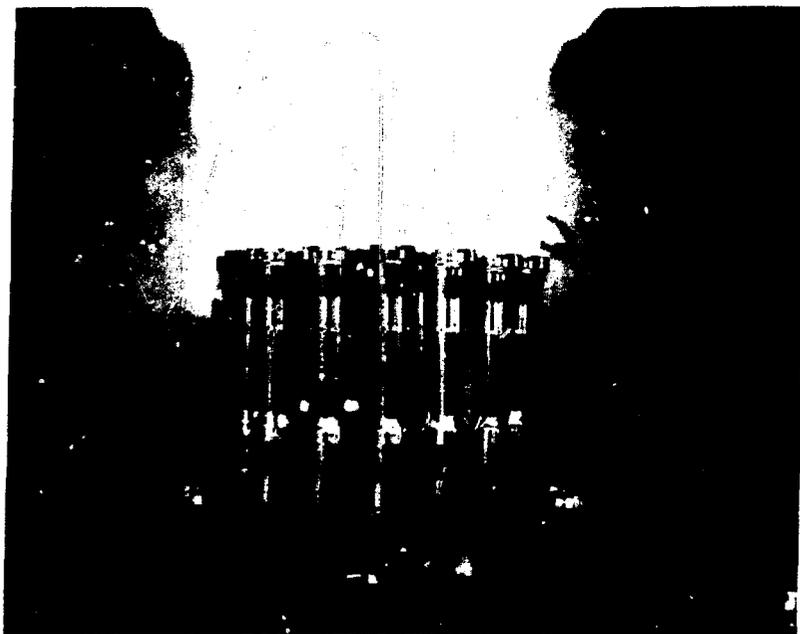


Figure 16. Fusing Apparatus

The flux should remain molten long enough to allow the uranium to be uniformly distributed in the flux and yet keep dish corrosion to a minimum, since quenching by dissolved platinum can be a major source of error. The duration of fusion depends upon the temperature. Typically, fusion times run approximately two minutes.

Various types of melt crystals with correspondingly different fluorescent properties are produced by different methods of cooling the molten flux. Rapid cooling of the melt can produce a fractured crystal, while annealing or slow cooling produces a more uniform surface and more transparent crystals. Lithium fluoride-sodium fluoride fluxes are not as subject to this phenomenon as the pure sodium fluoride fluxes. By using a consistent cooling method, reproducible results are achieved. Figure 17 is a photograph of the platinum dishes and flux pellet-forming tool.

Melt Stability--Blank Rise. High fluoride fused fluxes increase in fluorescence upon standing in moist air. The absorption of water vapor produces a faint luminescence in the fused flux itself that is apparently due to the presence of water vapor as an activating impurity. This phenomenon is called "blank rise." This necessitates the use of desiccators or the immediate measurement of fluorescence after fusion. This effect is generally only important in very low-level work, but its effect should be tested in any laboratory doing the work.

With a reflection fluorimeter, the fluorescence of the melt is measured from the same melt surface that is irradiated with ultraviolet light. The instrument employs a mercury lamp as an ultraviolet source



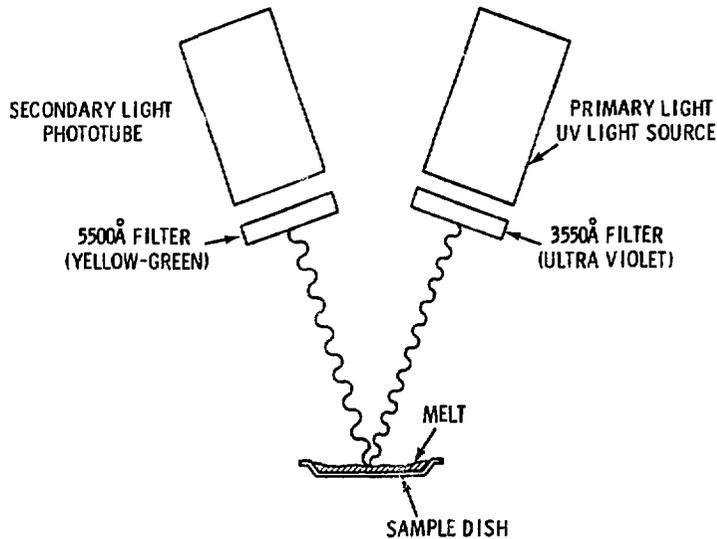
Figure 17. Sample Dish--Pellet Tool

phototubes to measure the fluorescence, and filters to isolate the ultraviolet and fluorescence regions. Schematic arrangements of the system are shown in Figure 18.

G. Conversion of Measured Fluorescence to Uranium Concentration. Two general methods are used to convert the fluorescent reading to uranium concentration. The first depends upon a calibration curve of the particular fluorimeter versus uranium content. This technique is used only when it can be safely assumed that the unknown melt contains no foreign elements which either enhance or decrease the fluorescence of uranium.

Where large quantities of foreign ions which reduce or enhance the fluorescence of uranium are present, the second method, called the "spike" or "internal standard" method, is used. In this method, a known amount of uranium is added to the sample melt and the calculation is made on the basis that the fluorescence is a linear function of the uranium content. This is the routine method in our laboratory.

Chemical separations can also be made to remove the quenchers, but this is not the preferred method, because of the time involved and the potential error from non-quantitative transfers of the uranium.



NOTE: ANGLES OF INCIDENT AND REFLECTED LIGHT ACCENTUATED FOR CLARITY

Figure 18. Fluorimeter Schematic

H. Procedure. The analytical procedure is very straight forward and consists of the following steps:

1. Acidify sample as required
2. Make dilution as required
3. Determine blank
4. Add sample to NaF flux
5. Fuse sample and flux
6. Measure fluorescence
7. Add spike and dry
8. Fuse
9. Measure fluorescence

Step one is especially important for samples that contain particulate uranium material.

I. Calculations. The concentration of uranium in the samples on a volumetric basis is determined as follows:

$$\mu\text{g/ml Uranium} = \frac{(F_s - F_b) (dF) (SV_s) (\text{ml of Spike Mounted})}{(F_t - F_s) (\text{ml of Sample Mounted})}$$

where:

- F_s = Sample fluorescence x multiplier reading
- F_b = Blank fluorescence x multiplier reading
- F_t = Sample plus standard fluorescence x multiplier reading
- dF = Dilution factor
- SV_s = Spike standard value in $\mu\text{g/ml}$

Example: Assume 500 λ of sample is dissolved in a 50 ml flask and 25 λ of sample and spike mounted

$$\begin{aligned}
 F_b &= 35 \times 0.1 = 3.5 \\
 F_s &= 50 \times 10 = 500 \\
 F_t &= 68 \times 10 = 680 \\
 SV_s &= 10.0 \text{ } \mu\text{g/ml} \\
 dF &= \frac{50}{0.5} = 100
 \end{aligned}$$

$$\mu\text{g U/ml} = \frac{(500-3.5)(100)(10.0 \text{ g/ml})(0.025)}{(680-500)(0.025)} = 2758 \text{ } \mu\text{g/ml}$$

J. Equipment Needs

Figure 19 lists the specific equipment needs for the fluorimetric analysis; equipment common to an analytical laboratory.

1. GALVANEK-MORRISON FLUORIMETER WITH SOLID SAMPLE CHAMBER (REFLECTANCE)
2. PLATINUM DISH-FORMING TOOL 19.05 MM (0.75 INCH)
3. PLATINUM DISHES
4. PELLET FORMING TOOL
5. DESICCATOR
6. FUSING AND ANNEALING BURNERS

Figure 19. Fluorimetric Uranium Analysis Equipment Needs

IV. EMISSION SPECTROSCOPY

A. Introduction

Spectroscopic analyses are widely used to measure the concentration of trace impurities. In some applications, e.g., foundry work, major constituents are measured with this tool. These specialized applications are beyond this paper, and comments presented herein will be directly related to trace impurity analysis.

Earlier in my presentation I discussed the determination of uranium by the gravimetric technique. It was noted that in this analysis it is important that impurities in the sample be taken into account when calculating the analysis. Large biases can, and do, result if the impurity corrections are not made. From this standpoint it is appropriate that we discuss spectrometry in some detail.

B. Instrument Type

You will note that so far I have used the term Spectroscopy, which describes the basic science. Two other names are more commonly used to describe this technique. These are Emission Spectrograph and Emission Spectrometer. These names seem to be used interchangeably, which technically is not correct. The distinction between the two is obvious from the last part of the word. A SpectroGRAPH utilizes film as the detection device. A Spectrometer utilizes a phototube and ultimately a meter as the detector.

The needs of the laboratory is the deciding factor in regard to which type of instrument to buy. Generally speaking, a spectrograph is more versatile since the entire spectra can be recorded within the limits of the instrument. Unless the film is interpreted with a densitometer, the results are not as accurate as with a spectrometer; however, use of a densitometer makes the work slower. A darkroom and photographic equipment are also needed.

A spectrometer is more accurate, is very fast and readily adapted to computer calculation of the output. It is limited to analysis of elements for which there is a defining slit and photomultiplier tube. Elements outside this program cannot be analyzed without changing the instrument.

In our laboratory, we use a spectrometer with 39 elements in the analytical program. With this number of elements, not being able to see the full spectra has not been a problem to us.

C. Theory

If sufficient energy (heat) is added to an element, its electrons are excited to a higher level and it is said to be in an excited state. Therefore, the element contains more energy than an unexcited one. When the material returns to the normal unexcited state, this energy must be released. Typically, this is in the form of light. Every element has a characteristic spectra that is produced from this phenomena. The blue color of a mercury vapor light, the yellow color of a sodium vapor light, or the red light of a neon sign are examples of this.

If the light is passed through a slit and onto an appropriate grating, the light is refracted into its components, and images of the slit will always appear at precisely known wavelengths. For example, the sodium spectra will always be at 5889.950 and 5895.924 Å. The spectra may be relatively clean or very complex, depending upon the element.

Figure 20 shows a "clean spectra," and Figure 21, a relatively complex spectra. These were obtained from a spectrograph, but would be the same, whether produced with a spectrograph or spectrometer. These examples are calibration curves and show the stepping, or loss in intensity, as the impurity concentration becomes smaller. From this it is obvious that the intensity of light is related to the concentration of the impurity. It is this property that is used to quantify emission spectroscopic analysis.

D. Instrumentation

The major features of our spectrometer and a schematic representation are shown in Figure 22. From the schematic drawing in Figure 23, it can be seen that the spectra is excited in graphite electrodes and focused onto a grating. From there it is diffracted onto one of four slit frames which cover the spectra from ultraviolet (1970 Å) to near infrared (8950 Å). The slit frame is a movable holder for the defining slit and phototube. Each frame has a mercury monitor light that allows it to be precisely adjusted. By having these frames "broken up" into four sections, the effect of thermal expansion is minimized, and for all practical purposes, eliminated. A typical slit-phototube-mirror assembly is also shown (Figure 24). The mirror is used only to direct the light.

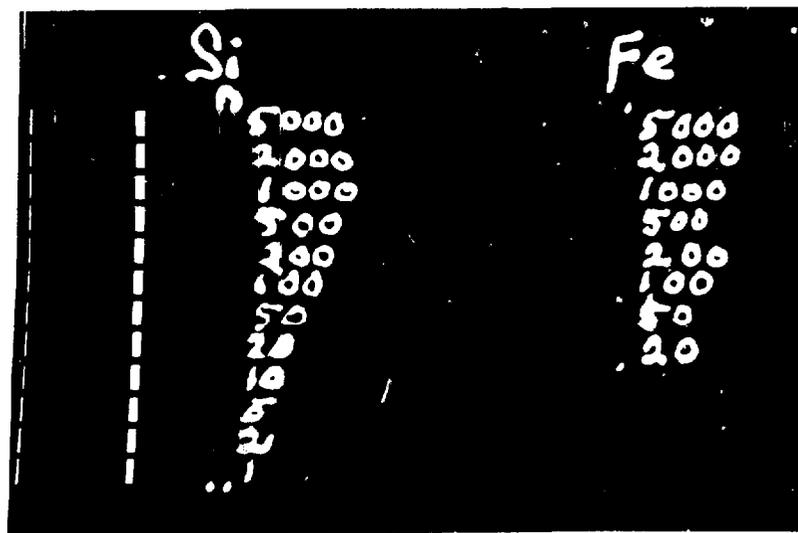


Figure 20. Example of Clean Spectra

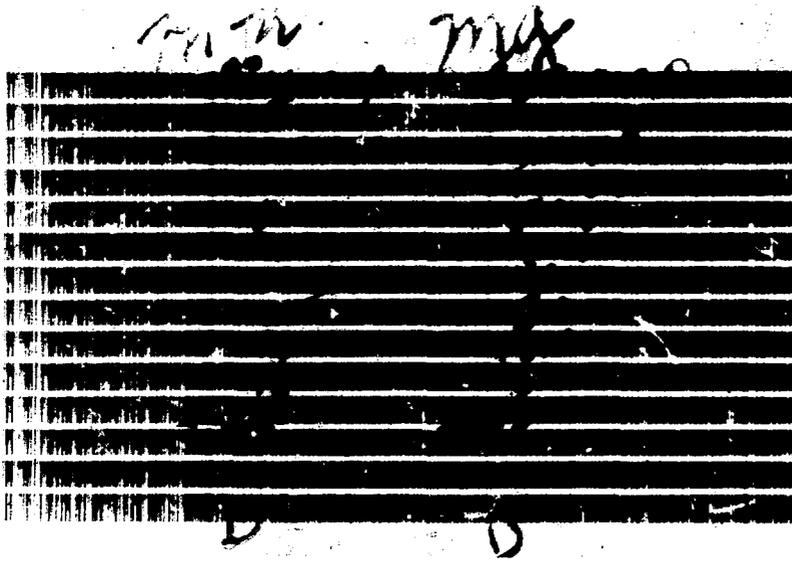


Figure 21. Example of a Complex Spectra

APPLIED RESEARCH LABORATORY QUANTOMETER

1. TWO-METER FOCAL LENGTH
2. 960 LINES PER MM GRATING (24,400/INCH)
3. 5.4 Å/MM DISPERSION
4. RANGE 1966 TO 8750 Å FIRST ORDER
5. THIRTY-NINE ELEMENTS IN PROGRAM
6. FOUR SLIT FRAMES
 - a. Hg PROFILE EACH FRAME
7. TIMING CIRCUITS

Figure 22. Spectrometer Description

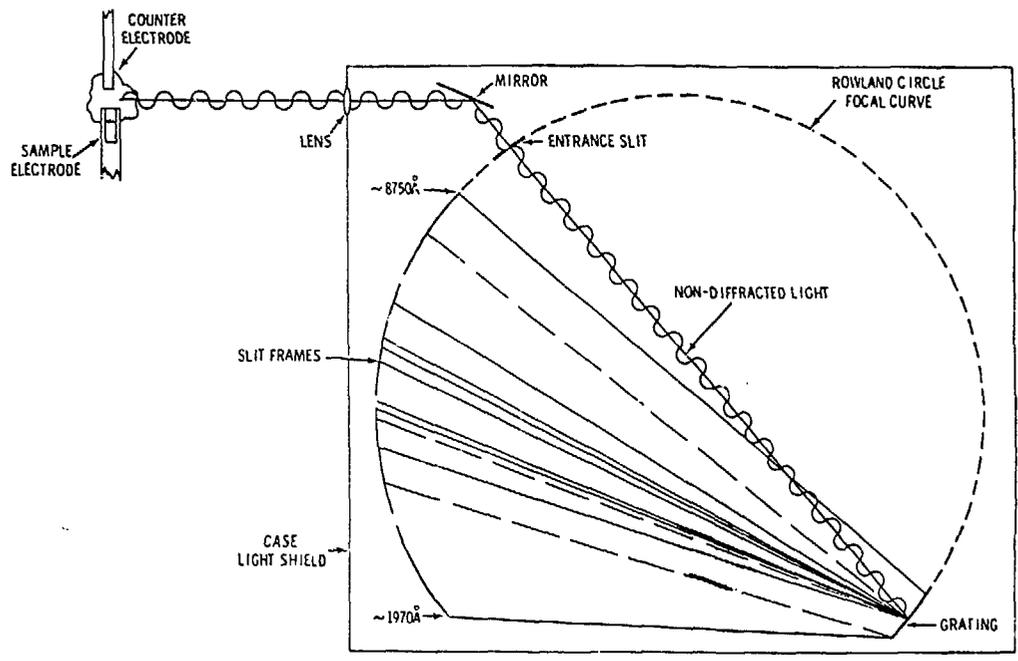


Figure 23. Emission Spectrometer Schematic

It should be noted that all optical components are shown on an imaginary circle. In our arrangement this is known as the Rowland Circle or Focal Curve. In this arrangement, any point on the circle is in optical focus with any other point.

E. Background Correction

Whenever a spectra is produced, there is a background or continuum associated with it. Electronics or film also have "noise" or fogging associated with them. For accurate work, the effect of background must be corrected. This is complicated somewhat, since each element has different excitation characteristics. Volatile, easily excited elements may excite early in the cycle and be present for only a few seconds. More refractory elements may be present in the arc for over a minute.

Some extremes in excitation profiles of impurities in U_3O_8 are shown in Figure 25, where relative excitations as a function of time are shown. For example, note the base line for phosphorous. This would represent the background. It is easy to see that the sum of the background is much greater than the spectral intensity for the element.

Our instrument has a timing circuit to compensate for this. We have four starting times and nine termination times. Elements are grouped and the spectra collected according to their excitation characteristics, reducing the background effect.

F. Uranium Interference

Generally speaking, the complexity of a spectra is related, exponentially, to the atomic number of the element. Uranium, therefore, has a multitude of spectral lines. This coupled with the fact that it is the major constituent, would produce such a dark, complex

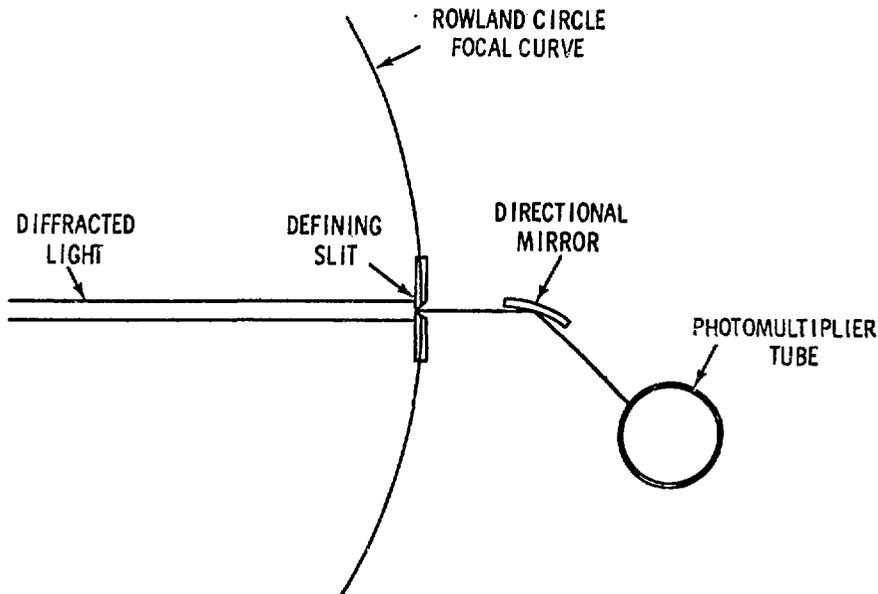


Figure 24. Typical Detection System

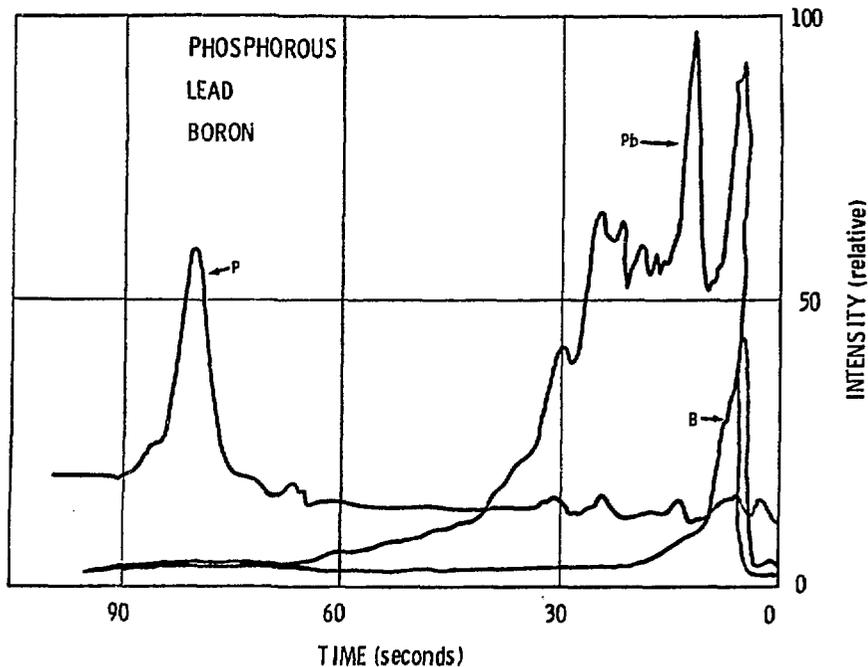


Figure 25. Excitation Profiles in U_3O_8

spectra that trace impurity analysis would be impossible if the uranium spectra were allowed to be recorded. Obviously the effect of the uranium must be eliminated. The following describes the two techniques we use to accomplish this.

G. Carrier Distillation

A carrier is added to the sample to prevent the excitation of the uranium spectra. Gallium oxide and silver chloride-lithium fluoride are used as carriers for most of our routine spectrometric analysis.

The carrier produces fractional distillation of the impurities into the arc where they are excited, while uranium, as U_3O_8 , is not appreciably vaporized, possibly from the temperature-limiting effect as the carrier evaporates. Usable trace impurity spectra are obtained by this technique; however, it is unacceptable for some refractory elements and the rare earths.

For accurate work with this technique, sample density, depth in the electrode, and a vent to facilitate vaporization of the impurities must be controlled. This is accomplished partially, by the use of a "tamping tool," as shown in Figure 26. The tool compresses the sample to a constant depth, and provides the venting necessary.

H. Solvent Extraction

Another technique we use to remove the uranium interference is solvent extraction. In this technique, uranium is separated from the impurities by extracting it into tributyl phosphate from a solution that is 6 M in HNO_3 . The impurities are left in the aqueous phase. The aqueous is evaporated to dryness in round-bottomed teflon beakers.

Graphite is added to the solution to provide an easily-seen bulk to facilitate removal. This technique had proven very effective for rare earths and some refractory elements. A relatively large sample size can be used and very low detection limits obtained. This technique can be used for other elements, where low detection limits are required.

I. Equipment Needs

Figure 27 describes the major equipment needed to establish a spectrometric laboratory. Small equipment, common to an analytical laboratory, is not included.

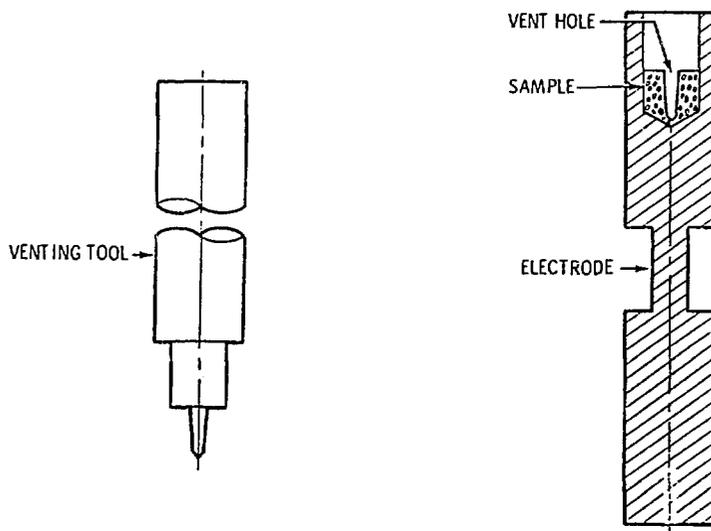


Figure 26. Sample Tamper Illustration

- A. EMISSION SPECTROMETER SYSTEM
 - 1. SPECTROMETER
 - 2. EXCITATION SOURCE
 - 3. ARC SPARK STAND
 - 4. READ-OUT SYSTEM INCLUDING TELETYPE
- B. MIXER MILL
- C. DENTAL AMALGAMATOR
- D. MORTAR AND PESTLE
- E. BALANCES
 - 1. ANALYTICAL ± 0.1 mg SENSITIVITY
 - 2. TORSION ± 0.1 mg SENSITIVITY
- F. VENTING TOOL
- G. MUFFLE FURNACE CAPABLE OF HEATING TO 1000°C
- H. QUARTZ CRUCIBLES

Figure 27. Equipment Needs

V. REFERENCES

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PROBLEMS

<u>Gravimetric Uranium</u>	<u>Sample 1</u>	<u>Sample 2</u>
Sample Weight (W_1)	14.7309 gm	5.1361 gm
Ignited Weight (W_2)	15.3026	5.2830
Impurity Oxides (I_m)	221	560
Atomic Weight U	237.884	238.133

<u>Fluorimetric Uranium</u>	<u>Sample 1</u>	<u>Sample 2</u>
Sample Fluorescence (F_s)	17.1	4.3
Blank Fluorescence (F_b)	2.3	2.2
Standard & Sample Fluor. (F_t)	39.0	26
Dilution Factor (dF)	10	5
Spike Value (SV_s)	10 $\mu\text{g/ml}$	10
ml Spike	0.025	0.025
ml Sample	0.025	0.025

ANSWERS

<u>Gravimetric</u>	<u>Factor</u>	<u>% U</u>
Sample 1	0.84792	88.064
Sample 2	0.84806	87.183

<u>Fluorimetric</u>	<u>ppm U</u>
Sample 1	67.6
Sample 2	4.8



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 27: NDA METHODS USED AT MODEL FACILITY

After this session, participants will be able to understand the principles and practical aspects of the non-destructive assay methods used in an LEU fuel fabrication facility.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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October 17-November 4, 1983

SESSION 27: NDA METHODS USED AT MODEL FACILITY

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I. SCINTILLATION DETECTORS

Scintillation detectors provide the input signals for the waste assay system, the powder assay system, and rod assay system NDA measurements.

A. General Description

A scintillation detector assembly consists of a material that converts ionizing radiation into pulses of light. The resultant pulses of light are then converted to electrical pulses by a photomultiplier tube.

The scintillation detectors we use utilize a sodium iodide (NaI) crystal for the scintillator. The NaI crystal provides a light pulse output that varies approximately linearly with the energy of the incident gamma radiation.

B. Gamma-Ray Interaction

There are three major ways that gamma rays interact with an absorbing material, specifically, the photoelectric effect, the Compton effect, and pair production. Pair production only occurs at gamma ray energy levels in excess of 1.02 MeV and since the gamma energizes of interest for assay of ^{235}U are much less than that, pair production will not be discussed.

1. Photoelectric Effect. In the photoelectric effect, the gamma ray photon interacts with an atom of the absorbing material in such a manner that all of the energy of the gamma-ray photon is transferred to an electron in the atom.

2. Compton Effect. In the Compton effect, the gamma ray photon makes an elastic collision with an outer electron in an atom of the absorbing material. In the elastic collision, both momentum and energy are conserved; that is, only part of the energy of the gamma-ray photon is transmitted to the electron and the gamma-ray photon is deflected and continues to travel at a lower energy.

C. Typical Gamma-Ray Spectrum

Figure 1 shows the energy spectrum obtained from a 3-in. diameter by a 3-in. thick NaI detector using a ^{137}Cs gamma source. The ^{137}Cs source has two prominent gamma ray energies, specifically, 662 keV and 32 keV. The prominent peaks in the spectrum in Figure 1 result from photoelectric absorption of the gamma rays in which the full energy of the gamma ray was deposited within the crystal. The center region of the spectrum results from the Compton scattering of some of the 662 keV gamma rays.

The performance of a scintillation detector is characterized by the energy resolution of the scintillation detector. The resolution is defined as:

$$\text{Resolution} = \frac{\text{FWHM Channel}}{\text{Peak Channel}} \times 100\%$$

where the FWHM value is the width of the photopeak at one-half of the peak count. Typical resolution for the NaI detector for the 662-keV is about 7%, the resolution for the spectrum shown in Figure 1 calculates to be 6.4%.

D. Gamma-Ray Spectrum Used in Assay of Uranium

Figure 2 shows the gamma spectrum, as measured with an NaI scintillation detector, resulting from depleted uranium. Figure 3 shows the gamma spectrum, as measured with an NaI scintillation detector, resulting from uranium with 3% enriched ^{235}U . The energy peak centered at 185 keV is used in measurements of ^{235}U , and

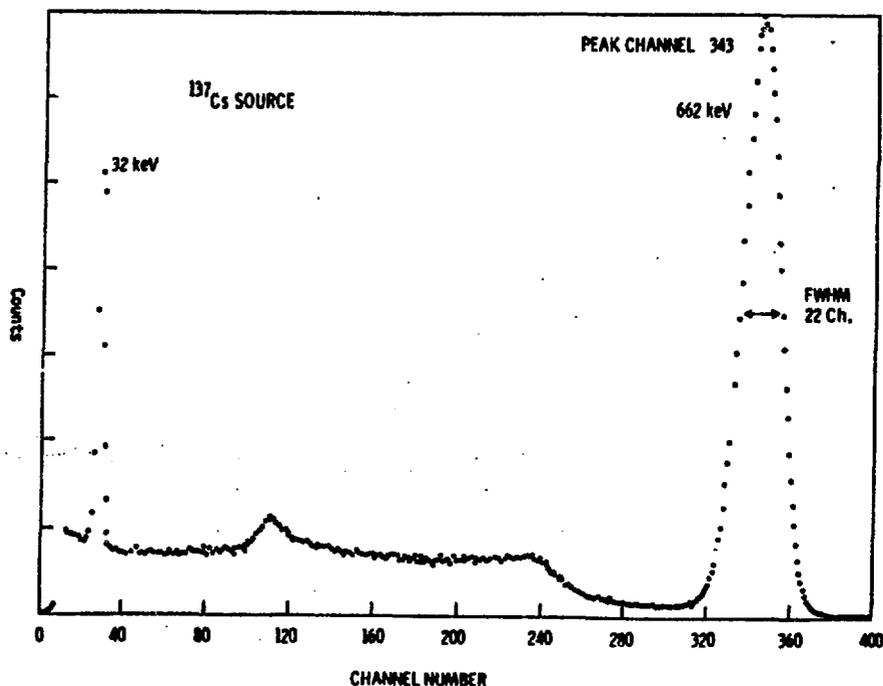


Figure 1. Typical NaI Energy Spectrum from a ^{137}Cs Source

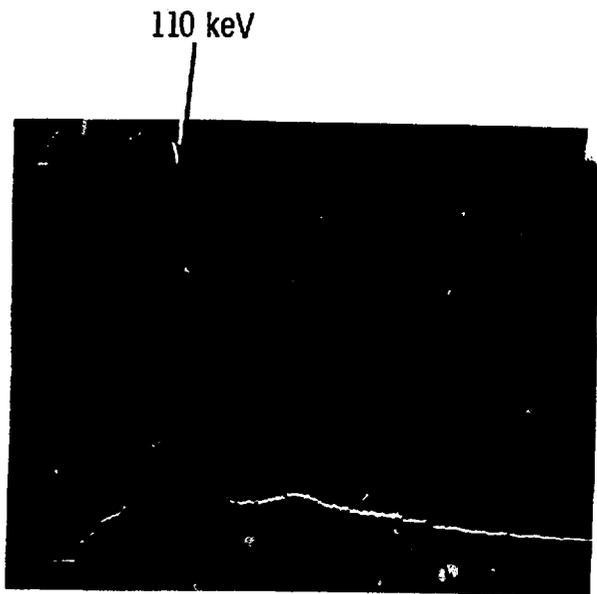


Figure 2. Low Energy Spectrum from Depleted Uranium

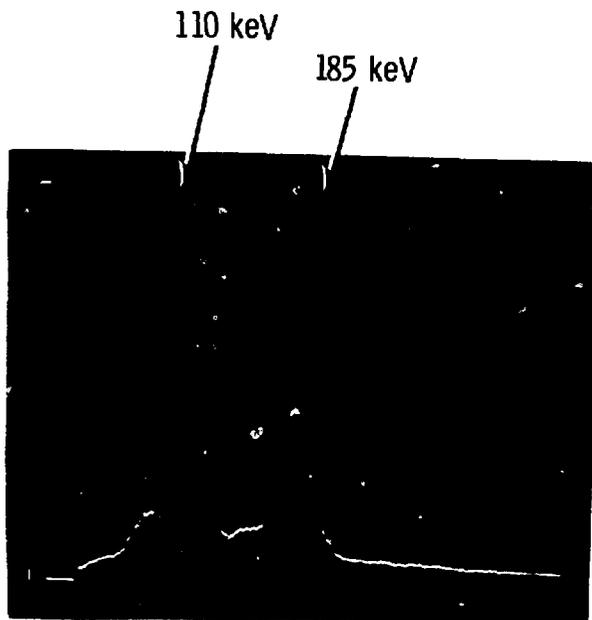


Figure 3. Low Energy Spectrum from 3% Enriched Uranium

techniques have been developed to essentially subtract the two spectrums to obtain the data resulting from the 185 keV gamma photon released by the ^{235}U atoms.

II. WASTE ASSAY MEASUREMENT

A. General Requirements

Fuel processing facilities in the United States are required to provide a measurement of all of their fissile material at specified intervals. At this facility, the material we designate as waste includes material stored in 55-gallon barrels and HEPA filters. For our plant, the waste assay system needs to process ~10 samples per day.

The material in the barrels consists of low density items such as paper, plastic and cloth. The gross barrel weights range from approximately 90 pounds to approximately 200 pounds. Fissile contents for both the barrels and HEPA filters range from less than one gram to approximately 30 grams.

B. Types of Measurement Systems

The amount of fissile material in the individual waste containers can be measured using either the passive technique of measuring the 185 keV gamma rays emitted by the ^{235}U , or by the active technique of using neutrons to induce fission of some of the ^{235}U atoms and measuring the resultant neutrons and/or gamma rays released as a result of the fission.

1. Passive Assay Measurement. There are a few U.S. vendors of passive assay systems using either an NaI scintillation detector or a germanium crystal gamma ray detector. The germanium crystal has significantly better energy resolution than the NaI detector, but has a lower detection efficiency, resulting in longer counting times, must be operated at liquid nitrogen temperatures, and cost significantly more than NaI detectors. Since uranium does not have any gamma rays that interfere with 185 keV ^{235}U gamma which would require the use of the high resolution germanium crystal, most passive systems use NaI detectors.

2. Active Assay Measurements. Waste assay systems using the active technique are also commercially available in the U.S. Due to the higher penetration capabilities of the interrogation neutrons and resultant fission neutrons and gamma rays, the active assay technique is less sensitive to density changes and fissile material concentration than the passive assay technique. The active system is sensitive to neutron poisons, thus are not acceptable for assay of uranium with neutron absorbers (poison), and also we have observed that at least some HEPA filters contain a neutron poison that seriously interferes with the assay measurement.

3. Model Plant Waste Assay System Description

The Model Plant waste assay system is a passive system using four NaI scintillation detectors, with lead shields around the detectors to collimate the gamma rays, associated electronics and a waste

container rotating platform. The rotating platform rotates at approximately five RPM to provide an average radial count from the waste container.

Figure 4 is a block diagram of the waste assay detectors and electronics. The signals from the four detectors are amplified by the preamplifiers and amplifiers and summed together by the summing amplifier to provide one composite signal. This composite signal provides the input to two single channel analyzers (SCAs). The SCAs have upper and lower level voltage controls (window adjustments) that can be adjusted to provide an output only if the amplitude of the input pulse is within a specified amplitude. One SCA is adjusted to cover an energy range of 155 keV to 215 keV, which brackets the 185 keV gamma ray produced by ^{235}U . The second SCA is adjusted to cover an energy range of 230 to 290 keV and measures the signal due to Compton scatter. The outputs from the SCAs are totalled by two gated scalers which are controlled by a timer.

The operator subtracts the two scaler values to obtain a value proportional to the quantity of ^{235}U in the waste container.

C. Standards

For the Model Plant waste assay system, five standards are used for the waste barrels and five standards are used for the HEPA filters with nominal values of 2, 8, 16, 24, and 30 grams of ^{235}U .

1. Waste Barrel Standards. The waste barrel standards are made by uniformly distributing the specified amount of ^{235}U throughout 30 one-gallon plastic jugs. Each plastic jug is initially filled approximately 3/4 full of dry sawdust, then the appropriate amount of low enriched UO_2 powder is placed in the plastic bottle. The plastic bottle is then sealed and the contents vigorously shaken to obtain a uniform mixture of sawdust and UO_2 powder. The 30 plastic jugs are then placed in a 55-gallon barrel in three layers. The lid is placed on the barrel and the barrel is then sealed with a nuclear material safeguards seal.

2. HEPA Filter Standards. The UO_2 powder for the HEPA filters standards is contained in plastic containers with outside dimensions of 1-1/2 in. x 5 in. x 3/16 in. The cavity for the UO_2 powder is approximately 1-in. x 4-1/2 in. x 1/16 in. When filled with low enriched UO_2 powder, each container will hold approximately 0.3 grams of ^{235}U . For each standard, the UO_2 powder is approximately equally divided among the number of containers required to hold the UO_2 powder.

For each standard, the plastic containers are then inserted into a HEPA filter. The HEPA filter is placed inside of a plastic bag and then inside of the HEPA filter cardboard shipping box. The shipping box is then sealed with a nuclear material safeguards seal.

D. System Performance

Accurate assay of waste barrels and HEPA filters is complicated since the passive assay is sensitive to several parameters in addition to the quantity of ^{235}U . Some of these parameters are listed below:

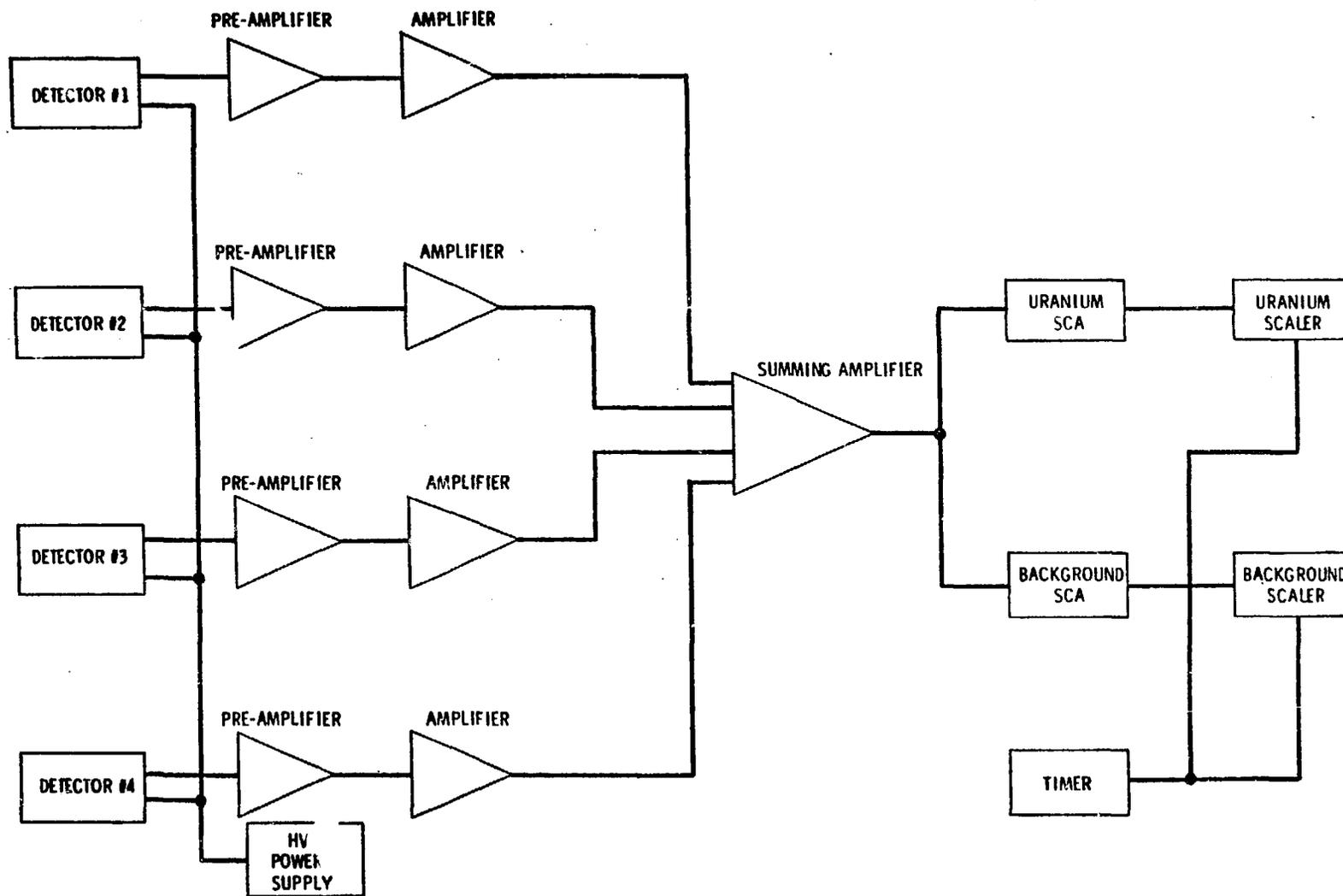


Figure 4. Block Diagram of Waste Assay Electronics

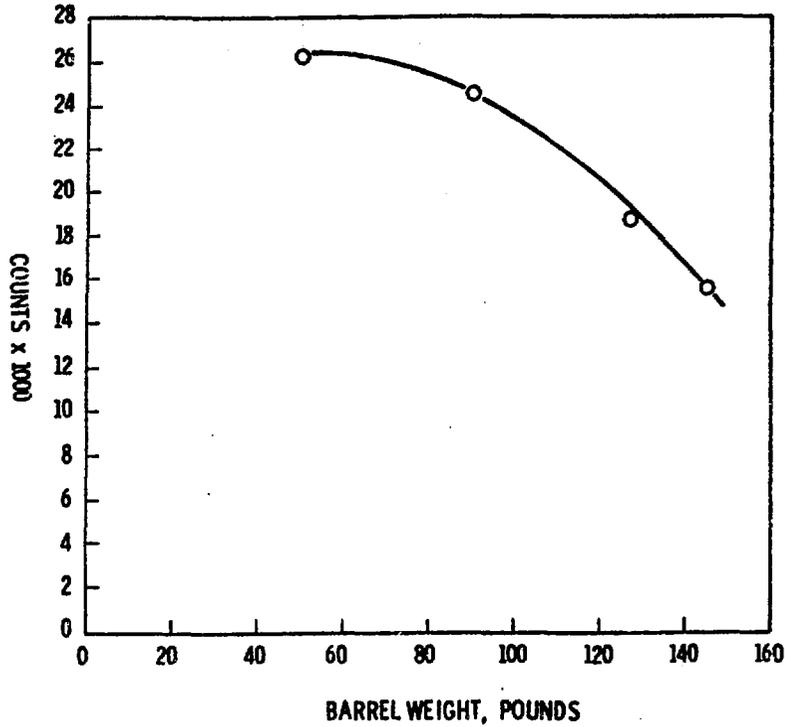


Figure 5. Variation of Count with Barrel Weight

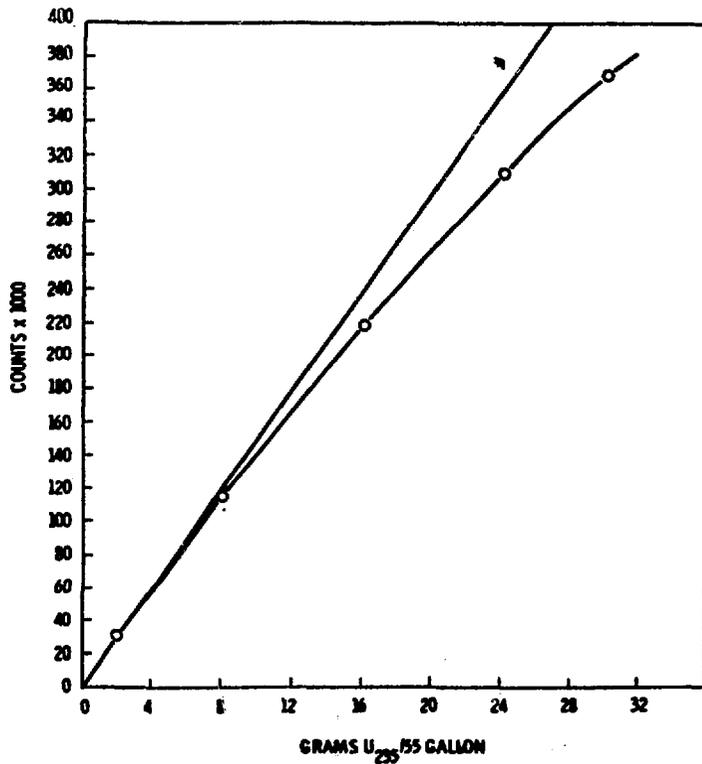


Figure 6. Variation of Count with ^{235}U Concentration

1. Gamma Absorption--Because of the low energy of the ^{235}U 185 keV gamma ray, changes in density of the waste material will change the gamma absorption. Changes in concentration of the ^{235}U also offset the gamma absorption of ^{235}U gamma rays. Figures 5 and 6 show the effect of changes in density of the waste barrels and changes in concentration of the ^{235}U , respectively.

2. Position Sensitivity--Sensitivity to source location is reduced by collimating the scintillation detectors and rotating the waste barrels and HEPA filters.

3. Standards--Waste assay measurements are made relative to measurements of standards. The ideal goal is to assemble standards that are representative of production waste barrels and HEPA filters. This is a particularly difficult goal to achieve for waste barrels. As a result, destructive measurements of production waste barrels have been made to provide more realistic standards.

III. ENRICHMENT METER--SAM-2

The Model Plant uses the commercially available SAM-2 enrichment meter for a non-destructive assay (NDA) verification of the powder enrichment immediately prior to loading the powder into the pellet press. The SAM-2 is also used to measure the enrichment of scrap powder and pellets contained in five-gallon cans (where the depth of material is equivalent to an infinitely thick source of ^{235}U).

A. General Description.

The SAM-2 is a gamma spectrometer system which has a gain stabilization circuit to account for gain changes due to temperature, component aging, etc. The SAM-2 contains two single channel analyzers and has scaler display and controls for readout of the counts from both of the individual channels, the sum of the two channels, and the difference of the two channels. Thus, when properly set-up, the SAM-2 will automatically subtract the Compton background data from the photopeak data providing a display of the net difference.

Gain stabilization is obtained by implanting a small ^{241}Am source in the NaI scintillation detector. The SAM-2 electronics automatically adjusts the amplitude of the detector high voltage supply to maintain a constant amplitude of the signal from the ^{241}Am source.

The SAM-2 also has a thumbwheel switch controlled digital rate multiplier circuit that provides a selectable multiplier for both of the single channel analyzer outputs. The range of the multiplier is from 0.000 to 0.999.

B. Calibration.

By use of the digital rate multiplier, we calibrate the SAM-2 enrichment meters so that the scaler display reads directly in percent enrichment. We use a two-minute count and adjust the digital rate multiplier to provide the correct readout.

We locate the detector approximately two inches below the bottom of the powder can to reduce the sensitivity to distance variations

between the detector and the powder. The distance variations can be caused by denting or bending of the bottom of the powder can.

With a two-minute count, the system precision at one standard deviation is approximately 0.02% absolute.

IV. ACTIVE ROD SCANNER

A. System Description

The active fuel rod assay system (Figure 7) uses a ^{252}Cf neutron source to induce fission in the ^{235}U . A moderator assembly provides biological shielding of the ^{252}Cf source and moderates the fast neutrons to an energy spectrum comparable to the neutron energies encountered in a reactor.

The system uses the fission product delayed gammas to verify the enrichment uniformity of the fuel rod and the fission product delayed neutrons to measure the fissile content of each fuel rod.

The system processes two fuel rods simultaneously. Storage racks are provided on the inlet and outlet and fuel rods are automatically loaded onto and off of the drive system.

The system can be operated both in a manual mode and in an automatic mode for detection of out-of-tolerance fuel rods. In the manual mode, a dual channel strip chart recorder displays the delayed gamma enrichment uniformity data and a digital printer records the count data obtained from the delayed neutron total fissile data and the operator analyzes the data to accept or reject the fuel rod. In the automatic mode, a computer processes both the delayed gamma and delayed neutron data and accepts or rejects the fuel rod. In the automatic mode rejected fuel rods are unloaded at a different axial location than accepted fuel rods for ease of identification. The computer outputs onto a teletype machine data for each fuel rod processed.

B. Enrichment Uniformity Sensitivity

When operated at a drive speed of 18 ft/min, the system can detect a single pellet, approximately 0.3 in. long, which differs from the average enrichment by about 22%, with 95% confidence, while providing a false reject signal for about 0.25% of the acceptable fuel rods.

C. Total Fissile Precision

When operated at a speed of 18 ft/min, the system precision for total fissile assay is about 0.6% at one standard deviation.

D. Safeguard Use

The rod assay system is used as a Quality Control check for enrichment control and as a safeguards overcheck on total fissile content. It is not used for accountability purposes. The accountability values for fuel rods are based on the weights of UO_2 loaded into each rod and the assay of the corresponding pellets for percent uranium and ^{235}U .

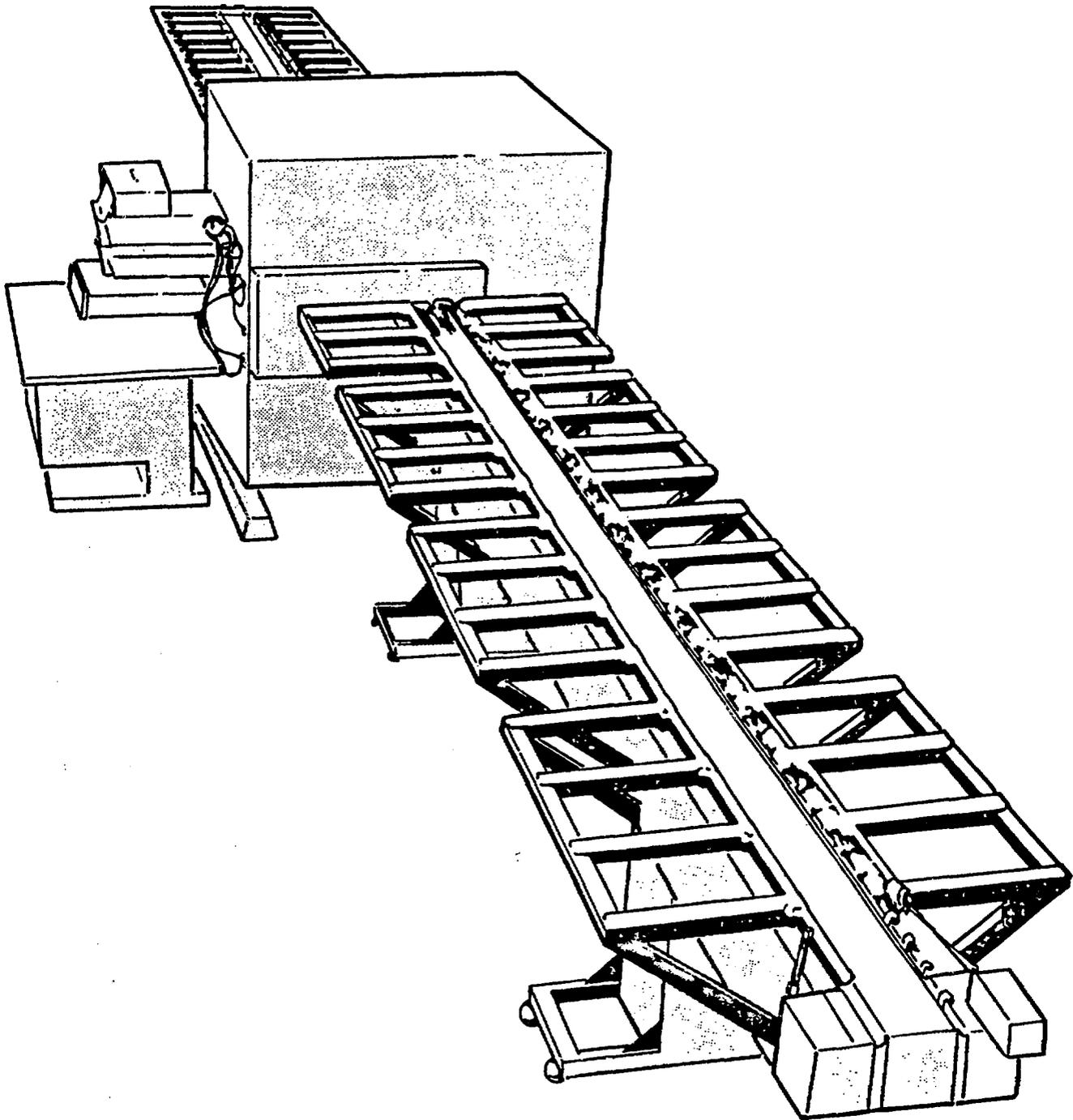


Figure 7. Rod Assay Unit



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October 17-November 4, 1983

Session Objectives

SESSION 28: MEASUREMENT CONTROL PROGRAM AT MODEL FACILITY

A measurement control program for the model plant is described. The discussion includes the technical basis for such a program, the application of measurement control principles to each measurement, and the use of special experiments to estimate measurement error parameters for difficult-to-measure materials. The discussion also describes the statistical aspects of the program, and the documentation procedures used to record, maintain, and process the basic data.

After the session, participants will be able to:

1. understand the criteria for this type of a measurement control program,
2. understand the kinds of physical standards required for the various measurement processes, e.g., weighing, analytical, NDA,
3. understand the need for and importance of a measurement control program,
4. understand the need for special experiments to provide an improved basis for the measurement of difficult-to-measure materials,
5. understand the general scope of the program's statistical aspects,
6. understand the basis and scope of the documentation procedures.



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October 17-November 4, 1983

SESSION 28: MEASUREMENT CONTROL PROGRAM AT MODEL FACILITY

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I. INTRODUCTION

For safeguards purposes measurement control programs are typically carried out to meet three objectives. The first is to ensure the control and quality of accountability and verification measurements. The second is to provide an experimental basis for the estimation of the random and systematic errors of measurement for calculating LEMUF and evaluating shipper-receiver differences. The third is to provide documented evidence that safeguards measurements have met quality criteria. This paper describes a measurement control program for a low-enriched conversion-fabrication plant.

The measurement control program encompasses all elements of the measurement processes used to determine quantities of uranium element and U-235 isotope in plant receipts, shipments, waste discards, and inventory.

The program focus is shown in Figure 1. The program is directed at the individual elements of the measurement processes rather than at the measurement components of the plant material balance. For each element of the measurement process, such as weighing, NDA and analytical measurement, a program of standards, replicate measurements, calibrations, and statistical analysis is applied. All data generated in the program are documented and subject to continual review. The program also includes special experiments to estimate weighing and sampling errors and the potential matrix bias arising from the passive gamma measurement of U-235 in solid wastes.

The measurement elements for the fuel fabrication plant considered in this paper are shown in Table I. As shown in the table, the control program covers five measurement elements and from one to five measurement applications for each of the five elements.

The remainder of this paper is presented in the following order:

1. Technical Requirements,
2. Application to Individual Measurement Elements,
3. Special Experiments,
4. Statistics, and
5. Documentation.

II. TECHNICAL REQUIREMENTS

A. Reference Standards

For safeguards measurements there are three general criteria for reference standards. First is the requirement for traceability of

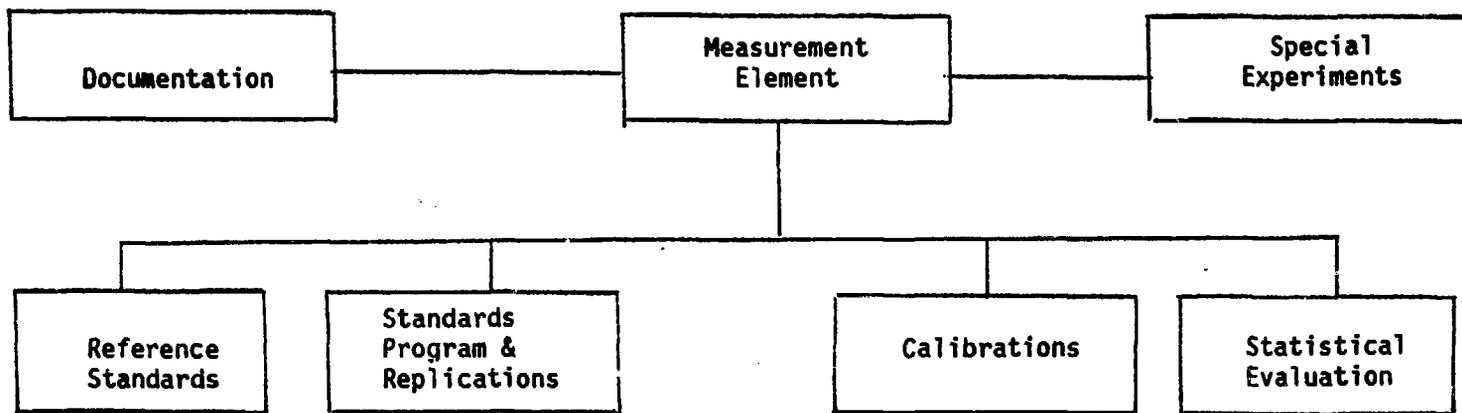


Figure 1. Measurement Control Program Focus

TABLE I. Fuel Fabrication Measurement Elements

- Mass --Weighing of UF₆ Cylinders, Pellet Columns, Trays, Boats and Buckets
- Analytical--Gravimetric, Fluorometric, and Volumetric U-Assays and U-235 by Mass Spectrometry
- NDA --Total U-235 by Passive Gamma in Solid Wastes
 --Barrels and HEPA Filters
- SAMPLING --Sampling of Powders, Sludges, Whole Pellets, and Liquid Wastes
- VOLUME --Volume of Liquid Wastes in Right Cylinder Tanks

the reference standards to a national or international system of measurement. Since nuclear materials are transferred within and between countries, this is an important requirement.

Second is the requirement that the reference standards meet the quality objectives of the measurement program. The tolerance or uncertainty associated with a reference standard should be smaller than the uncertainty objective of the measurement. A desirable, but not always attainable goal, would be for the uncertainty of the reference standard to be of the order of five to ten times smaller than the uncertainty goal for the measurement method. For example, if the goal is to weigh objects to an accuracy of two parts in ten thousand, then the tolerance goal of the standard weights would be two parts in fifty thousand or two parts in one hundred thousand; assuming, of course, that the scale has the desired sensitivity.

The third requirement is that the reference standards be representative of the measurement process and range of application; or in the case where the reference standard is not used directly, it should be possible to derive from the reference standard secondary standards or working standards which are representative.

B. Standards Replication Program

The frequency with which standards are measured should be sufficient to detect out-of-control situations in a timely manner in order to minimize the number of items which may have to be remeasured. Where standards are measured for the purposes of detecting small biases and to provide estimates of measurement bias, the frequency should be sufficient to provide a precise estimate of any possible bias.

C. Calibration Standards

Calibration standards should be traceable to primary standards, cover the range of application of the method, and be representative of the materials and items undergoing measurement. The last requirement is particularly important when the measurement process is affected by the material or object undergoing measurement. A case in point is the passive gamma counting of solid waste for U-235 where it

is necessary to duplicate both the composition of the waste and the container by the calibration standards.

D. Experimental Design

The experimental design of the measurement control program should be undertaken with the objective of providing valid estimates of the random and systematic errors of measurement. That objective is often more easily stated than achieved. Ideally, the program should be extensive enough to include factors which may vary over time and over measurement operators. Special consideration may need to be given to experimental designs to provide estimates of systematic sampling errors. Often, engineering scale experiments may be required to obtain valid estimates of systematic sampling errors.

III. MASS MEASUREMENTS

A. Reference Standards

Examples of the mass standards used in the measurement control program are shown in Table II. Also included in the program are sets of NBS Class S and S-1(1) standard weights which are used to recertify working weights and to calibrate the analytical balances.

B. Measurement of Mass Standards

Each scale is zeroed at first use on each operating shift and a control standard weighed. Once each week, at a random time, a quality control technician weighs a known standard in the working range on each scale using the same standard each time on all scales

TABLE II. Example of Mass Standards

<u>Scale Type</u>	<u>Standards</u>	<u>Certification</u>
1. Powder, Boat, and Tray Scales	Sets of 5, 10, 20, 25 kg Metal Weights.	NBC Class C. Certified by Metrology Lab. Recertify 18 Months.
2. Rod Loading Scales	Set of 0.6, 0.7, 2.4, 3.6, 4.9, 5.7 kg Metal Rods	Certified by Metrology Lab. Recertify 18 Months
3. UF ₆ Scales	Set of (5) 50, 250, 500, and (3) 1000 pound Metal Blocks.	Certified by Metrology Lab. Recertify 18 Months.
	<u>Replica Mass Standards</u>	Certified at Diffusion Plants versus NBS Weights
	2 Cylinders Depleted U	Recertify 2 Years.
	Tare Approximately 1650 Pounds	
	Full Approximately 6400 Pounds.	

to the extent possible. The standard is weighed while the scale is in use and the scale is not zeroed just prior to checking the standard.

Twenty-six observations per scale result during the six-month material balance period. The frequency is selected to produce sufficient data to obtain good estimates of systematic error limits.

D. Mass Calibrations

Prior to use, newly acquired scales and balances are evaluated with respect to accuracy and precision. After zeroing the balance and setting it up according to the manufacturer's instructions, known standards are weighed at approximately 50% and 100% of full scale and at a point within the expected working range. Standard weights listed in Table II are used. A series of 15 runs using these three weights are made. A second series of 15 runs is repeated at a later time (at least 24 hours later), where a second individual performs the weighing. A third series of 15 runs is repeated by either of these first two individuals or by a third individual again at a later time; that is, at least 24 hours removed from the second series of runs. These data form the basis for initial certification of the scale.

On a monthly basis, the quality control gauge technician calibrates each scale, documents the calibration records, and updates the calibration stickers. Calibration must be performed prior to use of a scale that has been out of service if the date is beyond that indicated by the due date sticker. Recalibration also takes place whenever the scale in question undergoes major repair that could affect overall performance in the opinion of the quality control gauge technician. On an annual basis, each key accountability scale is calibrated by the Plant Instrument Group.

IV. ANALYTICAL MEASUREMENTS

The reference standards for the analytical measurements are shown in Table III. With the exception of the sintered pellet standards and the grinder water standard, the analytical standards are either NBS standard reference materials⁽²⁾ (primary standards) or are prepared directly from those materials. The sintered pellet standards are secondary standards based on measurements made by New Brunswick and Ledoux Laboratories. The pellets were assayed by a titration method which was traceable to NBS standards.

The NBS isotopic standards are used for determining the multiplier correction factor (mass discrimination factor) for the mass spectrometer and also as routine control standards for the mass spectrometer.

A. Measurement of Analytical Standards

Standards are run using each analytical technique with a minimum frequency of two per week, except that during those periods when a given analytical technique is not in use, the standards need not be run. Under continued operation, this produces 52 results for each analytical technique employed in measuring uranium and U-235 during

TABLE III. Analytical Standards

<u>Measurement</u>	<u>Standard</u>	<u>Certification</u>
% U-Gravimetric	Sintered UO ₂ pellets	Depleted UO ₂ pellets certified by measurements made by New Brunswick and Ledoux Laboratories.
% U-Low-Level Solutions	Parts per million solution standards	Aliquots of NBS 950 A, 960, or their successors are weighed, dissolved with HNO ₃ , and diluted to volume and/or weight.
% U-Grinder Water	Grinder water-suspended UO ₂	Characterized, weighed quantities of sintered UO ₂ are diluted to volume with water.
% U-General	NBS-950 A or 960	NBS Standard Reference Materials
% U-235 by Mass Spectrometer	NBS UO10, UO15, UO20, UO50, U500, U100, U150, U200	NBS certified isotopic standards of standard reference material U ₃ O ₈

each six-month material balance period. The schedule provides bias estimates with a level of precision sufficient to detect real biases that are very small relative to random error limits. By running standards on a weekly schedule, timely indication of lack of control is given.

Laboratory technicians are instructed to exercise the same care when running standards that is used when running production samples. Only those technicians authorized to run production samples using a given analytical technique may produce standards data employing that technique.

B. Calibrations of Analytical Measurements

1. Fluorimetric (Low-Level Waste and Grinder Water). Each sample analyzed has a unique calibration which is derived by spiking the sample with a known quantity of dissolved NBS U₃O₈ or NBS metal. A calibration curve is not required.

2. Titration (Davies-Gray Method). When the Davies-Gray method is used for accountability analyses, the titrant and automatic recording titrator are calibrated against aliquots of the U Low-Level standards. The relationship between the volume of potassium dichromate titrant and uranium amounts is determined over the range of uranium amounts expected in sample aliquots. A minimum of four standard values within this range are used and each is assayed a minimum of three times. Recalibration is performed annually or whenever the titrant is changed or standards data indicate a need for recalibration.

3. Gravimetric Analyses. The accuracy of the gravimetric uranium analysis is directly related to weights and ignition to stoichiometric U_3O_8 . Balances are serviced annually by the manufacturer, calibrated monthly by plant personnel, and checked daily with a Class S-1 weight to assure proper operation. Nonvolatile impurities remaining in the U_3O_8 are measured by emission spectroscopy. An impurity correction is made for each sample.

An extensive study, using NBL 97 UO_2 standard and a Graeco-Latin square statistical design, was performed to determine the optimum ignition conditions.

4. ^{235}U Analysis. Multiplier correction factors are determined using NBS isotopic standards (NBS UO_{10} , UO_{15} , etc.). No other calibration is required. The factors are reestimated on an annual basis. More frequent estimation is not required because biases in the mass spectrometer are controlled through the running of standards.

V. NDA MEASUREMENTS

A. CALIBRATION STANDARDS

1. General. The NDA calibration standards for the waste assay counter are shown in Table IV. The waste assay counter measures the total U-235 content of solid wastes in 55-gallon barrels and HEPA Filters (High-Efficiency Particulate Air Filters) by passive gamma counting of U-235 (185 KeV gamma). The waste counter consists of four sodium iodide (NaI) detectors and the associated electronics and a rotation fixture. The barrel or filter is rotated at about five rpm to provide an average count independent of the radial location of the uranium.

2. U-235 in 55-Gallon Barrels. The 30 one-gallon jugs described in Table IV are used in preparing each of the five calibration standards. A given barrel calibration standard is created by uniformly dispersing known quantities of U-235 in 30 gallons of sawdust. The sawdust and uranium mixture is placed in the 30 one-gallon jugs. There are 3 layers of jugs in a barrel, with each layer comprising 10 jugs so that the barrel holds 30 jugs total. For each standard, three 500-second net counts are taken.

An upper limit of about 30 grams U-235 is chosen to correspond to the maximum amount of uranium within a process barrel. Barrels that exceed the upper limit are down loaded and the contents dispersed into other barrels so that the calibration curve limit is not exceeded.

3. U-235 in HEPA Filters. The plastic vials described in Table IV are used in preparing calibration standards. In preparing these calibration standards, a 10 x 10 grid pattern is marked on a typical HEPA filter, specifying 100 locations on each side of the filter. A HEPA filter calibration standard is created by placing vials at specified grid locations. The number of vials per filter standard is as follows:

TABLE IV. Waste Assay Calibration Standards

<u>Measurement</u>	<u>Standard</u>	<u>Certification</u>
Total U-235 in 55-gallon barrels	Five 55-gallon barrels each containing 30 one-gallon jugs containing a mixture of low-enriched uranium and sawdust with from 2.0 to 30.0 g U-235 per barrel approximately equally divided among the 30 one-gallon jugs.	The U-235 amounts in the barrels and filters are based on measurements made using the gravimetric and mass spectrometer analytical methods. They are traceable to NBS through the NBS analytical standards.
Total U-235 in HEPA Filters	5 HEPA filters with plastic containers, 1-1/2 in. x 5 in. x 3/16 in., made so that the thickness of UO ₂ powder is approximately 1/16 in., with from 2.0 to 30.0 g of U-235 per HEPA filter, approximately equally divided between the plastic containers in the HEPA filter.	See above.

<u>Filter Standard, Grams U-235</u>	<u>Vials and Grid Locations</u>
2	6
8	24
16	48
24	73
30	101

For each standard, three 500-second net counts are taken. An upper limit of about 30 grams of U-235 is chosen to correspond to the maximum amount of uranium expected on the filters. Filters whose counts exceed the calibration range are beaten to remove enough uranium to bring the filter within the range, or else they are cut up into smaller sections.

4. Calibration Frequency. The system calibration is repeated annually, or whenever measurement system changes are made that might affect the calibration. An annual calibration frequency is judged to be adequate because the system is carefully controlled through frequent running of the standards. Further, replicate measurements made monthly on four production barrels and three production filters than span the range of U-235 contents provide assurance that the calibration remains fixed throughout the entire range.

VI. VOLUME

The bulk of the uranium-bearing liquid waste is transferred to solar evaporation ponds after sampling and volume measurement in connected banks of right cylinder tanks. A bank consists of five nominally identical tanks of about 100 gallons volume each. The tanks are made of smooth inner bore spun fiberglass pipe which is reinforced on the outside by fiberglass wrapping to prevent bowing. The tanks are of uniform inner dimension and are used as upright, right cylinder, volume measurement tanks.

The tanks are calibrated by 1) dimensional measurement⁽³⁾ of the inside diameter and 2) measurement of the average liquid height of the bank at the time of discharge under normal operating conditions. Five calibration runs are made under normal operating conditions. The bank is allowed to fill until the liquid level alarm activates and the bank is manually valved out. The recirculation pump is shut off to allow the liquid level in all tanks in the bank to reach an equilibrium height (all tanks reach the same level). The liquid height of each tank is measured. The average of 5 runs is used to determine the batch discharge volume (gallons/batch) of each bank of liquid waste tanks.

The tanks are calibrated annually. The calibration data are submitted for statistical analysis and incorporation of the calibration data in the measurement control program records.

VII. SPECIAL EXPERIMENTS

A. Heterogeneous Scrap

For heterogeneous scrap items--ADU, grinder sludge and dirty powder--two experimental programs are carried out to estimate sampling errors.

For the estimation of random sampling errors a routine resampling program is carried out. During each six-month accounting period, 15 containers of each type of scrap are resampled and assayed for percent uranium to provide a basis for estimating random sampling errors.

Small scale oxidation experiments have been carried out in which the entire contents of scrap containers are converted to U_3O_8 in a quantitative manner. The experimental approach is equivalent to doing a gravimetric assay of the entire contents of a 5-gallon bucket of scrap. In the initial experiments performed using the new process tray oxidation unit, the contents of the scrap buckets were quantitatively transferred into tared oxidation trays such that each tray represented a gravimetric assay sample size of about five kilograms of scrap. The between-tray percent uranium values for trays from the same scrap container provide an estimate of the heterogeneity of the material (or inherent random sampling error). The difference between the original sample result for percent uranium and the percent uranium found by the oxidation-assay approach for the whole container provides an estimate of the systematic sampling error. Periodic oxidation experiments are planned as a continuing part of the measurement control program. Obviously, the need for such experiments would be eliminated if all difficult-to-measure scrap were routinely converted to readily measurable U_3O_8 .

B. Liquid Waste

The ADU precipitation process used for the conversion process generates an ammonical uranium-bearing liquid waste. Because of the possibility of suspended solids, a potential for systematic sampling error exists. Two types of experiments have been conducted to estimate possible systematic sampling errors.

One experiment consisted of making a running comparison between the normal samples taken from the circulating sampler on the banks and samples obtained by a continuous sampler located on the inlet line to bank tanks. That experiment showed that systematic sampling errors can be significant when suspended ADU solids are present.

The second experimental approach is to compare the total uranium as measured by discharged batches to the total uranium found by physical inventory of the solar evaporation ponds into which the liquid wastes are discharged. Experiments of this type show that systematic sampling errors for the ADU process liquid waste can be significant (approximately 20 to 30%).

C. Solid Waste

Solid waste which consists of contaminated gloves, rags, plastic sheets, etc., presents a potential matrix problem for the passive gamma counter. If the uranium in the waste is not uniformly distributed or if it is shielded by high density materials, the counter gives low results.

To estimate the potential systematic error which arises from such a matrix effect, special chemical leaching experiments have been carried out on process waste barrels. Those experiments show that a significant bias (passive gamma counting 30 to 40% lower than leaching) can result when the actual waste matrix is more dense and heterogeneous than the calibration standards. From the special leaching experiments, a matrix bias correction equation was developed which can be used for "after-the-fact" bias corrections. Because of practical difficulty of controlling the solid waste matrix in an exact manner, serious consideration is being given to including periodic quantitative leaching experiments in the measurement control program.

VIII. STATISTICS

A. General

The scope of the statistical aspects of the measurement control program is shown in Table V. As shown in the table, statistical techniques are applied to all elements of the measurement processes to estimate measurement errors, set control limits, derive calibration relationships, and estimate biases. In addition, comprehensive statistical evaluations are made periodically of the overall program and error propagation methods applied using current error estimates to calculate the plant LEMUF. The more important details of the statistical application are described next.

B. Statistical Applications

1. Calibrations. For the determination of U-235 in solid wastes (barrels and HEPA filters), a quadratic calibration curve⁽⁴⁾ is developed. For the multiplier correction factor for the mass spectrometer, an average correction factor is developed after a statistical evaluation of the data for non-random effects.

2. Control Limits. From the calibration and standards data, statistical control and action limits are developed for the waste assay system, analytical methods, and for the routine weighing of standards by the Quality Control technicians.

The general control philosophy for standards measurements is to remeasure the standard if the result falls outside the 0.05 limit but within the 0.001 limit. If repeated measurements fall within the 0.05 limit, no further action is required. Otherwise, the method is declared out of control. If a standard measurement falls outside the 0.001 limit, the method is declared out of control and remedial action initiated.

TABLE V. Scope of Statistical Program

<u>Weighing</u>	<u>Sampling</u>	<u>Overall</u>
Control Limits	Scrap resampling program data for error estimation	Comprehensive annual measurement review
Use Statistical Control to Keep Scales Within Error Limits-- No Bias Corrections	Lot-To-Lot variation of powder and pellets	Update error parameters each six months
Estimate Error Parameters from Routine Data and Experiments	U ₃ O ₈ experiments for sampling error	LEMUF calculations for each six months
Use S/R Data for UF ₆ Weighing Errors	Liquid waste experiments -LE and BIAS estimation	Monitor all program data
<u>Analytical</u>	<u>Volume</u>	
Control Limits	Volume calibration and error parameters	
Mass Spectrometer Calibration		
Bias Estimation and Test of Significance		
Random Error from Routine Data		
<u>NDA</u>		
Control Limits		
Calibration Equation		
Standards Data for Instrument Drift		
Chemical Recovery versus Counting for Matrix Bias		

C. Error Estimation

1. Random Errors. Replicate measurements data are analyzed by the method of paired differences to provide estimates of the random error variance. The variance among the paired differences is an estimate of twice the appropriate measurement error variance.

D. Systematic Errors

1. Weighing. In the case of scales and balances, the primary purpose of standard weighing is to detect when scale adjustments are needed and not to generate data that form the basis for making bias corrections. It is difficult to use the data generated by the standards program to obtain realistic estimates of systematic error limits. Generally speaking, the best statement that can be made is that all weighing of the standards were within, say, one scale division (or the rounding interval of digital readout scales).

To obtain more realistic estimates of systematic error limits for scales, special weighing experiments are conducted using unknown weights. These are weighed singly and in combinations on the various scales. Standard weights are then assigned these standards on the basis of the consensus data. A systematic error component, described by the variance of the population from which the systematic error for a given scale was selected at random, is then estimated by the square of the average difference between the observed weights for the standards (weighed singly and in combinations) and the corresponding assigned weights based on the consensus data.⁽⁵⁾

For the balances used in rod loading, the sensitivity is such that the systematic error variance can be estimated from the quality control data on the weighing of known standards. An analysis of accumulated standards data is used to estimate the systematic error variance. Down loading experiments are also carried out which provide additional data for error estimation.

For the UF₆ scale, shipper-receiver data are used to obtain a realistic estimate of the systematic error. The statistical techniques for estimating both the long-term and short-term systematic error variances from shipper-receiver data are described in Reference 6.

2. Analytical. The primary function of the standards program is to give an early signal of possible problems with the analytical technique in question rather than to create data that will form the basis for making bias corrections after the fact. The aim is to develop a bias-free analytical technique, although it is impossible to achieve this goal completely.

Recognizing that small biases will occur, the standards data for each analytical technique are analyzed at the end of a material balance period to estimate the bias that existed for that analytical technique during the material balance period. The estimated bias is the average difference between the observed measurements on the standard and the assigned standard value. Alternately, the statistic may be the difference in logarithms of the raw data or equivalently the logarithm of the ratio. This latter approach is followed when more

than one standard is used and where biases are consistent on a relative rather than absolute basis. This approach is followed with the mass spectrometer standards data.

The standard deviation of the estimated bias is calculated as the standard deviation among the differences divided by the square root of the number of differences comprising the average. The uncertainty in the standard is also taken into account. If the appropriate data are subsequently corrected for bias, the standard deviation of the estimated bias is regarded as a systematic error standard deviation. (7)

3. NDA. Systematic errors in the solid waste measurements are estimated from the calibration data and from the leaching experiments described earlier.

4. Sampling. Systematic errors in sampling heterogeneous materials are estimated from the special experiments described earlier.

5. Volume. Systematic errors in the volume measurement for liquid waste are estimated directly from the dimensional calibration data. In addition, quarterly acid flushes of the bank tanks are made and measured to estimate any volume bias which may be caused by solids build-up in the tanks.

6. Application to Overall Program. Regarding statistical applications to the overall measurement control program, the following activities are carried out:

1. Annually, a comprehensive measurement review is performed in which all the standards data and applicable shipper-receiver data are evaluated statistically. Error estimates are developed for key accountability measurements and yearly trends analyses are made. The measurement review is documented and a detailed report issued.
2. Error parameters for the LEMUF calculations are updated each six months and used in the LEMUF calculation which is performed at the end of the six-month inventory.
3. All data generated in the measurement control program are monitored routinely and appropriate statistical techniques applied to detect trends and identify possible problem areas.

IX. DOCUMENTATION

All data generated in the program are recorded as permanent records and a formal system of documentation followed. Examples of the various records and reports associated with the program are shown in Table VI.

TABLE VI. Example of Records and Reports

Records	Reports
CUSUM and Control Charts	LEMUF Reports
Out-of-Control Documentation	Measurement Reviews
Calibration Data and Calculations	Bias Adjusted MUF
LEMUF Data and Calculations	Standard and Reference Reports
Q.C. Weekly Standard Weighing Data	Audit Results
Standards Preparation Data	Special Experiment Reports
Mass Standards Calibration and Certification	Error Parameter Reports
Measurement Review	

X. REFERENCES

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 29a: TOUR OF SAFEGUARDS EQUIPMENT VAN

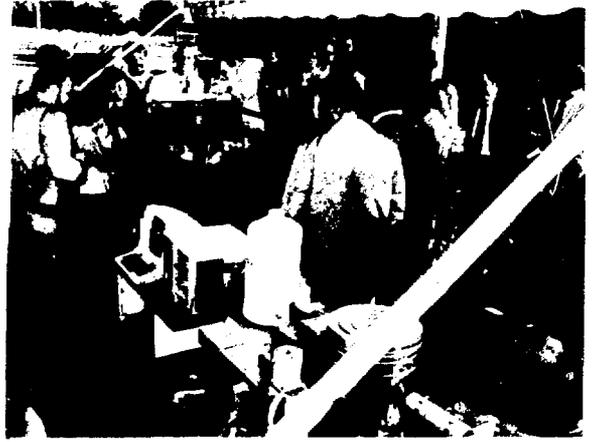
Increasing use is being made of nondestructive assay instruments for identification and measurements of nuclear materials. Important advantages of NDA are: timeliness, portability, and ease of use. Recent developments in computer systems and NDA allow for the integration of sample planning, control of NDA, and data analysis into one transportable system. This session acquaints the course participants with the use of mobile NDA safeguards measurement systems. This session considers the practical problems and the type of results that can be expected from field use of NDA instruments. An existing mobile safeguards system will be used to demonstrate some of the differences between field and laboratory conditions.

After the session, participants will be able to:

1. cite the advantages and disadvantages of a mobile NDA safeguards measurement system,
2. identify principle NDA instruments most applicable for use in a mobile system,
3. identify selected modifications to NDA instruments for field use.



Participants arrive at the safeguards equipment van.



Demonstration of the segmented gamma scanner



Neutron well coincidence counter



Battelle, DOE, and Los Alamos staff



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AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 29a: TOUR OF SAFEGUARDS EQUIPMENT VAN

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Pacific Northwest Laboratory

I. DEMONSTRATION OF A MOBILE NDA SAFEGUARDS MEASUREMENT SYSTEM

A. Introduction

This lecture will briefly discuss using a mobile nondestructive assay (NDA) safeguards system. The lecture will cover some of the advantages and disadvantages of a mobile NDA safeguards system, the principal NDA instruments most applicable for use in a mobile system, and some of the modifications to the NDA instruments needed for field use. After the lecture a demonstration of an existing mobile NDA system will be conducted in the parking lot outside. Figure 1 shows a schematic of the mobile NDA safeguards system that will be used in the demonstration.

Important advantages of NDA systems are timeliness, portability, and ease of use. At the Los Alamos Scientific Laboratory, you already received instruction in the use, selection, and operation of NDA instruments for various nuclear material measurement problems. In general those discussions were directed at in-plant uses. Here at the Pacific Northwest Laboratory we have assembled and have been using a mobile NDA safeguards system. This system is used primarily at PNL to perform measurements for materials accounting. The system has also been used by the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission at other sites to perform inventory verification measurements as part of the inspection process. This system has many characteristics that are similar to other mobile systems that have been developed. (1-7)

The need for a mobile NDA safeguards system exists both for the inspection process of national and international agencies, and for the purposes of performing measurements for material control and accounting at a facility. In an inspection situation it is not practical for the inspection team to have separate equipment at each facility because of the limited amount of use and because most of the calibration and measurement control experiments will be performed at the Headquarters office. Also, by using the same NDA instruments at each facility, the results may be tested for measurement control and bias between facilities. In a large research complex it is not practical to permanently locate such NDA measurement equipment wherever nuclear materials are being stored or used. Nuclear safety and safeguards considerations prohibit the extensive movement of nuclear materials for measurements. Therefore, mobile NDA safeguards measurement systems should be considered in the development of a nuclear materials control and accounting system.

B. Mobile NDA Safeguards Systems Concepts

Concepts for developing a mobile NDA safeguards system vary from the small, compact, and portable units to those that approach the capabilities of a central laboratory. Three basic concepts will be discussed: 1) the suitcase approach, 2) the mobile equipment approach, and 3) the mobile laboratory approach.

1. The Suitcase Approach. Recent developments in NDA instruments, including the associated electronic and data processing units, have made it possible to hand-carry some of the most important NDA measurement systems. Instruments like the SNAP neutron detector, small NaI(Tl) or Ge gamma-ray detectors connected to simple readout devices can be hand-carried and set up rapidly in remote locations with a minimum of impact on current operations in the area where the measurements are to be performed.

2. The Mobile Equipment Approach. This is a semiportable (via a "cart") system where the neutron or gamma system is built into the cart. Most NDA equipment, including the associated electronics and data processing equipment, can be mounted on wheels. Recent developments in microcomputers allow fairly sophisticated equipment to be packaged in portable units. An alternate to building the minicomputer into the cart would be to develop a telephone connection with the computer at a remote location or to use a teletype and magnetic tapes or disks to communicate with the computer.

This approach allows greater protection of the equipment than the suitcase approach, with greater flexibility in the type of equipment and data processing used. The cart could be transported to the location in a medium sized vehicle or by packaging in a crate and shipping with a commercial transport company.

3. The Mobile Laboratory Approach. The mobile laboratory approach consists of developing a vehicle to contain the elements of a small laboratory. This approach has greater flexibility than the previous approaches. The primary advantage is that the complete measurement task from planning to data evaluation may be performed at the measurement site. This decreases the time required for assays by reducing the time required to transfer nuclear material from storage to the measurement area. Collimators, extra shielding, etc., are part of each of the three systems, presenting certain difficulties in the smaller units. Any NDA system should have a support system that includes spare parts (fuses, cables, connectors), collimators, shielding, and voltage regulators.

The specific approach taken here can vary from a modified cart approach, where a vehicle is developed to handle several independent carts, to one where an NDA laboratory is packaged on wheels. The approach selected at PNL incorporates features selected from each of these. The remainder of the discussion about the mobile laboratory approach is directed to the system used at PNL.

The mobile safeguards system, shown in Figure 1, consists of a specially constructed vehicle that contains electronic signal and data processing equipment and carries portable radiation measurement equipment. Before measurements are made the necessary detection

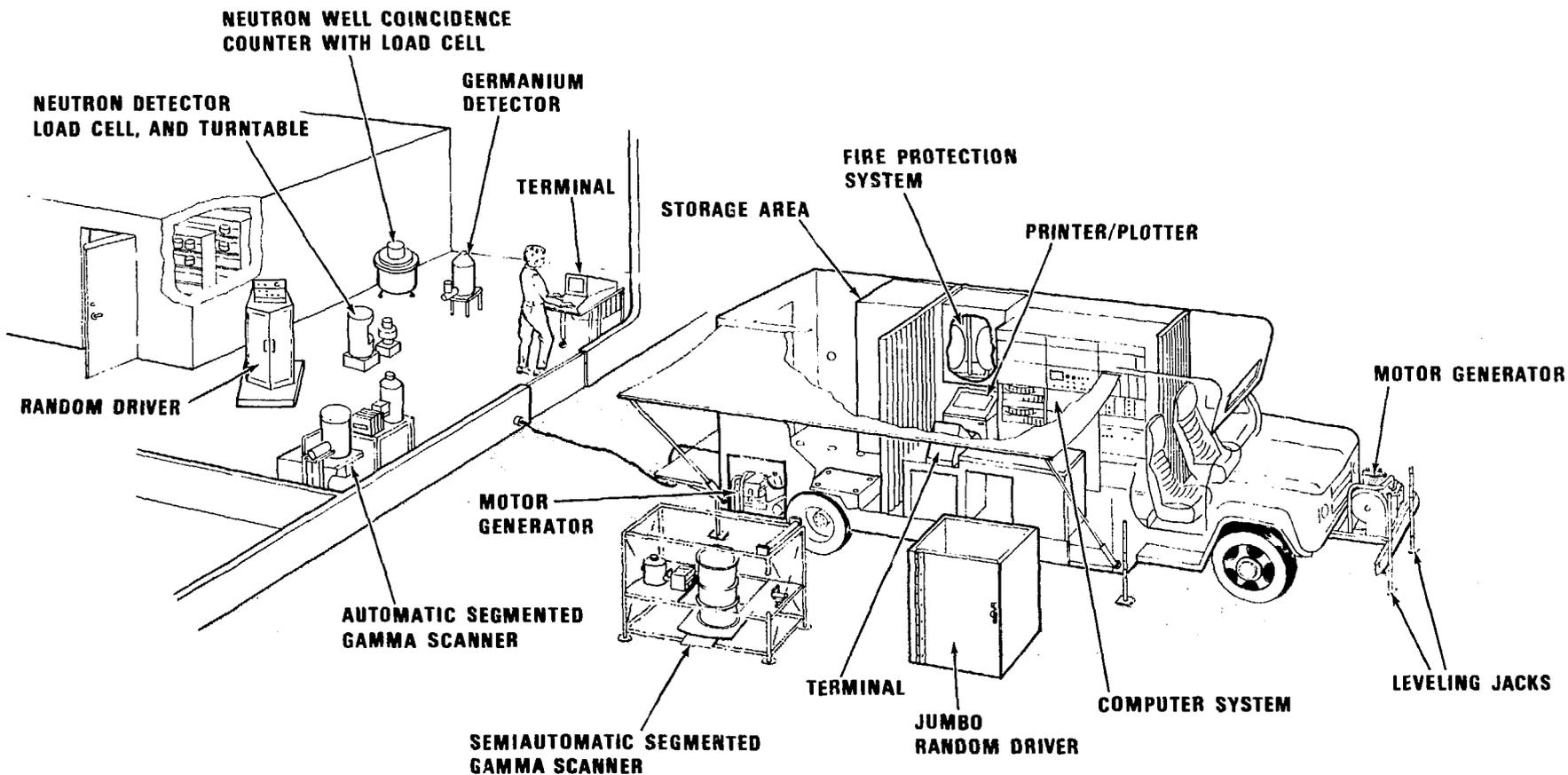


Figure 1. Schematic of an Existing Mobile NDA Safeguards System

equipment and a minicomputer terminal are moved from the vehicle to the measurement station, which may be up to 70 m from the vehicle. The detection equipment is connected via instrument cables to the equipment mounted in the vehicle. The size and amount of equipment that must be moved from the vehicle to the measurement station has been minimized for each desired analysis.

The vehicle, pictured in Figures 2 and 3, was constructed on an extensively modified two-ton truck chassis (10,000 kg gross vehicle weight). An enclosure on the truck designed to our specifications by a recreational vehicle manufacturer, houses most of the electronic instrumentation in a fixed position and carries the detection equipment along with the necessary cables. The enclosure has reinforced steel frames and is open to the cab of the truck. The interior can be separated by dust proof, accordion type doors to form three compartments: 1) a cab area, 2) a fixed electronic instrumentation and office area, and 3) a storage area for equipment and detectors used outside the vehicle. Built-in equipment includes shock-mounted instrument racks, storage cabinets, and a desk. The vehicle is equipped with both mechanical and hydraulic stabilizing and leveling jacks. Instrument power, air conditioning, heating, and lighting can be supplied from either two motor generators mounted on the vehicle, or from external 220-V AC power. A hydraulically operated platform outside the vehicle's large rear access doors moves equipment to and from the ground.

All equipment used in the mobile system is commercially available. The equipment was modified at Pacific Northwest Laboratory to minimize the instrumentation to be moved from the vehicle to the measurement area and to provide for remote operation with up to 70 m of cable between the vehicle and the measurement area. Figure 4 is a block diagram of the NDA system. Various other configurations are possible to suit specific measurement needs. Data storage and retrieval programs have been developed for storage of both raw data and assay results on disk files for future reference and recovery so that measurements can be compared with the past data. The measurement parameters associated with the system were evaluated in order to reduce measurement time and the amount of equipment required to be moved from the vehicle to the measurement site. These parameters include the effect of counting time, the length of cables between different parts of the system, the selection of components, and the method of data analysis.

A minicomputer system in the vehicle is used to control data acquisition, accumulate measurement results, perform real-time data analysis, store results, and prepare reports. The system consists of a PDP 11/05 minicomputer, two 1.2 million word disk units, CRT terminals, a graphic CRT terminal, a hard copy data terminal, a high speed printer-plotter, and interfaces for measurement equipment. Any of the terminals can be operated remotely with 70 m of cable. The computer and associated instrumentation is shown in Figure 3.

The operating software system is a RK-05 disk-based RT-11 system using FORTRAN and BASIC. Software packages have been assembled for a variety of uses. These include specific programs for calibration and

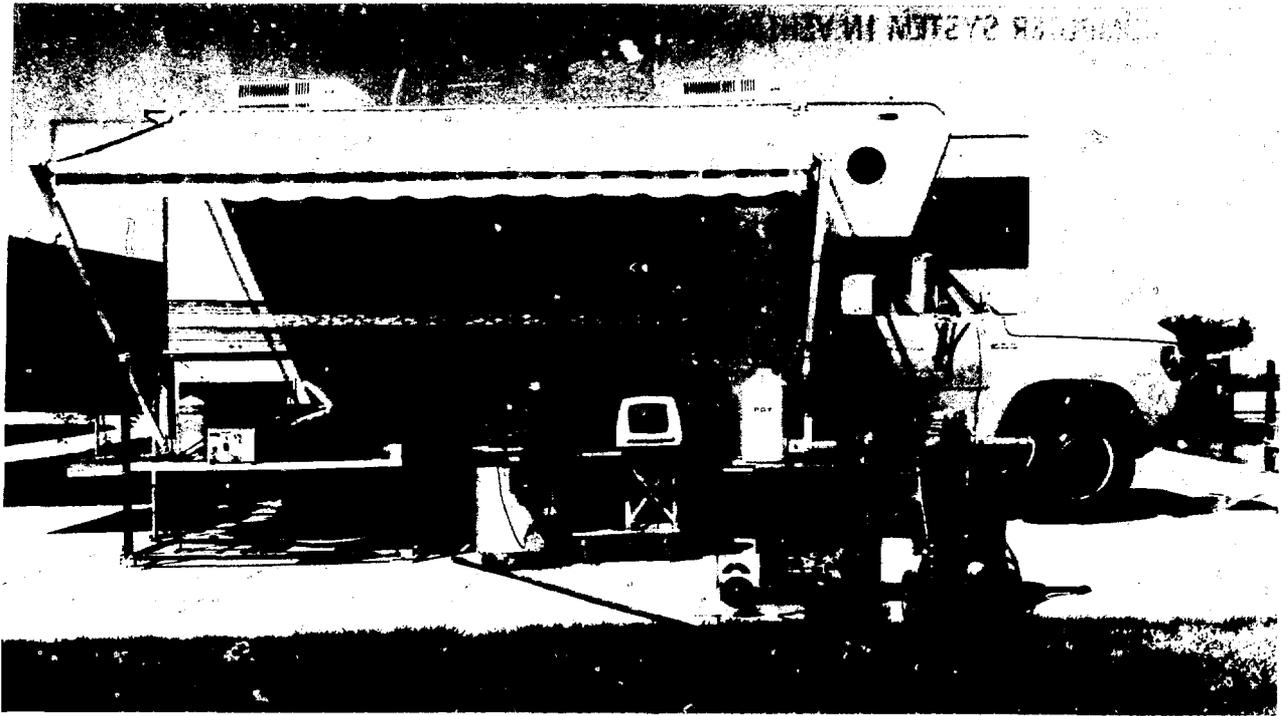


Figure 2. Mobile Safeguards Vehicle

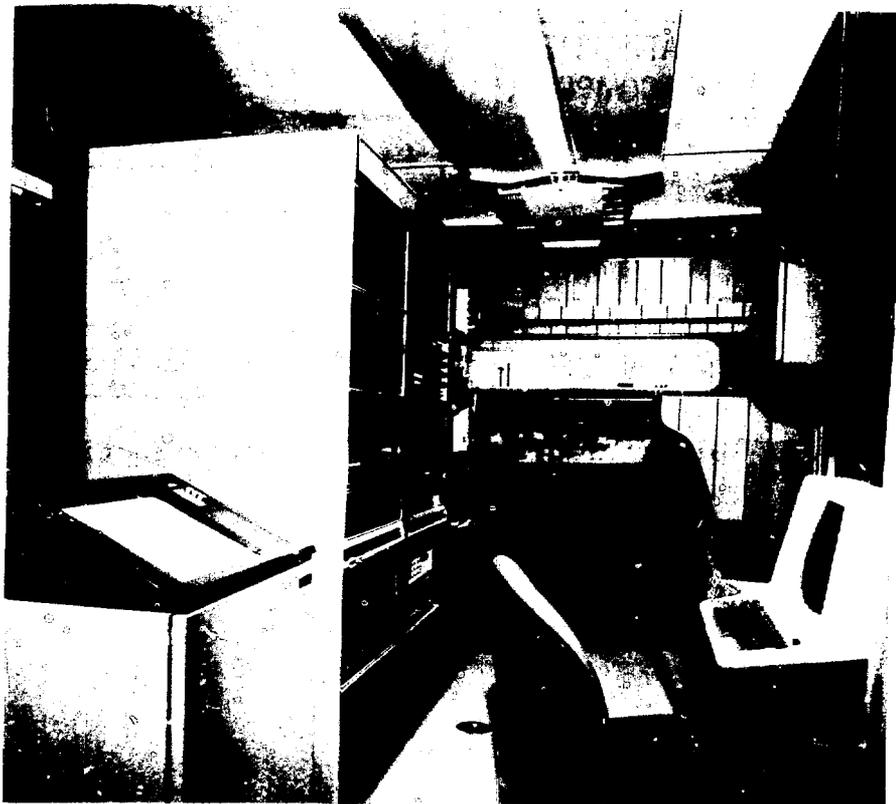


Figure 3. Electronic and Computer Equipment Inside the Mobile Safeguards Vehicle

COMPUTER SYSTEM IN VEHICLE ← (UP TO 70 METERS) → REMOTE EQUIPMENT

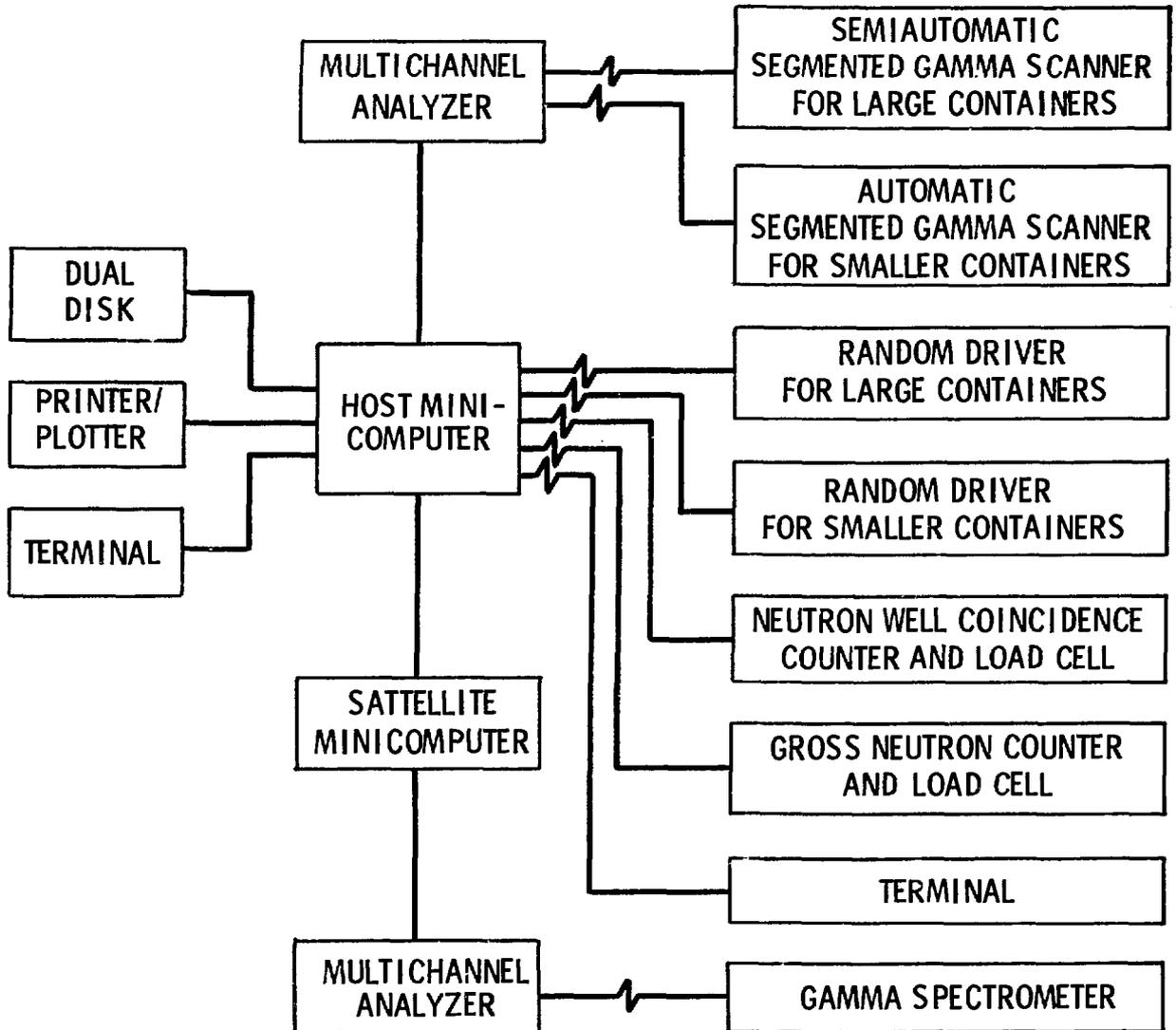


Figure 4. Block Diagram of Mobile Nondestructive Assay System

measurements with each detector system, programs for integrated verification and inspection operation, and data storage and retrieval programs.

In the inspection mode, information concerning containers to be verified can be entered into the minicomputer system before the measurements are taken by the inspection personnel. The computer then instructs the inspector, via the terminal, on the analysis operation required at the measurement site. The computer also: 1) controls the weight, neutron, and gamma-ray measurement equipment, 2) acquires the measurement data, 3) reduces the data to concentrations and isotopic ratios, 4) compares the measurement results with the data base previously stored in the computer, 5) notifies the inspector via the terminal of the results immediately after the measurement, 6) stores the results, and 7) prepares data reports.

4. Principal NDA Instruments for Mobile Usage. All of the NDA instruments that were demonstrated at the Los Alamos Scientific Laboratory earlier in the course are suitable for use in a mobile system. Many of the recent developments in NDA have been directed toward making the equipment more portable. Therefore, most of the current available NDA equipment can be used in mobile applications without modification. Following are brief descriptions of the NDA equipment in PNL's mobile safeguards system. These systems have been described elsewhere in greater detail.⁽⁵⁻¹⁸⁾ During the demonstration it is also useful to point out some of the differences between equipment used here and that at Los Alamos.

- Passive Neutron Measurements. Two passive neutron systems are included: a gross neutron counter with load cell and turn table, and a neutron well coincidence counter with load cell. These detectors are used for passive assay with total neutron and fission neutron measurements. The load cells are used to automatically record gross sample weight simultaneously with the passive neutron measurement.
- Active Neutron Well Coincidence Counter. The neutron well coincidence counter can be operated in the active mode for measurement of uranium. The well counter is converted to the active mode by the addition in the detection chamber of two Am-Li neutron sources.
- Random Drivers. Two commercial random drivers were selected for active and passive assay of fissile materials: a standard size random driver for assay of samples in the 250 ml to 19 l size range, and a larger unit for assay of material in containers with volumes of up to 200 l. The random drivers can be operated remotely under computer control. The larger unit is operated in the vehicle.
- Gamma Ray Detectors. Four intrinsic germanium (Ge) detectors were obtained for gamma-ray spectrometric measurements. The detectors are normally operated with the detector bias supply and linear amplifier close to the detector and up to 70 m of signal cable between the detector and the multichannel analyzer, which is located in the vehicle. An initial concern was the effect of having long signal cables between

the high resolution Ge detectors and the multichannel analyzer located in the vehicle. Measurements that were made with several different cable lengths have shown that only a slight resolution loss occurs when signal cables up to 70 m long are used.

- Gamma Ray Spectrometric Systems. The vehicle contains two multichannel analyzers (MCA) for gamma ray spectra accumulation. Both are commercial 4096 channel, hard-wired analyzer with cathode ray tube (CRT) display. Either the total spectrum or selected regions of the spectrum can be transferred to the PDP-11 computer. The analyzer can be operated under manual or computer control.
- Segmented Gamma Scan Assay System (SGSAS). The Ge detectors and the MCA system can be used as part of the two segmented gamma scan assay system. A commercial SGSAS was acquired and modified to increase its portability. The analyzer and computer are located in the vehicle and the detector and scan table located at the measurement site. Transmission sources are used for absorption corrections. A larger portable scan table system has been designed and built for field applications requiring measurements of 200 l waste drums. The large SGS uses a pipe, block, and turnbuckle construction so the unit can be disassembled for movement or storage.
- Calorimeter. Although a calorimeter is not included in this demonstration, a portable calorimeter has been used in conjunction with this mobile system. (19-20)

5. Modifications of NDA Equipment for Mobile Use. Most commercially available NDA equipment could be mounted in a mobile laboratory and used at remote locations if the nuclear material can be brought to the mobile laboratory. Such was the case for the large random driver described previously. When this mode of operation is not possible, most nonportable NDA equipment can be modified to make it portable, e.g., segmenting, structural strengthening, and in some cases weather proofing.

Most NDA instruments can be disassembled and individual parts mounted on wheels or specially designed carts. Special alignment pins and marks need to be added so the equipment can be reassembled to the calibrated geometry. Increasing the structural strength includes adding fasteners to hold electronic circuit board security, and removing or building protective housing around any exposed electronics or mechanical equipment that could be damaged during shipment. When the NDA equipment is connected to a mobile laboratory via an umbilical cord, this cord needs to be weather proof and the connectors must permit easy connection of the equipment. Pigtails should be replaced with connectors.

C. Evaluating A Mobile NDA Safeguards Measurement System

Before proceeding with the development of a mobile NDA safeguards system, it would be necessary to evaluate the advantages and disadvantages. Consideration of the numbers of locations containing

nuclear material, the availability of laboratory space and equipment at each location, and the practicality of moving equipment or nuclear materials will determine the necessity and feasibility of a mobile NDA safeguards system. The following is a short description of some of the advantages and disadvantages of the mobile NDA approach.

1. Advantages of a Mobile NDA Approach. The primary advantage of a mobile NDA safeguards system is that measurements and data evaluation may be performed where the nuclear material is located. This reduces the amount of transferring of nuclear materials or the amount of NDA instrumentation that is required. In cases where nuclear materials would be transferred for measurement, the use of a mobile NDA allows much more timely measurement as it is generally easier to move the NDA unit than the nuclear materials, especially where a large number of items is involved.

A secondary advantage of the mobile NDA safeguards measurement concept is that all measurements within a specific category can be performed with the same instrument by the same measurement personnel. This allows comparison of results for the same type of material located at different places. Also to be considered is that in the event of a contamination incident or special plant activities, the NDA instrument is easily transferred and set up in another location since the mobile NDA unit is self-contained. This is most effective if the mobile system is used to supplement a central laboratory and the mobile system is kept separate.

2. Disadvantages of a Mobile NDA Approach. The disadvantages listed here are numerous but it should be noted immediately that none are insurmountable and that not all of them apply to all the approaches of a mobile NDA safeguards measurement system previously described. Rather, these should be treated as a check list for consideration when developing a system. Some of the disadvantages listed below have no easy solutions but fortunately they can be treated as inconveniences that require greater patience and time to set up the NDA equipment and perform a given set of measurements.

Past experience has shown that the most readily identifiable disadvantage is the number of measurements that can be performed is limited by the manual recording and analysis of the measurement data. This is a significant problem in plutonium facilities where operator exposures must be considered. This is solved by the development of an automated measurement and data analysis system. The extent of development of such an automated system should consider that it is not always practical to return to perform replicate measurements. By extending the analysis of the data, the operator could identify all possible items that might require remeasurement. This package should record all available data.

When moving the equipment into a location where the material is present the operator must consider the possibility of contamination. This danger is reduced if the amount of equipment moved with the NDA instrument is reduced. In the case of the mobile system to be used in the demonstration, this has been accomplished by mounting the minicomputer and many of the electronics in the vehicle and connecting them to the NDA instrument with umbilical cords. This can also be accomplished by using a telephone connection from the NDA

instrument to the data processing system. Some of the problems associated with telephone links may be summarized as follows:

- Either the telephone line must be continuously tied up, a call must be placed after each count, or a method must exist for storing the raw data until the data can be transmitted.
- Telephone transmission rates are normally extremely slow. Transmission of a 1000 channel GE(Li) spectrum of 24 bits per channel at 10 cps is estimated to take about ten minutes per spectrum. Using a 30 cps system would still require about three minutes. Faster transmission rates are possible if a minicomputer, synchronous data transmission controller, and high speed modem are used.
- If an extension telephone is picked up during transmission, the system may be interrupted or some of the transmitted data garbled.
- The equipment would be limited to locations where good phone connections to a computer center are possible. During extended data transmission intervals (several minutes), our local experience has been that error rates are very high.
- If multidimensional spectra were to be transmitted, the volume of data would prohibit transmission over a telephone line.

When a mobile NDA measurements system is used the operator has less control over the background conditions. Factors to be considered include: background radiation, temperature variations, humidity variations, acoustical vibration, and power fluctuations. In general the effect of these factors is to increase the measurement uncertainties.

As the NDA equipment does not always operate in a predetermined place, there may not be a standard power supply. This may be handled by the use of gasoline or diesel generators. However, the use of generators is limited by the fuel supply. The PNL system is limited to about 20 hours of operation. At some locations combustion engines are not allowed. At other locations policy does not permit nuclear materials where the vehicle could be located. In general there will not be a routine place to set up the vehicle.

Environmental conditions present several problems when the material is to be measured outside, as would be the case with waste barrels. These include condensation on electrical connectors, acoustical effects from wind, and the effects of dust on mechanical equipment.

Safeguards and safety present several problems. Continuous operations of NDA in the vehicle are limited to the amount of nuclear materials allowed in the vehicle. If the NDA is performed inside the facility and the data is transmitted to a data processing system in the vehicle via an umbilical cord, often the vehicle cannot be placed close enough to the building or security prevents the cables from running through a door without the presence of a guard.

Another aspect to be considered in the development of a mobile NDA safeguards system is the extent of security involved in placing and removing the NDA equipment at a specific location. Guards may be required to observe the operators at all times since they are not normally members of the work force where the measurements are being performed. In some areas the operator is not allowed to handle nuclear materials, and normal area personnel are required to assist the NDA operator.

The lack of standard reference materials for equipment calibration is also a disadvantage of a mobile NDA safeguards system. By its nature a mobile NDA safeguards system will be used to measure a wide variety of materials in many locations. It is not always practical to have individual standards for the different forms or types of materials expected. With a mobile system it is not practical to construct standards at the measurement site, and it may not be practical or even possible to carry nuclear materials in the vehicle that could be used for standards.

D. Analysis of Costs

The cost of a mobile safeguards system is dependent on the concepts used. The cost can be divided into capital and maintenance components. The total cost of the PNL system was approximately \$250,000. This is broken down into \$50,000 for the vehicle (which includes power generators and the fire protection system), \$175,000 for hardware (which includes NDA instruments and the computer system), and \$25,000 for installation of the hardware. Typical maintenance costs are divided into approximately \$5,000 for a maintenance contract on the computer system, \$200 per year for the fire protection system, \$500 per year for miscellaneous items, and \$1,000 per year for replacement of gamma transmission and neutron interrogation sources.

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INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 29b: TOUR OF MODEL PLANT AND DEMONSTRATION OF MEASUREMENT
TECHNIQUES

The students will observe and participate in the weighing of UF_6 cylinders. They will observe the weighing of fuel pellet columns.

The analytical equipment and procedural steps for the gravimetric and fluorimetric methods will be shown. The students will also be given a tour of the mass spectrometer laboratory.

The active fuel rod scanner will be shown and its operation and technical basis explained.

The measurements of scrap containers will be illustrated by showing the students how SAM-2 enrichment meter measurements are made on 5-gallon containers and how those containers are weighed. The homogenization of scrap oxide powder is illustrated by showing how the 5-gallon containers are tumbled prior to sampling and the SAM-2 enrichment measurement.

After the session, the students will better understand the basis of the measurements and how they are actually performed.



The mass spectrometer laboratory



Participants examine data from the multiple Merker Burner Assembly (foreground).



SSAC Students, Course Staff, and Exxon Staff



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 30: CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES: ERROR
PROPAGATION

Statistical methods play an important role in making references about a MUF, shipper-receiver difference, operator-inspector difference, and other safeguards indices. This session considers the sources and types of measurement errors and treats a specific example to illustrate how the variance of MUF is calculated for the model plant.

After the session, participants will be able to:

1. identify the sources of measurement errors pertinent to safeguards for model plant and similar plants,
2. characterize the types of measurement errors as they affect the uncertainties of safeguards indices,
3. calculate the variance of any arbitrary function of random variables,
4. calculate the variances of the plant MUF for plants similar to the model plant.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 30: CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES:
ERROR PROPAGATION

John L. Jaech
Exxon Nuclear

Error propagation refers to the process in which the net effect of all errors affecting a given reported result is developed. When propagating errors, it is essential to have in mind a mathematical model that relates the random variable of interest to other variables or factors. With experience, it may not always be necessary to write the model explicitly, but the form of the model must be kept in mind.

A mathematical model is important for a number of reasons. It identifies the factors and establishes the importance of each to the random variable of interest (e.g., MUF); it dictates how the errors are to be propagated; it makes a distinction between the error types (systematic and random).

No mathematical model will ever provide a perfect description of reality, except perhaps in very simple cases. The aim in writing a model is to obtain a good approximation to reality. At the same time, the model should be sufficiently simple to permit error propagation without introducing undue complexities. A proper balance between these two objectives is essential.

The additive or linear model is the simplest one with which to work, and is often a suitable approximation to reality. However, in many safeguards applications, measurement errors are expressed on a relative basis; this calls for the use of a multiplicative model. Further, the amount of uranium or U-235, or of plutonium, is often determined by multiplying net weights or volumes by concentration. The model describing this process is clearly non-linear.

In developing error propagation formulas, an important result for the linear model is first developed. This is then applied to a non-linear model by approximating the non-linear model by a linear one through expansion of the model around the means of the random variables using the linear terms of a Taylor's series expansion. The specifics are as follows: For a linear model if

$$x = a_1x_1 + a_2x_2 + \dots + a_kx_k \quad (1)$$

where the a_i are constants, where x_1, x_2, \dots, x_k are random variables with means $\mu_1, \mu_2, \dots, \mu_k$ and variances $\sigma_1^2, \sigma_2^2, \dots, \sigma_k^2$, and with the covariance between x_i and x_j being σ_{ij} , then the mean and variance of x , denoted by μ and σ^2 respectively, are

$$\mu = a_1\mu_1 + a_2\mu_2 + \dots + a_k\mu_k \quad (2)$$

and

$$\begin{aligned} \sigma^2 = & a_1^2 \sigma_1^2 + a_2^2 \sigma_2^2 + \dots + a_k^2 \sigma_k^2 \\ & + 2a_1 a_2 \sigma_{12} + 2a_1 a_3 \sigma_{13} + \dots \\ & + \dots 2a_{k-1} a_k \sigma_{k-1,k} \end{aligned} \quad (3)$$

There are $k(k-1)/2$ covariance terms, some or all of which may be zero. Suppose that the model is now non-linear, written symbolically as

$$x = \phi(x_1, x_2, \dots, x_k) \quad (4)$$

This function may be approximated by

$$\begin{aligned} x \approx & (\mu_1, \mu_2, \dots, \mu_k) + \frac{\partial \phi}{\partial x_1} (x_1 - \mu_1) + \frac{\partial \phi}{\partial x_2} (x_2 - \mu_2) + \dots \\ & + \frac{\partial \phi}{\partial x_k} (x_k - \mu_k) \end{aligned} \quad (5)$$

This is now of the form (1) and so Equations (2) and (3) may be applied. In applying (3), $\phi(\mu_1, \mu_2, \dots, \mu_k)$ is, of course, a constant and does not affect the variance of x . The partial derivatives, all evaluated at μ_i for all i , are all constants, and represent the a_i constants of Equation (1). Thus, assuming that the approximation in (5) is valid, as is usually the case in safeguards applications, the approximation to the variance of x is

$$\sigma^2 = \sum_{i=1}^k \left(\frac{\partial \phi}{\partial x_i} \right)^2 \sigma_i^2 + 2 \sum_{i=1}^{k-1} \sum_{j>i} \left(\frac{\partial \phi}{\partial x_i} \right) \left(\frac{\partial \phi}{\partial x_j} \right) c_{ij} \quad (6)$$

Equation (6) forms the basis for calculating the variance of MUF and other safeguards indices. Calculation of the variance of MUF is now addressed.

The MUF for a material balance period is given symbolically by the formula:

$$MUF = I - O + BI - EI \quad (7)$$

where I = Inputs
 O = Outputs
 BI = Beginning Inventory
 EI = Ending Inventory

Each term in (7) may represent symbolically the net effect of a large number of measurements. Each measurement, in turn, may reflect several measurement errors, some systematic in nature and some random. Further, systematic errors may affect several individual items and, depending on their nature, may even affect items in more than one component of the MUF equation.

In principle, one can write down the complete model for a given MUF and calculate the variance of MUF by applying the propagation of errors formula just given. In practice, this is not done because of the hundreds of terms that would normally be included, except for a very simple material balance.

Some general rules for propagating errors in the MUF equation, i.e., for calculating the variance of MUF are given. These rules are based on strict application of the standard propagation of error formulas, but approximations may come into play when stating the assumptions on which the rules (or general formulas) are based. Moderate departures from some of these assumptions have negligible effect, as can easily be demonstrated. If there is concern about the importance of a departure from a given assumption, more exact calculations can be made.

Key assumptions underlying the general propagation of MUF errors formulas are as follows:

- A.(1) A stratum is composed of like materials and may contain several batches, where a batch is defined as a number of items related by a common element concentration factor. It is assumed that within a stratum, the number of items per batch is constant.
- A.(2) An average concentration factor is based on \bar{r} samples and \bar{c} analyses per sample. It is assumed that within a stratum, \bar{r} and \bar{c} are the same for all batches.
- A.(3) It is assumed that each measurement has an associated systematic error variance and random error variance, but that there are no short-term systematic error variances.

With respect to this last assumption, there are ways to extend the error propagation formulas if the assumption is not valid. This extension creates additional complexity in the model, and may often be avoided by appropriately modifying the input data.

As an example, in the calculation of the variance of MUF for the model plant, one key measurement point involves the weighing of the input UF_6 cylinders. From experience, it is known that the weighing operation is made up of three error types:

random standard deviation = 0.0286% relative
 short-term systematic (day to day) standard deviation = 0.0429%
 relative systematic standard deviation = 0.0107% relative

In the example, there are 84 cylinders received in 17 shipments, giving an average of 4.9412 (or about 5) cylinders per shipment. Assuming that all the cylinders in each shipment are weighed on the same day, then the effective random error standard deviation per cylinder is found by appropriately combining the random error and short-term systematic error standard deviations, as follows:

$$(.0286)^2 + 5(.0429)^2 = 0.100\% \text{ relative}$$

Alternately, and equivalently, one could consider each group of 5 cylinders and assign a random error standard deviation per group of

$$(.0286)^2/5 + (.0429)^2 = 0.045\% \text{ relative}$$

Another assumption is:

A.(4) Only one measurement method of each type is used in each stratum.

In practice, for a large plant, one would use several scales in certain strata. It is reasonable to assume that the same numbers of items are weighed on each scale and make simple modifications to the general formulas. This is illustrated in the lecture example.

A further assumption:

A.(5) A given element concentration factor does not apply to more than one stratum.

One can usually satisfy this assumption by appropriately defining strata. For example, all unsintered UO_2 powder, whether in powder or pellet form, can be combined into one stratum. It may also be that more than one stratum may have the same assigned factor, but the actual concentration factor would not be the same. This would be true, for example, of sintered pellets in inventory, say, and in the product stratum. It is the actual factor that is important. As a final note on assumption A.(5), if in fact strata are so defined such that a common actual concentration factor exists in more than one stratum, this can also be properly accounted for. This situation will often occur for the isotope, U-235, and methods of error propagation for the isotope can also be applied for the element.

In calculating the variance of MUF, most attention is focused on the element MUF as opposed to the isotope MUF. This is because major emphasis is given control of the element in plants where there are no changes in enrichment, other than those caused by blending. However, general formulas for calculating the variance of isotope MUF follow rather easily from those for element MUF. The principal difference is that for isotope MUF, there are common concentration factors that apply across several strata of material. When computing the effects of sampling and analytical errors on these factors, it is first necessary to algebraically sum the isotope amounts for common factors. If material in general is inputted and outputted at the same factors, it is clear that the impact on the variance of isotope MUF due to the uncertainty in the isotope concentration factors is minimal.



**INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



October 17-November 4, 1983

Session Objectives

SESSION 31: CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC

In continuing the discussion of Session 20, this session centers on calculating the variances of a difference statistic. This statistic arises in shipper-receiver difference analyses, and in inspection situations.

After the session, participants will be able to:

1. explain the role of statistics in making inferences based on variables inspection data.
2. calculate the variance of a difference statistic, either a shipper-receiver difference or a facility-inspector difference.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 31: CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC

John L. Jaech
Exxon Nuclear

Paired difference data arise in a number of situations in the safeguarding of nuclear materials. Such data are those in which a measured value obtained by one measurement method is compared on a one-by-one basis with a corresponding measured value for the same item obtained by a second method. This situation occurs with shipper-receiver data and also with inspection data. Also, within a facility, one measurement method may be compared with another by measurement of a number of items using both methods.

There are two types of statistical problems associated with the analyses of paired data. On the one hand, such data may provide estimates of measurement error parameters. This topic is covered later. The other problem that is statistical in nature involves calculating the variance of some function of the paired data, e.g., the total shipper-receiver difference, or the difference between facility and inspection data projected to evaluate its effect on the facility reported MUF. This latter problem is discussed in this lecture.

Calculation of the variance of difference data is introduced by considering shipper-receiver data for 22 cylinders of UF_6 in which the shipper's value of pounds of UF_6 is compared with the receiver's value for each of the cylinders. A number of points are made in the discussion of these example data:

- (1) One cannot simply apply the usual Student's t-test to see if the average (or total) difference between the shipper and the receiver is significantly different from zero. This statistical test, which would appear on the surface to be the logical one to apply, only takes into account the random error of measurement. It also ignores a priori information on the magnitudes of the random error variances for both parties.
- (2) It is important to keep in mind the structure of the data, (i.e., the mathematical model), when calculating the variance of the difference statistic. Otherwise, the errors are likely to be propagated incorrectly.
- (3) Known values for the measurement error parameters are used in calculating the variance of the statistic. One can use

the data to confirm the validity of the "known" values, and this confirmation becomes part of the analysis of such paired data.

The mathematical model is explicitly written for this example problem, and Taylor's series approximation is used to calculate the variance of the total shipper-receiver difference, expressed as pounds of U-235. For cylinder i , the shipper's value for pounds U-235 is written as a function of a number of measurement errors.

$$s_i = X_i \delta_s \theta_s \gamma_s \epsilon_{si} \omega_{sj} \nu_{sj} \quad (1)$$

where s_i = reported shipper's pounds of U-235 for cylinder i

X_i = true amount of U-235 for this cylinder

$\delta_s, \theta_s, \gamma_s$ = systematic errors of measurement for the shipper: weighing, uranium concentration analysis, and U-235 concentration analysis, respectively.

ϵ_{si} = random error in weighing for shipper, cylinder i

ω_{sj}, ν_{sj} = random errors in analytical for U concentration, respectively, for factors j , associated with cylinder i . (Several cylinders have the same element and isotope concentration factors).

Each error is assumed to be distributed with mean value of 1 and variance $\sigma^2 \delta_s, \sigma^2 \theta_s, \dots, \sigma^2 \nu_s$, respectively.

A similar model applies to the receivers' value, r_i , where the s subscripts are replaced by r subscripts. The overall shipper-receiver difference is then

$$S = \sum_{i=1}^{22} (s_i - r_i) \quad (2)$$

When errors are propagated using Taylor's series approximation, it is easily seen that:

$$\frac{\partial S}{\partial \delta_s} = \frac{\partial S}{\partial \theta_s} = \frac{\partial S}{\partial \gamma_s} = \frac{\partial S}{\partial \epsilon_{si}} = \frac{\partial S}{\partial \omega_{sj}} = \frac{\partial S}{\partial \nu_{sj}} = \sum_{i=1}^{22} x_i \quad (3)$$

$$\frac{\partial S}{\partial \epsilon_{si}} = \frac{\partial S}{\partial \epsilon_{ri}} = x_i \quad (4)$$

$$\frac{\partial S}{\partial \omega_{sj}} = \frac{\partial S}{\partial \omega_{rj}} = \frac{\partial S}{\partial \nu_{sj}} = \frac{\partial S}{\partial \nu_{rj}} = x_i \text{ for cylinders having concentration factor } j \quad (5)$$

The calculation of the variance of the total shipper-receiver difference, S , then follows very simply, as will be shown in the lecture.

Next, general formulas are illustrated for calculating the variance of a difference statistic. The formulas are similar to those given for calculating the variance of MUF, and are based on similar assumptions. The important difference is that measurement errors for both parties involved in the paired differences are factored in.

The difference statistic for inspection data is of particular interest. The inspector samples and measures a number of items in each of the material strata and compares his measured results with those given by the facility operator. The average difference per item in stratum k is denoted by \bar{d}_k . If there are N_k total items in stratum k , then $N \bar{d}_k = D_k$ is the projected total difference between the operator and the inspector in stratum k . This is algebraically summed over all strata to estimate the impact on the reported MUF of the operator-inspector differences. The key assumption is that the inspector results are unbiased so the purpose of the inspection is either to confirm that the operator's reported MUF is unbiased, i.e., that the total difference statistic does not differ significantly from zero, or else to adjust the Operator's MUF for biases as estimated from the paired difference data. The overall difference statistic, called the \hat{D} statistic, is of the form

$$\hat{D} = \sum_{k=1}^K A'_k D_k \quad (6)$$

where $A'_k = \pm 1$ depending on the stratum. For input and beginning inventory strata, $A'_k = 1$ and for output and ending inventory strata, $A'_k = -1$. With all differences being of the form: operator-inspector, and with D defined as in (6), then $(\text{MUF} - \hat{D})$ is the MUF value adjusted for operator bias.

The calculation of the variance of a difference statistic is demonstrated for selected strata of the LEU fuel fabrication facility.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 32: ESTIMATION OF MEASUREMENT VARIANCES

In the previous two sessions, it was assumed that the measurement error variances were known quantities when the variances of the safeguards indices were calculated. These "known quantities" are actually estimates based on historical data and on data generated by the measurement program. Session 34 discusses how measurement error parameters are estimated for different situations. The various error types are considered.

After the session, participants will be able to:

1. estimate systematic error variances from standards data,
2. estimate random error variances from such data as replicate measurement data,
3. perform a simple analysis of variances to characterize the measurement error structure when biases vary over time.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 32: ESTIMATION OF MEASUREMENT VARIANCES

John L. Jaech
Exxon Nuclear

The first problem under consideration is that of estimating biases or systematic errors by measuring known standards. Initially, it is assumed that the uncertainty in the assigned standard value is negligibly small.

The mathematical model is written very simply. Let x_i denote the i -th measurement on a standard with assigned value μ_0 . The model is

$$x_i = \mu_0 + \theta_1 + \varepsilon_i; \quad i = 1, 2, \dots, n \quad (1)$$

Here θ_1 is the bias or systematic error while ε_i is the random error, assumed to have zero mean and variance σ_ε^2 . A production item is then measured by the same measurement system, the measured value being denoted by y_j . Its structure is, (where T_j is the true value),

$$y_j = T_j + \theta_2 + \varepsilon_j \quad (2)$$

Clearly, it is only reasonable to correct y_j for the bias, θ_2 , if $\theta_1 = \theta_2 = \theta$. In this case, the bias θ is estimated by

$$\hat{\theta} = (\bar{x} - \mu_0). \quad (3)$$

and the y_j value adjusted for bias is

$$y_j' = y_j - \hat{\theta} \quad (4)$$

It is noted that in correcting y_j for the bias, it does not mean that y_j' is now free from bias. This is because y_j is not corrected for the bias, θ , but rather for the estimated bias, $\hat{\theta}$. The uncertainty in $\hat{\theta}$ affects all future observations similarly corrected for bias, and hence, becomes a systematic error. Specifically, the variance of $\hat{\theta}$ is, by (3), the variance of \bar{x} , which is σ_ε^2/n , and which is estimated by s^2/n , where s^2 is the sample variance among the n x_i measurements.

It does not necessarily follow that a bias correction will be applied, especially if it is either very small in magnitude, or if it does not differ significantly from zero in a statistical sense. The systematic error in the uncorrected y_j value may then be expressed by considering the mean square error of \bar{y}_j , defined to be

$$\begin{aligned} \text{MSE}(Y_j) &= E(Y_j - T_j)^2 \\ &= \theta^2 + \sigma_{\epsilon}^2 \end{aligned} \quad (5)$$

The quantity θ^2 may be regarded as a systematic error variance. It may be replaced by its maximum likelihood estimate, $(\bar{x} - \mu_0)^2$.

In another formulation of the problem, $\theta_1 = \theta_2$, but both θ_1 and θ_2 are drawn at random from a distribution with zero mean and variance σ_{θ}^2 . The aim of the experiment in which the standard is repeatedly measured is to estimate σ_{θ}^2 . Two estimates are considered. Denoting these by E_1 and E_2 , they are:

$$E_1 = (\bar{x} - \mu_0)^2 \quad (6)$$

$$E_2 = (\bar{x} - \mu_0)^2 - s^2/n \quad (7)$$

It is shown that although E_1 is biased in a statistical sense, and E_2 is not, yet there are reasons for preferring E_1 to E_2 . The net result is that, regardless of the assumed structure for θ_1 and θ_2 , the following simple rule may be applied:

Rule: If the bias correction is applied, the systematic error variance is s^2/n ; if it is not applied, this variance is $(\bar{x} - \mu_0)^2$.

The model is extended to include the possibility that the uncertainty in the standard value is not negligible. This uncertainty is added as a variance to the systematic error variance only if the bias correction is applied. Clearly, if the bias correction is not applied, the uncertainty in the standard value does not affect the uncertainty in the reported result.

It is not uncommon for biases to fluctuate from time to time because of changing measurement conditions, some known and identified and others not. Estimation of measurement error parameters in this situation is accomplished through a one-way analysis of variance. An example is considered to illustrate the analysis.

Turning to the estimation of random error variances, although such error variances can also be derived from repeated measurements of physical standards, it is preferable to base such estimates on replicate measurements of actual production items. This more nearly reflects all sources of variation likely to affect a given result. As with the case of the fluctuating bias, the one-way analysis of variance may also be used to provide estimates of random error variances. Some examples are given.

As a special case, when duplicate measurements are made on a number of items, with both measurements using the same technology, then analysis of the paired data provides a rapid method for estimating the random error of measurement. If d_i is the paired difference for item i , then the random error variance, σ_F^2 , is estimated by

$$\hat{\sigma}_r^2 = \sum_{i=1}^n d_i^2 / 2n \quad (8)$$

It is possible that the two measurements, possibly made at different points in time, are biased relative to one another. To guard against this possibility, another estimate of σ_r^2 might be preferable. This is

$$\hat{\sigma}_r^2 = s_d^2 / 2 \quad (9)$$

Where s_d^2 is the sample variance among the d_i values.

Equations (8) and (9) assume that both measurements are made by the same method, or at least have the same measurement error variance. In the event two measurement methods are used (as might occur, for example, with shipper-receiver or with inspection data), then d_i^2/n or s_d^2 estimates $\sigma_1^2 + \sigma_2^2$, the random error variances for methods 1 and 2, respectively. One can, under certain conditions, obtain separate estimates of σ_1^2 and σ_2^2 by a modified data analysis, called the Grubbs' method. With this method, letting s_i be one method's measurement of item i and r_i be the other, compute s_s^2 and s_r^2 , and also s_{sr} , where s_{sr} is the sample covariance among the s_i, r_i values, given by

$$s_{sr} = \left(\sum_{i=1}^n s_i r_i - \sum_{i=1}^n s_i \sum_{i=1}^n r_i / n \right) / (n - 1) \quad (10)$$

Then, the estimates of σ_s^2 (associated with s_i) and of σ_r^2 are:

$$\hat{\sigma}_s^2 = s_s^2 - s_{sr}; \quad \hat{\sigma}_r^2 = s_r^2 - s_{sr} \quad (11)$$

The Grubbs' method for two measurement methods will only provide useful estimates if the measurement errors are large relative to the variation among the items being measured. The method can easily be extended if more than two measurement methods are used. In this event, the item-to-item variation does not affect the quality of the measurement error estimates. The estimation procedure involves forming all columns of paired differences for the $N(N - 1)/2$ pairs of measurement methods, N being the number of such methods. The variance is calculated for each column of differences, and each variance estimates the sum of the measurement error variances for the measurement methods comprising the difference in question. The $N(N - 1)/2$ equations in the N unknowns are easily solved by least squares to provide the estimates of the N parameters. An example illustrates the method.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 33: TOURS OF WNP-1 and FFTF MUSEUM

Participants will be transported to WNP Unit #1 for a tour of a nuclear power plant under construction. Then the participants will be taken to the DOE Fast Flux Test Facility Visitor Center.



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SESSION 33: TOURS OF WNP-1 and the FFTF MUSEUM

Participants and course staff were transported to WNP unit #1, a pressurized water reactor under construction and approximately 60% complete. The tour of the facility was a unique opportunity for a close-up view of a large nuclear power plant, not possible in operating facilities. Figure 1 shows a schematic view of unit #1. WNP unit #2, a boiling water reactor facility, was in the fuel loading stage during our visit. A schematic of that plant is shown in Figure 2.

Following the tour of WNP-1, the group was taken to the Fast Flux Test Facility (FFTF) museum. The FFTF staff presented detailed information on the status of the project, and the attendees had an opportunity to examine displays of the FFTF facility and its components.

A HANFORD PROJECT FACT SHEET • WASHINGTON PUBLIC POWER SUPPLY SYSTEM

WNP-1/4 FACTS**GENERAL INFORMATION**

Location Hanford, Wash.
 Number of units 2
 Type Pressurized water reactor
 Reactor Babcock & Wilcox
 Turbine generator Westinghouse

Containment ... Reinforced steel structure
 with a welded steel liner plate
 attached to the inside face of the shell
 to function as gas/vapor barrier
 Generating capacity . 1250 MW each (net)
 Seismic design 0.25G acceleration

Cooling Tower, forced draft
 Site Approximately 972 acres
 Access By plant road from Rt. 4
 By plant rail spur from U.S. Govt. RR
 By barge at Columbia River mile 343

WNP-1/4 PROJECT FACTS

The WNP-1/4 Project is large and complex. Consider that the project will include:

ELECTRICAL

2,776 miles of electrical cable, enough to reach from Seattle to New York city.

CIVIL

5,800,000 cubic yds. of earth moved (equivalent to a city block stacked about 81 stories high with dirt). 534,200 cubic yds. of concrete placed, enough to build a 70-mile highway. Structures include 37,600 tons of structural steel and 77,903 tons of reinforcing steel—enough to make more than 543 miles of railroad track.

PIPING

More than 109 miles of large pipe and 82 miles of small pipe (2-inches and under in diameter) will be installed—enough to reach from the Hanford site to Seattle.

CONTAINMENT

A steel liner ranging from ¼ to ¾ in. thick is surrounded by 4½ ft. thick steel-reinforced, concrete walls. The building is 150 ft. across and 23 stories high (235 ft.) with a domed top. It encloses the Babcock and Wilcox nuclear steam supply system. Additional shielding walls surround the reactor vessel itself.

REACTOR VESSEL

With internals, the reactor vessel weighs 1,107 tons. It measures 43 ft. high and 15 ft. across with steel walls 9¼ in. thick. Water will flow in at 569°F and out at 676°F to steam generators, also in containment.

FUEL AND CONTROL ASSEMBLIES

93.5 metric tons of uranium oxide (UO₂) pellets, enriched with U-235 to 1.9-2.9 percent of weight. Fuel pellets are encased in Zirconium tubes. There are 264

tubes per assembly with 205 assemblies making up the reactor core. 76 roller nut drives move the control rods in or out of the core. Core thermal power is 3,760 MW.

STEAM GENERATORS

Two per plant, each weighing 540 tons; 75 ft. long, 12.5 ft. in diameter. Combined steam output from both steam generators is 16.7 million pounds/hour, 1,060 psia.

REACTOR COOLANT PUMPS

Four 12,500-hp pumps, turning 1,800 rpm, pump 108,000 gpm through the primary loop (reactor vessel and steam generators).

GENERAL SERVICES BUILDING

Adjacent to the reactor building, measures 363 ft. long and 223 ft. wide. Overall height is 120 ft. with 82 ft. below ground. Contains fuel-handling and storage facilities, plant control room, and systems to support operation of the nuclear steam supply system.

TURBINE GENERATOR BUILDING

The turbine generator for each plant is a Westinghouse unit situated in the high bay of the turbine generator building. The building is 200 ft. wide, 323 ft. long and is 132 ft. above ground level. Each unit rotates at 1,800 rpm to produce 1,250 MW of power.

FORCED DRAFT COOLING TOWERS

Cooling water is pumped from condensers to three circular cooling towers for each plant. Each tower measures 242 ft. in diameter at the base and is 63 ft. high. 19 mechanical fans each 28 ft. in diameter draw air through the tower to cool the water.

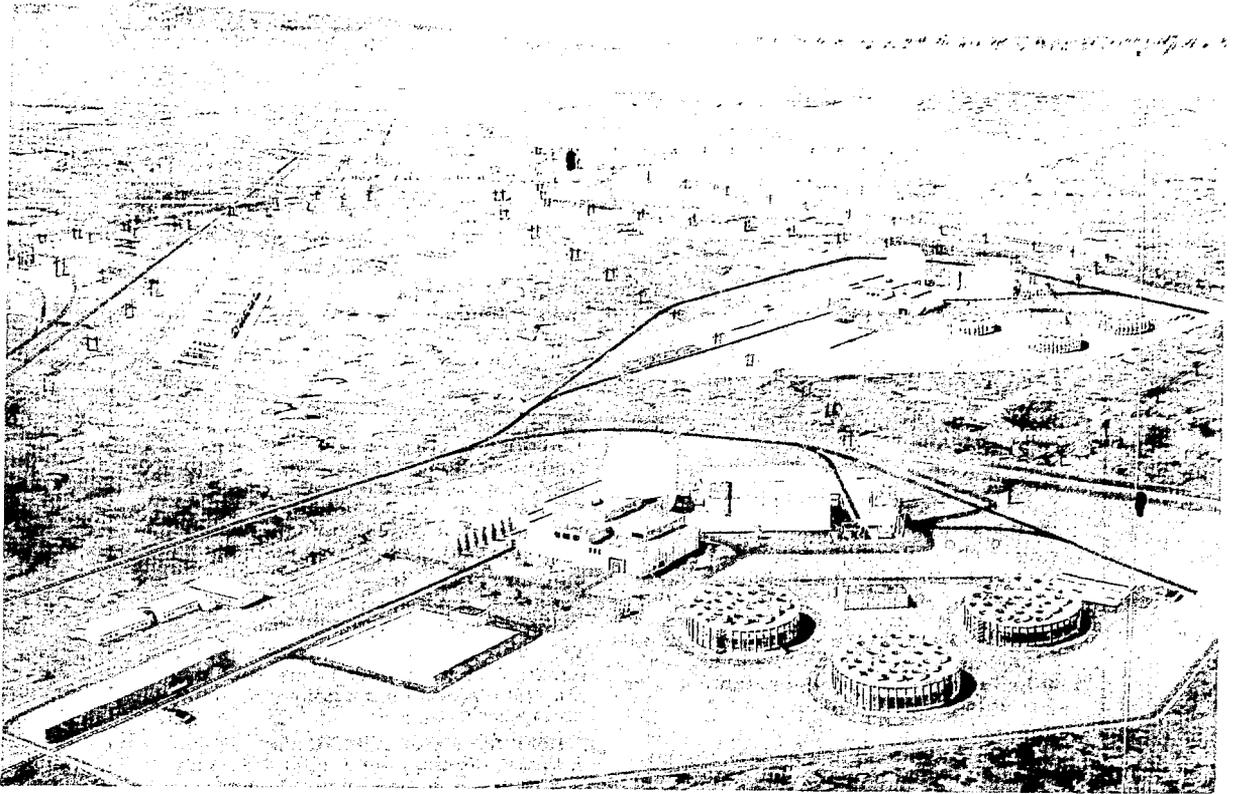


Figure 1. View of WNP Unit 1.

A HANFORD PROJECT FACT SHEET • WASHINGTON PUBLIC POWER SUPPLY SYSTEM

PLANT 2 FACTS**GENERAL INFORMATION**

Location.....Richland, Wash.
 Number of units.....1
 Type.....Boiling water reactor
 Reactor.....General Electric

Turbine generator.....Westinghouse
 Containment.....Mark II, over/under
 pressure suppression steel vessel
 with concrete outer barrier
 Generating capacity.....1,100 MW

Cooling.....Forced draft towers
 Site.....Approximately 1,089 acres
 Site access.....By plant road from Rt. 4
 Fuel load.....Fall 1983
 Commercial operation.....Spring 1984

PLANT 2 FACTS

The WNP-2 Project is large and complex. Consider that the project includes:

ELECTRICAL

1,570 miles of electrical cable—enough to reach from Seattle to San Francisco and back.

CIVIL

194,432 cubic yds. of earth moved (equivalent to a city block stacked about 3 stories high with dirt). 192,000 cubic yds. of concrete placed. If laid flat, the framework would cover approximately four city blocks (453,622 sq. ft.). Structure includes 19,217 tons of reinforcing steel and 5,879 tons of structural steel—enough steel for more than 124 miles of railroad track.

PIPING

More than 40 miles of large pipe and 24 miles of small pipe (2-in. and under in diameter) have been installed—enough to reach from the project site to Yakima.

REACTOR BUILDING

20 stories tall. Inside, surrounded by 5½ ft. thick wall of steel reinforced concrete, is the 85 ft. diameter cylindrical containment vessel with a conical top section. The vessel stands 16 stories (163 ft.) tall and has 1¼ in. thick steel walls.

REACTOR VESSEL

A 1,140-ton vessel (with internals) is 76 ft. high and 21 ft. across, with steel walls ranging from 6-9 in. thick. Water flows in at 420°F and is heated to 547°F. Steam exits at 541°F. Steam output is 14.3 million pounds/hr. Steam pressure is 970 psia. Core thermal power is 3,323 MW.

FUEL ASSEMBLIES

139.3 metric tons of uranium oxide (UO₂) pellets. Enrichment ranges from .71 to 3.0 percent U-235 by weight. Pellets are encased in Zirconium (Zircaloy-2) tubes—64 per assembly. 764 fuel assemblies make up the reactor core. 185 locking-piston drives can move boron carbide control rods in or out of the core.

REACTOR COOLANT PUMPS

Two 8,900 hp pumps turning 1,780 rpm can each pump up to 47,200 gpm through the recirculation system.

RAD-WASTE AND CONTROL BUILDING

Measures 209 ft. x 160 ft. high and contains the plant control room and systems to support operation of the nuclear steam supply system.

TURBINE GENERATOR BUILDING

A Westinghouse turbine generator is situated in a large building 190 ft. wide and 300 ft. long. The turbines and generator will turn at 1,800 rpm to produce 1,100 MW of power.

FORCED DRAFT COOLING TOWERS

Cooling water is pumped from condensers at 570,000 gallons per minute to six cooling towers. The towers are 55 ft. high and 200 ft. at the base. Water is poured over fill material and 6 fans pull air through the fill material, cooling the water. 16,000 gpm are pumped into the system to make up for evaporation.

SPRAY PONDS

Two spray ponds provide a back-up cooling system. Each pond holds 6.2 million gallons of water. The water can then be sprayed above the ponds to cool it.

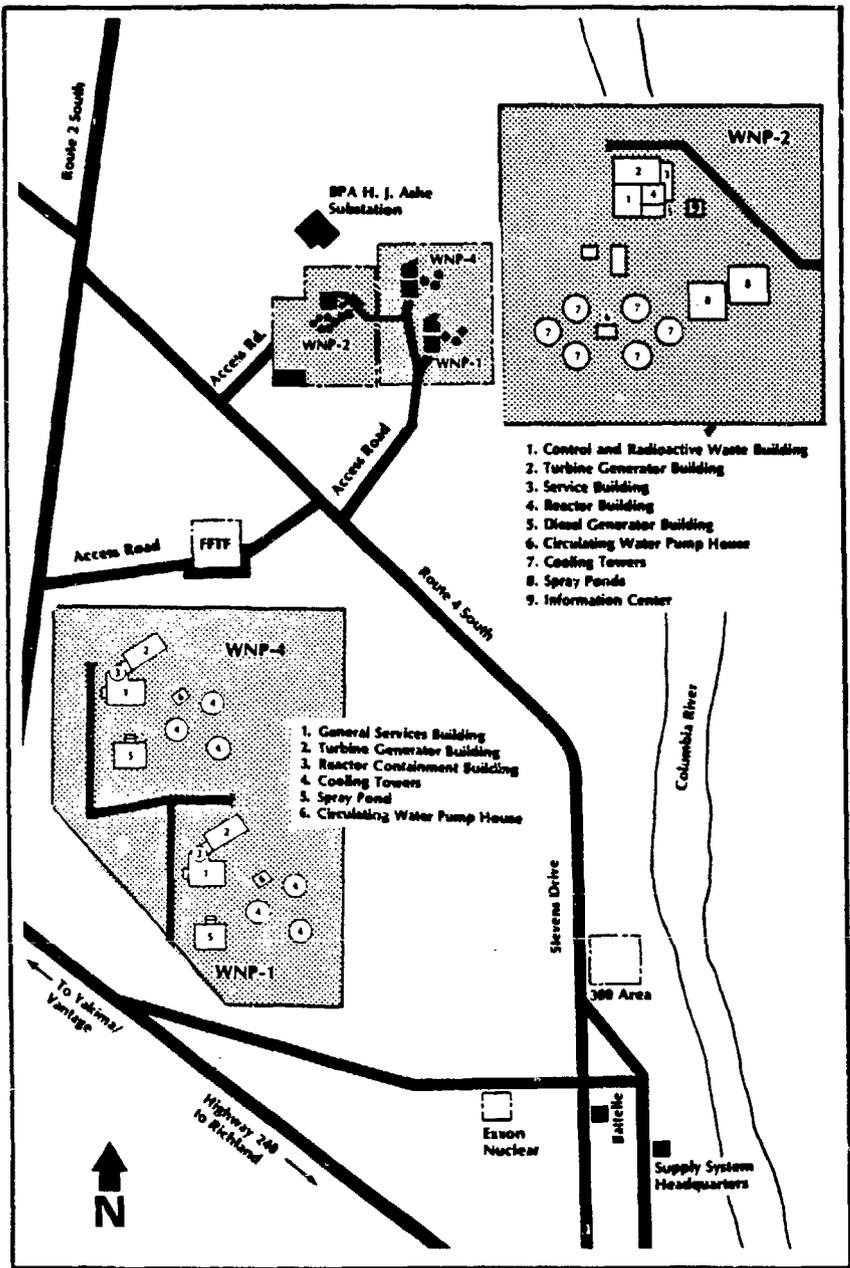
SIGNIFICANT PROJECT ACHIEVEMENTS

WNP-1

Site certified by state.....	6/75
Limited work authorization issued.....	8/75
Construction permit issued.....	12/76
Initial structural concrete placed....	5/76
Piping installation started.....	8/78
Electrical installation started.....	8/78
Reactor pressure vessel set.....	9/79
Dome containment set.....	3/81
Received "N" certificate.....	6/82
Completed containment concrete.....	4/82
Extended construction delay.....	4/82
Containment structural integrity test.....	1/83

WNP-4

Site certified by state.....	6/75
Limited work authorization issued.....	8/75
Initial structural concrete placed....	11/76
Construction permit issued.....	2/78
Piping installation started.....	4/80
Electrical installation started.....	4/80
Slowdown recommended.....	6/81
Plant terminated.....	1/82

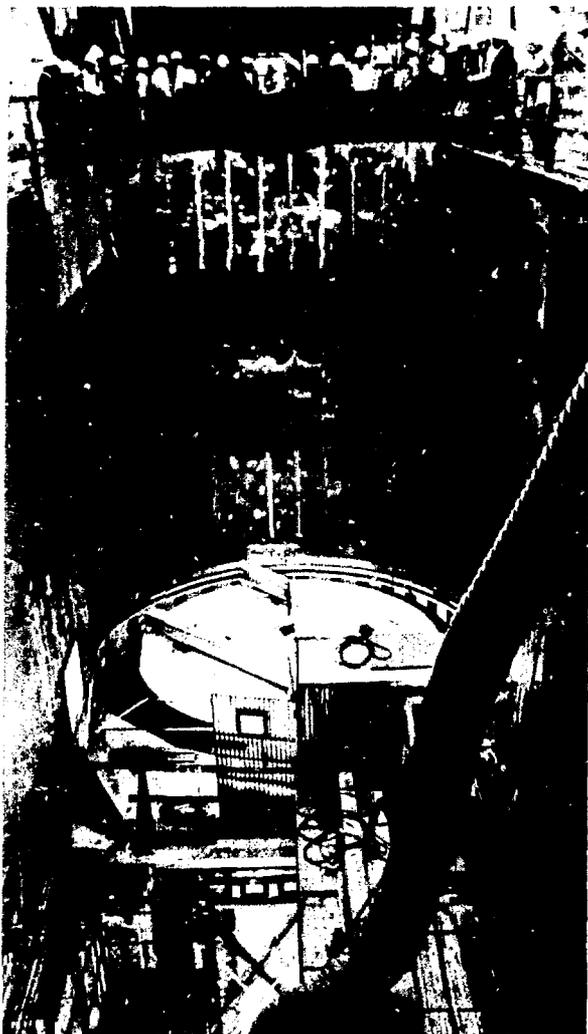


SIGNIFICANT PROJECT ACHIEVEMENTS

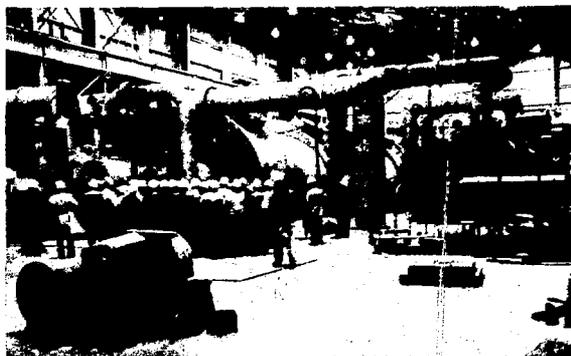
WNP-2

Site certified by state.....	5/72
Limited work authorization issued.....	8/72
Construction permit issued.....	3/73
Initial structural concrete placed....	5/73
Reactor pressure vessel set.....	3/77
Systems acceptance testing initiated.....	11/77
Final safety analysis report issued.....	3/78
Reactor building structure completed.....	1/79
Turbine on turning gear.....	1/82
Vacuum test on main condenser....	6/82
Hydrostatic test of the reactor pressure vessel.....	8/82
Wetwell completed.....	8/82
Began preoperation tests on the nuclear steam supply system....	1/83
Received nuclear fuel.....	5/83
Emergency preparedness drill.....	6/83
First group of operators receive NRC licenses.....	8/83
Security system operational.....	8/83
Plant systems turned over from construction to operations.....	9/83

THE WNP-1 TOUR



Getting a rare view
of the Reactor core
pit



Looking Over the Reactor
Control Room



Taking in the turbine generators



Visit to the FETF Visitor Center



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October 17-November 4, 1983

Session Objectives

SESSION 34: STATISTICAL SAMPLING PLANS

In auditing and in inspection, one selects a number of items by some set of procedures and performs measurements which are compared with the operator's values. This session considers the problem of how to select the samples to be measured, and what kinds of measurements to make. In the inspection situation, the ultimate aim is to independently verify the operator's material balance. The effectiveness of the sample plan in achieving this objective is briefly considered. The discussion focuses on the model plant.

After the session, participants will be able to:

1. understand the basis for inspection plans and procedures,
2. perform simple calculations for selecting attributes inspection sampling plans,
3. understand how a sample plan may be evaluated for effectiveness.



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SESSION 34: STATISTICAL SAMPLING PLANS

John L. Jaech
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In auditing for such anomalies in an accountability system as clerical errors and procedural violations, attributes inspection sampling plans are used. Such plans are also used as part of the verification of facility MUF, where, as an initial step, assurance must be provided that there is not an intolerable frequency of large discrepancies between book and actual values before closer inspection using the \hat{D} statistic is implemented.

In attributes inspection, each sampling unit or item is classified as being either acceptable or a defect based on some defect criteria. Specifically, the statistical problem in inspection planning for attributes inspection may be stated as follows:

Let N = number of items in population
 n = number of items in sample (sample size)
 D = number of defects in population of size N
 d = number of defects in sample of size n .

The number of defects, d , is observed. If d equals or exceeds some critical value, d_0 , then the audit is declared to be unacceptable. From an inspection design viewpoint, the problem is to select values for n , the sample size, and d_0 , the critical value.

To choose n and d_0 , two criteria are set up:

1. If $D = D_0$, conclude that the audit is unacceptable with small probability, α . D_0 corresponds to "acceptable" quality.
2. If $D = D_1$, conclude that the audit is unacceptable with large probability, $(1 - \beta)$. D_1 corresponds to "unacceptable" quality.

The problem is not a simple one to solve. For a population of finite size, N , the random variable, number of defects in the sample, is distributed according to the hypergeometric probability density function. Although some tables exist that give solutions to the problem, the tables are necessarily very limited in scope because of the large number of parameters involved.

Two solutions to the problem are discussed in the lecture. One solution is given for N large relative to n , in which case the random

variable is approximately distributed according to the binomial density function. The solution is based on an approximation to this latter function. In the other formulation of the problem, the special case in which $d_0 = 1$ is considered. This solution is often used by the IAEA in their attributes inspection plans, and is very simple to remember and apply. The sample size is given by

$$n = N(1 - \beta^{1/D}) \quad (1)$$

In applying this formula to the problem in which a quantitative verification of the facility MUF is to be made, it is applied in each stratum in two ways:

1. In attributes inspection for "gross" defects, the largest defect is assumed to be \bar{x} , the average amount of element per item. The goal quantity of M units (same units as x) is assumed to be achieved in each stratum. The number of defects, D_1 , is then M/\bar{x} .
2. In attributes inspection using variables measurements, a "medium" defect is assumed to be one that would escape detection if inspected by the attributes tester. The size of a medium defect is assumed to be $\gamma\bar{x}$ so that D_1 is $M/\gamma\bar{x}$.

As a final part of quantitative verification, the \hat{D} difference statistic discussed previously is used to investigate the significance of small biases. Specifically, their cumulative effect on the facility MUF is measured by the \hat{D} statistic. From an inspection planning viewpoint, the problem is to choose the number of measurements to perform in each stratum. This is done to meet the following type criterion:

Criterion: If the true value for the difference statistic, \hat{D} , is M units, detect this fact with a statistical test using \hat{D} with probability $(1 - \beta)$. The significance level of the statistical test is α . This is a common type statistical problem in selecting a sample size and critical value, but is somewhat complicated by a number of considerations:

1. One must not only determine the entire sample size, but must also allocate the total sample size among the various strata. This is done by allocating such that the variance of \hat{D} is minimized for fixed total sample size.
2. Because of limitations imposed by systematic errors, it may not be possible to meet the criterion. In this case, the relationship between sample size and \hat{D} is examined and some compromising value is chosen for the sample size.
3. The variance of \hat{D} under the alternative when its mean is not zero may be larger than that under the null hypothesis when its mean is zero. This will affect the sample size, and, in planning, an inflation factor on this variance should be applied.

In a full scale general solution to the problem there are a number of parameters that may be identified. In addition to assigning values to M , α , β , and C^2 (the variance inflation factor), one can also perform the planning for the $(MUF - \hat{D})$ statistic rather than the \hat{D} statistic. The general formula is solved for the specific case in which $\alpha = \beta = 0.05$, $C^2 = 4$, and the \hat{D} statistic is used. In this event, the sample size is inversely proportional to

$$0.2053 m^2 - 0.1642 m \sqrt{6.0886 m^2} \quad (2)$$

where m is the ratio of M to the systematic error standard deviation for the \hat{D} statistic.

A numerical application is made to the model plant discussed in previous lectures.

In inspection planning, it is assumed that all M units (the goal quantity) is diverted by the particular route to be responded to by the given inspection. For example, in determining the sample size for attributes inspection in stratum k , it is assumed that all M units are diverted through large defects (data falsifications) in that particular stratum. Clearly, if any amount smaller than M units is so diverted, the probability of detection will be less than the design value of $(1 - \beta)$ for that particular part of the inspection.

There are, of course, a virtually limitless number of strategies that might be used by the diverter to accumulate his goal quantity of M units in a material balance period. For any given strategy, one can calculate the probability of non-detection (or its complement, the probability of detection) for the statistical tests employed. "Detection" occurs if at least one of the following conditions occurs:

1. A gross defect is found in at least one of the strata using the attributes tester
2. A defect is found in at least one of the strata using the variables tester in the attributes mode.
3. The absolute value of the \hat{D} statistic exceeds its critical value, i.e., there is statistical evidence that the mean of \hat{D} is not zero.
4. The operator's calculated MUF exceeds its critical value, i.e., there is statistical evidence that the mean value of MUF is not zero.

As an alternate to steps (3) and (4), one may not perform separate tests of significance for \hat{D} and MUF but may choose to detect the combined effects of two diverter strategies (diversion by small data falsifications and into MUF). Thus, (3) and (4) may be replaced by:

5. The $(MUF - \hat{D})$ statistic exceeds its critical value, i.e., there is statistical evidence that the mean value of $(MUF - \hat{D})$ is not zero.

There are distinct operational advantages using $(MUF - \hat{D})$ as the test statistic rather than \hat{D} and MUF separately. Most importantly,

both \hat{D} and MUF require information about the operator's systematic errors. This information is often difficult to develop or, if available, may be poorly based and somewhat unreliable. On the other hand, the $(MUF - \hat{D})$ statistic is independent of the operator's systematic errors. It does, of course, require information about the inspector's systematic errors but such information is easier to derive and, from the inspector's viewpoint at least, should be more reliable.

As another advantage of the $(MUF - \hat{D})$ statistic, when calculating the probability of non-detection by the \hat{D} and MUF tests separately administered, one must take into account the covariance between \hat{D} and MUF. This can be done, but the computations can be complicated involving table look-up in a table of bivariate normal distribution. Computer programs do exist that perform the calculation of non-detection probabilities for \hat{D} and MUF, but unless such a program is available to the user, or unless a table of the bivariate normal distribution is available, the non-detection probabilities for the \hat{D} and MUF test in combination cannot even be calculated. This is not the case with the $(MUF - \hat{D})$ statistic. In passing, it is noted that one cannot simply ignore the covariance between \hat{D} and MUF and assume that the test statistics are independent; this is far from true and gives incorrect and misleading results.

The interesting relationship among MUF, \hat{D} , and $(MUF - \hat{D})$ variances is, for the case in which both parties do not commit the same systematic errors:

$$V(MUF - \hat{D}) = V(\hat{D}) - V(MUF) \quad (3)$$

This may also be written as:

$$\text{Covariance } (\hat{D}, MUF) = V(MUF) \quad (4)$$

Equation (3) is basic in the evaluation of the inspection plans. Since $V(\hat{D})$ and $V(MUF)$ will already have been calculated, $V(MUF - \hat{D})$ follows immediately.

Restricting further attention to points (1), (2), and (5) detailed above, the probability of non-detection for a given diverter strategy reduces to

$$Q = \beta^{a_2} Q_1 \quad (5)$$

where a_2 is the fraction of M diverted into some combination of large and medium data falsifications, where β is the design parameter for all strata in the attributes inspection (or the largest such value if is not the same for all strata), and Q_1 is the probability of non-detection of an amount $(1 - a_2)M$ with the $(MUF - \hat{D})$ test. The probability Q_1 is a function of how the diverter splits the amount $(1 - a_2)M$ into MUF and into D. Thus, the strategy space open to the diverter involves his choice of a_2 and his further choice on how much of the remaining amount of M, the goal quantity, is diverted into MUF.

The quantity Q_{Max} is that value of Q corresponding to optimal diverter strategy, i.e., that strategy which yields the largest value for Q .

An example application dealing with the inspection of the model plant is given. The example illustrates how strongly dependent on diverter strategy is the probability of non-detection.



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Session Objectives

SESSION 35: TYPICAL NRC INSPECTION PROCEDURES FOR MODEL PLANT

A summary of NRC inspection procedures for a model LEU fuel fabrication plant will be presented. Procedures and methods for combining inventory data, seals, measurement techniques, and statistical analysis will be emphasized. Questions from participants will be encouraged and answered.



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SESSION 35: TYPICAL NRC INSPECTION PROCEDURES FOR MODEL PLANT

J. Blaylock
United States Nuclear Regulatory Commission

I. INTRODUCTION

The NRC inspection program for low enriched uranium (LEU) fabrication plants is designed to assure that effective, on-going safeguards are maintained. The inspection program has been segmented into modules; the routine program assigns an inspection frequency for each module.

For LEU fuel fabrication plants the routine inspection effort includes the following modules and the indicated frequency of application:

85202	Facility Organization	Annual
85204	Facility Operation	Annual
85206	Measurement Control	Annual
85208	Ship/Rec. Verification	Annual
85210	Internal Control Program	Annual
85212	Physical Inventory	Annual
85213	Inventory Verification	Annual
85214	ID/LEID Evaluation	Annual
85216	Records and Reports	Annual
85218	Nuclear Material Control Management	Annual
30703	Ent/Exit Management Meetings	
92706	Independent Inspection	On-going

The inspection program schedules four routine visits a year; most modules will be completed during these visits. Some modules may be completed during a single visit, others may require more than one visit. The manpower allocated for the inspection program at a given facility is based on prior inspection experience and projection by the appropriate regional office.

The safeguards inspection program draws the program requirements from three sources: 10 Code of Federal Regulations (CFR), the Materials and Plant Protection Amendment (license conditions), and the approved Fundamental Nuclear Material Control (FNMC) plan submitted in accordance with 10 CFR Part 70.51, 70.57, and 70.58.

The 10 CFR is the most general document, giving a broad framework for the safeguards program. In response to 10 CFR requirements, licensees submitted written programs in three sections. The 10 CFR 70.51 plans were implemented during 1974 and cover tamper-safing, inventory frequency, record keeping requirements, and ID/LEID. The 10 CFR 70.58 plans were implemented during 1976 and cover such topics

as organizational structure, separation of function, the material balance area/item control area (MBA/ICA) structure, reviews and audits, scrap controls, and inventory procedures. The 10 CFR 70.57 program was implemented during 1978-79 and covers measurement control. Collectively, these three sections comprise the fundamental nuclear material control program.

The MPP amendment (licensee conditions) either gives exemptions to 10 CFR requirements or places additional requirements on the licensee.

II. TEXT

The individual inspection modules will next be described. Each inspection module describes specific areas for the inspector to examine. The purpose is to make the inspection both uniform and comprehensive among Regional Offices.

A. Module 85202: Facility Organization

This module examines the management structure of the organization, the safeguards function within that organization, the authority and responsibilities assigned to the management positions, and the reporting channels established by written procedures.

To complete this module the following items are checked:

- The safeguards material control and accounting function is vested in a single individual; this requirement prevents the fragmenting of the program among several functions or offices. This designated individual is the primary contact at a facility for questions or requests for information about the safeguards program.
- The safeguards manager is independent of production functions. The individual responsible for administering the program should have the safeguards program as his primary function. This prevents conflicts with production schedules or responsibilities.
- The safeguards organization structure identifies key positions and is approved by NRC.
- Delegation of the MC&A responsibility and authority has been established in writing. This pinpoints individual authority and responsibility for such positions as control coordinator, custodians, measurement control coordinators, and various safeguards staff function.
- Reporting channels for safeguards are clearly defined. The safeguards program generates information that flows up and down the organizational structure. By clearly defining the reporting channels, both routine and nonroutine information are directed to the individual responsible for reviewing or responding to the data.

- o Management conducts annual reviews and audits of the safeguards program. An audit confirms the accuracy and flow of information. The review assures that the program is adequate in fulfilling the requirements as set forth by regulations, license conditions, and other legal authority.
- o Recommendations contained in the licensee's annual review and audit have been implemented.

B. Module 85204: Facility Operation

This module in the LEU fabrication plant inspection program focuses on the facility operation within the constraints of the fundamental fuel cycle license, the MBA/ICA structure, and changes to the FNMC plan. This module includes checks of:

- The special nuclear material (SNM) license is current. If the license is active but has expired, the licensee must have a renewal application pending action by NRC.
- Current conditions of the license are confirmed. Among those items that are checked are ownership, authorized SNM possession limits, type of activity, and type, form, and enrichment of SNM at the facility.
- The MBAs/ICAs must be described in the FNMC plan. The MBA/ICA structure should be sufficiently small as to allow the localization of losses. As an example, assume one area consistently shows an inventory gain and another processing area consistently shows an offsetting inventory loss. The MBA structure should be able to identify such conditions so that corrective action can be taken before a significant inventory difference is reported.
- Custody and control of the SNM within the MBA/ICA are consistent with the approved FNMC plan. A custodian may have control over only one MBA and cannot sign a material transfer form both as shipper and receiver. A custodian may have multiple ICAs; however, an authorized alternate must sign the material transfer form as either shipper or receiver to preclude the custodian from signing the form twice.
- Changes to FNMC plan are submitted to the NRC on a timely basis. If the licensee plans to make any significant changes to the safeguards program, prior approval by NRC is required before implementation becomes effective. Examples of such changes would be major process modifications, reorganization of the safeguards, and so on. If the licensee makes minor changes that do not decrease the effectiveness of the safeguards, the changes may be implemented, provided the NRC is notified within the statutory time limits specified in 10 CFR Part 70. These latter changes are made in accordance with 10 CFR Part 70.32(c).

C. Module 85206: Measurement Control Program

Another area that is examined at a LEU fabrication plant is the measurement control program. A module that addresses this subject covers all aspects of measurement control. This segment of the inspection program assures the credibility of the licensee's accountability measurements and includes such topics as measurement techniques, standards, calibration, training of personnel, and generation of error data to calculate limit of error associated with inventory differences and SRDs. Items checked included:

- Overall program management is vested in the measurement control coordinator. The safeguards manager cannot be designated the measurement control coordinator.
- The measurement control plan has primary responsibility for developing, planning, coordinating, and administering the measurement control program. This assures that the program is not fragmented among various functions.
- The measurement control plan is current. Chapter Four of the FNMC plan describes most of the measurement control program. This chapter should accurately define the program, as implemented.
- Mathematical models for determining random and systematic errors are appropriate and described in the FNMC plan. All accountability measurement systems, such as mass, volume element analysis, isotopic analysis, and NDA are to be included, as appropriate.
- Calibration and control of measurement systems are described in the approved FNMC plan. Also, the licensee should describe criteria for recalibration once every two months regardless of standards data, or until such time as standards data fall into the warning region or the out-of-control region. The number of standards measured at the time of calibration, the range of calibration, and the use of point calibration should be included in the description.
- Control charts monitor the measurement system performance. Related areas to be inspected include the warning limits and out-of-control limits associated with control charts and actions taken when these limits are exceeded.
- Control chart limits are updated periodically and on a timely basis. This should be addressed in the FNMC plan.
- The measurement control program is subject to an annual audit. This may be done at the same time as the audit required by 10 CFR 70.58. The results must be forwarded to higher management and any identified weaknesses corrected.

- If the licensee uses a contractor laboratory for SNM measurements, the measurement control program of the contractor laboratory is subject to an annual audit. This audit may be conducted by either the licensee or his designated agent. The inspector also verifies that the contractor laboratory provides adequate measurement information to the licensee for his use in the measurement control program.
- The licensee must maintain a current list of reference standards. This includes both standards purchased from the National Bureau of Standards or other recognized sources and any working standards fabrication by the licensee or his agent.
- Records and reports are accurate and timely.
- Training is described for personnel measuring SNM. This training may consist of classroom instruction, reading assignments, on the job training, or some combination of methods.

. Module 85208: Shipper/Receiver Verification

An important area to be explored during the inspection is the shipper/receiver verification. This segment of the program compares the measurement capabilities of both parties. Thus, this module verifies the control over shipment and receipt of SNM at the licensed facility. Elements of the module are:

- Shipments of SNM are made to authorized recipients only. The licensee is responsible for validating the recipients' authorization.
- The shipper is responsible for completing a Material Transfer Document (Form 741) and mailing it the same day the SNM is shipped.
- The licensee has an active shipper/receiver program to monitor and evaluate:
 1. Identification and measurement of SNM shipped and received,
 2. Review and evaluation of shipper/receiver data on an individual or lot basis, as appropriate,
 3. Action taken to investigate and correct statistically significant differences, and
 4. Records of shipper/receiver evaluations, investigation, and corrective actions maintained a minimum of 5 years.
- Incoming Material Transfer Documents (Form 741) are received and returned to the sender within 10 days. If receipts measurements have not been complete, Form NRC-284 is used. When

receiver measurements are completed the results are reported on Form NRC-741. This data must be reported within 30 days after receipt of shipment.

- The shipper/receiver function must be independent.
- All pertinent information relating to a shipment is reported to control accounting records at completion of shipment.

E. Module 85210: Internal Control Program

The requirements of 10 CFR 70.58 require the licensee to have an internal control system designated to protect SNM from loss and theft. For LEU facilities this module examines the control exercised over internal SNM transfer and the associated documentation.

- Inventory records reflect current status of all special nuclear material to include location, item identification, and source and disposition of all such items. Accuracy of the inventory records can be verified by randomly selecting items and checking that the information is complete. Completeness of inventory records can be verified by selecting items in the facility and verifying that an accurate record exists.
- Source and disposition records are kept for a minimum of 5 years.
- Controls are maintained over distribution and use of internal transfer documents. Internal transfer documents are serial-numbered with a record maintained of the distribution of the form.
- Internal transfer documents are signed by authorized personnel. Those signature authorizations must be in writing.
- Movement of SNM between MBAs/ICAs is controlled and documented; all are accounted for.
- SNM procedures provide control over scrap accumulation and its associated measurement uncertainty. The licensee may not routinely retain scrap having a measurement uncertainty greater than 10% for more than 12 months.

F. Module 85212: Physical Inventory

An important segment of the inspection of a LEU fabrication plant is the physical inventory performed by the licensee and the inventory verification performed by the inspector. This module examines the schedule, performance, and reconciliation of the physical inventory by the licensee. The next module describes the verification.

- Physical inventories are scheduled at the required frequency which, with one exception, is every 6 months.

- Within 30 calendar days after the start of the physical inventory, the licensee has:
 1. Calculated the inventory difference associated with the material balance period for both element and isotope, and
 2. Reconciled and adjusted the book value to the results of the physical inventory for both element and isotope.
- Both the central accounting records and all appropriate subsidiary journals are checked.
- Physical inventory procedures address the following:
 1. Cutoff procedures have been established such that transfers and processed SNM are counted only once,
 2. All items on inventory are counted only once, and
 3. All quantities of SNM are based on measured values.
- Written procedures for physical inventory provide for:
 1. Assignment of inventory duties and responsibilities,
 2. Identification of SNM requiring a measurement for the physical inventory,
 3. Identification and location of items,
 4. Verification of inventory records, and
 5. Reconciliation of all prenumbered inventory stickers.

3. Module 85213: Inventory Verification

The inspection program provides for a periodic overcheck of inventory practices through observation and independent sampling and measurement.

- Observation is made of the licensee's practices for identification of SNM requiring measurement for closure of the material balance. This should consist of unsealed material not maintained under tamper-safing.
- Item verification is observed or double-checked on a random selection basis.
- Independent determination of material in process can consist of sampling process SNM for analysis or measurement for hold-up in processing equipment.
- The NRC has an independent measurement capability.

1. Regions I and II have measurement vans and portable NDA equipment; Region V has all portable NDA equipment.
2. Samples can be taken for destructive analysis at Department of Energy laboratories under contract to NRC.

H. Module 85214: ID/LEID Evaluation

The licensee's inventory difference and limit of error are subject to constraint by 10 CFR 70.51(e). The module verifies that the inventory difference and its associated limit of error are appropriate and accurate. In addition, the licensee's mathematical model and data base are reviewed.

- The limit of error associated with the inventory difference must be controlled within the regulatory requirement of 10 CFR 70.51. Most LEID models have many components. Normally, three to six of the components dominate the calculation. These components would be examined by the inspection in the event LEID exceeded the regulatory limit.
- Large contributors to ID are identified, documented, and evaluated.
- Significant ID/LEIDs are reported to the appropriate NRC Regional Office.
- A significant ID is one that exceeds both its associated LEID and the deminimis quantity as defined in the regulations.
- The licensee's mathematical model and data base are reviewed.

I. Module 85216: Records and Reports

An essential part of the accounting system for SNM is the records and reports that are used to determine material status and material control performance.

Completion of this module entails the checking of the following elements of the records and reports system.

- The records and reports system has been described in the FNMC plan. This description usually includes transaction codes, flow charts of forms, assignment of responsibilities for preparing the information, and internal audits performed on the system.
- The records and reports system provides accurate and timely information in sufficient detail to locate all SNM charged to a facility and to close a material balance around the process.
- SNM has been confined to the location and purposes authorized by license.
- Central accounting records are supported by transaction reports or journal entries and properly authorized with appropriate detailed supporting documentation.

- All licensees are required to submit a Material Status Report on Form NRC-742. These reports are to be filed semiannually on the licensee's holdings as of March 31 and September 30 of each year. The report is due within 30 days after the end of the period covered by the report.
- Each licensee who transfers or receives SNM shall complete and distribute a Nuclear Material Transaction Report on Form NRC-741 in accordance with the instructions for completing that form.
- SNM inventory reports are prepared, reconciled, and accurately reflect the results for the reporting period. Inventory reports must be submitted within the time constraints allowed by regulations and/or license conditions.
- All records, with the exception of training records, are retained for a minimum of 5 years. Records in long-term storage must be retrievable in a timely manner.
- Reports required by the regulations/license condition are accurate and are submitted on a timely basis.

Module 85218: Management of the Material Control System

The licensee's safeguards program is a dynamic function requiring on-going revision and change. The module reviews those aspects of the management of the material control system.

- The licensee has established, maintained, and followed a management system that provides for the development, revision, and implementation of the material control and accounting program.
- This system provides for the written approval of procedures and any modifications thereto. The approval chain for such modifications is described and has been followed.
- An annual review of the nuclear material control system was conducted. Those individuals conducting the review were independent of both the nuclear material control management and those who had direct responsibility for any part of the system.
- There was an annual audit of the material control and accounting procedures, practices, and records.
- The results of the annual review and audit and any associated recommendations were forwarded to corporate management. Copies of the results and recommendations from the review and audit are available for inspection at the facility for a minimum of 5 years.
- Any corrective action taken as a result of the review or audit has been documented.
- Any abnormal event has been investigated and reported, as required by 10 CFR 70.52.

K. Module 30703: Entrance/Exit Management Meetings

The module is performed whenever an inspector visits a LEU fabrication plant and consists of two elements:

- At arrival on-site, the inspector briefs licensee management as to the overall scope and schedule for inspection visit.
- Prior to leaving the site, the inspector briefs the licensee as to inspection findings.

L. Module 92706: Independent Inspection Effort

Approximately 20% of the inspector's time on-site during an inspection visit at a facility is set aside for the inspector to examine areas outside the defined inspection program to include such as:

- An inspector may conduct a walk-through inspection for an overview of current plant operations.
- An inspector may explore potential problems before they escalate into major problems.
- An inspector may interview employees.
- An inspector may need to acquire specific knowledge of facility operations.
- An inspector may explore areas of the inspector's specific interest or concern.

III. SUMMARY

The safeguards inspection program is a dynamic program--changing to best insure that the inspection objectives and goal are accomplished. This evolving program may be influenced in many ways: new regulations, better equipment, more efficient accounting practices, and so on. This also requires the training and retraining of the field inspectors.

As you have seen, there is slight overlapping of requirements among a few modules. The philosophy is to assure a complete and comprehensive inspection program. In many cases, the same inspector may be responsible for inspecting the modules that might contain the overlap.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 36: TYPICAL IAEA INSPECTION PROCEDURES
FOR MODEL PLANT

This session will briefly refer to the legal basis for IAEA inspections and to their objectives. It will describe in detail the planning and performance of IAEA inspections, including the examination of records, the comparison of facility records with State reports, flow and inventory verifications, the design of statistical sampling plans, and Agency's independent verification measurements.

In addition, the session will address the principles of Material Balance and MUF evaluation, as well as the content and format of summary statements and related problems.

After the session, participants will be able to:

1. understand the basic objectives of IAEA operations at a LEU fabrication plant,
2. understand the main features of Agency's inspection activities,
3. make a judgment on the scope and adequacy of inspection activities,
4. analyze Agency's evaluation activities and summary statements, and
5. understand better the problems related to inspections and faced by inspectors.



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SESSION 36: TYPICAL IAEA INSPECTION
PROCEDURES FOR MODEL PLANT

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International Atomic Energy Agency

I. INTRODUCTION

During this session we are going to consider Agency inspection procedures at a bulk facility, or to be more specific, at a Low Enriched Uranium (LEU) fuel fabrication plant. After this session, I expect you not only to know the basic objectives of Agency operations at a LEU fabrication plant but also to understand the features of Agency inspection activities. You should be able to make your own critical judgement on the scope and adequacy of these inspection activities, which in turn will help you to understand the problems related to inspections and problems inspectors are confronted with.

Please note the following: this presentation makes reference to a model LEU plant, however, since the Agency is not in a position to reveal information on inspections, any data quoted here may or may not reflect actual plant data. The inspection procedures described later may or may not be identical to actual practices; it is obvious that there may be many variations in safeguards approaches at different facilities.

I take the risk of repeating certain facts and issues which were discussed during the many preceding sessions, but I believe that the following introductory remarks will put the operational part of Agency activities into the right perspective, i.e. what is done and why it is done.

International safeguards is committed to produce something, the product being a statement sent formally to the government of the country. There are 2 types of such statements: one simply summarises the activities carried out and the other presents the conclusions drawn as a result of these activities. There is a sequence of actions and interactions to achieve this product:

- The State provides Design Information on a given facility, (DIQ = Design Information Questionnaire).
- Examination by the Agency of design information and conclusion of a facility attachment.
- Provision of accounting reports by the State.
- IAEA inspections to verify information provided in reports.
- Evaluation of inspection data, preparation of inspection reports and production of statements.

In other words, there are two groups of actions, the providing of information and the verification of this information through inspections. These inspections, i.e. the

operational aspect of Agency safeguards, will be described in more detail later on.

From the data provided by the State in the DIQ the Agency has information on the location of the facility, its use or purpose, its throughput, its material accountancy procedures, its storage locations and its nuclear materials management system. This information and information collected during so-called "ad hoc inspections" enables the Agency to negotiate a facility attachment and thereby provide the necessary "infrastructure" for safeguards implementation, namely MBAs, KMPs, procedures for PITs and PIVs, provisions for records and reports, and most important, inspection effort and scope of inspections.

Once more, let me emphasize that international safeguards is not a police kind of operation. It will never search for undeclared material, but rather verify the correctness of an operator's statement regarding the possession of nuclear material. In other words, the object of Agency safeguards is to verify the compliance with the provisions of a voluntary safeguards agreement (e.g., INFCIRC/153 or 66) as specified in a facility attachment.

II. SAFEGUARDS OBJECTIVES OF AGENCY SAFEGUARDS

Our model plant is a bulk facility covered by an NPT-type of safeguards agreement. What is the task of this technical instrument called safeguards? According to paragraph 28 of INFCIRC/153, the safeguards objectives are described as "timely detection of diversion of significant quantities and deterrence by the risk of early detection". It is necessary to translate such terms as "timely", "significant" or "risk" into technical detection goals (quantities). These goals serve as guidelines for developing plant specific safeguards approaches which then contain concrete instructions for inspection activities (inspection goals). The connection between safeguards objectives, detection goals, safeguards approach, and inspection goals is illustrated in Annex A.

Briefly, for a LEU fuel fabrication plant, the safeguards objective is the detection of the diversion of 75kg (= 1 SQ) or more of contained U235 within a time not exceeding one year. Do not confuse this detection goal quantity, which we may call a basic safeguards target value, with the inspection goal which I will explain in a moment.

III. PLANT DESCRIPTION AND SELECTION OF SAFEGUARDS APPROACHES

The plant under consideration is a typical medium size capacity plant with the following characteristics:

- It produces assemblies for LWRs containing uranium of low enrichment, normally within the range of 2 to 4%, maximum 5%.
- The annual throughput is about 400t of uranium, nominal enrichment of 3%.

- The feed material is low enriched UF₆, conversion to UO₂ is made at this plant.
- The main process steps are: conversion of UF₆ to UO₂ powder, preparation of sintered pellets, canning of pellets in rods or packing of pellets into boxes for shipment, assembling of rods in fuel assemblies; scrap recovery is possible.
- Products leaving the plant are fuel assemblies and sintered pellets.
- Physical Inventory Taking by plant operator = twice a year.
- Based on past experience, an operator had closed his material balance with an accuracy that met international standards.

When designing a safeguards approach, one would first analyse diversion possibilities and associated concealment methods; a few typical examples are listed in Annex B. The selected safeguards approach must incorporate measures to counter these concealment methods. Generally, these safeguards measures fall into two categories; careful audit procedures to detect falsifications and physical inspection of the material to confirm its presence.

Accordingly, for bulk facilities in general, Nuclear Material Accountancy is established as a safeguards measure of fundamental importance, or more specifically, material balance verification based on random sampling.

In a simple form the material balance equation reads:

$MUF = BI + R - S - EI$, where: BI = beginning physical inventory; R = all receipts during MB period; S = all shipments during MB period; EI = ending physical inventory; MUF = material unaccounted for.

MUF can occur because of process holdups, operator measurement errors, losses during processing and, last but not least, as a result of diversion. The establishment of a material balance is necessary for the plant operator, primarily because of economical viewpoints, and, secondly because of requirements and obligations arising from the operating license. From the Agency's point of view, MUF could be an indication of possible diversion.

The use of MUF as a statistical indicator for safeguards is only meaningful if two conditions are met:

- If all components of the material balance equation are subject to independent verification by the Agency.
- If the error limits of MUF (= itself a statistical value) can be determined. Of course, if these limits are exceedingly high, they will again prohibit a statement on the significance of MUF.

In practice, at our LEU model facility, the verification of beginning and ending inventory (PIVs) will be no problem; however, regarding the verification of increases and decreases (i.e. flow verification) we do run into problems. The limited financial resources of the Agency do not allow the presence of Agency inspectors for flow verification whenever inventory changes occur. Therefore, without going into details, it can be stated that with regard to LEU in fuel fabrication plants,

the safeguards approach adopted by the Agency is a certain compromise of basic detection goals (remember significance, timeliness, etc). A limited inspection scheme is being implemented using intermittent inspections for flow verifications on a random basis as practicable. In addition, provision will be made in the facility attachment for "strategic points" to allow inspector access to specified locations within the facility for the purpose of obtaining operating data and establishing the operator's measurement uncertainty which are necessary for material balance verification and evaluation.

IV. INSPECTION PROCEDURES

We could say that a number of comprehensive or less comprehensive safeguards measures such as nuclear material accountancy or containment and surveillance, as applicable, form the basic safeguards approach. These measures require the performance of inspection activities; these activities in turn require a certain infrastructure. In the facility attachment is where this infrastructure (MBAs, KMPs, records-reports system, etc.) is described and where the provisions for inspection implementation (inspection frequency, inspection effort, scope of inspections) are defined.

The structure and content of facility attachments has been discussed elsewhere. Here I will only refer to those codes of the facility attachment which are of particular interest for the inspection activities at our model LEU fuel fabrication plant. You may wish to consult Annexes C (codes 3.1, 3.2 and 3.3); D (codes 5.1 and 5.2) and E (codes 7.1, 7.3, 7.4, 7.5 and 7.6).

A. Inspection Planning

Our verification period is one year according to our timeliness criteria of one year for LEU. Within this period the Agency's inspection activities have to be allocated. For planning purposes the inspectors use form RS1, see Annex F, which lists the Agency's standard inspection activities.

The very first step of our inspection procedures, therefore, is the "Inspection Planning", i.e. defining the periods covered by inspection activities and the intensity or scope of an inspection (audit only or in conjunction with a physical verification).

B. Inspection Frequency

Assuming that operator's accuracy for the Material Balance Closing (σ_{MUF}) meets international standards (at present for LEU fabrication plant $\sigma = 0.3\%$) and assuming a goal to detect the protracted diversion of 1 SQ per year (75kg) with a 90% confidence level, only one PIV will do the job up to a throughput of $T = \frac{75 \times 10^{-3}}{3(\%) \times 3.29 \times 0.3(\%)} = 250t \text{ U/year}$.

This is far below the nominal throughput (400t) of our model plant. Nevertheless, the Agency decided to verify only one of

two operator's PITs per year provided for in the facility attachment. State's reports (PILs, MBRs) on both PITs are received and evaluated by the Agency. Intermittent routine inspections, with approximately 1 month intervals, are scheduled usually using 2 inspectors for 2-3 days and 5 to 7 inspectors for several days during the annual PIV.

In order to economize on the time available, I intend to touch on only 3 more topics of inspection procedures as practically implemented at the model plant:

- Examination of records.
- Aspects of verification of the quality of operator's measurement system.
- Physical verifications (flow and inventory).

C. Examination of Records

The activity of primary importance during all inspections is the examination of the accounting records and their reconciliation with operating records. The facility keeps a General Nuclear Material Ledger, a journal type ledger, where any transactions are recorded specifying the date, transfer number or batch name, type of inventory change, material description code, number of items and material quantities. Individual entries in the ledger are checked for arithmetical correctness and consistency with source documents, such as originals of transaction documents, shipping lists, weighing protocols and analytical reports. As in conventional financial accounting, the thesis on which this approach is based is that while one or several documents may be falsified, the probability of successfully falsifying all documents is small and diminishes as the number of documents increases.

Discrepancies detected during the audit activity are discussed with the operator and corrections made as applicable. All discrepancies are recorded by the inspector and included in the inspection report; unresolved discrepancies will be listed in the relevant statement.

Usually the inspector receives a copy of the facility ledger, so that he can mark the checked entries and make notes; it serves the purpose of comparing these facility records (ledger) with the reports (ICRs) submitted by the State to the Agency at a later date.

Based on the audited ledger, the inspector establishes a book figure for the material on site as of a given date, e.g. end of month or date of PIT. This book figure is the operator's commitment for which he accepts responsibility.

D. Verification of quality of operator's measurement system

Any physical verification of nuclear material automatically includes the collection of information on the operator's measurement system. For example, samples for destructive analysis are taken and results compared with operator's data; scales are recalibrated using Agency standards and compared with design information, etc. Here I would like to mention a specific activity carried out at the rod loading station. The accountancy data used for fuel rods are of primary importance at our plant; they consist of analytical

data for U-factor, U-235 enrichment and weight data. They originate in the pelletizing area of our plant and when loading pellet columns into the rods. The inspector then witnesses the loading process, calibrates the scales used for this purpose, records the weight data and takes pellet samples for destructive analysis of the pellet lot in process. The results are evaluated by paired comparison with operator's declared production data or design data.

The data collected during inspection over a longer period of time (one or more material balance periods) allow the inspector to derive his own estimate of the operator's measurement uncertainties. He needs these estimates to perform his own evaluation of MUF as stated by the operator and to draw conclusions regarding the significance of MUF. The operator's overall measurement capability affects the inspection effort spent by the Agency at the model plant (reference is made to paragraphs 7 and 31 of INFCIRC/153).

E. Flow verification

According to the Agency's Safeguards Glossary, flow verification is an activity conducted to confirm a recorded increase or decrease (in terms of batches) of nuclear material in a material balance area. The principal reason for inventory change verification is that the uncertainty associated with these changes can represent a large part of the uncertainty in the material balance equation; this is not so much due to the poor measurement capability for flow items but rather to the amount of material involved. For our model plant, the inventory is only a fraction of the material involved in flow (or compared to the throughput).

- Our model plant receives LEU in the form of UF_6 in large cylinders. During each inspection, the inspector first audits the relevant nuclear material ledger entries, after having received a list of all UF_6 cylinder receipts since the previous inspection. Some cylinders (probably the major part) will have gone into the conversion process already. From the remaining population, the inspector randomly selects a few cylinders for physical verification. Based on historical data for the UF_6 stratum, a statistical sampling plan is prepared and sample sizes computed; at the closing of the material balance, it is compared with the actual number of cylinders verified and retroactively the confidence level for this verification may have to be adjusted. The verification is done by NDA enrichment measurements by means of a Ge/multi-channel analyser system. The measurements are corrected for attenuation through the cylinder walls, the thickness of which is measured with an ultrasonic device. A subsample of the measured cylinders is selected for taking a UF_6 hydrolysis sample for destructive analysis in the Agency's laboratory where the enrichment is determined by mass-spectrometry. These very samples are used as reference standards for calibrating the instrument and correcting the results.

In addition to NDA, the cylinder gross weights are measured using a load-cell based weighing system which has been developed by the Brookhaven National Laboratories and subjected to Agency field tests; the results were encouraging. The system, as well as the tests, are described elsewhere. All data are carefully recorded on inspector's data sheets, Annex G.

There are certain limitations; first, the selection of the sample is not random since the inspector only has access to a small part of the UF₆ population; second, the U-factor cannot be verified since the Agency's laboratories cannot process UF₆-gas samples, and third, the weight verification is restricted to gross-weight verification.

- The final product of our model plant are LWR assemblies. The finished assemblies are temporarily stored in hangers before being packed in shipping containers. NDA measurements are performed using the Neutron Coincidence Collar. The sensitivity of the instrument enables detection of the removal or substitution of 3-4 rods in a PWR assembly; the measurements have to be complemented by measurements of the active length of the assemblies. The evaluation of the results obtained so far is in process.

In some cases, it is possible to witness, after the NDA measurement, the packaging of the assembly into the shipping cask and attach a seal; the Agency can then at least confirm the receipt at the power station.

However, it is not yet possible to verify an assembly and attach a permanent seal which would follow the assembly throughout its lifetime; such seals are not yet available.

- A peculiarity of our model plant is that intermediate products, namely sintered pellets, are shipped out of the plant. The pellets are loaded onto trays, a number of trays are loaded into wooden boxes, and a few boxes are packed into 50 gallon drums for shipment. The verification consists of weighing trays of pellets and sampling pellets for destructive analysis to determine the U-factor and U235 enrichment. It has been possible to witness packaging into drums and attach Agency seals for verification at the receiving facility.

F. Inventory Verification

Frankly speaking, a successful PIV is to a large degree an organizational task. At first glance, a PIV carried out by a team of inspectors, in our case probably 5 to 7, seems to be a rather plant intrusive undertaking. An operator will try to minimize the loss of production time; the inspector, on the other hand, is forced to take a snapshot of the plant's situation in terms of nuclear material inventory. A PIV requires careful planning usually months ahead of time. In our case, the Agency's PIV will coincide with the operator's PIT; as a matter of fact, it will "somehow" be carried out

"simultaneously". I am inclined to continue by giving the sequence of necessary actions, rather than describing them in detail. I invite you to ask questions where the information provided is not sufficient.

1. Inspection Team. We assume 5 inspectors, one being the coordinating inspector; preferably 2 inspectors should be specialized in NDA methods, 2 in destructive analysis and bulk handling procedures and 1 conversant with records auditing.

2. Time schedule. A matrix is prepared and agreed upon with the operator, showing which material strata (or plant areas) would be due for verification, on which day and by which team, when the inventory lists can be expected, how much time may be used for a stratum, when material movements are expected to be resumed, etc.

For a full PIV, the inspector will have expected the operator to have stopped production and to have cleaned out the plant. Nuclear material should have been accumulated into a few previously agreed inventory KMPs; the material should have been stratified, and lists of the items in each stratum prepared by the operator. Some of these prerequisites may turn out to be unrealistic; but nevertheless the inspector(s) must not compromise their inspection goals.

3. Sampling Plan. A statistical sampling plan is used to select a random subset of items for verification. Two sample sizes, one for attributes and one for variables measurements, are computed (see Annex H). Our inspection goal quantity M is the minimum quantity of nuclear material which, if diverted, could be detected with a 95% probability by assuming a verification accuracy goal (as % of throughput) equal to or comparable with the expected operator's measurement uncertainty.

Example: $T = 440t$]
 $E = 3\%$] = 12000kg U235

$$M = K \cdot \sigma \cdot T$$

$$K = 3.3 \rightarrow \gamma = \beta = 0.05$$

σ = verification accuracy goal (= 0.3% for LEU fuel fabrication plant)

$$M = 3.3 \times 0.003 \times 12000 \\ \approx 120\text{kg}$$

Our goal quantity M is larger than $15Q$ for our model plant; it implies that nuclear material accountancy (basis of our safeguards approach) is limited by measurement uncertainty.

Historical data from previous material balance periods (or PIVs) will be used to compute preliminary sample sizes for individual strata.

4. Stratification. In theory, i.e. according to the provisions of the facility attachment, the operator prepares, as a result of his PIT, an itemized list of the inventory (IIL), stratified and generally organized by material composition and by internal material control areas. By looking through Annex C, you may have realised that the inventory KMPs of our model plant do indeed represent a stratification scheme; material belonging to one stratum may be found at different plant locations.

The next task is to calculate N and \bar{x} for all strata, compute sample sizes n_a and n_v and assign consecutive numbers to inventory items as the basis for subsequent random selection. A programme developed for HP-97 is used to compute sample sizes and generate random numbers.

I ought to mention here that in reality a straightforward stratification of IILs and subsequent sample size calculations may not be possible, either because the IILs are issued according to areas regardless of stratification criteria, or because strata are distributed over several areas, or because the stratification criteria are not met. Such a situation may require a rather unconventional approach for statistical sampling and verification. We may discuss this further during the workshop sessions.

5. Sampling. In this context sampling means selection of items for sampling. The size of the inventory and number of items do not permit a complete 100% verification of the item population. The mere inspection goal of detecting missing items can be attained equally well and with a satisfactory confidence level by employing a "heavily designed" attributes sampling plan. Exceptions to this are strata with a significant average item size (such as UF_6 cylinders and assemblies). The items selected for attributes testing are marked on the IILs, let's say in blue, a subsample is selected for variables testing and marked with an additional colour. The IILs are, of course, kept by the inspector as one of the fundamental PIV documents; they are part of the working papers attached to the inspection report.

6. Verification. The Agency's verification starts immediately after completion of the PIT; the inspectors work in parallel with several teams, each one being accompanied (supported) by operator's personnel. Usually item selection then has to be completed within the first day, items for variables testing are sealed (paper seal) until verification during the following day(s).

The following attributes methods are used individually or in combination, as appropriate, in order to detect gross defect items:

- weighing (gross).
- NDA qualitative.
- visual examination.
- UF_6 cylinders filled to the top by knocking.

The variables methods employed should serve to detect partially defective items and biases respectively:

- weighing (gross, tare, net).
- sampling for destructive analysis (bulk items only).
- NDA (bundles).
- rod scanner and downloading.

Any verified items (attributes or variables) are recorded on data sheets, Annex I. The careful and complete recording of verification data is a prerequisite for a successful PIV evaluation (post inspection activity) and closing of the material balance.

Our past experience has shown that the inventory, as it is found at the model plant, is accessible and verifiable; adequate verification techniques are available to the Agency. It is, of course, true that the verification of some parts of the inventory is associated with a relatively large uncertainty, either because of the verification technique (NDA for assemblies) or because of the type of material (scrap, waste).

7. Audit. It is obvious that the auditing of records and the establishing of an updated book value (BE) for the nuclear material on the inventory are important parts of any PIV; the BE figure is the operator's commitment which is made prior to physical verification by the inspection team.

The operator's assistance is required and extensively used during the whole PIV. The location of items randomly selected from the IILs is done by plant personnel who are familiar with every corner of the plant. Even though consecutively numbered stickers are attached to items during PIT, it is often a puzzle to find one item. The taking of samples for destructive analysis (pellets, powders, etc.) is done by plant personnel upon request of the inspector; packaging of samples, and, later on, shipment is also the responsibility of the operator. Occasionally, operator's instruments are used by inspectors, e.g. SAM-2 enrichment meters, rod scanners, scales, tumblers, etc.; operator's personnel will operate the equipment witnessed by inspectors.

V. STATEMENTS

Finally, a few words regarding the statement. At the beginning, I mentioned the "end product" of the Agency's safeguards activities. Let me quote paragraph 254 of the Agency's Safeguards Glossary: "Statement, an official communication by the Agency to a State, indicating the results of an inspection carried out in the State or the conclusions the Agency has drawn from its verification activities".

Usually, "Summary Statements" (i.e. results of inspection) are "produced" after each routine inspection; "Conclusion Statements", under an NPT safeguards regime, are only made after a PIV, i.e. when closing the material balance. The preparation of statements requires substantial "post-inspection" activities; the inspection data need to be evaluated and the results have to be analyzed for their safeguards significance. Let me simply list a few steps of these activities:

- Stratification of FLOW and INVENTORY, over whole material balance period.
- "Paired comparison" of operator-inspector data for verified items, resulting in error estimation and average item differences.
- Error preparation techniques applied for Flow and Inventory strata.
- Compute MUF_{op} , \hat{D} , $\sigma_{\hat{D}}$, $\sigma_{\text{MUF-op}}$, MUF_{Ag} , $\sigma_{\text{MUF-Ag}}$

- Test MUF values for statistical significance; illustration in a bar chart.
- Test MUF values for safeguards significance (relative to SQ or M).
- Check σ_{MUF} against expected international standards for measurement uncertainty.
- Check for adequacy of detection sensitivity, i.e., $\sigma_{(MUF-\hat{D})}$ versus M?

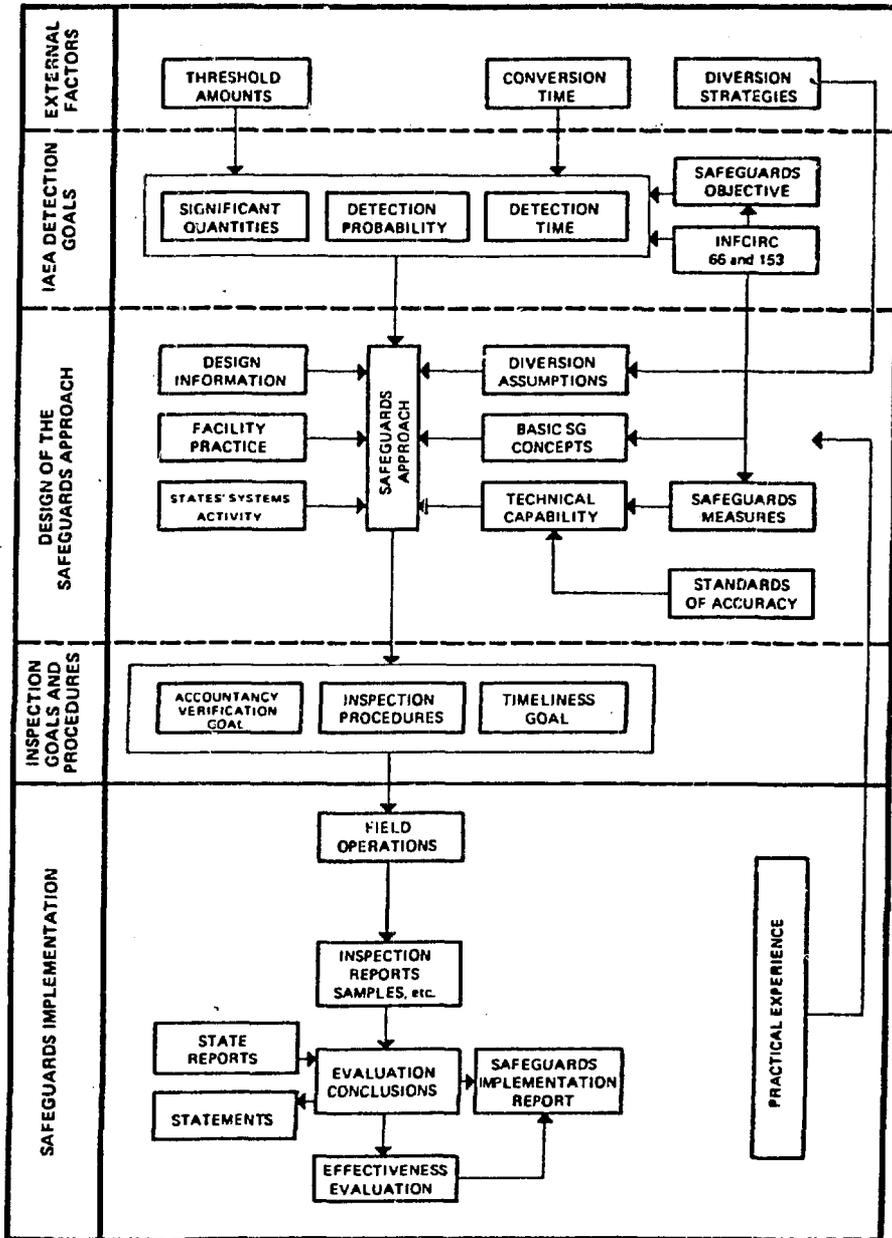
As mentioned earlier, the careful recording of inspector's findings (data, differences, discrepancies) is compulsory since the quality of the input data determines the quality of the evaluation results.

I presume that the actual structure and content of the statements was discussed earlier.

VI. CONCLUSION

I would like to conclude by saying that Agency inspection procedures are always designed in a way as to impose the minimum possible burden on the plant operator. However, it should be recognized that this requires in general a well functioning State system of accounting for and control of nuclear material, as well as a high degree of operator-inspector cooperation and mutual understanding.

Design of Safeguards Approach



36-13
ANNEX B

<u>Diversion Possibilities</u>	<u>Concealment Methods</u>	<u>Safeguards Measures</u>
- Removal of natural or enriched uranium in bulk form	- failure to record receipts - understating amount received - inflation of measurement uncertainty - substitution with natural or depleted uranium (for enriched uranium) - borrowing from other facilities - hollow or low density pellets	- comparison of reports - weighing, sampling and analysis of random selection of drums received - IAEA standards - analysis of SRDs - seals - NDA measurements - simultaneous inspections - weighing - NDA measurements
- Removal of Fuel Assemblies	- changing serial number of assembly and offering for re-inspection plus substitution with dummies - invention of shipment - borrowing from other sites	- seals - verification upon receipt at reactor - careful checking of records and item counting - simultaneous inspection
- Removal of Nuclear Material from Rods and Assemblies	- physical removal from rods and assemblies	- weighing - NDA measurements
- Diversion of scrap pellets	- inventing shipments and inflating amounts shipped (if separate recovery plant) - inflation of measurement uncertainty - inflated processing losses	- thorough checking of records and on-site verification at recovery plant

ANNEX C

3.		<u>Safeguards measures</u>
3.1	29	<u>Accountancy</u>
3.1.1	46(b)	Material balance area and identification codes. The whole fuel fabrication plant is one material balance area MBA This MBA includes the entire plant, storage of nuclear material (feed, product, scrap and waste), production processes for the conversion and fabrication of LEU fuel, scrap recovery, and laboratories.
3.1.2	46(b) 37, 38	Strategic points which are key measurement points (KMPs). (For their specifications see Code 4.) ^{2/} (a) For determination of nuclear material flow: KMP1 - Receipts, de-exemptions and accidental gains.
6.3		
3.1.2 (cont'd)	3.5, 3.7 6.2, 7.1	KMP2 - Shipments, exemptions and accidental losses. KMP3 - Uranium blending (material category changes only). KMP4 - Measured discards. KMP* - SR differences and transfers of material to process. - This is a KMP in which all SR differences must be recorded and reported even if numerically zero. - All material received in KMP1 is considered to be in process as of the date of recording the SR difference. (b) For determination of physical inventory: KMPA - UF6 cylinders and heels. KMPB - Unsintered UO2 powder and pellets. KMPC - Sintered UO2 in pellets and hard scrap. KMPE - Fuel rods. KMPE - Fuel assemblies. KMPE - Scrap (ADU, grinder sludge, and dirty powder). KMPE - Solid waste (barrels and filters). KMPE - Liquid waste (plant effluents). KMPE - Nuclear material in small quantities each containing less than 0.01 effective kilograms, such as laboratory QC archive samples, etc. KMPE - Other nuclear material not included in KMPs A through I.

^{2/} These KMPs include the locations, within the facility, where instrument readings and measurements, relevant to the source data, are made wherever and whenever these source data are generated.

- 3.1.3 46(c) Physical inventory taking.
 Nominal frequency for physical inventory:
 Semiannual.
 Procedures:
 As described in the design information for the
 Exxon nuclear fuel fabrication plant.
 A stratified list is compiled in preparation for
 the Agency's verification of the physical inventory
 taking showing on the basis of the information in
 the facility's records, the anticipated number of
 items in each stratum and the description and
 location of the items such as drums, trays, rods
 and assemblies, etc. The list shows nominal values
 in the weight of compound, element content and
 enrichment for the items in each stratum.
-
- 3.2 29 Containment and surveillance
- 3.2.1 46(f) Strategic points for the application of containment
 and surveillance measures:
 Storage and process areas as appropriate.
- 3.2.2 73(d)(e) Installed Agency instruments and devices:
 (i) - Seals on fuel assemblies; (when available
 and mutually agreed).
 - Seals on shipping containers of product
 material subject to IAEA safeguards at the
 receiving facilities.
 - Seals on Agency sample containers.
 - Seals on Agency standards.
 - Seals on Agency installed devices including
 measurements and surveillance equipment.
 - Seals used for physical inventory
 verification purposes during the
 verification time.
 - Surveillance equipment (e.g. for detection
 of unrecorded movements of nuclear material
 during P.I. verification if agreed by the
 - Seals on items to be re-shipped on
 shipper's value.

If the operator needs to remove a seal or to interfere with the operation of safeguards instruments as listed above, the Agency shall be informed in advance by the fastest means. The information shall include the probable date on which the removal of the seal or the interference with the safeguards instruments will take place. If a seal is removed in the absence of an Agency inspector without the operator being able to inform the Agency in advance, a special report will be prepared as specified in Code 6.4.1.

(ii) Seals may be broken by the operator if needed without advance notification:

- On nuclear material which could be left sealed up to the next physical inventory verification.
- On containers with input material received in KMP1 sealed upon receipt.

3.3			<p><u>Additional strategic points</u></p> <p>Inventory KMPs (3.1.2 (b)) are also considered strategic points for access at other times than the P.I. verification.</p>
3.4	6.1	11, 35	<p><u>Specific provisions and criteria for termination of safeguards on nuclear material</u></p> <p>Safeguards on measured discards will be considered to be terminated upon receipt by the Agency of the inventory change reports pertaining to such discards if less than 0.3 effective kg are involved in a 6 month period.</p> <p>In the case of discarding quantities of uranium exceeding 0.3 effective kg in six months, the Agency shall be consulted before such discarding takes place.</p>
3.5	6.2	36, 37	<p><u>Specific provisions and criteria for exempting nuclear material from safeguards</u></p> <p>None.</p>

ANNEX D

Code	General Part Reference (Codes)	Agreement Reference (Articles)	
4.3			<u>Additional strategic points; source and operating data</u> Source/operating data as for inventory KMPs.
5.	3.5, 3.7	46(d), 49	<u>Records System</u>
5.1	2.1.2	54, 32(f)	<u>Specific provisions for accounting records</u>
5.1.1		54(a)	Inventory changes (for the specifications of source data see Code 4.1 above), time of recording: - Receipt (KMP 1): Upon receipt.
	6.3		- De-exemption (KMP 1): Upon the accounting transfer of the nuclear material.
			- Accidental Gain (KMP 1): Upon determining the amount of the gain.
			- Shipment (KMP 2): Upon shipment.
	6.2		- Exemption (KMP 2): Upon the accounting transfer of the nuclear material.
	7.1		- Withdrawal (KMP 2): Upon withdrawal.
			- Accidental loss (KMP 2): Upon determining the amount of the loss.
			- Uranium blending (KMP 3): Upon blending.
			- Measured discard (KMP 4): Upon discard.
			- SRD (KMP*): Upon measurement by the operator of the material received and recorded on shipper's data.
5.1.2	2.1.1	54(b)	Measurement results used for determination of the physical inventory (for the specifications of source data see Code 4.2 above), time of recording: - For all inventory KMPs: Upon identification and measurement as applicable.

ANNEX D

Code	General Part Reference (Codes)	Agreement Reference (Articles)	
5.1.3	2.1.2	54(c)	<p>Adjustments and corrections, time of recording:</p> <ul style="list-style-type: none"> - MUF: <ul style="list-style-type: none"> After a physical inventory has been taken. - Corrections (all KMPs): <ul style="list-style-type: none"> (a) Whenever errors have been found; (b) When the results of a more precise measurement have become available; or (c) Whenever measurement bias has been observed.
5.2	2.1.2	56	<u>Specific provisions for operating records</u>
5.2.1		56(a)	<p>Operating data used to establish changes in the quantities and composition of nuclear material:</p> <ul style="list-style-type: none"> - Location of the nuclear material as described in the design information. *- The fuel rod loading stations: <ul style="list-style-type: none"> Date and the relevant source data (see Code 4.1) for each fuel rod loaded. *- Information on any accident which results in a loss of nuclear material. *- The assembling stations for fuel assemblies: <ul style="list-style-type: none"> Date and the relevant source data (see Code 4.1) for each assembly. - The list of seals removed by the operator. *- Blending operations will be described with the information on quantities of material used for blending. - Compound quantities, nominal U-factor and nominal U-enrichment for each powder and pellet lot.
5.2.2		56(b)	<p>Calibration of tanks and instruments, sampling and analysis, procedures to control the quality of measurements, derived estimates of random and systematic error:</p> <ul style="list-style-type: none"> - All KMPs: <ul style="list-style-type: none"> (a) Date, method of calibration, original calibration data and calibration results for all measurements used for purposes of nuclear material accounting, including equipment for measuring weight, volume, density, uranium, U-235 and impurity content.

ANNEX D

Code	General Part Reference (Codes)	Agreement Reference (Articles)
5.2.2 (cont'd)		<p>(b) Date, procedure, data and derived estimates of random and systematic errors associated with measurements for nuclear material accountability, including errors associated with weighing, volume determination, density determination, sampling analysis of uranium and U-235 content, calibration, and other relevant error sources.</p> <p>(c) Date, procedure, data and results of analyses of standards and process samples used to control the quality of measurements in nuclear material accountability.</p> <p>(d) Date, type of material sampled, method of sampling, name or number of batch, weight or volume of each sample taken and its destination.</p> <p>(e) Date and method of the analyses of each sample taken, data and results of analyses and obtained measurement precision.</p> <p>(f) Information on any malfunctioning of the measurement equipment.</p>
5.2.3	56(c)	<p>Sequence of the actions taken in preparing for and in taking the physical inventory:</p> <p>- All physical inventory KMPs: Dates and description of the actions taken and the results obtained.</p> <p>An itemized list, stratified and generally organized by material composition and by internal material control areas after completion of inventory taking by the operator.</p>
5.2.4	56(d)	<p>Actions taken in order to ascertain the cause and magnitude of any accidental or unmeasured loss:</p> <p>- Date and description of the actions taken and the results obtained.</p>

ANNEX E

Code	General Part Reference (Codes)	Agreement Reference (Articles)	
6.4.2			<p>Contents in relation to Code 6.4.1 (a):</p> <ul style="list-style-type: none"> - Date when the incident or circumstance occurred. - Description of the actions taken in order to ascertain the cause of the incident or circumstance and the magnitude of the loss. - Cause and features of the incident or circumstance. - Estimated amount of nuclear material which has been lost.
7.	4.2		<u>Inspections</u>
7.1		78, 82	<p><u>Mode of routine inspections</u></p> <p>Continuous during physical inventory taking; Intermittent otherwise.</p>
7.2		78	<p><u>Applicable formula and procedure for determination of maximum routine inspection effort</u></p> <p>Article 78(b) or (c) as applicable.</p>
7.3		76, 79	<p><u>Indication of the actual inspection effort under ordinary circumstances</u></p> <p>An estimate of the actual routine inspection effort, as far as can be foreseen and assuming:</p>
	3.1		(a) Circumstances at the facility to be as described in the information provided in respect of the facility; and
	2.		(b) The continued validity of the information on the national system of accounting for and control of nuclear material as set out in the General Part of the Subsidiary Arrangements. 100 - 120 man-days per year for normal production.

ANNEX E

Code	General Part Reference (Codes)	Agreement Reference (Articles)	
7.4		72, 73	<u>Indication of the scope of routine inspections under ordinary circumstances</u>
7.4.1			General: <ul style="list-style-type: none"> - Examination of the records, verification for self-consistency and consistency with reports. - Observation of the calibration of scales and other nuclear material measuring equipment used for accounting purposes, including the calibration of scales by means of weights standards provided by the Agency. - Verification of the quality of the operator's measurement system including analytical and NDA equipment using independent standards. - Taking representative analytical samples from complete population. - Other activities as appropriate.
7.4.2	9.4		At flow KMPs: <ul style="list-style-type: none"> - Observation of weighing; - Selection of items to be sampled for the Agency and observation of sampling (see Code 7.6 below); - Observation of the treatment and analyses of accountability samples; - Application, examination, removal and exchange of Agency seals provided for under Code 3.2.2; - Identification and counting of the fuel assemblies and rods; - Non-destructive measurements using the Agency's portable instruments; - Use of operator's solid waste assay system, and enrichment control instruments (e.g. rod scanner and SAM 2) when feasible.
7.4.3			At inventory KMPs: <ul style="list-style-type: none"> - Verification of the operator's physical inventory taking for completeness and accuracy; - Weighing of containers with bulk materials and pellets on a random basis in accordance with the Agency's sampling plan; - Selection of items to be sampled for the Agency in accordance with the Agency's sampling plans and observation of sampling; - Identification of and counting the fuel rods and assemblies in accordance with the Agency's sampling plans; - Use of the Agency's portable instruments for non-destructive measurements; - Use of operator's solid waste assay system, and enrichment control instruments (e.g. rod scanner and SAM 2) when feasible; - Application, examination, exchange or removal of Agency seals.
7.4.4			At additional strategic points: <ul style="list-style-type: none"> - As listed above for the corresponding inventory KMPs as appropriate.

INSPECTION PLAN (RS/1)

1.1 IDENTIFICATION OF INSPECTION AND INSPECTORS

Section		Country	Facility Code	Year / Rep. No.	Ref. No.	Last day of previous inspection
V	R	A	S			
Inspection Type	Date from	Date through	CDI	Md/153	Total No. of MBA at the Facility	

INSPECTION TO BE CONDUCTED BY THE FOLLOWING INSPECTORS (the first name is the coordinator)

1.	2.	3.	4.	5.	6.
7.	8.	9.	10.	11.	12.

1.2 INSPECTION ACTIVITIES TO BE PERFORMED AT MBA(S)

1-1	Follow-up actions	Y	N	Date from	Date through	
1-2	Accounting Records Examination	Y	N			
1-3	Operating Records Examination	Y	N			
1-4	Accounting and Operating Records Reconciliation	Y	N	Date from	Date through	
1-5	Records and Reports Comparison	Y	N	Date from	Date through	
1-6	Book Inventory Up-dating	Y	N	Date from	Date through	
1-7	Verification of the Inventory Changes	Y	N	Type of Verific.	As of	Verification Method
1-8	Verification of Inventory	Y	N	Ph	I	A B C D E F G Z
1-9	Verification of quantities at the strategic points that are neither KMPs nor strategic points for C/S	Y	N	Date from	Date through	Verification Method
1-10	Surveillance Application	Y	N	TV activity		MC
1-11	Seals Application	Y	N	I S R C I S R C		
1-12	Verification of adequacy of the operator's measurement system	Y	N	Attach. Detach. Replace Check		
1-13	Evaluation in respect of the SRD's, accidental losses, MUF and measured discards in excess of specified limits	Y	N			
1-14	Other Activities	Y	N			
	Use of Inspection Equipment	Y	N	Type of equipment		
	Explanatory Notes	Y	N	Attachment(s)		

Prepared by _____ / _____ / on _____ Clearance: Section Head _____ on _____
 Name Signature Signature
 If necessary: Director _____ on _____

MB-1. / UF₆: NDA + WEIGHING + SAMPLING

MBA: INSPECTION DATE:		INSPECTION REPORT NO.: REFERENCE NO.:						INSPECTORS:						
Date Time	Cylinder No.	Peak Integrated (channels)	Counts/1000''	Counts/200'' Im	E(%) $n = \frac{C}{200}$	Wall Thickness d [mm]	E(%) - measured $E = Im \cdot e^{-1.12262 \cdot d \cdot n}$	OPERATOR		G T N	OPERATOR Weight Data	IAEA [load-cell]		Additional Info. (Sample No.,)
								E(%)	C(%)			Reading	Corrected	
	Standard RM0042													
	Standard 2.9456%													
	Standard 3.8197%													
	Standard 4.9550%													

SAMPLING PLAN

$$n_i = N_i (1 - \beta^{\gamma \bar{X}_i / M})$$

where:

n_i - sample size for the stratum i

N_i - number of items in stratum i

$1 - \beta$ - diversion detection probability
(for 95% det. prob. $\beta = 0.05$)

γ - Coefficient of fractional falsification
of item size according to operators
diversion approach ($\gamma \leq 1$)

\bar{X}_i - average fissile weight per item (kg)

M - goal quantity for this facility
(inspection goal quantity, $M = k \times \sigma \times A$)



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 37: INTRODUCTION TO MC&A SYSTEM DESIGN WORKSHOP

The purpose of this introductory session is to prepare the students for the subsequent workshop (Session 38) in which they will design the main features of the material control and accounting system for a low enriched uranium fuel fabrication plant.

To aid the students in their systems design work, the key features which must be included to meet IAEA and State systems requirements are illustrated. This is done by showing how a Fundamental Nuclear Material Control Plan (FNMC Plan) is prepared to meet State systems requirements and how a Design Information Questionnaire (DIQ) is prepared to meet IAEA requirements. The Reference (or Model) Plant to be used in preparing the FNMC Plan and DIQ is described first.

Texts for the Reference (or Model) Plant and for Preparation of a FNMC Plan and a DIQ are included as Sessions 37a, 37b and 37c, respectively.

The goals and mode of operation of the four subgroups into which the student will be divided during the workshop are explained. At the end of the workshop, each group is to present the main features of its design and the reasons for its choices. The use of the workshop outline and worksheets (texts for Session 38) to be used in the system design work is explained. A questionnaire summarizing the key design features which were selected is also to be completed by each subgroup.

After the session, participants will be better able to design a material control and accounting system for a similar type plant and to more fully contribute to their subgroup task.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 37: INTRODUCTION TO MC&A SYSTEM DESIGN WORKSHOP

R. A. Schneider, Exxon Nuclear
E. A. Hakkila, Los Alamos National Laboratory
N. L. Harms, Pacific Northwest Laboratory
and W. Theis, International Atomic Energy Agency

I. INTRODUCTION

The purpose of the workshop which follows this session is to give the students an opportunity to design the main features of a safeguards material control and accounting system (MC&A) for a low enriched uranium fuel fabrication plant.

II. PREPARATION FOR WORKSHOP

To prepare the participants for the workshop on MC&A system design, the following items are covered in this session:

1. Description of the Reference or Model Plant;
2. Preparation of a FNMC Plan;
3. Preparation of a DIQ, and
4. Description of the objectives, tasks, and mode of operation of the workshop.

A. Reference or Model Plant

The basis for the safeguards system design is the Reference or Model Plant described in condensed form next in Session 37a and in more detail in the example DIQ which follows later in Session 37c. The information for the Model Plant is presented in Session 37a in eight sections. These are:

1. Process Assumptions;
2. Six-Month Material Balance Model;
3. Measurements;
4. Error Parameters, Measurements, and Sigma MUF Calculations;
5. Material Control Areas;

6. Accounting, Records, and Reports;
7. Tamper-Safing; and
8. Measurement Control Program.

B. Preparation of a FNMC Plan

The key elements of a safeguards MC&A system which need to be considered in designing a system to meet State systems requirements are illustrated in Session 37b which shows how a FNMC Plan is prepared. The key topics which need to be considered in the system design to meet U.S. requirements are:

- o Organization;
- o Material Control Areas;
- o Measurements;
- o Measurement Control Program;
- o Physical Inventory;
- o Material Accounting System;
- o Internal Control, and
- o Management.

C. Preparation of a DIQ

The key elements of the safeguards MC&A system which need to be considered for IAEA safeguards are illustrated in Session 37c where the preparation of a DIQ is described.

D. Objectives and Operation of Workshop

After completion of Session 37c, the function, mode of operation, and objectives of the workshop are described. The students are to be divided into four groups with each group independently developing the safeguards MC&A system which they believe is best. To aid the students in their design work, a workshop guide is provided (which is one of the texts for the workshop, Session 38). The guides suggest the various factors which should be considered for each of the 10 main design elements which determine the safeguards MC&A system. Worksheets (also part of the text for Session 38) are provided upon which the participants may record their design choices.

Instructors will be available to serve on each team or to act as consultants when requested.

Each of the four groups is to select a rapporteur to present its results at the plenary session (Session 39) which follows the workshop. The rapporteurs present the safeguards system design features chosen by their group as representing the best MC&A system. Each group is also asked to complete a questionnaire. The questionnaire is to be completed and turned in at the end of the workshop session. The completed questionnaire which summarizes the main design features chosen by each group will be used by the course instructors to evaluate and compare the results of the four subgroups by the course instructors.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 37a: DESCRIPTION OF REFERENCE (MODEL) PLANT

R. A. Schneider
Exxon Nuclear

I. INTRODUCTION

For the workshop on Safeguards System design for a fuel fabrication plant, we use a generic example of a LEU bulk-handling facility that is based on the Exxon LWR fuel fabrication plant. This reference (or "model") plant description is to be used in developing system design features during the workshop. The same basic information has also been incorporated into the Design Information Questionnaire given later in this session (Session 37c).

The model plant information is given in the following separate sections:

- II Process Assumptions;
- III Six-Month Material Balance Model;
- IV Measurements;
- V Error Parameters, Measurements, and Sigma MUF Calculations;
- VI Material Control Areas;
- VII Accounting, Records, and Reports;
- VIII Tamper-Safing; and
- IX Measurement Control Program.

For convenience, a brief summary of each section is given below.

Section II--Process Assumptions. A one tonne-a-day plant having two process lines for UF_6 conversion, pellet preparation, and rod loading is described. Plant feed is UF_6 and plant product is finished fuel bundles. All scrap is converted to U_3O_8 and processed to UO_2 . Poison preparation is excluded. All enrichment blending is assumed to take place in scrap recovery as UNH. Liquid wastes are stored in solar evaporation ponds and all solid wastes (barrels and filters) are either stored on-site or sent to burial.

Section III--Six Month Material Balance Model. The plant material balance model is described in terms of the number of items, item quantities, and U-factors for all components of the model plant material balance.

Section IV--Measurements. The key measurements and measurement points for the model plant are described. Brief descriptions of the sampling, analytical, volume, and mass measurements are given.

Section V--Error Parameters, Measurements, and Sigma MUF Calculations. The measurement error parameter values, the number and kind of measurements made for the example six-month material and an example of the measurement uncertainty of MUF are given.

Section VI--Material Control Areas. A simplified material control area structure is given for the model plant. The material control area structure is described in terms of its purpose in the accounting structure.

Section VII--Accounting, Records and Reports. The concepts of accounting by project and enrichment, and by a combination of MBAs and ICAs are described. The concept of perpetual inventory is also included. The main accounting records and reports for satisfying U.S. national system requirements are also given.

Section VIII--Tamper-Safing. The use of seals and their purpose in materials accounting are described in terms of meeting U.S. national system requirements.

Section IX--Measurement Control Program. The measurement control program is described in terms of its basic elements and its relationship to U.S. national system requirements.

II. PROCESS ASSUMPTIONS

For purposes of illustrating accountability in a conversion-fabrication plant, the model or example process is assumed to have the characteristics listed below and shown in Figure 1.

A. Production Rate

One tonne U per day and 5 days per week of production. Nominal enrichment of 3.0 weight percent U-235.

B. UF₆ Conversion

UF₆ conversion to aqueous UO₂F₂, precipitation of ammonium diuranate (ADU) with NH₄OH, and conversion of ADU to UO₂ powder.

C. Powder Preparation

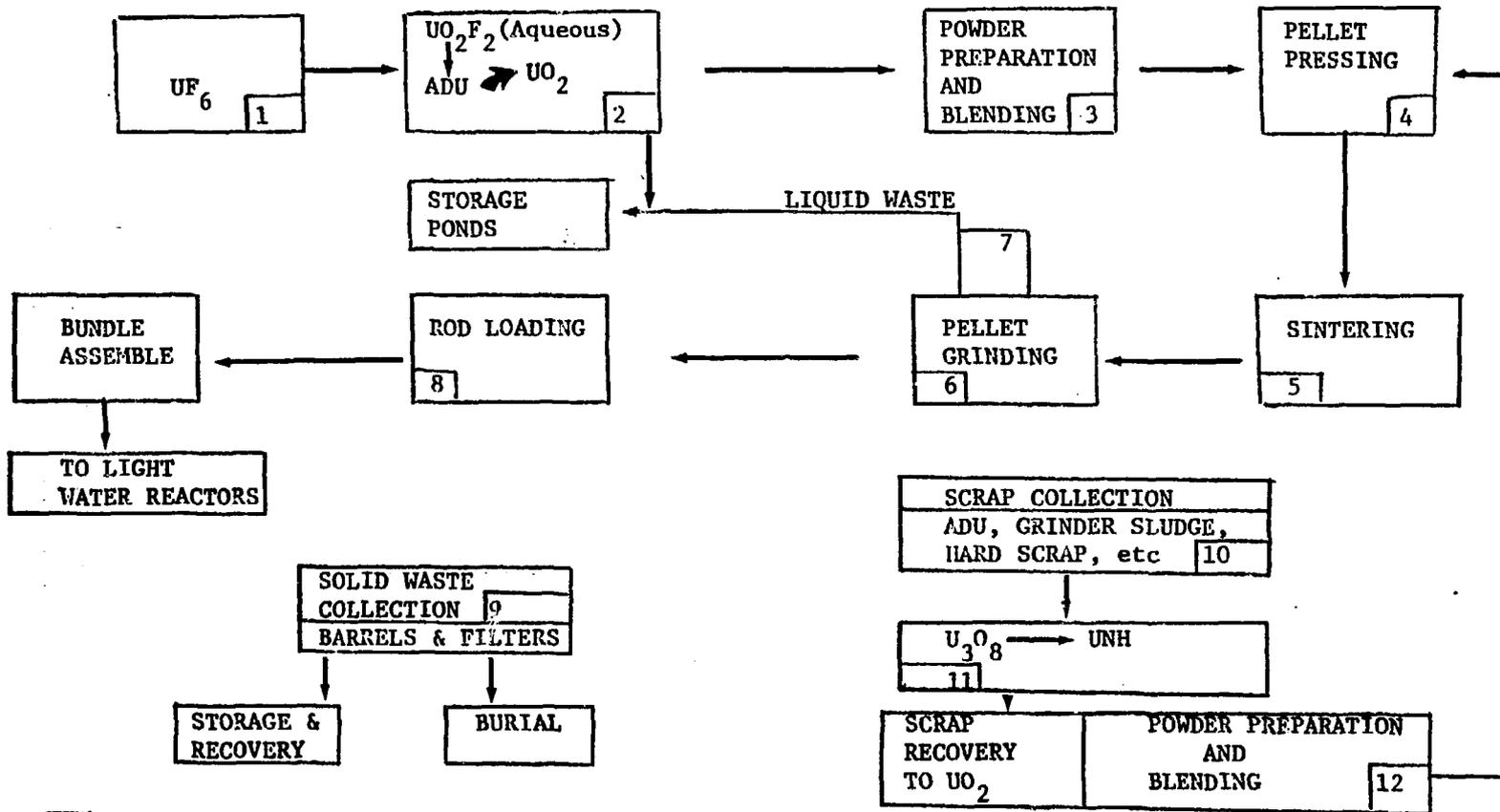
Calcined powder is processed through preparation steps and blended to yield homogeneous lots of green UO₂ powder.

D. Pelletizing

Green powder is pressed mechanically to produce green fuel pellets.

E. Sintering

Green pellets are sintered in high temperature furnaces under a reducing atmosphere to yield sintered fuel pellets.



X Key Measurement Points

Figure 1. Process Flow Diagram for Model Plant

F. Grinding

Sintered pellets are ground by wet grinding to size specifications.

G. Rod Loading

Columns of finished sintered pellets are weighed and loaded into fuel rods.

H. Rod Finishing and Bundle Assembly

Loaded fuel rods are processed through rod finishing steps and assembled into fuel bundles.

I. Product Shipments

Finished fuel assemblies are packed in fuel assembly shipping containers and shipped via trucks to light water reactors.

J. Waste

The plant generates solid wastes of contaminated handling materials (gloves, paper, plastic) and process filters and liquid wastes from the ADU process and pellet grinding. The solid waste barrels and filters are either stored for recovery or shipped to burial. All liquid wastes are transferred to solar evaporation ponds for concentration and waste treatment. For the accountability model, the plant is assumed to generate solid waste at a rate of 0.2% of thruput and liquid waste at a rate of 0.3% of thruput or total waste of 0.5% of thruput. Note that the 0.5% value is selected as a typical industry value to give emphasis to waste measurements and the need for a measured material balance as opposed to by-difference accounting (zero MUF) practices which the IAEA is trying to eliminate.

K. Scrap Recovery and Enrichment Blending

Scrap materials--grinder sludge, ADU, hard scrap, and dirty powder--are converted to U_3O_8 dissolved to form UNH and processed through scrap recovery which produces prepared, blended green powder lots for pressing. All enrichment blending is assumed to take place in scrap recovery. For U-235 LEMUF calculation, a scrap recycle rate of 15% of thruput is assumed to illustrate the effect of booking 15% of thruput as measured U-235, and 85% of thruput as verified virgin (no enrichment change between input and output) material.

III. SIX-MONTH MATERIAL BALANCE MODEL

The six-month material balance model for the example plant assumed for the IAEA course is shown in Table I. The plant is assumed to operate at a one-tonne-U-per-day rate, 5 days a week and 20 days per month. The recycle of scrap is assumed to be 15% input with all scrap oxidized to U_3O_8 and then either going to storage or processed through scrap recovery and returned to the product stream during the current accounting period. Inventory holdings, which contribute to MUF and LEMUF are assumed to consist of ADU generated from inventory and enrichment cleanouts, green powder,

TABLE I. Six Month Uranium Material Balance Model for Example Plant

<u>Material Balance Component</u>	<u>Percent Uranium</u>	<u>Number of Items</u>	<u>Kgs. U per Item</u>	<u>Total U per Type</u>
<u>Additions</u>				
UF ₆	67.60	84	1,400	117,600
<u>Removals</u>				
Rods (UO ₂ pellets)	88.10	46,800	2.5	117,000
Waste Barrels	--	470	0.4	188
Filters	--	240	0.2	48
Liquid Wastes	50 ppm	176 (21)	2.0	352
UF ₆ Heels	67.60	84	2.0	168
<u>Inventory (a)</u>				
Green Powder	87.6	300	17	5,100
Green Pellets	87.6	20	18	360
Sintered Pellets (on trays)	88.10	1,000	6	6,000
Sintered Pellets (in boats)	88.10	20	18	360
U ₃ O ₈ Powder	84.5	250	17	4,250
Hard Scrap	88.10	40	21	840
ADU	60.0	40	10	400
Grinder Sludge	80.0	20	12	240
Dirty Powder	86.0	20	17	340

(a) Quantities present for both beginning and ending inventory.

green pellets, grinder sludge, U₃O₈, hard scrap, dirty powder, and sintered pellets. Wastes transferred to storage or sent to burial are treated as removals from the MBA (going to burial or retained waste).

IV. MEASUREMENTS

The key measurement points for the model plan were shown previously in Figure 1. The corresponding measurements for each measurement point are given in Table II. A summary of the uranium element and isotopic measurements are given in Table III and described briefly below. Sampling methods are given in Table IV.

The gravimetric method is used to determine the weight percents of uranium in UF₆ (outside laboratory), in UO₂ powders and pellets, and in scrap. For the powders and pellets, five to ten grams of sample is loaded into an ignited, tared crucible, weighed, and the UO₂ ignited to U₃O₈ in a muffle furnace at 900° ± 25°C. The weight percent uranium calculation depends on the sample weights before and after ignition, the impurity content as determined from the spectrographic analysis, the calculated U₃O₈ to U gravimetric factor.

TABLE II. Description of Key Measurements for Model Plant

Key Measurement Points	Measurement Description
(see Figure 1)	
1	Each cylinder of UF ₆ is weighed upon receipt and the cylinder tare weight is used to determine the net weight of UF ₆ .
(1)	Percent of uranium and U-235 are determined for each cylinder or for each group of cylinders with the same nominal composition using sealed samples taken at the diffusion plant and witnessed by an Exxon Nuclear employee or authorized agent.
(1)	After UF ₆ removal, the cylinder is weighed to determine the net weight of any residual heel using the cylinder tare weight.
2	The uranium concentration in liquid wastes is measured when the material is discharged to the lagoon on a batch basis. The batch volumes are also determined.
3	After powder preparation, each bucket of UO ₂ is weighed and buckets are tared individually. The cans of UO ₂ powder are randomly selected on a sample basis for measurement of percent uranium and U-235.
4	Each boat is weighed with the boats tared individually for green pellet inventory.
5	The loaded boats containing the sample pellets, as at measurement point 4, are weighed for inventory of sintered pellets.
6	The loaded pellet trays are weighed; each tray is individually tared for sintered UO ₂ inventory.
7	Centrifuged grinder water is sampled for uranium concentration and a volume measurement is made of each batch transferred to the storage ponds.
8	Pellet samples sent to the analytical laboratory are weighed. Percents of uranium and U-235 are determined. The weight of the UO ₂ in each rod is determined by weighing the fuel column stack before inserting into the rod. Accountability is maintained thereafter on a piece count basis.

TABLE II. (Continued)

<u>Key Measurement Points</u>	<u>Measurement Description</u>
9	Low grade wastes (filters, solid wastes in barrels) are contained as a heterogeneous mass and measured for total U-235 by NDA.
10	All containers of dirty powder, ADU scrap, and grinder sludge are individually weighed, sampled, and assayed. The percent of uranium factor for hard scrap is the same as for sintered pellets.
11	Blended lots of U ₃ O ₈ are sampled for percent U and U-235. Each bucket of U ₃ O ₈ is weighed and buckets are tared individually.
12	Same as measurement point 3.

TABLE III. Summary of Uranium Methods

<u>Measurement Point</u> (see Figure 1)	<u>Analytical Method</u>	
	<u>Element</u>	<u>Isotope</u>
1 UF ₆	Gravimetric	Mass Spectrometer
2 Liquid Waste	Fluorimetric, Titration	Factor
3,12 UO ₂ Powder	Gravimetric	Mass Spectrometer
8 UO ₂ Pellets	Gravimetric	Mass Spectrometer
10 Dirty Powder, ADU	Gravimetric or Titration	Factor
11 U ₃ O ₈	Gravimetric	Factor
10 Grinder Sludge	Gravimetric or Titration	Factor
9 Solid Waste	Factor	NDA

TABLE IV. Model Plant Sampling Method

Key Measurement Point (see Figure 1)	Materials	Description
1 UF ₆ Receipts	UF ₆	Sampled at diffusion plants. See UF ₆ sampling procedures, TID-7029, "Selected Measurement Methods for Plutonium and Uranium in the Nuclear Fuel Cycle," USAEC, 1963.
2,7 Liquid Waste Lagoon Inventory	Centrifuged Grinder Water	Line sample from transfer line.
	Filtrate (Centrate Hold Tank)	Tank solution mixed by circulating pump and sampled through built-in circulating sampling lines.
3,12 UO ₂ Green Powder	UO ₂ Powder	Thief or scoop sampled after blending. Three buckets from each lot are sampled and each sample assayed.
11 U ₃ O ₈	U ₃ O ₈ Powder	
8 Sintered Pellets UO ₂ Product	UO ₂ Pellets	Random samples of whole pellets are taken for U assay and U-235 verification. Five pellets per lot are taken for U assay and two for percent U-235 verification.
10 Scrap Inventory	Grinder Sludge, ADU, Dirty Powder, U ₃ O ₈	All scrap is sampled by scoop after mixing of container (5-gallon cans) contents by mechanical stirring or by tumbling the container.

The titration method may be used to determine the percents of uranium in scrap and liquid waste. An excess of ferrous sulfate is used to reduce U(VI) to U(IV) in a phosphoric acid medium containing sulfuric acid. Excess ferrous ion is destroyed with nitric acid using Mo(VI) as a catalyst. The titration is made potentiometrically with standard potassium dichromate in a sulfuric acid solution. The primary variables used in the calculation include the weight and normality of $K_2Cr_2O_7$, the volume of the titrant, the equivalent weight of U, the sample weight, and the effective oxidation of NBS $K_2Cr_2O_7$.

The mass spectrometer is used to determine isotopic composition (percent U-235). A solid sample deposited on a filament is thermally ionized. The ions travel through electrical and magnetic fields that accelerate and separate the ions into beams, each beam consisting of ions having the same mass-to-charge ratio. Separation of the ions is explained by an equation expressing the mass-to-charge ratio as a function of the magnetic field strength, the radius of curvature of the ion path, and the accelerating voltage. The magnetic field is varied to focus a specific ion on the detector. The detector output is recorded on a strip chart and isotopic content is calculated from the voltages of the ion beams.

Analysis of liquid wastes for uranium concentration is performed using the fluorometric technique. Samples are fused with NaF-LiF and the amount of uranium determined by measuring the amount of fluorescence when activated with ultraviolet radiation. Samples are purified via solvent extraction where interfering materials are present.

Nondestructive Assay Measurements: Uranium in 55-gallon drums of solid wastes is measured by an NDA system consisting of four sodium iodide (NaI) detectors and associated electronics and a barrel rotating fixture. The barrel is rotated at about five rpm to provide an average count from the barrel independent of the radial location of the uranium. Lead shields around the detectors provide vertical and horizontal collimation to flatten out the system response due to variations in source location in the vertical direction.

Uranium retained in HEPA filters after they have been shaken to remove loosely adhered particles is measured by the same NDA system as described above. The filters are packaged in boxes about one foot by two feet by two feet in size during the measurement operation.

Volume Measurements: The volumes of liquid wastes transferred to the storage ponds are measured as follows:

1. Filtrate (Centrate Waste from Conversion and Scrap Recovery): Volumes are measured by a liquid level (full) sensor for each batch transfer to the lagoon system. A typical batch transfer is about 500 gallons.
2. Centrifuge Grinder Water: Small volumes of clean grinder water (~15 gallons) are measured by the liquid level (sight markings) change of each discharge to the lagoon. The liquid level markings are calibrated for the small volume horizontal tanks by adding known volumes of water.

Mass Measurements--UF₆ cylinders are weighed on a UF₆ cylinder scale of 4000 kg capacity. All other weighings except fuel pellet columns are done on load cell digital read-out scales of 50 kg capacity. Fuel pellet columns are weighed on load-cell digital readout scales of 5 kg capacity.

V. ERROR PARAMETERS, MEASUREMENTS, AND SIGMA MUF CALCULATIONS

The measurement errors for illustrating uranium sigma MUF (LEMUF) calculations are given in Table V. The table also gives the measurement methods by name. The number of measurements made by each measurement instrument or method, the measurement batch sizes, and the number of items or quantities affected by short-term and long-term systematic errors are given in Table VI.

An example calculation of the uranium element sigma MUF (σ_{MUF}) for a six-month material balance is given in Table VII. The example calculation for σ_{MUF} includes several simplifying assumptions. Long term systematic weighing errors for the UF₆ scale are assumed to be of the same magnitude and direction for both full cylinders and heels, e.g., they cancel. For scales used to establish inventory weights, the long-term systematic weighing errors of beginning inventory and ending inventory items are assumed to be of the same magnitude but a different and unknown direction, e.g., independent. Long-term systematic errors for sampling and analytical measurements are assumed to be constant throughout the accounting period. Since the model material balance has identical quantities in the beginning and ending inventory, those errors are self-cancelling in the example. The example errors and subsequent σ_{MUF} give high emphasis to the potential systematic errors associated with sampling liquid waste and in assaying solid waste. It should be noted that the combination of an equilibrium inventory model and the conversion of difficult-to-measure material such as ADU to U₃O₈, results in a very low σ_{MUF} . For example, if the inventory quantity of U₃O₈ shown in the model were a quantity of ADU and grinder sludge accumulated during the accounting period, the sigma MUF would be about 2 times larger due to the systematic sampling errors for those materials.

TABLE V. Error Parameter Values for Model Plant Uranium Material Balance

<u>Method</u>	<u>Description</u>	<u>Number</u>	<u>Component and Class (a)</u>	<u>σ, % RSD U (or as noted) (b)</u>		
				<u>Random</u>	<u>S.T. System</u>	<u>L.T. System</u>
Weighing	Scale 1 UF ₆ Scale	W ₁	<u>Additions</u> --UF ₆ Full Cylinders, Class I <u>Removals</u> --UF ₆ Heels, Class 2e	0.40 kg	0.60 kg	0.15 kg
Weighing	Scales 2-13	W ₂ -W ₁₃	<u>Inventory</u> --Class 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i	8 gm	---	6 gm
Weighing	Scales 14,15	W ₁₄ ,W ₁₅	<u>Removals</u> --Rods Class 3a	0.30 gm	---	0.20 gm
Sampling	Sampling by Scoop or by Thief	S ₁	<u>Inventory</u> --Scrap, Class 3g, ADU	6.0	---	3.0
Sampling	Sampling by Scoop or by Thief	S ₂	<u>Inventory</u> --Scrap, Class 3h, Grinder Sludge	3.0	---	2.0
Sampling	Sampling by Scoop or by Thief	S ₃	<u>Inventory</u> --Scrap, Class 3i, Dirty Powder	3.0	---	0.5
Sampling	Circulating Sample	S ₄	<u>Removals</u> --Liquid Waste, Class 2d	5.0	---	15.0
Volume	Liquid Level Constant Volume Discharge	V ₁ ,V ₂ V ₃	<u>Removals</u> --Liquid Waste Class 2d	5.0	---	3.0(c)

37a-11

TABLE V. (contd)

<u>Method</u>	<u>Description</u>	<u>Number</u>	<u>Component and Class (a)</u>	<u>σ, % RSD U (or as noted) (b)</u>		
				<u>Random</u>	<u>S.T. System</u>	<u>L.T. System</u>
U-Factor	Gravimetric	U ₁	<u>Receipts--UF₆ Input,</u> <u>Class 1</u> <u>Removals--UF₆ Heels,</u> <u>Class 2e</u>	0.013	---	0.005
U-Assay	Gravimetric	U ₂	<u>Removals--Class 2a</u>	0.02	---	0.015
U-Factor	Gravimetric	U ₃	<u>Inventory--Class 3a,3b</u>	---	0.30	0.015
U-Factor	Gravimetric	U ₄	<u>Inventory--Class 3c,</u> <u>3d,3f</u>	---	0.030	0.10
U-Factor	Gravimetric	U ₅	<u>Inventory--Class 3e--</u> <u>U₃O₈</u>	---	0.10	0.10
U-Assay	Gravimetric	U ₆ -U ₈	<u>Inventory--Scrap</u> <u>Class 3g,3h,3i</u>	0.04	---	0.10
U-235 Assay	Passive NDA	U-235 ₁	<u>Removals--Waste,</u> <u>Class 2b, 2c, Barrels</u> <u>and Filters</u>	15.0	---	20.0 (d)
U-Assay	Fluorimetric	U ₉	<u>Removals--Liquid</u> <u>Waste, Class 2d</u>	10	---	8

(a) RSD denoted relative standard deviation. * S.T. System and L.T. System denote short-term and long-term systematic errors. Weighing errors for UF₆ cylinders are given as absolute standard deviations for gross weights of uranium. The tare is assumed to be constant. The other weighing errors are given as absolute standard deviations for net uranium weight.

(b) The material classes correspond to those given in Table 1.

(c) Combined systematic error for 2 banks of identical tanks for each discharge point, e.g., line 1, Line 2, and Scrap Recovery.

(d) Illustrative composite value. Actual NDAs are calculated for each Class 2b and 2c from calibration error equations.

TABLE VI. Measurements for Model Plant Six-Month Uranium Material Balance

Measurement	Material	Class	Method Number	Batch Size Kgs U	Total Kgs U by Method	Measurements by Method		Total Affected by L.T. System Error
						Random	S.T. System	
Weighing	UF ₆	1	W ₁	1,400	117,600	84	17 (a)	84 Items
Weighing	UF ₆ Heels	2e	W ₁	2.0	164	84	17	84 Items
Weighing	Pellet Columns (rods)	2a	W ₁₄	2.5	58,500	23,400	--	23,400 Items
Weighing	Pellet Columns (rods)	2a	W ₁₅	2.5	58,500	23,400	--	23,400 Items
Weighing	Green Powder	3a	W ₂	17	4,590	270	--	135 Items (2)
Weighing	Hard Scrap	3f	W ₂	21	420	20	--	10 Items (2)
Weighing	ADU	3g	W ₂	10	400	40	--	20 Items (2)
Weighing	Dirty Powder	3i	W ₂	17	340	20	--	10 Items (2)
								W ₂ = $\frac{10 \text{ Items (2)}}{175 \text{ Items (2)}}$
Weighing	Green Powder	3a	W ₃	17	4,590	270	--	135 Items (2)
Weighing	Hard Scrap	3f	W ₃	21	420	20	--	10 Items (2)
Weighing	ADU	3g	W ₃	10	400	40	--	20 Items (2)
Weighing	Dirty Powder	3i	W ₃	17	340	20	--	10 Items (2)
								W ₃ = $\frac{10 \text{ Items (2)}}{175 \text{ Items (2)}}$
Weighing	Green Powder (scrap recovery)	3a	W ₁₀	17	1,020	60	--	30 Items (2)
Weighing	Green Pellets	3b	W ₄	18	360	20	--	10 Items (2)

TABLE VI. (contd)

<u>Measurement</u>	<u>Material</u>	<u>Class</u>	<u>Method Number</u>	<u>Batch Size kgs U</u>	<u>Total kgs U by Method</u>	<u>Measurements by Method</u>		<u>Total Affected by L.T. System Error</u>
						<u>Random</u>	<u>S.T. System</u>	
Weighing	Green Pellets	3b	W ₅	18	360	20	--	10 Items (2)
Weighing	Sintered Pellets (on trays)	3c	W ₆	6	6,000	1,000	--	500 Items (2)
Weighing	Sintered Pellets (on trays)	3c	W ₇	6	6,000	1,000	--	500 Items (2)
Weighing	Sintered Pellets (in boats)	3d	W ₈	18	360	20	--	10 Items (2)
Weighing	Sintered Pellets (in boats)	3d	W ₉	18	360	20	--	10 Items (2)
Weighing	Grinder Sludge	3h	W ₁₁	12	240	20	--	10 Items (2)
Weighing	Grinder Sludge	3h	W ₁₂	12	240	20	--	10 Items (2)
Weighing	U ₃ O ₈	3e	W ₁₃	17	8,500	500	--	250 Items (2)
Sampling	ADU	3g	S ₁	10	800	80	--	--
Sampling	Grinder Sludge	3h	S ₂	12	480	40	--	--
Sampling	Dirty Powder	3i	S ₃	17	680	40	--	--
Sampling	Liquid Waste	2d	S ₄	2.0	352	176	--	352 Kgs
Volume	Liquid Waste (line 1)	2d	V ₁	2.0	158	1,659	--	158 Kgs

37a-14

TABLE VI. (contd)

Measurement	Material	Class	Method Number	Batch Size kgs U	Total kgs U by Method	Measurements by Method		Total Affected by L.T. System Error
						Random	S.T. System	
Volume	Liquid Waste	2d	V ₂	2.0	158	1,659	--	158 Kgs
Volume	(line 2) Liquid Waste	2d	V ₃	2.0	36	378	--	36 Kgs
U-Assay	UF ₆	1	U ₁	1,400	117,600	171	(full- heels)	117,432 Kgs
U-Assay	UF ₆ Heels	2e	U ₁	2.0	164	171		
U-Assay	UO ₂ in Rods	2a	U ₂	1,200	117,000	488		
U-Factor	UO ₂ Unsintered	3a,3b	U ₃	1,200	10,920	--	9 (lot-to- lot) (variation)	--
U-Factor	UO ₂ Sintered on Inventory	3c,3d	U ₄	1,200	14,400	--	12 (lot-to- lot) (variation)	--
U-Factor	U ₃ O ₈	3e	U ₅	500	8,500	--	17 (lot-to- lot) (variation)	--
U-Assay	ADU	3g	U ₆	10	800	80	--	--
U-Assay	Grinder Sludge	3h	U ₇	12	480	40	--	--
U-Assay	Dirty Powder	3i	U ₈	17	680	40	--	--

37a-15

TABLE VI. (contd)

<u>Measurement</u>	<u>Material</u>	<u>Class</u>	<u>Method Number</u>	<u>Batch Size kgs U</u>	<u>Total kgs U by Method</u>	<u>Measurements by Method</u>		<u>Total Affected by L.T. System Error</u>
						<u>Random</u>	<u>S.T. System</u>	
U-235 Assay	Waste Barrels	2b	U-235 ₁	0.4	188	470	--	288 Kgs
U-235 Assay	Filters	2c	U-235 ₁	0.2	48	240	--	48 Kgs
U-Assay	Liquid Waste	2d	U ₉	2.0	352	176	--	352 Kgs

(a) The short-term systematic error for UF₆ cylinder weighing is assumed to affect all cylinders weighed on a given day. For the 84 cylinders and heels, 5 cylinders are weighed per day for 16 days and 4 cylinders weighed during one day.

TABLE VII. Example Calculation of Uranium Sigma MUF for a Six-Month Material Balance

Measurement	Material	Class	Items or Quantities Affected ^(a)			σ ^(b)			σ^2 Kgs ² U by Method			
			Method	Random	S.T. System	L.T. System	Random	S.T. System	L.T. System	Random	S.T. System	L.T. System
Weighing	UF ₆	1	W ₁	84	17	84	0.40 Kg	0.60 Kg	0.15 Kg	13.44	149.76	158.76
Weighing	UF ₆ Heels	2e	W ₁	84	17	84	0.40 Kg	0.60 Kg	0.15 Kg	13.44	149.76	158.76
Weighing	Sintered Pellets (rods)	2a	W ₁₄	23,400	—	23,400	0.30 gm	—	0.20 gm	0.002	—	21.90
Weighing	Sintered Pellets (rods)	2a	W ₁₅	23,400	—	23,400	0.30	—	0.20 gm	0.002	—	21.90
Weighing	Green Powder	3a	W ₂	270	—	135 (2)	8 gm	—	6 gm	Variance Computed for Total Weighing on Scale 2		
Weighing	Hard Scrap	3c	W ₂	20	—	10 (2)	8 gm	—	6 gm			
Weighing	ADU	3g	W ₂	40	—	20 (2)	8 gm	—	6 gm			
Weighing	Dirty Powder	3i	W ₂	20	—	10 (2)	—	—	—			
				350		175 (2)				0.023		2.21
Weighing	Green Powder (scrap recovery)	3a	W ₃	270	—	135 (2)	8 gm	—	6 gm			
Weighing	Green Pellets	3b	W ₄	20	—	10 (2)	8 gm	—	6 gm	0.004	—	0.065
Weighing	Green Pellets	3b	W ₅	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.007
Weighing	Green Pellets (on trays)	3b	W ₆	1,000	—	500 (2)	8 gm	—	6 gm	0.064	—	18.00
Weighing	Sintered Pellets (on trays)	3c	W ₇	1,000	—	500 (2)	8 gm	—	6 gm	0.064	—	18.00
Weighing	Sintered Pellets (in boats)	3d	W ₈	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Sintered Pellets (in boats)	3d	W ₉	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Grinder Sludge	3h	W ₁₁	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	Grinder sludge	3h	W ₁₂	20	—	10 (2)	8 gm	—	6 gm	0.001	—	0.004
Weighing	U ₃ O ₈	3c	W ₁₃	500	—	250 (2)	8 gm	—	6 gm	0.032	—	4.815
								Total Weighing		27.100	299.52	116.815
Sampling	ADU	3g	S ₁	80	—	—	6%	—	(3.0%) (c)	28.80	—	—
Sampling	Grinder Sludge	3h	S ₂	40	—	—	3%	—	(2.0%) (c)	5.184	—	—
Sampling	Dirty Powder	3i	S ₃	40	—	—	3%	—	(0.5) (c)	10.404	—	—
Sampling	Liquid	2d	S ₄	176	—	—	5%	—	15%	1.76	—	2,787.84
								Total Sampling		46.148	—	2,787.84

TABLE VII. (contd)

Measurement	Material	Class	Method Number	Items or Quantities Affected ^(a) by Types of Error			σ (b)			σ^2 Kgs ² U by Method		
				Random	S.T. System	L.T. System	Random	S.T. System	L.T. System	Random	S.T. System	L.T. System
Volume	Liquid Waste (line 1)	2d	V ₁	1,659	—	158	5%	—	3.0%	0.0376	—	22,468
Volume	Liquid Waste (line 2)	2d	V ₂	1,659	—	158	5%	—	3.0%	0.0376	—	22,468
Volume	Liquid Waste (scrap recovery)	2d	V ₃	378	—	36	5%	—	3.0%	0.009	—	1,166
U-Assay	UF ₆	1	U ₁	17	—	117,432 Kgs (full-heels)	0.013%	—	0.005%	13.74	—	34,475
U-Assay	UF ₆ Heels	2c	U ₁	17	—	—	0.013%	—	0.005%	—	—	—
U-Assay	Sintered UO ₂ (in rods)	2a	U ₂	488	—	117,000	0.02%	0.02	0.015%	1.122	—	308.00
U-Factor	Unsintered UO ₂	3a,3b	U ₃	—	10,920 Kgs (9 lots)	—	0.30	—	—	119.246	—	—
U-Factor	Sintered UO ₂ (in inventory)	3c,3d	U ₄	—	14,400 Kgs (12 lots)	—	0.030%	—	—	1.555	—	—
U-Factor	U ₃ O ₈	3e	U ₅	—	8,500 Kgs (17 lots)	—	0.10%	—	—	4.25	—	—
U-Assay	ADU	3g	U ₆	80	—	—	0.04%	—	(0.10) ³	0.001	—	—
U-Assay	Grinder Sudge	3h	U ₇	40	—	—	0.04%	—	(0.10) ³	0.001	—	—
U-Assay	Dirty Powder	3i	U ₈	40	—	—	0.04%	—	(0.10) ³	0.002	—	—
U-Assay	Waste Barrels	2b	U-235 ₁	470	—	188 Kgs	15%	—	20%	1.692	—	Total by Method
U-Assay	Filters	2c	U-235 ₁	240	—	48 Kgs	15%	—	20%	0.216	—	2,227.840
U-Assay	Liquid Waste	2d	U ₉	176	—	352 Kgs	10%	—	8%	7.04	—	792
				Total All Methods			Random	S.T. System	L.T. System			
				Weighing			27,100	299.52	116.815			
				Sampling			46.148	—	2,787.84			
				Volume			0.0842	—	46.102			
				U-Assay			23.8113	125.051	3,363.301			
				Subtotal			97.145	424.571	6,314.058			

Total $\sigma^2_{MUF} = 6,835.774$ Kgs² U
 Total $\sigma_{MUF} = 82.679$ Kgs U

(a) Unless specified as kilogram quantities the numbers shown refer to the number of items affected by random or short-term systematic errors.
 (b) Percent errors are in units of relative standard deviations.
 (c) Long-term systematic sampling and analytical errors are assumed to cancel when the quantities in the beginning and ending are identical.

VI. MATERIAL CONTROL AREAS

For IAEA Safeguards the entire plant area is treated as a single material balance area. The concept of internal material control areas is not relevant to IAEA accounting requirements. For a single plant MBA, emphasis is given to the plant book inventory and the plant MUF. In this case, changes in the plant book inventory are reflected in the plant receipts and shipments. Those inventory changes are reported in the Nuclear Material Transaction Records (Form NRC-741) which are submitted to the U.S. NRC (or IAEA safeguards). A modified 741 form will be used which corresponds to the IAEA Inventory Change Report.

Using the plant ending physical inventory as a starting point, the submission of Inventory Change Reports for shipment and receipts will provide the IAEA with a plant book inventory which is essentially the same as the book inventory maintained by the plant. The plant accounting system for the plant material balance is the Nuclear Material Reporting System (NMRS) which maintains a historical record of all plant receipts, shipments, waste discards, MUF's and ending physical inventories. Internal material control areas are not identified in this system.

To meet U.S. national system requirements, a system of internal material control areas is established and maintained. These are established in order to localize possible MUF losses and to provide internal administrative and custodial control over the nuclear materials. The material control area structure for the model plant is shown in Figure 2. The various material control areas are shown in their approximate locations on the plant site.

For the material control area structure shown in Figure 2, all nuclear materials enter and leave the plant as discrete items through Item Control Area-1 (ICA-1). UF_6 cylinders received from off-site enter the plant accounting records as item receipts to ICA-1. Finished fuel bundles, waste barrels and filters which are to be shipped are transferred to ICA-1 as discrete items prior to shipment off-site.

UF_6 cylinders enter the process as a transfer from ICA-1 to MBA-1 (Conversion and Scrap Recovery). Prepared UO_2 powder is transferred from MBA-1 to ICA-3A (Powder Storage) and then to MBA-2 (Pellet Preparation). Finished pellets are transferred from MBA-2 to MBA-3 for rod loading. Loaded fuel rods are transferred as discrete items to ICA-2 (Rod Storage and Bundle Assembly) for rod finishing and bundle assembly. Analytical samples are transferred from MBA-1, -2, and -3 to MBA-4, the Analytical Laboratory. Fuel bundles ready for shipment are transferred from ICA-2 (Rod Storage and Bundle Assembly) to ICA-1 (Shipping and Receiving). Waste Barrels designated for on-site storage are transferred from MBA-1 to ICA-3K, the Waste Barrel Storage Area.

Containers of scrap and intermediate products are transferred from the originating MBA to the various storage ICAs for storage as discrete items. The letter designations for ICA-3 (3A-3K) specifies a particular location within ICA-3 such as the powder storage room, 3A, the radioactive materials warehouse 3B, or one of the storage

SOLAR EVAPORATION PONDS
MBA-1

ICA-1
Shipping-Receiving

ICA-3K
Waste
Barrel
Storage

ICA-3B-H
Storage

MBA-1 Conversion Scrap Recovery	ICA -3A Powder Storage	Warehouse & Trailers	
	MBA-2 Pellet Preparation	MBA-3 Rod Loading	
MBA-4 Analytical Laboratory	Rod Storage and Bundle Assembly ICA-2		

UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

Figure 2. Model Plant Material Control Areas

A main purpose of the combination of item control areas and material balance areas within the plant is to maximize the amount of inventory present as previously measured discrete items and to minimize the amount of inventory present as bulk quantities. The plant accounting system for the internal material control areas is the Nuclear Inventory Control System (NICS) which maintains a continuous plant book balance by MBA and ICA.

VII. ACCOUNTING, RECORDS, AND REPORTS

A. General

This section describes the details of the Model Plant accounting and reporting system for special nuclear material. The accounting system employs double-entry bookkeeping and is established and maintained centrally.

The nuclear materials accounting records are maintained in two computer data bases:

1. The Nuclear Inventory Control System (NICA) maintains a continuous material balance for the plant by MBA and ICA. Additions, removals, and MUF transactions are processed in the time sequence in which they are recorded; and
2. The Nuclear Material Reporting System (NMRS) maintains a historical record of all plant receipts, shipments, discards, MUFs and ending physical inventories. MBAs and ICAs are not identified in this system.

B. Account Structure

The following types of accounts are established and maintained:

Plant Location. MBA or ICA designation as identified in Figure 2.

Material Type. Currently, there are three accounts: 1) depleted uranium; 2) enriched uranium; and 3) natural uranium.

Enrichment. An account is set up for each nominal enrichment for enriched uranium.

Project. Each job or activity is assigned to an account, i.e., a reactor reload batch.

A chart of project and enrichment accounts is maintained in a separate manual.

A separate record is maintained of additions to and removals from the process, of the quantities of material in unopened receipts, and the ultimate product maintained under tamper-safing or in the form of sealed sources.

C. Accounting Forms

The following basic accounting forms used to record and transmit accounting data are shown in Table VIII. The various accounting forms and methods of preparation are to be illustrated in class-room workshops.

D. Operational Description

The operating mode of the internal accounting system is shown in Figure 3. The NICS systems maintains a continuous book inventory of each internal MBA by quantities of U element and U-235 and by project and by enrichments within each project. The computer-based system also maintains an item listing of each item by ICA designation along with the associated U-element, U-235, and project designation.

The internal accounting system operates via the movement of material from one control area to another. Each movement of material is recorded on a location transfer form which is processed into the computer-based system. That system then credits the receiving MBA with the quantities of element and isotope for that project and enrichment and removes those quantities from the project and enrichment account of the shipping MBA. A similar receipt and removal transaction is made in the case of transfers between ICA's or transfer between an ICA and an MBA.

Two basic data records are used in conjunction with the location transfer forms. As each item of material is generated, the applicable weight data, material composition, item identification number, project and nominal enrichment are recorded on a material record card. The material record card is attached to the container. When a container (or other similar item) is transferred, the data on the record card are entered on the location transfer form which is processed into the computer-based system via key punching of the data and submittal of key punch cards. The corresponding data (or U-factors are selected from the memory for each appropriate material composition such as green UO_2 or sintered UO_2 . For items such as ADU and grinder sludge, which require a U-assay for each item, the laboratory result is entered into the system along with the location transfer form.

U-235 factors are determined for most materials as the weighted average enrichment of each nominal enrichment within each project. The computer-based system updates the (U-235 factors for all material within a given project and enrichment once isotopic measurements are complete. Some scrap items of mixed enrichment are assigned a specific isotopic factor based on measurement of the item.

Accounting Records

An example of the accounting records and their retention periods are shown in Table IX.

Accounting Reports

A number of accounting reports are generated from the master record accounting system data. An example listing is shown in

TABLE VIII. Model Plant Accounting Forms

<u>Title</u>	<u>Descriptions</u>
Receipt-Shipment	This form documents receipts and shipments between the Model Plant and other licensees of power locations. The data from this form are used to complete NRC/DOE 741 forms.
NRC/DOE Form 741	Procedures for completing this form are provided by NRC/DOE.
Location Transfer	This form is used to transfer material between internal MBA or ICA location accounts.
Project/Enrichment Transfer	Transfers between material type, enrichment, and/or project accounts are documented on this form.
Seal Number Replacement	This form is used to record a replaced tamper-indicating seal on a container in an ICA.
MBA Physical Inventory	All containers in a MBA are recorded on this form during a physical inventory.

Table X. Two reports are generated, specifically to meet U.S. national system requirements. These are: Material Balance Reports and Material Status Reports.

The Material Balance Report is prepared within 30 calendar days after the start of each six-month inventory. That report includes a listing of the quantities of element and isotope in shipments, receipts, discards, beginning and ending inventory, and in MUF. The Material Balance Report also includes the calculated LEMUF (2MUF) and a comparison of MUF to LEMUF and applicable U.S. limits.

The Material Status Reports (742 Form Reports) are also prepared after the six-month inventories. An example 742 form (or the model plant will be prepared for the course.

Bias Adjustments

A separate measurement bias account is maintained in which bias adjustments based on standards measurements can be made to all components of the material balance. A bias adjusted MUF is computed for each physical inventory using all estimated biases (whether statistically significant or not). The bias adjusted MUF is used and reported to NRC as a separate index. However, bias adjustments to permanent components of the plant material balance (shipments and receipts) and to the corresponding permanent records and transfer documents are not made unless the measurement bias is statistically

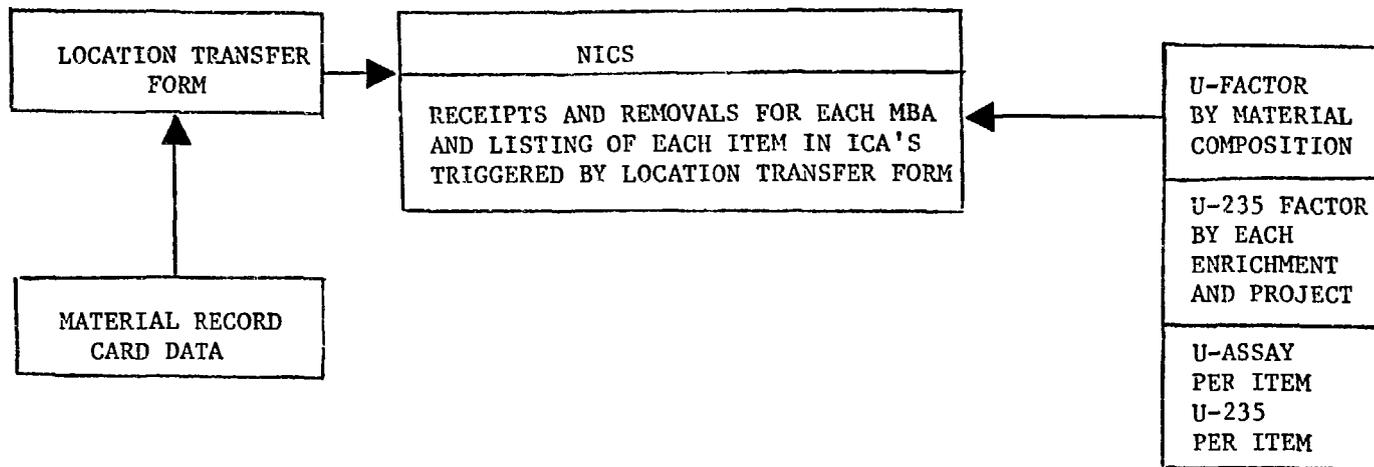


Figure 3. Operating Mode of Internal Accounting System

TABLE IX. Example of Accounting Records and Reports Retention

<u>Document</u>	<u>Issued by</u>	<u>Maintained by</u>	<u>Retention Period</u>
<u>Source Documents</u>			
NRC/DOE 741	NM Accounting	NM Accounting	Permanent
Receipt-Shipment	S/R ICA Custodian	NM Accounting	Five Years
Location Transfer	MBA/ICA Custodian	NM Accounting	Five Years
Project/Enrichment Transfer	MBA Custodian	NM Accounting	Five Years
Seal No. Replacement	ICA Custodian	NM Accounting	Five Years
MBA Physical Inventory	MBA Custodian/ NM Accounting	NM Accounting	Permanent
<u>Internal Records</u>			
Analytical Lab Results	Analytical Lab	Analytical Lab	Item Identity Retained While on Inventory plus Five Years
Physical Inventory Count Sheets	MBA/ICA Custodian	NM Accounting	Permanent
Error Control for Scales and Balances	MBA/ICA Custodian	Statistical Consultant	Five Years
Physical Inventory Instructions and Results	NM Accounting	NM Accounting	Five Years
Packing Slips	S/R ICA Custodian	S/R ICA Custodian	Ten Years
Tamper-Indicating Seal Logs	MBA/ICA Custodian	MBA/ICA Custodian	Five Years
Perpetual Inventory Listing	NM Accounting	NM Accounting	Five Years
Material Balance Ledger	NM Accounting	NM Accounting	Permanent
Ending Inventory Summary	NM Accounting	NM Accounting	Permanent

TABLE IX. (contd)

<u>Document</u>	<u>Issued by</u>	<u>Maintained by</u>	<u>Retention Period</u>
Detailed Transaction Listing	NM Accounting	NM Accounting	Five Years
MUF Calculations	NM Accounting	NM Accounting	Permanent
MUF and Measured Discard Summary	NM Accounting	NM Accounting	Permanent
Possession Limits	NM Accounting	NM Accounting	Five Years
NRC/DOE 742 Material in Process	NM Accounting Systems Analyst	NM Accounting Systems Analyst	Permanent Five years
MUF and LEMUF Analysis	Statistical Consultant	Statistical Consultant	Five Years
Inter-Lab Comparisons	Analytical Lab	Analytical Lab	Five Years
Shipper/Receiver Differences	Statistical Consultant	Statistical Consultant	Five Years

significant. Measurement control measures generally maintain measurement bias well below the level of statistical significance.

VIII. TAMPER-SAFING

Tamper-safing seals are used to protect the integrity of previously made measurements. Two kinds of seals are used. One is the Type E-seal consisting of two metallic parts that, when snapped together form a closed flat cylinder about the knot (wire crimped within a metal sleeve) on the seal wire passing through the two holes in the cylinder. This seal is used primarily for long-term storage items. The E-seal may also be used as a fingerprinted seal by photographing the random distribution of solder droplets adhering to the inside of the seal cap. A serial number is pre-stamped on each of the metal caps.

The second seal is a pressure-sensitive paper seal. It is a fully opaque paper seal with an adhesive backing. The company name and serial number are pre-printed on the seal.

The U.S. national system requires that items in item control areas be tamper-safed to protect the integrity of prior measurements. Items present as inventory items with broken seals must be verified by re-measurement.

TABLE X. Example of Accounting Reports

<u>Title</u>	<u>Data Base</u>	<u>Description</u>
Perpetual Inventory Listing	NICA	Shows current MBA and ICA status. Element and isotope quantities are shown for each MBA by material type, project, and enrichment accounts. Individual containers are shown for each ICA inventory.
Material Balance Ledger	NMRS	Periodic summary of beginning inventory, receipts, shipments, discards, MUF, and ending inventory. Material type, project, and enrichment account detail is given.
Ending Inventory Summary	NICS	Periodic summary showing all containers on ending inventory.
Detailed Transaction Listing	NICS	Shows all transactions which modify the perpetual inventory.
MUF Calculation	NICS/ Physical Inventory	Matches MBA physical inventory and NICA book inventory by material type, project, and enrichment accounts.
MUF and Measured Discard Summary	NMRS	Summarizes MUF and measured discards by enrichment account.
Possession Limits	NMRS	A weekly report comparing inventory levels with license limits.
NRC/DOE Form 742	NMRS	Prepared in accordance with printed instructions.

The U.S. national system also requires that the seals be controlled. Unused seals are kept under lock and records are kept of all seals applied to items. Log books are maintained of the disposition of each seal issued for use. The log book entry includes the container number, the seal type, the seal number, date of application, and signature of two witnesses to the measurements made (such as sampling and weighing) just prior to sealing.

IX. MEASUREMENT CONTROL PROGRAM

The measurement control program is carried out to meet three safeguards objectives. The first is to ensure the control and quality of accountability and verification measurements. The second is to provide an experimental basis for the estimation of the random and systematic errors of measurement in order to calculate the measurement uncertainty of the material accounting term, MUF. The third is to provide documented evidence that safeguards measurements have met quality criteria.

The measurement control program encompasses all elements of the measurement processes used to determine quantities of uranium element and U-235 isotope in plant receipts, shipments, waste discards, and inventory.

The program is directed at the individual elements of the measurement processes rather than the measurement components of the plant material balance. For each element of the measurement process, such as weighing, sampling, and analytical measurement, a program of standards, replicate measurement, calibrations, and statistical analysis are applied. In addition, the program includes special experiments to estimate weighing and sampling errors and the potential matrix bias arising from the passive gamma measurement of U-235 in solid wastes.

For mass measurements, the program includes a set of standard weights for each scale type, replica mass standards, routine check weighings, replicate standard weighings, and initial and periodic certifications.

A similar program of standards, replicate measurements and certification is carried out for analytical measurements. The high-quality features of the analytical measurements form the basis for the preparation, traceability, and certification of the NDA standards.

The control program for the passive gamma assay of U-235 in solid waste (barrels and filters) includes calibration standards, replicate measurements, daily control measurements, matrix control procedures, and special chemical leaching experiments.

The sampling program consists of two aspects. One part is aimed at homogeneous materials for which sampling error control is an inherent part of the production process. The other part is directed to non-homogeneous materials such as ADU and grinder sludge. For these types of materials, a special resampling program is carried out for estimating random error. Special oxidation experiments of entire items using the U₃O₈ process facility may be used to estimate systematic sampling errors.

All data generated in the program are documented and subject to routine review and statistical analysis. Control program results are used for taking immediate corrective actions in the case of an out-of-control measurement and also for the estimation of long-term trends and measurement error parameters for LEMUF calculations. A detailed measurement review is performed annually and error parameter estimates are updated at least every six months.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 37b: PREPARATION OF A FUNDAMENTAL
NUCLEAR MATERIAL CONTROL PLAN

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Exxon Nuclear

I. INTRODUCTION

The general features of U.S. Regulations and the general provisions for low enriched uranium were discussed in Session 4. The general requirements for materials accounting and the corresponding approach taken to meet each general requirement were covered in Session 17a. The work of those previous sessions is extended to the preparation of two formal safeguards documents. These are: 1) the Fundamental Nuclear Material Control Plan (FNMC) which is required by U.S. Regulations and 2) the preparation of a Design Information Questionnaire (DIQ) for the IAEA.

The preparation of an FNMC Plan is described in this session and the preparation of a DIQ in the session that follows.

II. PREPARATION OF FNMC PLAN

The preparation of an FNMC Plan is described in detail in Regulatory Guide 5.45, "Standard Format and Content for the Special Nuclear Material Control and Accounting Section of a Special Nuclear Material License Application."

For a fuel fabrication plant, the Guide consists of an introduction, eleven chapters of text and an appendix. The content of each chapter and the appendix are discussed separately in the remainder of presentation.

III. USE OF REGULATORY GUIDE 5.45

A. Guide Introduction

The Introduction describes the purpose and basis for the Guide. A main purpose is to provide a standard format to give uniformity and completeness to the preparation and review of license applications to possess special nuclear materials.

The Introduction gives instructions for using the Guide in preparation of an FNMC. It also gives examples of substantiating and clarifying information which an applicant may wish to submit to strengthen the application.

The standard format gives rules for numbering pages and sections, the desired style and composition, and the physical specifications of

the document. Those include page size, margin, printing and binding. Procedures for updating or revising pages are given.

The Introduction to the Guide would be particularly useful to students who will be establishing Regulatory procedures in their countries.

B. Chapter 1--Design of Structures, Components, Equipment, and Systems

Chapter 1 provides guidance to the applicant for describing the design characteristics which are important to nuclear materials control and accounting. This part of the application, which is submitted prior to construction, should describe those permanent characteristics of the plant and process in sufficient detail to allow the Regulatory staff to determine if the plant can be constructed with adequate provisions for the accounting and control of nuclear materials.

Materials accounting and control topics for which the applicant is asked to provide design criteria and design features include the following:

1. Material Control Areas,
2. Automated Special Nuclear Material and Accounting Capability (if any),
3. Measurement Capability,
4. Waste Accountability,
5. Scrap Control, and
6. Special Nuclear Storage and Handling.

The design criteria discussed in Chapter 1 of the Guide are somewhat different than the criteria discussed in Session 17. The design criteria discussed in Session 17, "Basis of Accountability System" were for achieving material accounting objectives, whereas the criteria discussed in Chapter 1 of the Guide are to assure that the plant will be constructed in such a way that the desired material accounting and control features of the safeguards system will be achieved (e.g., material balance areas); or, at least, such that the permanent features of the plant do not preclude their achievement.

For the low enriched uranium fuel fabrication plant used as the Model Plant for this course, important design considerations include the following:

1. Complete process containment to assure that there are no unmeasured losses,
2. Capabilities to quantitatively measure all uranium bearing effluents,

3. Capabilities to monitor all plant effluents and local environment to provide positive assurance that containment integrity was maintained,
4. Identifiable, cleanable, and inspectable process equipment, duct work, plenums, and transfer lines so that in-process inventories can be periodically measured by cleanout and measurement of the removed nuclear material, along with inspection of all associated equipment to assure that no hidden inventory remains after cleanout,
- 4a. Equivalent to design considerations for cleanout inventories could be design features for quantitative NDA measurements of all or part of the in-process inventory,
5. Sufficient structural stability (freedom from vibration) such that accurate weight measurements can be made in the analytical laboratories and at all key weight measurement points, and
6. Sufficient electrical stability and isolation from radio frequency sources so that accurate instrumental measurements (mass spectrometer, quantometer) can be made in the analytical laboratory.

C. Chapter 2--Quality Assurance

This chapter describes the features of the quality assurance program which the applicant should establish or consider to assure that the desired design features and properties are actually obtained.

The purpose of the Quality Assurance Program is to assure that the specified design criteria and resulting design features for meeting special nuclear materials control and accounting are actually achieved.

The Safeguards Quality Assurance Program for the construction phase of the Model Plant would not require a large effort. Usually, an integrated QA approach is used to meet the needs of all plant functions, e.g., safeguards, health and safety, operations, quality control, engineering, and process control.

D. Chapter 3--Organization

In this chapter, management structure and functional assignments for special nuclear material control and accounting are described. The relationship of the special nuclear material control and accounting to other functions and the separation of functions for special nuclear material control and accounting are shown. The custodial, measurement, accounting, and audit functions should be in different organizational units so as to provide independent checks and controls for safeguards purposes. Also described are the minimum qualifications for principal positions having responsibilities for special nuclear material control and accounting to assure that the positions will be staffed by personnel with appropriate training and experience.

1. Organization Structure. This section describes the overall management function and its relationship to special nuclear material control and accounting. The applicant describes verbally and with organization charts the corporate organization and the plant organization in relation to their functions in performing the task of special nuclear materials control and accounting.

Examples of organization charts for the Model Plant used for the course are shown in Figures 1 and 2. Examples of job descriptions are given in Table I. Example descriptions of safeguards functions are given in Table II.

2. Responsibilities and Authorities. In this section, various organizational units concerned with special nuclear materials and the specific duties, responsibilities and authorities are described. Examples of the various units and the associated responsibilities for nuclear materials are shown in Figure 3 for the Model Plant. The letter designations and descriptions below each organizational unit in Figure 3 correspond to the safeguards functions, which were identified in the Guide for inclusion by the applicant.

3. Training Programs. In this section, the training programs to be carried out to assure that a nucleus of qualified personnel exist to make the safeguards measurements and perform the various safeguards related duties are described.

An example of a training program used at the Model Plant is given in Table III.

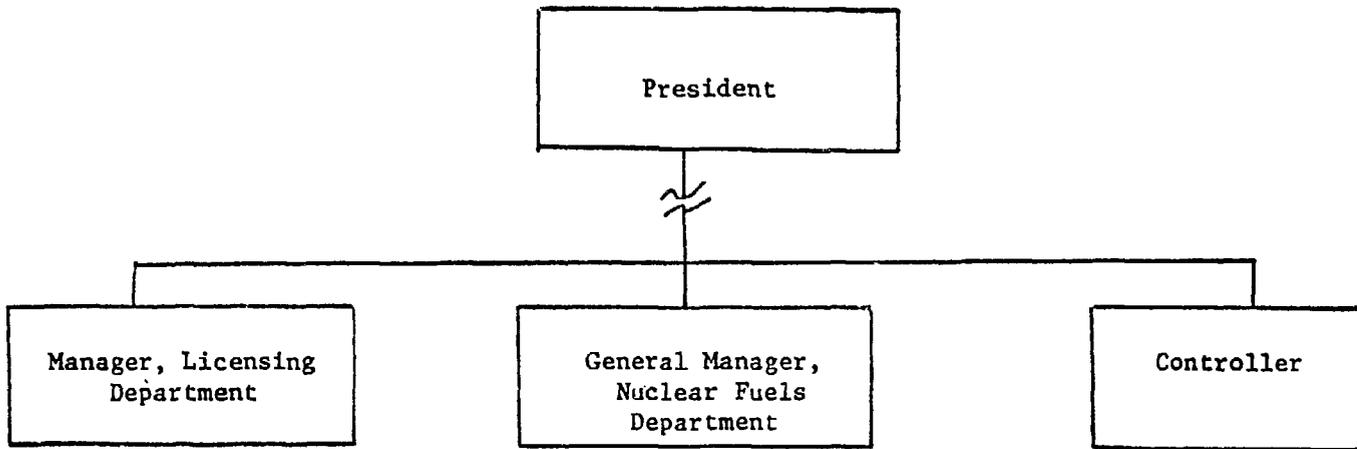
E. Chapter 4--Material Control Areas

In this chapter, the division of the site into material control areas (MCAs) is described. The overall site area containing nuclear material is divided into smaller control zones to facilitate custodial responsibility, establish a set of internal checks and balances, and to localize material losses.

The division into material balance areas (MBAs) and into item control areas (ICAs) is described in terms of location, designation, physical boundaries and process boundaries.

The material control area arrangement for the Model Plant is shown in Figure 4. The rationale for selection of that MCA arrangement was discussed previously in Session 17 and summarized below.

The material control areas for the Model plant were selected on the basis of process, administrative, accounting, and physical considerations. The operation of each MBA is the responsibility of one of the Plant supervisors. Each MBA has defined physical boundaries and each MBA represents a natural grouping of like processing and handling operations. Lastly, the natural flow of material between MBAs involves the transfer of discrete measureable items so that flows into and out of the MBA can be accurately accounted for.



Overall Program Definitions

- Criteria
- Technology
- Licensing Liaison
- Overall Audit

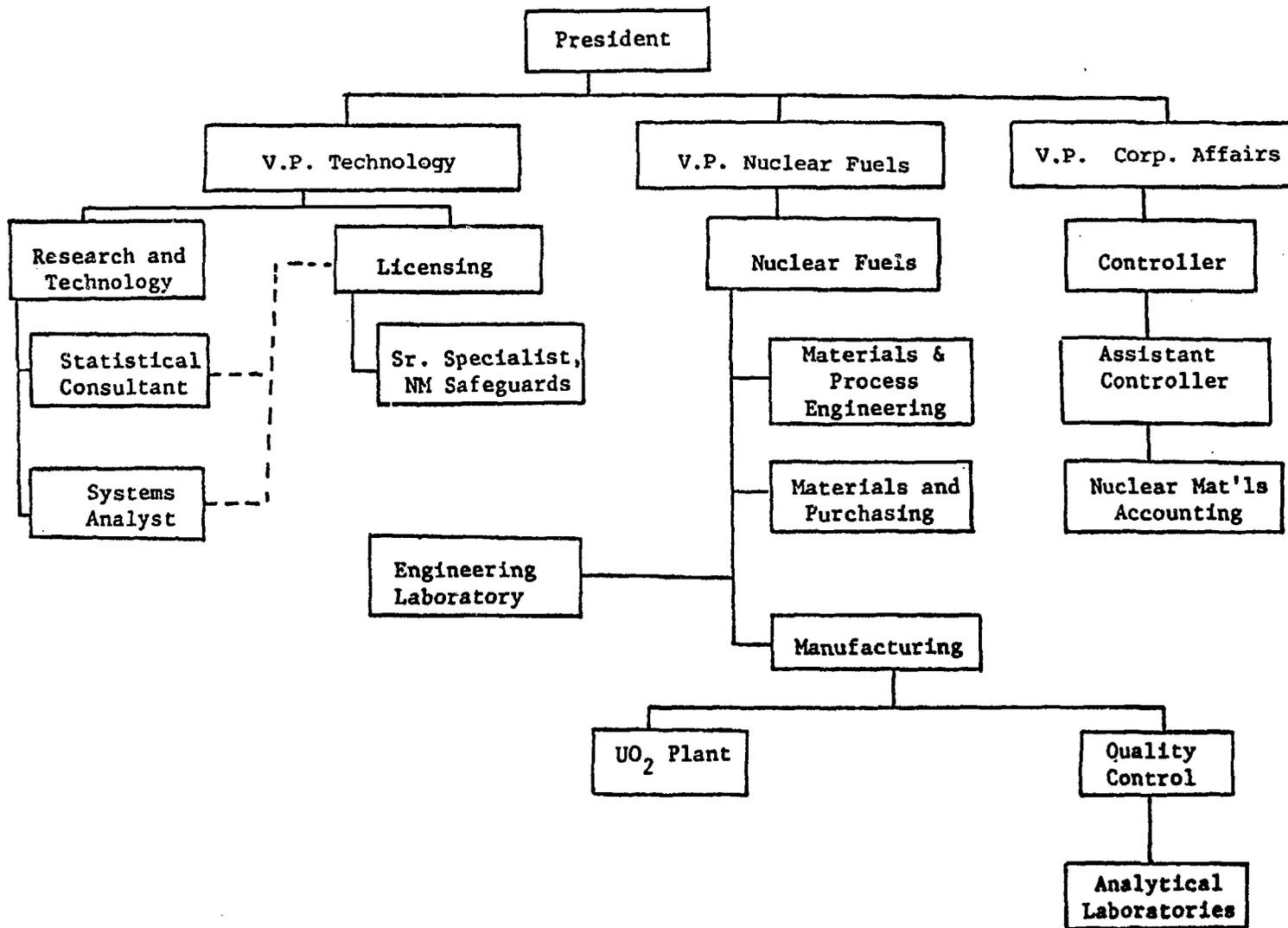
Physical Control

- Custodianship
- Protection
- Measurements

Accounting

- Accounting Records
- Audit of Operations
- Routine Reporting

Figure 1. Model Plant Primary Safeguards Responsibility Components



37b-6

Figure 2. Model Plant Organizational Substructure of Components and Safeguards Responsibilities

The item control area structure was designed to provide maximum inventory and administrative control over all materials not in an immediate processing status and over all items amenable to item control. ICA-1 (Shipping and Receiving) is established so that all materials entering and leaving the Plant are under item control upon receipt and prior to shipment. The storage ICAs were established to place all bulk materials not in an immediate processing status under item control.

TABLE I. Example Safeguards Job Descriptions

Manager, Analytical Laboratories

The Analytical Laboratories Manager is responsible for directing the activities of the laboratory that performs measurements pertinent to SNM control. He is to maintain a continuing program of analytical development; establish an evaluation program to monitor repeatability and accuracy of each analysis; audit plant processes to assure the proper application of analytical techniques through sampling, evaluation, and feedback of information; and establish referee and backup laboratories. The minimum qualifications of the Manager, Analytical Laboratories, shall be a BS degree in Chemistry or Chemical Engineering and ten years of experience in the analyses of nuclear materials.

Accountant, Nuclear Material

The Accountant, Nuclear Materials, is responsible for keeping the nuclear materials accounting records; establishing and maintaining an accounting procedure manual; performing audits of SNM custodian accountability activities; and handling routine contacts with the Region V, U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Walnut Creek, California. The minimum qualifications of the position shall be a BA degree in Business Administration and five years of experience.

TABLE II. Examples of Safeguards Functional Descriptions

The Manager of the Licensing Department has overall program definition responsibility. This includes establishing the objectives and criteria for the program; defining, implementing, and providing assistance as necessary in solving the technological problems related to SNM control, in particular, those related to all aspects of the measurement operations; managing the development programs in safeguards; establishing and maintaining primary safeguards liaison with regulatory agencies; and providing for overall program management and audit.

The General Manager of the Nuclear Fuels Department has line responsibility to carry out the established safeguards requirements dealing with material custodianships, physical inventory, and the transfers of SNM. He also has the responsibility for providing the data and information of safeguards importance specified by the Manager of Licensing and keeping him informed of safeguards-related problems and developments. In providing these data, he is responsible for controlling their quality and for generating the additional information needed to provide assurance of this quality.

The Controller has the responsibility for keeping the nuclear material accounting records; for auditing of SNM custodian accountability activities; for establishing and maintaining an accounting procedure manual; and for handling routine contacts with Region V, U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Walnut Creek, California. In performing the auditing function, he has the authority to witness measurements, make independent measurements, and inspect internal MBA and ICA records.

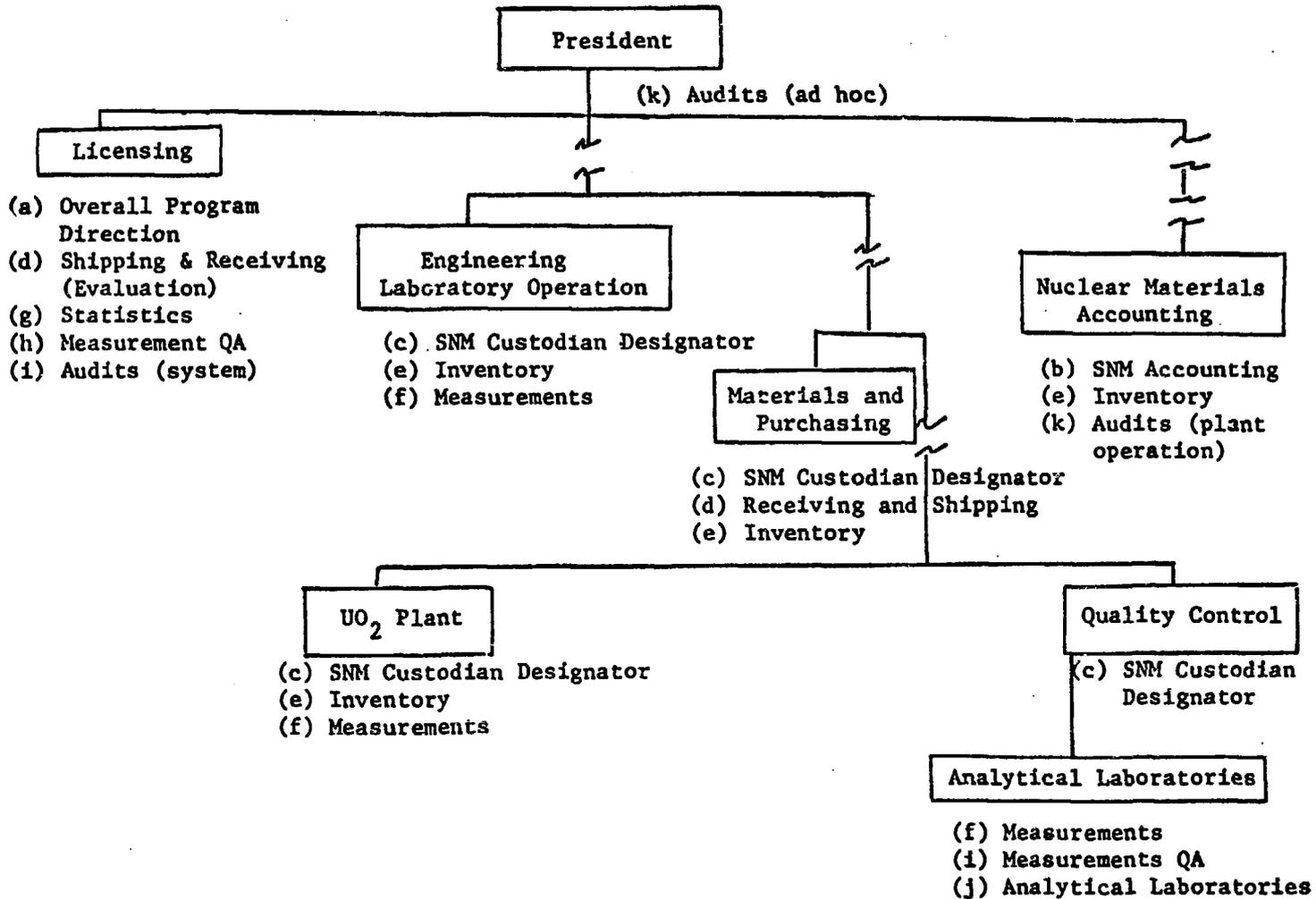


Figure 3. Example of Safeguards Functional Responsibilities

TABLE III. Example of Training Program DescriptionAnalytical Measurements

The analyses performed by the analytical laboratories are of considerable importance to SNM control and accounting. A formal training program for the training of technologists for a given procedure consists of providing the trainee with a copy of the analytical procedure in question, having him witness the analytical procedure as practiced by a qualified individual, and then having him gain experience in applying the procedure with standards until he can achieve consistently acceptable standard recoveries. He is then allowed to run samples under supervision of a certified technologist, and shall finally be certified by a chemist to permit him to run samples without supervision when he has demonstrated his ability to run standards and samples competently under supervision. Requalification is on a continuing basis as part of the standards program with all technologists who are certified to conduct given analyses participating in the standards program. Formal requalification shall take place annually to coincide with the completion of the annual measurement review.

NDA Measurements

Training of individuals qualified to perform NDA measurements shall be the responsibility of the Manager, Facilities and Equipment Engineering. He shall certify in writing that a given individual is qualified to perform the measurement in question, based on the operator's adherence to the written procedures. A recertification statement shall be made on an annual basis.

SOLAR EVAPORATION PONDS
MBA-1

ICA-1
Shipping-Receiving

ICA-3K
Waste
Barrel
Storage

ICA-3B-H
Storage

MBA-1 Conversion Scrap Recovery	ICA -3A Powder Storage	Warehouse & Trailers	
	MBA-2 Pellet Preparation	MBA-3 Rod Loading	
MBA-4 Analytical Laboratory	Rod Storage and Bundle Assembly ICA-2		

UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

Figure 4. Model Plant Material Control Areas

37b-11

F. Chapter 5--Measurements

In this chapter, the measurements used for special nuclear material control and accounting are described.

The general approach used to describe the measurement system is to:

1. Identify on a process flow sheet or plant site layout each measurement point,
2. For each measurement point, describe the nuclear material composition and measurements made at each point,
3. Briefly describe each measurement method, e.g., volume, analytical, weighing, sampling, and NDA, and
4. For each measurement point and each measurement method list the expected random and systematic error of a single measurement.

An example of the measurement methods and manner of description is given on pages 8-18 of the Reference Plant Description (Model Plant) used for Sessions 37 and 38. That example presentation of a measurement system is probably acceptable for a small low-enriched uranium fuel fabrication plant using well established measurement methods. For a plant using new and not fully established measurement methods, a more detailed description, including a detailed discussion of the rationale, planned preoperational tests, etc., is required.

G. Chapter 6--Measurement Control Program

In this chapter, the Measurement Control Program used for special nuclear material and accounting is described. The technical basis for the measurement control program for a low-enriched uranium fuel fabrication plant was just presented in a previous session (Session 28).

In preparing a Fundamental Nuclear Material control Plan according to the Regulatory Guide 5.45, the technical information just presented would be used to prepare the technical descriptions requested in the Guide. However, that material would not cover the management and organizational descriptions required by the first section of the chapter. These descriptions are summarized below (taken from U.S. Regulatory Guide 5.45):

6.1 Organization and Management

This section should describe the organizational relationship, showing in particular how the special nuclear material measurement quality assurance function is assigned so that it is independent of the analytical laboratory and operating departments and is at a level to assure objectivity and independence of action.

6.1.1 Functional Assignment

In this section, show how the position assigned responsibility for the measurement Quality Assurance Program is related to the positions responsible for the analytical laboratory or other functions responsible for processing and measuring special nuclear material. Show the relative management level at which the measurement quality assurance function is assigned. Personnel qualifications for the measurement quality assurance function also should be set forth.

6.1.2 Procedures

Affirm that a special nuclear material measurement quality assurance manual will be established and maintained. Identify the organizational units responsible for the preparation, modification, and approval of measurement quality assurance procedures and the periodic review of the manual.

6.1.3 Management Review

Describe the program established for the conduct of an annual management review of the measurement quality assurance program.

6.1.4 Internal Audits

Describe the auditing program established to determine compliance with the measurement quality assurance procedures. Indicate the frequency for conducting program audits.

6.1.5 Contractor Program Audit

If measurement services are provided by an outside contractor or another company laboratory, describe the audit program established to monitor such off-site performance. Specify the frequency of such audits.

H. Chapter 7--Limits of Error

In this chapter, the expected error of MUF (LEMUF) and the associated error models and error propagation methods are described. The error models are not actually included in the Fundamental Nuclear Material Control Plan, but are submitted as an appendix so as not to constitute a license condition.

A detailed example of an error model and the completed error propagation to give the uranium element LEMUF are shown on pages 52-71 of the DIQ. The same example is also given on pages 16-22 of the Reference Plant (or Model Plant) Description used for Sessions 37 and 38.

I. Chapter 8--Physical Inventory

In this chapter, the applicants program for taking physical inventories is described. Most of the points to be described in this chapter have been discussed earlier in the course in Sessions 17a, 21, and 24.

An example of the topics to be described in Chapter 8 of the Fundamental Material Control Plan are shown in Table IV.

TABLE IV. Physical Inventory Topics for Chapter 8 of FNMC

<u>Discussion Topic</u>	<u>Example</u>
1. Basic Approach	1. Cleanout inventory, all material converted to measured items.
2. Schedule	2. Physical inventory every six months.
3. Organization	3. Two-party teams of accounting and custodial personnel.
4. Procedures	4. Written inventory procedures prepared and discussed in advance.
5. Source Data	5. Described in written procedures.
6. Form control	6. Physical count sheets controlled by two-party teams.
7. Typical Inventory Composition	7. A table of typical inventories is given in text (see Table 1 of Reference of Model Plant, Sessions 37 and 38).
8. Prelisting of Inventory	8. ICA listings, rod printout prior to inventory.
9. Cut-off Procedures	9. Written instructions for each area.
10. Special Processing	10. Written cleanout and equipment shutdown schedule.
11. Inventory Reduction	11. Not applicable.
12. Current Measurement	12. All materials present as measureable or premeasured items.
13. Item Inventories	13. Written inventory instructions including reconciliation of ICAs and MBAs.

TABLE IV. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
14. Prior Measurements	14. Only tamper-safed items accepted on basis of prior measurement.
15. Use of Factor	15. Use of element and isotopic factor explained in Section 3.1-1.
16. Residual Holdup	16. Estimated holdup in ducts, plenums, and processing equipment is estimated to be less than 20 kilograms of uranium element by visual inspection, and previous measurements of material removed by cleaning specific items.

J. Chapter 9--Material Accounting System

In this chapter, the applicant describes the system of records and reports which locate special nuclear material within the site, and which are used to calculate a measured material balance around each material balance area and the total plant.

The individual discussion topics and examples are given in Table V. A brief example of a completed Chapter 9 for the Model Plant is given in the DIQ (Session 29-2) on pages 33-41.

K. Chapter 10--Internal Control

In this chapter, internal control practices used in receiving, storing, transferring, and shipping of special nuclear materials are described. The individual discussion topics and examples are given in Table VI.

L. Chapter 11--Management

In this chapter, the management system used for the development, revision, implementation, and enforcement of special nuclear materials accounting procedures is described. The individual discussion topics and examples for Chapter 11 are given in Table VII.

TABLE V. Material Accounting Topics for Chapter 9 of FNMC

<u>Discussion Topic</u>	<u>Example</u>
1. System Description	1. A centralized double-entry computer based bookkeeping system is maintained by the Controller.
2. Account Structure	2. Accounts are: Plant Location--MBA or ICA Material Type--Depleted U --Enriched U --Natural U Project--Reactor Load Enrichment--Each nominal U-235.
3. Accounting Forms	3. NRC/DOE 741 • Receipt-Shipment • Location Transfer • Physical Inventory Recording Form
4. Flow Chart	4. See Table 8, page 36 of the Model Plant DIQ, Session 37.
5. Accounting Procedures	5. The Nuclear Safeguards Procedures Manual MP-3 includes nuclear material accounting procedures.
6. Course Data	6. The data elements for each material transfer (external and internal) and physical inventory are recorded on the form.
7. Adjustments to Records	7. Adjustments to records can only be made through a revised document.
8. Bias Adjustment	8. A separate bias account is maintained.
9. Inventory Reconciliation	9. See page 37, DIQ.
10. Account Reconciliation	10. All accounts reconciled to physical inventory. Plant MUF and sum of MBA MUFs reconciled at end of each accounting period.
11. Location and Identity of Records	11. See page 40-41 of DIQ.
12. Electronic Data	12. Computer services are procured from offsite.

TABLE V. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
13. Records and Reports	13. See page 38 of DIQ and pages 40-41 for retention of records and storage.
14. Audits	14. Internal audits are performed by three groups--President's Committee, Internal Auditor, and Licensing Department.

TABLE VI. Internal Control Topics for Chapter 10 of FNMC

<u>Discussion Topic</u>	<u>Example</u>
1. Receiving Procedure	1. See pages 38 and 39 of DIQ.
2. Shipper-Receiver Comparisons	2. See page 42 of DIQ.
3. Acceptance Criteria	3. See page 43 of DIQ.
4. Conditions for Transfer	4. UF ₆ cylinders may be transferred to process after weight measurement and weight verification are complete.
5. Records	5. Shipper-Receiver difference evaluations and shipper-receiver records are kept for five (5) years.
6. Timeliness of Internal Transfers	6. Transfer forms are executed at time of transfer and processed daily.
7. Storage Program	7. All items are covered such as UF ₆ cylinders and heels, UO ₂ powder buckets, boats and trays of pellets, buckets of ADU, dirty powder, and grinder sludge.
8. Identification	8. Each item is uniquely identified. UF ₆ cylinders have unique number identifications. Buckets of powder and scrap items have preprinted, sequenced numbers attached to the lid and the body. Pellet boats and trays are all prenumbered. Fuel rods are all uniquely numbered. Each barrel of solid waste is numbered in sequence.
9. Quantity Determination	9. Each item measured by procedures described in Chapter 5.
10. Tamper-Safing Program	10. See page 40 of Model or Reference Plant used for Session 37 and 38.

TABLE VI. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
11. Scrap and Waste Control	
a. Location	a. Scrap generated in all processing areas is collected on a current basis, converted to U ₃ O ₈ , dissolved and recovered as prepared UO ₂ for pressing.
b. Processing and Storage	b. Typical scrap inventories were shown in Table I of Chapter 8 (page 24 of DIQ also). Scrap generated and recovered at rate of 15% of main product flow. Solid wastes, barrels and filters measured and stored onsite for later recovery.
c. Measurement	c. Waste measurements are described in Chapter 5. At inventory time, about 400 kilograms of ADU will be present with a total (2 sigma) limit of error of about 25.2 kilograms of uranium or about 6.3%.
d. Scrap Inventory Control	d. ADU items have a limit of error of 13.4% per item which exceeds the Regulatory limit of 10% per item. All ADU items not in current recovery schedule are listed in ICA listing and the lists are checked quarterly to assure no ADU on inventory for more than 12 months.

12. Shipping

Special procedures apply to the shipment of SNM. Licensed transport containers and packages are used. Typically, exclusive use vehicles or cargo aircraft are employed. Packages are sealed and labeled. Seal integrity is checked frequently enroute and at destinations. Special communication equipment is provided and frequent reporting is required during the transport period. Oral and written instructions are given to drivers and escorts prior to shipment departure. Quality Assurance check lists are used to assure compliance to all procedures and Federal Regulations. Such check lists require signatures of personnel wholly independent of the custodian. Complete records are maintained of all key documents involved with the shipment of SNM.

TABLE VI. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
-------------------------	----------------

Internal Transfers

The Custodian for the Shipping and Receiving ICA receives a listing of SNM contained in each shipment. In the case of fuel assemblies, an accounting record provides the data identified by assembly and by enrichment within the assembly. The data include, in the case of uranium, the UO₂ weight, the uranium weight, and the U-235 weight.

Similar data are provided for other shipments, e.g., of waste barrels.

The Shipping and Receiving ICA personnel affix the tamper-safe seals before shipment.

Overchecks

Shipping and Receiving personnel perform a 100% item check to ensure that the information on the listing provided them is consistent with that affixed to the items to be shipped.

Records

Shipping and Receiving retains the records described in Chapter 9 for a minimum period of five (5) years.

TABLE VII. Management Topics for Chapter 11 of FNMC

<u>Discussion Topic</u>	<u>Example</u>
1. Procedures	1. The authorship and approval responsibilities for each procedure that appears in this manual are given in Chapter 3.
2a. Management Review	2a. Management review is conducted annually by the President's Safeguards Committee.
b. Report	b. The management review is reported to the President and copies retained for 5 years.
c. Action	c. The President reviews the report, extracts action, and sends that information to responsible individuals for action.

TABLE VII. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
3. Measurement Controls	3. The Manager of Licensing is responsible for reviewing measurement data to assure the measurement performance remains within limits. If an out-of-control situation is detected, he is responsible for initiating action and assuring that the problem is resolved.
4. Shipper-Differences	4. The Manager of Licensing is responsible for the evaluation of shipper-receiver differences. When a significant difference is detected, this is brought to the attention of the affected MBA and ICA custodians, plus others who generated the data used in the SRD analysis. The Manager of Licensing conducts an investigation to reconcile the significant SRD and recommends appropriate action to reduce the probability of future occurrences of significant SRDs. If the nature of the SRD provides evidence of a diversion, e.g., if a container is missing, the Manager of Licensing shall promptly notify the Region V, Walnut Creek Office of the NRC.
5. Material Balance Discrepancies	5. The Manager of Licensing is responsible for the MUF and LEMUF evaluation. When the MUF exceeds its approved limits, he is responsible for reporting this to the NRC and to the affected custodians and for conducting an investigation into the cause of the excessive MUF. He has the authority to require that another inventory be taken if necessary. Results of his investigation plus corrective action are reported by him to the Company President, to the NRC and to affected plant personnel.
6. Item Discrepancies	6. An apparent loss of a discrete item or container of SNM that cannot be resolved by an immediate investigation is reported to the Manager of Licensing, who promptly notifies NRC in accordance with the requirements of 10 CFR 70.52 and conducts an investigation of the apparent loss. The results of the investigation are reported to the Company President and to the Region V, Walnut Creek Office of the NRC.

APPENDIX A

SITE DESCRIPTIONA.1 GENERAL DESCRIPTION

In this section, the general physical layout of the site and its operations are described. Drawings and verbal descriptions are used to explain the overall distribution and involvement of special nuclear material. It is useful to also show material. It is useful to also show material control areas on the site plan view. An example description is given on pages 4-7 of the DIQ for the Model Plant (Session 37).

A.2 PLANT OPERATIONS

In this section, detailed descriptions of plant operations, manufacturing processes, flowsheets, and material flows are described. Each process is described in narrative and flow diagrams form. A condensed process diagram is shown on page 16 of the DIQ. An identical diagram with a narrative is given on pages 4-8 of the Model Plant (or Reference Plant) Description used for Sessions 37 and 38. A top view of the process building identifying activities (page 14 of DIQ) is also useful.

This section should also identify gaseous, liquid and solid effluents which could but do not normally contain nuclear materials.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 37c: PREPARATION OF DESIGN INFORMATION QUESTIONNAIRE
(DIQ) FOR MODEL FUEL FABRICATION PLANT

R. A. Schneider
Exxon Nuclear

EXAMPLE

DESIGN INFORMATION QUESTIONNAIRE
MODEL PLANT FUEL FABRICATION PLANT

July, 1979

Model Plant, Inc.
Richland, Washington

EXAMPLE

Prepared for submission to the Department of Safeguards and Inspection of the International Atomic Energy Agency in accordance with the proposed Agreement Between the United States of America and the International Atomic Energy Agency for the Application of Safeguards in the United States of America. This report contains information proprietary to the Model Plant Company and information specified as proprietary under 10 CFR 2.790(d).

EXAMPLE

DESIGN INFORMATION QUESTIONNAIRE
MODEL PLANT FUEL FABRICATION PLANT

Prepared By:

Senior Safeguards Specialist, Quality
Assurance and Licensing Department

Date

Reviewed By:

Controller

Date

General Counsel

Date

General Manager, Nuclear Fuels
Department

Date

Manager, Licensing

Date

Manager, Research and Technology
Department

Date

Approved By:

President, Model Plant Company, Inc.

Date

EXAMPLEDESIGN INFORMATION QUESTIONNAIRE
MODEL PLANT FUEL FABRICATION PLANTDISTRIBUTION LISTCopy Number

1	NRC - Washington, D.C.
2	NRC - Washington, D.C.
3	NRC - Washington, D.C.
4	NRC - Washington, D.C.
5	NRC - Washington, D.C.
6	State Department - Washington, D.C.
7	Model Plant Internal Distribution
8	Model Plant Internal Distribution
9	Model Plant Internal Distribution
10	Model Plant Internal Distribution
11	Model Plant Internal Distribution
12	Model Plant Internal Distribution
13	Model Plant Internal Distribution
14	Model Plant Internal Distribution
15	Model Plant Internal Distribution
16	Document Control Library
17	Document Control Central File
18-23	Extra

DESIGN INFORMATION QUESTIONNAIRE
EXXON NUCLEAR FUEL FABRICATION PLANT

CONTENTS

GENERAL INFORMATION	37c-8
I. Name	37c-8
II. Location and Postal Address	37c-8
III. Owner	37c-8
IV. Operator	37c-8
V. Description	37c-8
VI. Purpose	37c-8
VII. Status	37c-8
VIII. Construction Schedule	37c-8
IX. Normal Operating Schedule	37c-8
X. Facility Layout	37c-8
XI. Site Layout	37c-13
XII. Names and/or Titles and Addresses of Responsible Officers	37c-13
OVERALL PROCESS PARAMETERS	37c-17
XIII. Facility Description	37c-17
XIV. Process Description	37c-17
XV. Design Capacity	37c-17
XVI. Anticipated Throughput	37c-17
NUCLEAR MATERIAL DESCRIPTION AND FLOW	37c-24
XVII. Main Material Description	37c-24
XVIII. Waste Materials	37c-26
XIX. Containers, Packaging, and Storage Area Descriptions	37c-26

XX.	Recycle Processes	37c-27
XXI.	Measured Discards and Retained Waste	37c-27
XXII.	Inventory	37c-29
PLANT MAINTENANCE		
XXIII.	Maintenance, Decontamination, and Cleanout	37c-29
PROTECTION AND SAFETY MEASURES 37c-29		
XXIV.	Basic Measures for Physical Protection of Nuclear Materials	37c-29
XXV.	Specific Health and Safety Rules for Inspector Compliance	37c-29
NUCLEAR MATERIAL ACCOUNTANCY 37c-30		
XXVI.	System Description	37c-30
XXVII.	For Each Key Measurement Point Identified Under Questions 14 and 23, Give the Following	37c-38
XXVIII.	Overall Limit of Error	37c-50
OPTIONAL INFORMATION 37c-56		
XXIX.	Optional Information	37c-56

Note: Roman numeral heading numbers correspond to the Arabic numbered questions of the Design Information Questionnaire.

DESIGN INFORMATION QUESTIONNAIRE
EXXON NUCLEAR FUEL FABRICATION PLANT

TABLES

1	Description of Key Measurements	37c-21
2	Chemical and Physical Forms	37c-24
3	Typical Inventory of Low Enriched Uranium	37c-25
4	Typical Waste Inventories	37c-26
5	Material Container Descriptions	37c-27
6	Storage Descriptions	37c-28
7	Model Plant Accounting Forms	37c-31
8	Flow Chart of Accounting Forms	37c-31
9	Accounting Reports	37c-33
10	Accounting Records and Reports Retention	37c-34
11	Model Plant Sampling Methods	37c-39
12	Summary of Uranium Methods	37c-41
13	Error Parameter Values for Model Plant Uranium Material Balance	37c-42
14	Calculational Methods	37c-45
15	Measurements for Model Plant Six Month Uranium Material Balance	37c-46
16	Example Calculation of Uranium Sigma MUF for a Six-Month Material Balance	37c-52

DESIGN INFORMATION QUESTIONNAIRE
EXXON NUCLEAR FUEL FABRICATION PLANT

FIGURES

1	Plant Site Location	37c-9
2	Plant Location in State	37c-10
3	Model Plant Fuel Fabrication Facility	37c-11
4	Primary Safeguards Responsibility Components . . .	37c-14
5	Organizational Substructure of Components and Safeguards Responsibilities	37c-15
6	Uranium Oxide Fuels Building, First Floor Plan . .	37c-18
7	Uranium Oxide Fuels Building, Second Floor Plan . .	37c-19
8	Process Flow Diagram for Model Plant	37c-20
9	Model Plant Material Control Areas	37c-23

EXAMPLE
DESIGN INFORMATION QUESTIONNAIRE
MODEL PLANT FUEL FABRICATION PLANT

GENERAL INFORMATION

I. NAME

Model Plant Fuel Fabrication Plant

II. LOCATION AND POSTAL ADDRESS

2101 Horn Rapids Road
Richland, Washington USA
Zip Code 99352

The Model Plant plant site is shown in relation to the City of Richland in Figure 1 and in relation to the State of Washington in Figure 2.

III. OWNER

Model Plant Company, Inc.

IV. OPERATOR

Model Plant Company, Inc.

V. DESCRIPTION

A commercial fuel facility for the manufacture of nuclear reactor fuels.

VI. PURPOSE

Commercial manufacture of nuclear reactor fuels.

VII. STATUS

UO₂ plant is in operation.

VIII. CONSTRUCTION SCHEDULE

Not applicable--in operation.

IX. NORMAL OPERATING SCHEDULE

Three shifts per day, five to six days per week. The facility is manned at all times.

X. FACILITY LAYOUT

The facility layout including supporting structures is shown in Figure 3. The site is completely within a chain link security fence. Personnel access to the uranium production and storage areas is

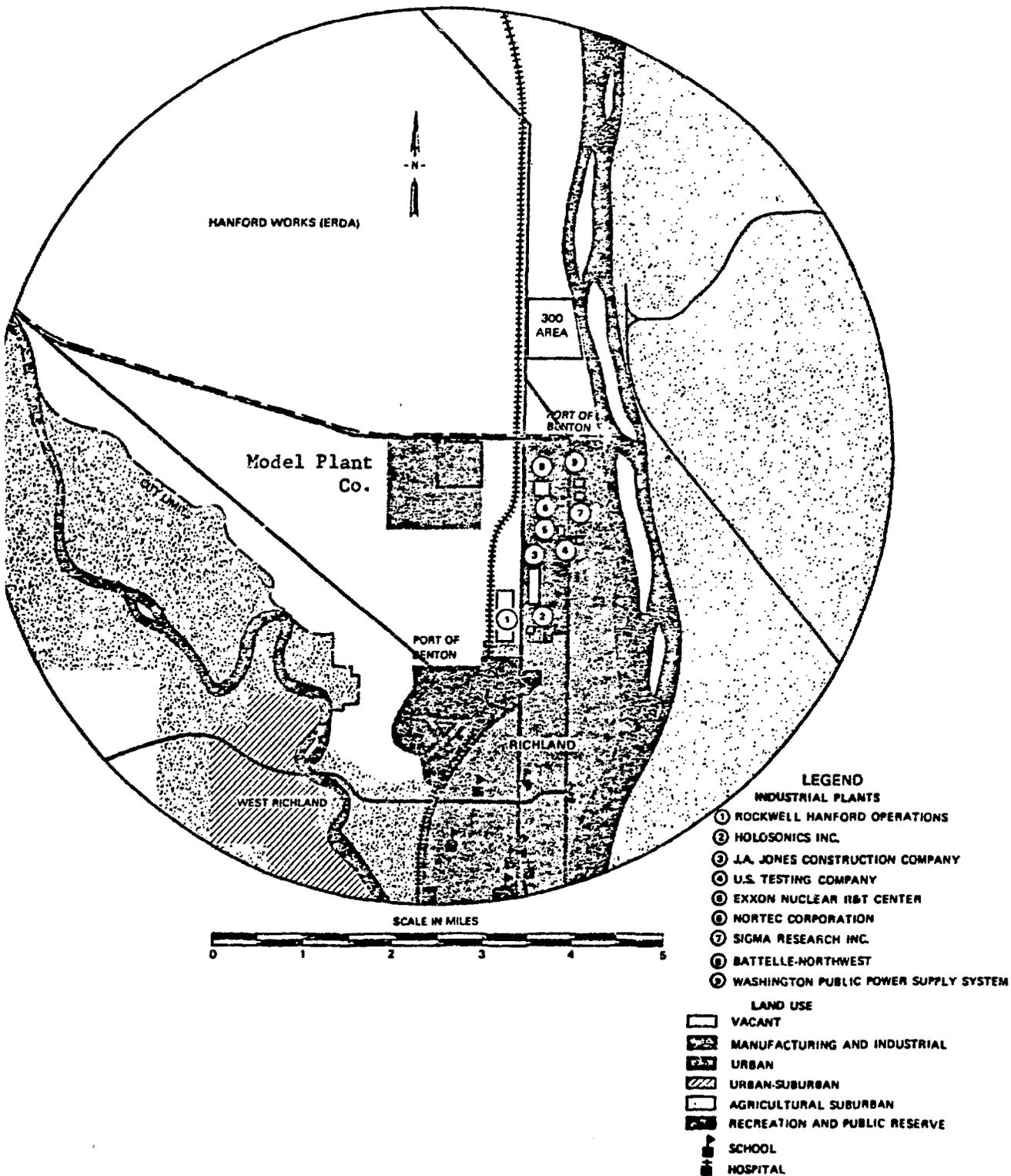
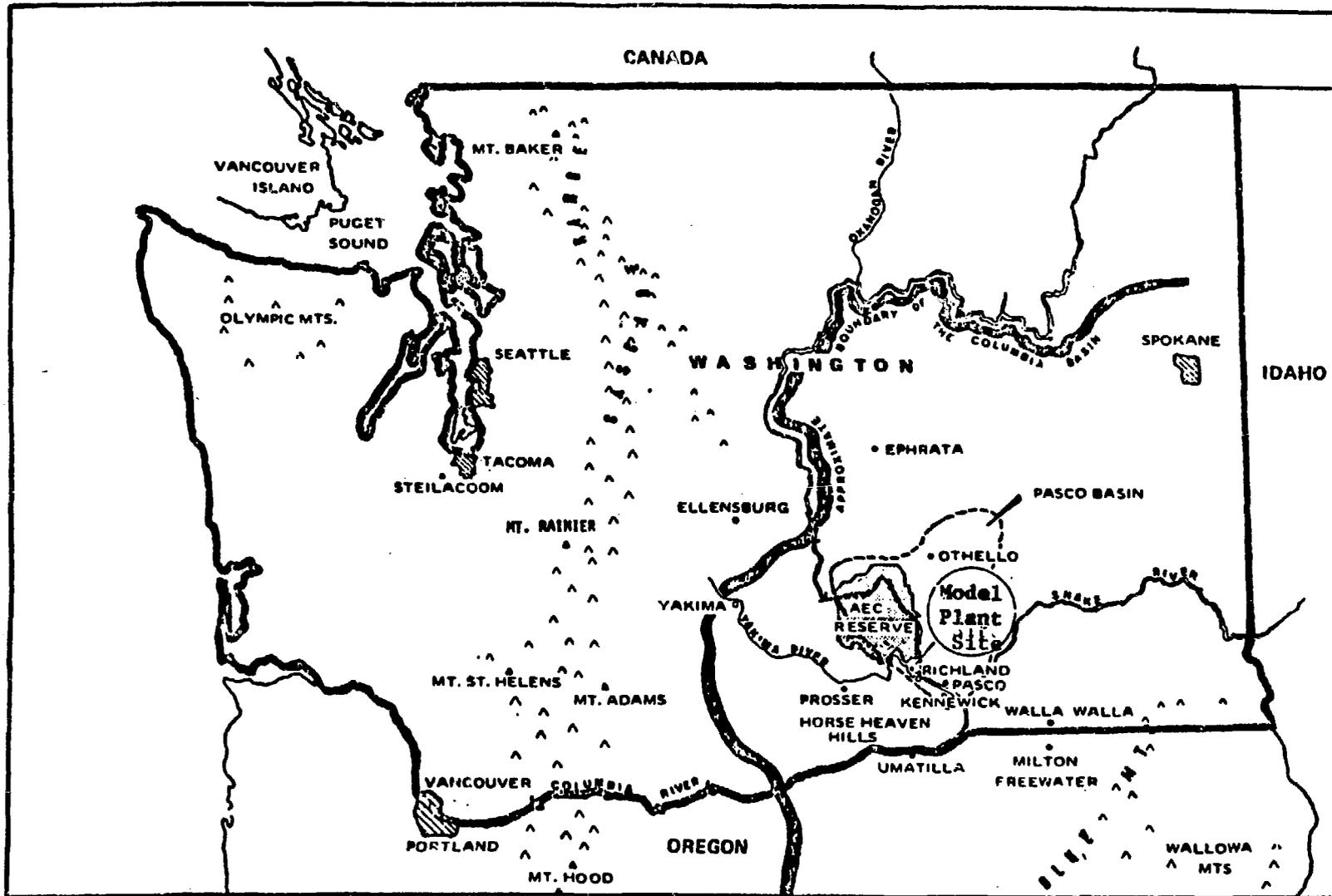


FIGURE 1. Plant Site Location



370-10

FIGURE 2. Plant Location in State

through the main west portal or through the controlled entry station (guard station) at Office Building No. 2. Vehicle entrance is through the main west vehicle gate. Limited vehicle access to the back of the warehouse is permitted through the southwest gate (by the warehouse) and within the inner fenced aisle which limits vehicle access to the back of the warehouse.

Nuclear material storage locations which are separate from the main process building include the following areas shown in Figure 3:

- a. Warehouse. Southwest corner.
- b. Contaminated Storage Building and Trailers (Scrap Storage). Southeast area.
- c. UF₆ Storage Area. Between northeast corner of UO₂ Building and the northernmost lagoon.
- d. Waste Barrel Storage. Adjacent to warehouse and on storage pad (shown in Figure 3) between warehouse and the southernmost lagoon.
- e. Liquid Waste Storage. Lagoon system on east side of site.

Nuclear materials routings are described in more detail in Parts 13, 14, and 26. Those which are pertinent to the layout shown in Figure 3 include the following:

- a. UF₆ Cylinders. Move to and from the UF₆ cylinder storage area and the UO₂ Building. Incoming full UF₆ cylinders and returning empty cylinders are moved by truck to and from the storage area and the main west gate.
- b. Packaged Fuel Assemblies (in shipping containers). Move from the UO₂ Building to the warehouse area for loading on trucks and exit from the site via the main west gate.
- c. Scrap Containers. Move to and from the UO₂ Building and the contaminated storage area located in the southeast area.
- d. Solid Waste Containers (barrels and filter boxes). Move from the UO₂ Building to storage areas near the warehouse or the storage pad near the southernmost lagoon. Waste containers assigned to burial are assembled near the warehouse area for loading on trucks and then exit from the site via the west gate.
- e. Liquid Wastes. All uranium-bearing liquid wastes (centrate and grinder water) are transferred after measurement from the UO₂ Building via underground lines to the lagoon system.
- f. Miscellaneous Nuclear Material Routes. Archive samples move from the UO₂ Building to the archive storage area. Small quantities of low enriched uranium in the form of samples and standards enter the site via the warehouse receiving gate and move from the warehouse to the laboratory in the UO₂ Building.

The main analytical laboratory is located in the northwest corner of the UO₂ Building.

Uranium-bearing wastes are not disposed of on-site. Solid wastes (after measurement) are stored on-site in metal barrels awaiting future recovery or shipment to an approved burial site. Liquid wastes are stored in the lagoon system (asphalt sealed, solar evaporation ponds) awaiting future recovery or waste treatment.

XI. SITE LAYOUT

The site layout in relation to local surroundings is shown in Figure 1. The site area is bounded on the north by Horn Rapids Road, a secondary highway. The site locale is bounded on the west by the Yakima River and on the east by the Columbia River (shown in black in Figure 1). The railroad shown passing north and south near the east boundary of the site is the ERDA (now Department of Energy) railroad spur which connects the Hanford Works to a transcontinental line which passes south of the City of Richland; the spur connects near the City of Kennewick shown in Figure 2. The Horn Rapids Road intersects to the east of the site (0.9 miles) with Stevens Drive, the main highway from the City of Richland to the Hanford Works. Roads from the City of Richland connect to main highways leading to other parts of the northwest and other parts of the United States.

XII. NAMES AND/OR TITLES AND ADDRESSES OF RESPONSIBLE OFFICERS

(For nuclear material accountancy and control and contact with the Agency.)

a. Primary Liaison with Agency. Primary contact with the Agency on safeguards matters will be with the Manager of Licensing.

Manager
Licensing
Model Plant Company, Inc.
2955 George Washington Way
Richland, Washington 99352

b. Routine Contacts with Agency. To be furnished later in the event routine contacts with the Agency are required.

c. Safeguards Organizational Structure. The components having primary safeguards responsibilities for the fuel fabrication plant are shown in Figure 4. A further breakdown of organizational components with safeguards responsibilities is shown in Figure 5.

The President of Model Plant Company has the ultimate responsibility for the safeguarding of SNM. He has delegated major program elements applicable to the fuel fabrication plant to three components within the company. These are the Licensing Department, the Nuclear Fuels Department, and the Finance Department. In addition, technical assistance is provided by the Research and Technology Department.

The Manager of the Licensing Department has overall program definition responsibility. This includes establishing the objectives and criteria for the program; defining, implementing, and providing

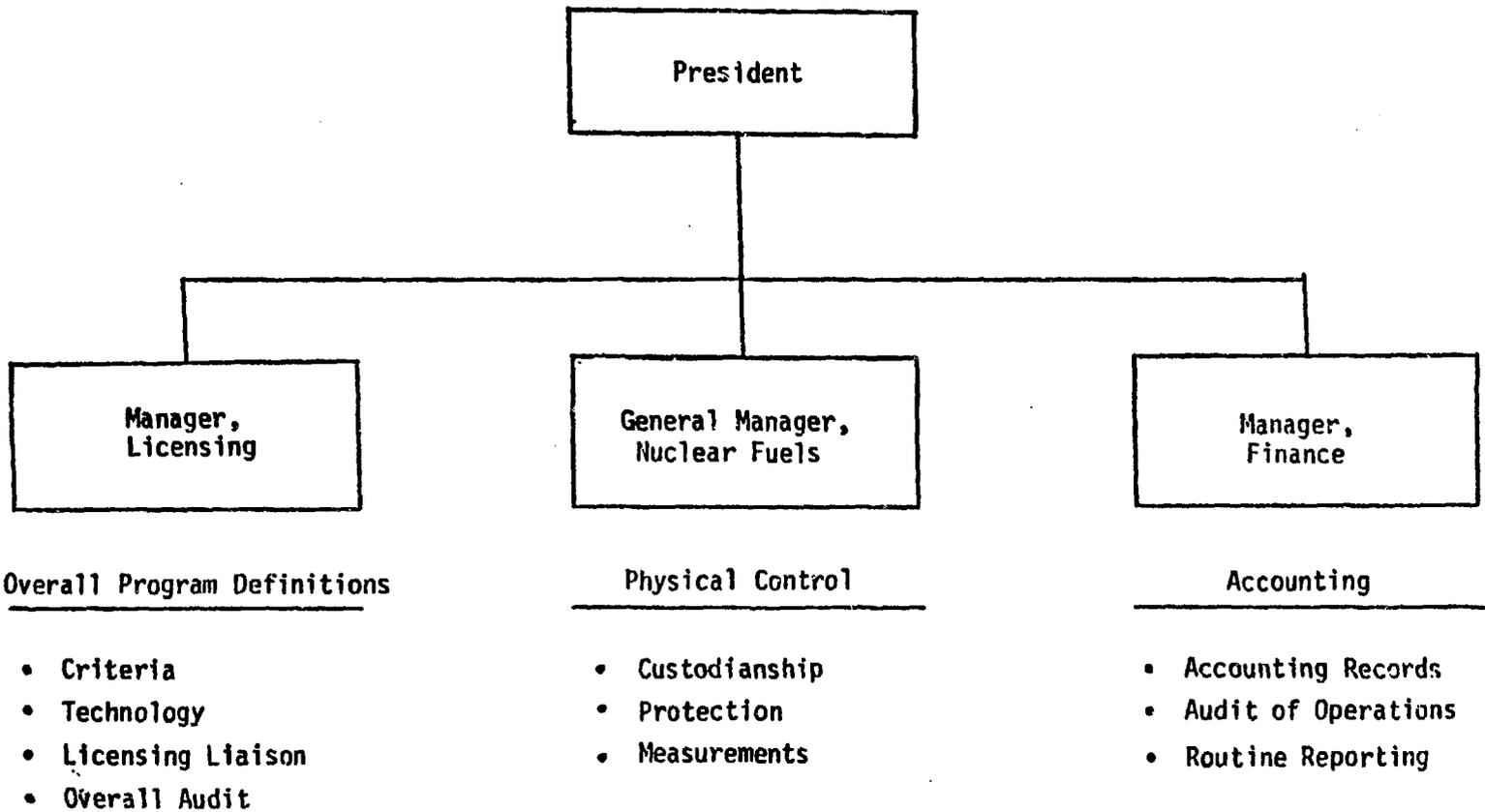
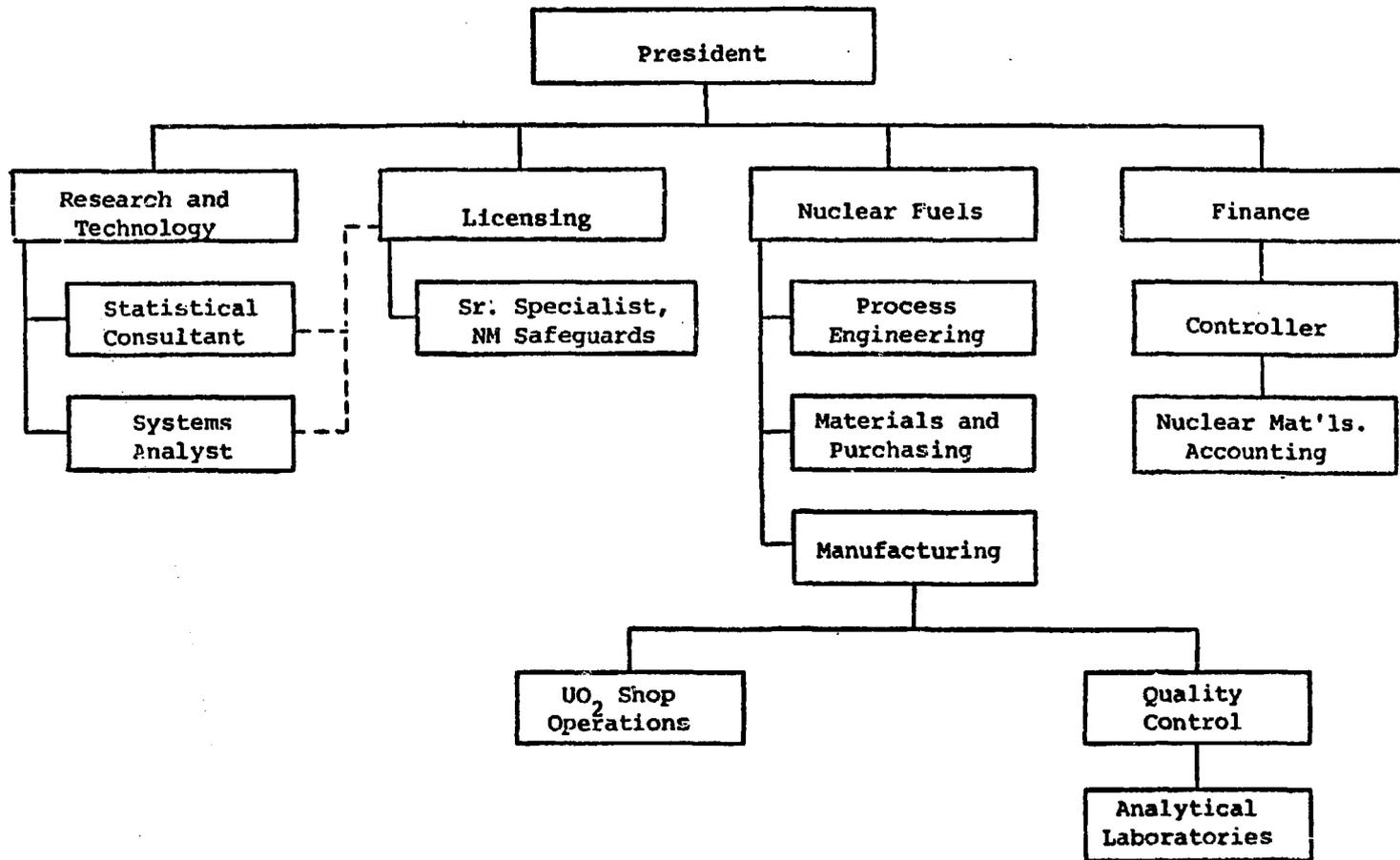


FIGURE 4. Primary Safeguards Responsibility Components



37c-15

FIGURE 5. Organizational Substructure of Components and Safeguards Responsibilities

assistance as necessary in solving the technological problems related to SNM control; in particular, those related to all aspects of the measurement operations; managing the development programs in safeguards; establishing and maintaining primary safeguards liaison with regulatory agencies; and providing for overall program management and audit. He is assisted by the Senior Specialist, Nuclear Materials Safeguards, who acts for the Manager of Licensing in safeguards accountability matters. Technological assistance is provided to the Manager of Licensing by the Research and Technology Department. Assistance in the areas of statistics and computer program development is provided by the Statistical Consultant and by the Systems Analyst, respectively, who also assist the Manager of Licensing in other safeguards accountability matters.

The General Manager of the Nuclear Fuels Department has line responsibility to carry out the established safeguards requirements dealing with material custodianships, physical inventory, and the transfers of SNM. He also has the responsibility for providing the data and information of safeguards importance specified by the Manager of Licensing and of keeping him informed of safeguards-related problems and developments. In providing these data, he is responsible for controlling their quality and for generating the additional information needed to provide assurance of this quality.

In carrying out his function, the General Manager of the Nuclear Fuels Department has delegated the responsibility for designating MBA and ICA custodians to the Managers of Materials and Purchasing, Process Engineering, and through the Manager of Manufacturing to the Managers of UO₂ Shop Operations and Quality Control. The responsibility of the Nuclear Fuels Department General Manager to provide analytical data and supporting information is carried out through the Manager of Manufacturing by the Manager of Quality Control. Analytical data is provided by the Manager of the Analytical Laboratories who reports to the Manager of Quality Control.

The Manager of Finance has the responsibility for keeping the nuclear material accounting records; for auditing of SNM custodian accountability activities; for establishing and maintaining an accounting procedure manual; and for handling routine accounting contacts with Region V, U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Walnut Creek, California. In performing the auditing function, he has the authority to witness measurements, make independent measurements, and inspect internal MBA and ICA records.

The Manager of Finance carries out his safeguards responsibilities through the Accountant of Nuclear Materials.

OVERALL PROCESS PARAMETERS

XIII. FACILITY DESCRIPTION

The principal building of the facility is shown in Figure 6 and 7. Figure 6 shows the first floor plant of the main processing building (UO₂ Building). Material control areas, processing steps, and storage areas are shown.

Figure 7 shows the second floor plan of the UO₂ Building which houses the scrap recovery process and the conversion precipitation and calcining equipment.

Outside storage areas for nuclear materials were described previously in relation to Figure 3.

XIV. PROCESS DESCRIPTION

Process and Measurement Points

The basic process steps and measurement points are shown in Figure 8. The key measurement points are indicated by the numbers in parenthesis in the block diagrams. The key measurements are described in Table I for each of the key measurement points using the measurement point numbers shown in Figure 8.

Material Control Areas

The plant is currently divided into 7 material control areas, four material balance areas, and 3 item control areas. Item control area 3 is further subdivided into eight locations within ICA-3. The control areas are shown in Figure 9.

Inventory Locations

Plant inventory locations correspond to the material control areas described previously in Figure 9.

XV. DESIGN CAPACITY

The current licensed plant possession limit is 5000 kilograms of U-235 contained in low enriched uranium enriched up to 5 wt% U-235. Uranium production fluctuates due to schedule variations, but currently is approximately one tonne/day.

XVI. ANTICIPATED THROUGHPUT

Anticipated throughput will be approximately 250,000 kilograms of uranium per year, as the plant is currently being equipped. Space exists in the existing building for adding additional equipment for increasing capacity to about 500,000 kilograms/year or about two tonnes/day. The plant feed is primarily UF₆. The product is ceramic UO₂.

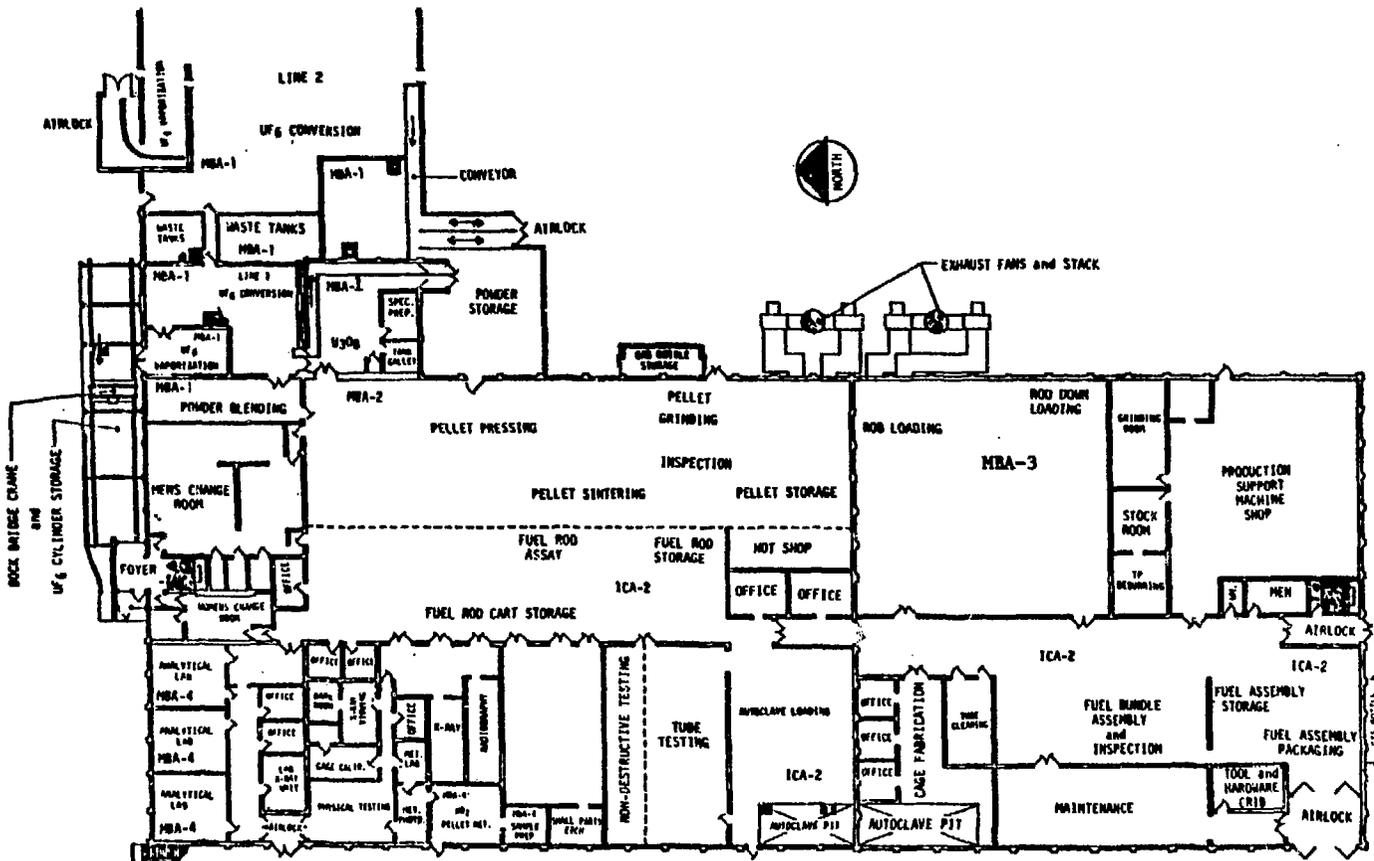


FIGURE 6. Uranium Oxide Fuels Building, First Floor Plan

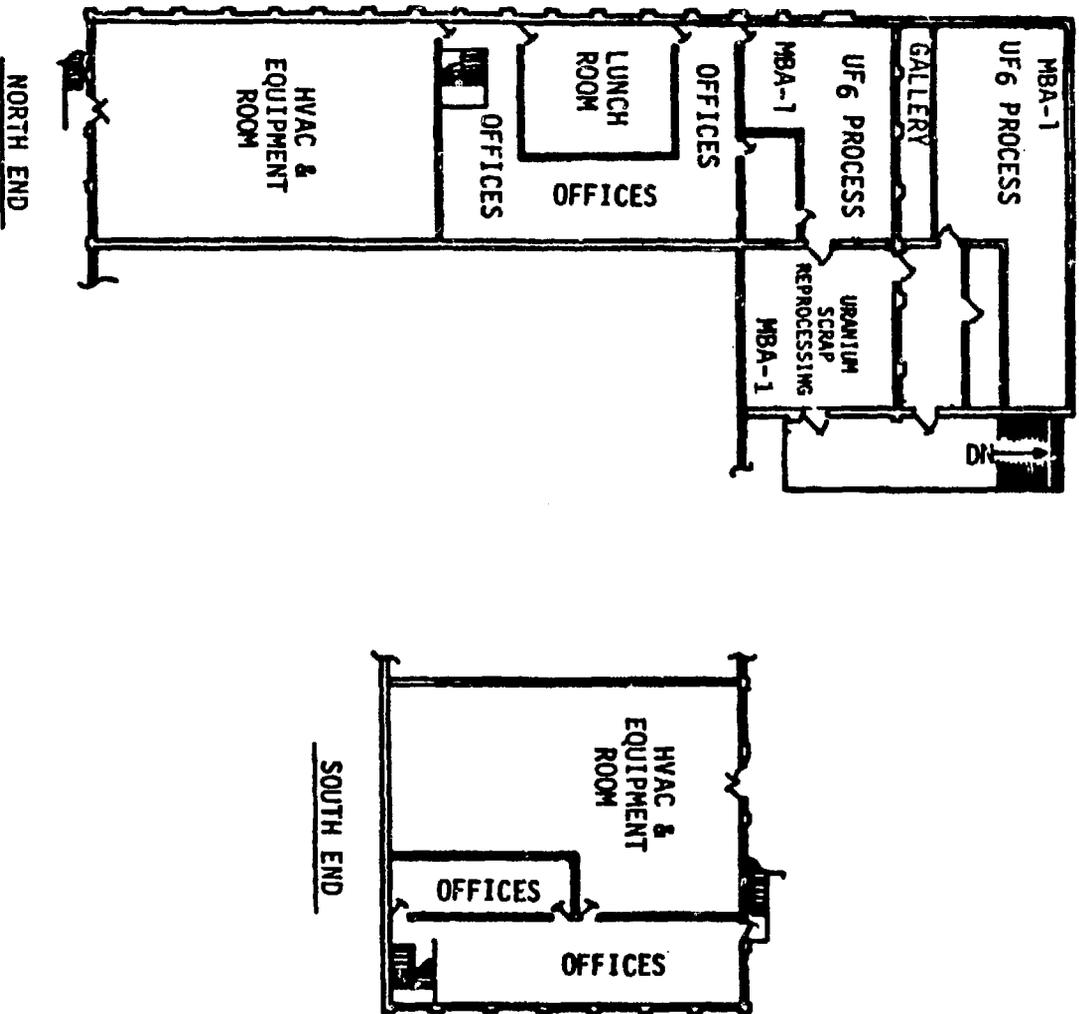
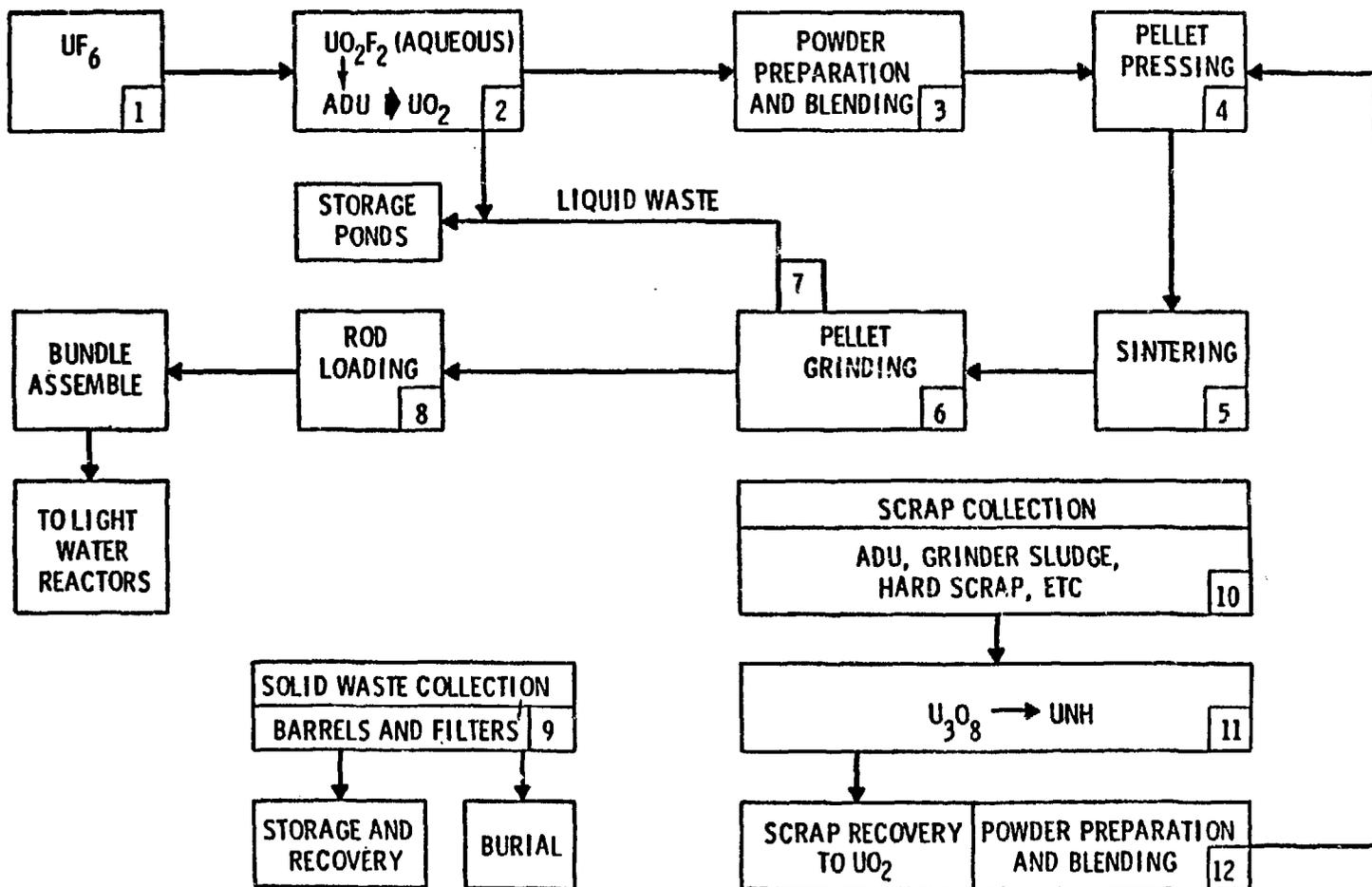


FIGURE 7. Uranium Oxide Fuels Building, Second Floor Plan



☐ KEY MEASUREMENT POINTS

FIGURE 8. Process Flow Diagram for Model Plant

TABLE 1. Description of Key Measurements for Model PlantKey Measurement PointsMeasurement Description

(See Figure 9)

- | | |
|-----|--|
| 1 | Each cylinder of UF ₆ is weighed upon receipt and the cylinder tare weight is used to determine the net weight of UF ₆ . |
| (1) | Percents of uranium and U-235 are determined for each cylinder or for each group of cylinders with the same nominal composition using sealed samples taken at the diffusion plant and witnessed by a Model Plant employee or authorized agent. |
| (1) | After UF ₆ removal, the cylinder is weighed to determine the net weight of any residual heel using the cylinder tare weight. |
| 2 | The uranium concentration in liquid wastes is measured when the material is discharged to the lagoon on a batch basis. The batch volumes are also determined. |
| 3 | After powder preparation, each bucket of UO ₂ is weighed and buckets are tared individually. The cans of UO ₂ powder are randomly selected on a sample basis for measurement of percent uranium and U-235. |
| 4 | Each boat is weighed with the boats tared individually for green pellet inventory. |
| 5 | The loaded boats containing the same pellets, as at measurement point 4, are weighed for inventory of sintered pellets. |
| 6 | The loaded pellet trays are weighed; each tray is individually tared for sintered UO ₂ inventory. |
| 7 | Centrifuged grinder water is sampled for uranium concentration and a volume measurement is made of each batch transferred to the storage ponds. |
| 8 | Pellet samples sent to the analytical laboratory are weighed. Percents of uranium and U-235 are determined. The weight of the UO ₂ in each rod is determined by weighing the fuel column stack before inserting into the rod. Accountability is maintained thereafter on a piece count basis. |
| 9 | Low grade wastes (filters, solid wastes in barrels) are contained as a heterogeneous mass and measured for total U-235 by NDA. |

TABLE 1. (Continued)

<u>Key Measurement Points</u>	<u>Measurement Description</u>
10	All containers of dirty powder, ADU scrap, and grinder sludge are individually weighed, sampled, and assayed. The percent of uranium factor for hard scrap is the same as for sintered pellets.
11	Blended lots of U_3O_8 are sampled for percent U and U-235. Each bucket of U_3O_8 is weighed and buckets are tared individually.
12	Same as measurement point 3.

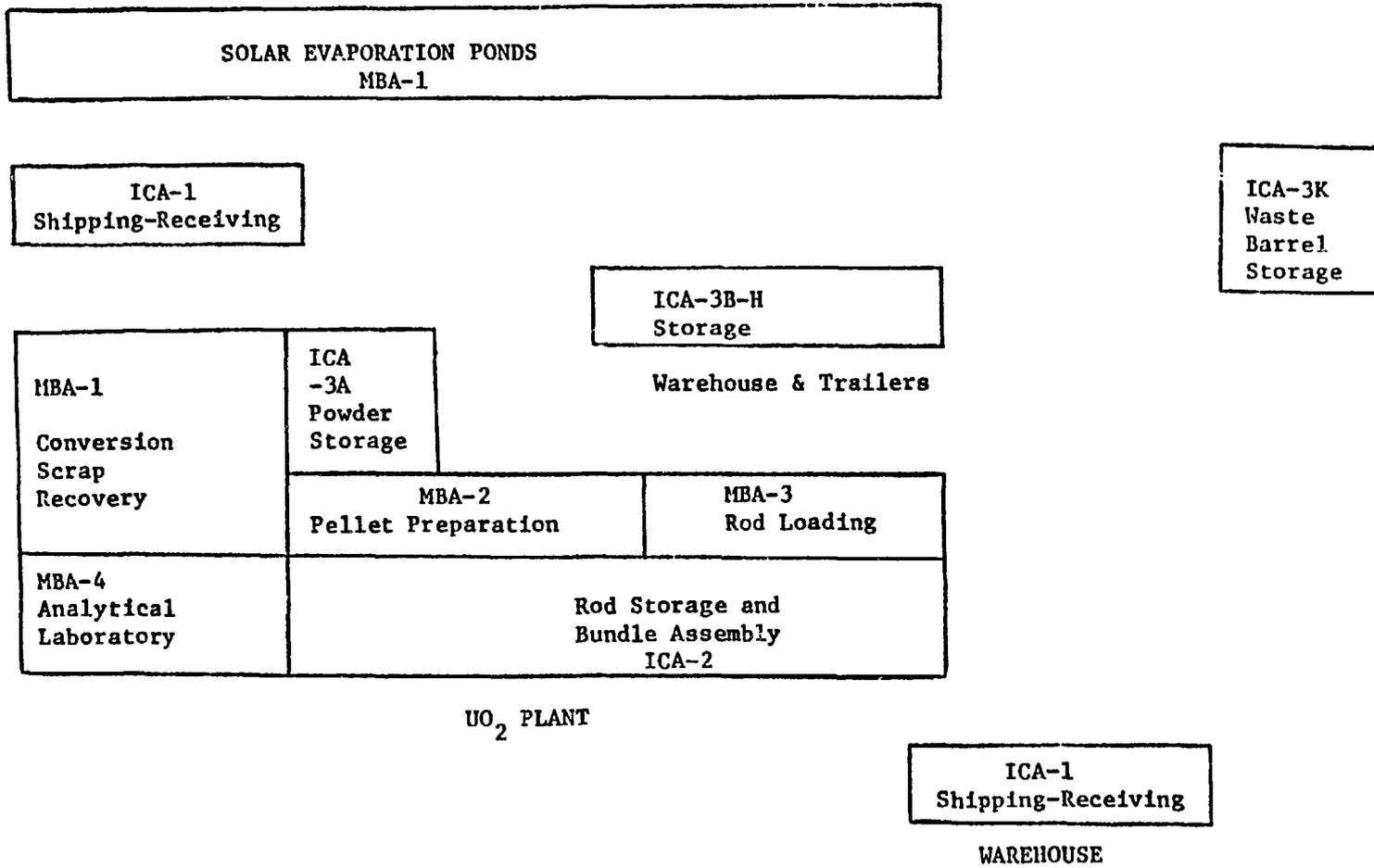


FIGURE 9. Model Plant Material Control Areas

NUCLEAR MATERIAL DESCRIPTION AND FLOW

XVII. MAIN MATERIAL DESCRIPTION

Chemical and Physical Form

The chemical and physical forms of the materials are shown in Table 2.

Throughput and Enrichment Ranges

The facility operates primarily as a reload fuel supplier for light water (PWR and BWR) reactors. Enrichment ranges from about 1.5-5.0 wt% U-235. Current throughput is approximately 250,000 kilograms of uranium per year, with an anticipated future throughput of approximately 500,000 kilograms of uranium per year as the plant is currently being equipped.

Both recycle and blending take place. Approximately 15 percent of feed input is recycled after processing through scrap recovery as indicated on Figure 8. Selective enrichment blending is carried out in scrap recovery by blending UNH solution to yield UO₂ powder of a specified enrichment. Enrichment blending of powders is not done at this time. Recovered UO₂ powder lots are kept separate from virgin powder lots.

For each reactor fuel contract, specified quantities and enrichments of UF₆ are converted to UO₂ powder, which is pretreated and mixed to provide uniform lots of about 1200 kilograms of UO₂ powder. Lot identification is maintained through to the rod loading process.

TABLE 2. Chemical and Physical Forms

<u>Production Component</u>	<u>Description</u>
Feed	UF ₆ in metal cylinders ~1400 kgs U/cylinder ~2.5 ton cylinders <u>Model 30-B</u> 30 inch diameter - 81 inches high Goodyear Atomic Portsmouth, Ohio Drawing Reference CX-761-M2028
Intermediate Product	Unsintered UO ₂ powder
Products	Sintered UO ₂ pellets Fuel assemblies - typical BWR and PWR fuel assemblies ~7-14 feet long 6 x 6-17 x 17 arrays of fuel rods

The plant is operated on a near-continuous basis with equipment cleanouts (enrichment cleanouts) between enrichments and fuel supply jobs. Production control is by fuel supply job (reactor load), by enrichment, and by lot designation. Typically, the plant will have fuel materials for several different reactors in various stages of production at the same time. The preparation period for the production of a reactor load from UF₆ gas to completed fuel assemblies is typically about four months.

Storage Inventory

A typical current uranium inventory listing is shown in Table 3. Inventory quantities are not quantitatively related to throughput; however, some increase in the total inventory is expected as plant capacity is increased.

Frequency of Receipts and Shipments

Incoming shipments of UF₆ take place about one to three times per month and shipments of fuel assemblies take place about one to two times per month. Generally, shipments and receipts take place between 0800 and 1600 hours. Monday through Friday.

TABLE 3. Typical Inventory of Low Enriched Uranium 1979

<u>Stratum</u>	<u>No. of Items</u>	<u>Total Uranium (kg)</u>
UF ₆ Cylinders (a)	21	29,400
UF ₆ Cylinder Heels	15	340
UO ₂ Powder	300	5,100
Sintered Pellets	1,000	6,000
Hard Scrap	40	840
Dirty Powder	20	340
ADU Scrap	40	400
Grinder Sludge	20	240
Fuel Rods	8,000	20,000
U ₃ O ₈	250	4,250
Waste Barrels	1,000	400
Fuel Assemblies (a)	<u>71</u>	<u>11,000</u>
Total	10,777	78,000

(a) Material not in process.

XVIII. WASTE MATERIALS

Source and Form

Uranium solid waste consists of 1) filters (HEPA filters approximately one foot by two feet by two feet), and 2) contaminated rags, gloves, paper, and equipment. The second class of solid waste is collected and placed in 55-gallon barrels (approximately 22 inches in diameter by 35 inches high). Filters are placed in cardboard boxes, measured by nondestructive assay (NDA), and shipped to an approved burial site. The solid waste in the 55-gallon barrels is measured by NDA and either shipped to the burial site or stored on-site for future recovery.

Liquid waste consists of uranium-bearing effluents from the ammonium diuranate precipitation process, and centrifuged grinder water. After measurement by volume concentration methods, all liquid wastes are transferred to the waste storage lagoons shown in Figure 3.

Storage Inventory Range, Method and Frequency of Recovery or Disposal

A typical current waste inventory is shown in Table 4. Waste shipments (filter boxes and barrels) to burial take place about once or twice a month. All uranium-bearing liquid wastes are stored in the lagoon system (shown in Figure 3) awaiting future recovery or waste disposal treatment. Waste barrels selected for future recovery are stored in the waste barrel storage area shown in Figure 3.

XIX. CONTAINERS, PACKAGING, AND STORAGE AREA DESCRIPTIONS

Material container descriptions and approximate sizes are shown in Table 5. Descriptions of storage areas and storage modes or waste disposal treatment. Waste levels selected for future recovery are given in Table 6.

The container sizes shown in Table 5 are approximate dimensions. If exact outer dimensions and container thicknesses are required for verification by nondestructive means, empty (clean) containers are available on-site for use in instrument calibrations.

Table 6 describes the general features of all storage locations, storage modes, and storage containers. All discrete items are uniquely numbered and identified. For items stored in item control areas (ICA's), all discrete items are carried on the computer-based inventory listing.

TABLE 4. Typical Waste Inventories 1979

<u>Waste Type</u>	<u>Number of Containers</u>	<u>Kgs. Uranium</u>
Filters (awaiting shipment)	40	8
Barrels (awaiting shipment)	20	8
Barrels (in storage)	1.000	400
Liquid Waste (in lagoon system)	---	2,000

TABLE 5. Material Container Descriptions

<u>Material Type</u>	<u>Container Description</u>
1. <u>Feed</u> UF ₆	2.5 ton UF ₆ cylinders (see Table 2 for dimensions)
2. <u>Product</u> Fuel Assemblies	Metal or wooden shipping cylinders or boxes - typical LWR shipping containers, e.g., 18(l)x3.6(w)x3.8(h) feet
3. <u>Waste</u> Filters	Cardboard boxes ~1(l)x2(w)x2(h) feet
Solid Waste	55-gallon barrels ~22 inch diameter by 35 inches high
4. <u>Inventory</u> Bulk Forms (powder, hard scrap, dirty powder, grinder sludge, etc.)	5-gallon buckets ~11.5 inches in diameter and 13 inches high; plastic covered when in noncontamination zone
Green Pellets	Sintering boats - rectangular metal pans ~12(l)x9(w)x4(h) inches
Sintered Pellets	Pellet trays - flat rectangular tubed metal trays for holding horizontal pellet columns ~24(l)x8(w)x

X. RECYCLE PROCESSES

Recycle processes were shown previously in Figure 8. All usable scrap is eventually recycled. Process-generated scrap, such as grinder sludge, ADU, and dirty powder are processed through oxidation and scrap recovery processes before return to the process as purified O₂ powder. Typical quantities and categories of materials awaiting recycle were shown in Table 3.

Recycle takes place on a near-continuous basis. However, scrap recycle is not necessarily current with some newly generated scrap being stored in the warehouse prior to processing through scrap recovery.

XI. MEASURED DISCARDS AND RETAINED WASTE

Percent of Inputs

Measured discards in the form of filters and solid waste in barrels typically amount to about 0.2 percent of input. Retained waste in the form of solid wastes in barrels and in liquid wastes retained in the lagoons amounts to about 0.5 percent of cumulative input.

TABLE 6. Storage Descriptions

<u>Material Type</u>	<u>Storage Description</u>
1. <u>Feed</u> UF ₆	Stored in UF ₆ cylinder storage (see Figure 3) in a horizontal position.
2. <u>Product</u> Fuel Assemblies	Fuel assemblies are stored on an interim basis on hangers in a vertical position in the UO ₂ Building (see Figure 6) or after packaging in shipping containers in the shipping and receiving warehouse.
3. <u>Wastes</u> Filters	Filters awaiting shipment are stored in the contaminated storage warehouse (see Figure 3).
Waste Barrels	Waste barrels awaiting shipment are stored inside and also outside of the contaminated storage warehouse.
Waste Barrels (inventory)	Waste barrels stored for future recovery are stored on the barrel storage pad on pallets (four barrels to a pallet and three tiers high); the four barrels on each pallet are tied together with a steel band.
Liquid Wastes	Liquid uranium-bearing wastes are stored in the four storage lagoons.
4. <u>Inventory</u> Scrap	Scrap (grinder sludge, ADU, dirty powder, hard scrap) is stored in 5-gallon buckets on the floor of the contaminated storage warehouse in identified positions or in the storage trailers in a similar mode.
UO ₂ Powder	UO ₂ powder is stored in 5-gallon buckets as working storage in the powder storage room (see Figure 6) or near the presses as press feed.
Unground Pellets	Green and sintered pellets are stored in sintering boats on tables near the furnaces awaiting either sintering or grinding.
Ground Pellets	Ground pellets are stored on pellet trays in banded groups in pellet storage bins (see Figure 6).
Rods	Fuel rods are stored in long rod bins or on fuel rod carts awaiting further processing steps (see Figure 6).
5. <u>Working Storage</u>	Normal working storage is maintained at all process steps with materials in their normal containers.

XXII. INVENTORY

In Process

Typical current inventory holdings in bulk form within the plant were shown previously in Table 3. Material in bulk form heldup in equipment during normal operation consists mostly of UO₂ powder and ADU heldup in the ADU dryers, the calciners, powder preparation equipment, and offgas phenums in the conversion and scrap recovery areas. Normal holdup is estimated to be between 200 and 400 kilograms of uranium. Prior to inventory taking, equipment cleanouts are carried out and all the materials which are removed are measured and inventoried.

Other Locations

Inventory not already specified includes small quantities in filters, duct work, and hood floors in the various processing stages in the plant. After cleanouts (such as at inventory time), the material heldup (unmeasured) within the plant is estimated to be less than ten kilograms of uranium. Other measured inventories not specifically noted before include analytical samples and archive samples and specimens which are stored in the archive storage trailer.

PLANT MAINTENANCE

XXIII. MAINTENANCE, DECONTAMINATION, AND CLEANOUT

Normally, equipment maintenance does not interfere with safeguards material accounting in a fuel fabrication plant. All contaminated equipment, lagging, rags, paper, etc., used in equipment maintenance and equipment cleanouts are measured by nondestructive assay before discard.

Prior to inventory and between enrichment changes, all normal hood and process equipment holdup is removed by cleaning out centrifuges, vacuuming hoods and duct work, flushing process tanks in scrap recovery, cleaning calciners, etc. All nuclear materials removed in cleanouts are placed in containers and measured.

In areas where traces of uranium accumulate on floor areas, decontamination is done by mopping. All mop water is measured by volume concentration methods.

PROTECTION AND SAFETY MEASURES

XXIV. BASIC MEASURES FOR PHYSICAL PROTECTION OF NUCLEAR MATERIALS

Physical protection measures are in accordance with USNRC regulations and applicable license conditions.

XXV. SPECIFIC HEALTH AND SAFETY RULES FOR INSPECTOR COMPLIANCE

Health and safety provisions and rules are in accordance with 10CFR20. The inspectors will be given health and safety orientation prior to entering the plant areas. The inspectors will also be

escorted by plant personnel who are familiar with safety practices and Radiation Work Procedures. The inspectors will be furnished with dosimeters to be worn during plant visits. Dosimeter measurements will be furnished.

NUCLEAR MATERIAL ACCOUNTANCY

XXVI. SYSTEM DESCRIPTION

General

This section describes the details of the Model Plant accounting system for special nuclear material. The accounting system employs double-entry bookkeeping and is established and maintained centrally by the Controller's Department.

The nuclear materials accounting records are maintained in two computer data bases:

1. The Nuclear Inventory Control System (NICS) maintains a continuous material balance for the plant by MBS and ICA. Additions, removals, and MUF transactions are processed in the time sequence in which they are recorded; and

2. The Nuclear Material Reporting System (NMRS) maintains a historical record of all plant receipts, shipments, discards, MUF's, and ending physical inventories. MBA's and ICA's are not identified in this system.

Account Structure

The following types of accounts are established and maintained:

Plant Location. MBA or ICA designation as identified in Table 2.

Material Type. Currently, there are three accounts: 1) depleted uranium, 2) enriched uranium, and 3) natural uranium.

Enrichment. An account is set up for each nominal enrichment for enriched uranium.

Project. Each job or activity is assigned to an account, i.e., a reactor reload batch.

A chart of project and enrichment accounts is maintained in a separate manual.

A separate record is maintained of additions to and removals from the process, of the quantities of material in unopened receipts, and the ultimate product maintained under tamper-safing or in the form of sealed sources.

Accounting Forms

The following basic accounting forms used to record and transmit accounting data are shown in Table 7.

TABLE 7. Model Plant Accounting Forms

<u>Title</u>	<u>Description</u>
Receipt-Shipment	This form documents receipts and shipments between the Model Plant and other licensees or power locations. The data from this form are used to complete NRC/DOE 741 forms.
NRC/ERDA Form 741	Procedures for completing this form are provided by NRC/DOE.
Location Transfer	This form is used to transfer material between internal MBA or ICA location accounts.
Project/Enrichment Transfer	Transfers between material type, enrichment, and/or project accounts are documented on this form.
MBA Physical Inventory	All containers in the MBA are recorded on this form during a physical inventory.

TABLE 8. Flow Chart of Accounting Forms

<u>Source Documents</u>	<u>Prepared By</u>	<u>Reviewed By</u>	<u>Posted By</u> (Nuclear Materials Accounting)	<u>Reports</u>
NRC/ERDA Form 741	NM Account- ing	Materials and Purchasing		Perpetual Inventory Listing
Receipt- Shipment	Shipping/ Receiving ICA Custodian	NM Account- ing		Material Balance Ledger
Location Transfer	MBA or ICA Sending Custodian	MBA or ICA Receiving Custodian	{Master Record System}	Ending Inventory Summary
Project/ Enrichment Transfer	MBA Custodian	NM Account- ing		Detailed Transaction Listing
MBA Physical Inventory	MBA Custodian	NM Account- ing		

Flow Chart. The use of the various accounting forms and assignment of responsibilities for preparing and reviewing the transactions are shown in schematic form in Table 8.

Accounting Procedures. The Nuclear Safeguards Procedure Manual MP-3 includes nuclear materials accounting procedures.

Source Data. The source data are the data elements that are recorded on the source documents described in Table 7.

Adjustments to Records. Adjustments to source data contained in the record can only be made through a revised source data document. Record posting errors may be corrected with the approval of the Accountant, Nuclear Materials.

Bias Adjustments. A separate measurement bias account is maintained in which bias adjustments based on standards measurements can be made to all components of the material balance. A bias adjusted MUF is computed for each physical inventory using all estimated biases (whether statistically significant or not). The bias adjusted MUF is used and reported to NRC as a separate index. However, bias adjustments to permanent components of the plant material balance (shipments and receipts) and to the corresponding permanent records and transfer documents are not made unless the measurement bias is statistically significant. Measurement control measures generally maintain measurement bias well below the level of statistical significance.

Inventory Reconciliation. The physical inventory of an ICA consists of verifying all items listed in the perpetual inventory data base for a particular ICA. Any differences between the inventory listing and the physical count are promptly identified and the proper transactions recorded. No MUF is recorded within an ICA. The physical inventory of a MBA consists of summing quantities of nuclear material by project and enrichment accounts and comparing these values with book inventory values. All differences between the book and physical inventory quantities are reviewed by the MBA Custodian. Adjustments are made as appropriate. Remaining differences between book and physical inventory values are recorded as MUF. All reconciliation transactions and adjustments are reviewed by Nuclear Materials Accounting prior to entry into the records.

Account Reconciliation. Same as inventory reconciliation.

Electronic Data Processing. Electronic data processing is used extensively in the processing of nuclear materials accounting data. The plant currently uses off-site computer services. Data entry and reporting is done locally.

Accounting Reports. The accounting reports are generated from the master record accounting system data bases. A listing of the accounting reports is shown in Table 9.

Material Balance Reports. Material balance reports containing all the information required in 10CFR70.51(e)(4) are completed within 30 calendar days after the start of each ending inventory required by 10CFR70.51(e)(3).

TABLE 9. Accounting Reports

<u>Title</u>	<u>Data Base</u>	<u>Description</u>
Perpetual Inventory Listing	NICS	Shows current MBA and ICA status. Element and isotope quantities are shown for each MBA by material type, project, and enrichment accounts. Individual containers are shown for each ICA inventory.
Material Balance Ledger	NMRS	Periodic summary of beginning inventory, receipts, shipments, discards, MUF, and ending inventory. Material type, project, and enrichment account detail is given.
Ending Inventory Summary	NICS	Periodic summary showing all containers on ending inventory.
Detailed Transaction Listing	NICS	Shows all transactions which modify the perpetual inventory.
MUF Calculation	NICS/ Physical Inv.	Matches MBA physical inventory and NICS book inventory by material type, project, and enrichment accounts.
MUF and Measured Discard Summary	NMRS	Summarizes MUF and measured discards by enrichment account.
Possession Limits	NMRS	A weekly report comparing inventory levels with license limits.
NRC/ERDA Form 742	NMRS	Prepared in accordance with printed instructions.

Material Status Reports. Material status reports are submitted in accordance with the requirements of 10CFR70.53.

Accounting Records. A listing of the accounting documents that are retained as a part of the accounting record is shown in Table 10.

TABLE 10. Accounting Records and Reports Retention

<u>Document</u>	<u>Issued By</u>	<u>Maintained By</u>	<u>Retention Period</u>
<u>Source Documents</u>			
NRC/ERDA (a) 741	NM Accounting	NM Accounting	Permanent
Receipt-Shipment	S/R ICA Custodian	NM Accounting	Five Years
Location Transfer	MBA/ICA Custodian	NM Accounting	Five Years
Project/ Enrichment Transfer	MBA Custodian	NM Accounting	Five Years
MBA Physical Inventory	MBA Custodian/ NM Accounting	NM Accounting	Permanent
<u>Internal Records</u>			
Analytical Lab Results	Analytical Lab	Analytical Lab	Item identity retained while on inventory plus five years
Physical Inv. Count Sheets	MBA/ICA Custodian/ NM Accounting	NM Accounting	Permanent
Error Control for Scales and Balances	MBA/ICA Custodian	Statistical Consultant	Five Years
Physical Inv. Instructions and Results	NM Accounting	NM Accounting	Five Years
Packing Slips	S/R ICA Custodian	S/R ICA Custodian	Ten Years
Tamper- Indicating Seal Logs	MBA/ICA Custodian	MBA/ICA Custodian	Five Years
Perpetual Inventory Listing	NM Accounting	NM Accounting	Five Years
Material Balance Ledger	NM Accounting	NM Accounting	Permanent

TABLE 10. (Continued)

<u>Document</u>	<u>Issued By</u>	<u>Maintained By</u>	<u>Retention Period</u>
<u>Internal Records</u> (Continued)			
Ending Inventory Summary	NM Accounting	NM Accounting	Permanent
Detailed Transaction Listing	NM Accounting	NM Accounting	Five Years
MUF Calculations	NM Accounting	NM Accounting	Permanent
MUF and Measured Discard Summary	NM Accounting	NM Accounting	Permanent
Possession Limits	NM Accounting	NM Accounting	Five Years
NRC/ERDA (a) 742	NM Accounting	NM Accounting	Permanent
Material in Process	Systems Analyst	Systems Analyst	Five Years
MUF and LEMUF Analysis	Statistical Consultant	Statistical Consultant	Five Years
Inter-Lab Comparisons	Analytical Lab	Analytical Lab	Five Years
Shipper/Receiver Differences	Statistical Consultant	Statistical Consultant	Five Years

(a) Now Department of Energy.

Audits. The internal auditing program for the special nuclear materials accounting system is performed by three major groups. These are the President's Ad Hoc Review Committee, the Licensing Department, and the Nuclear Materials Accounting group.

Receipts

UF₆ is contained in approved cylinders (typically 30 inches in diameter). The cylinders are off-loaded from trucks by forklift or overhead crane. Cylinders are removed from their overpacks and stored in the UF₆ storage area (see Figure 3 for site description). UF₆ cylinders are weighed on the UF₆ cylinder scale as soon after off-loading as possible. Verification of cylinder contents of uranium and U-235 is made by witnessing the filling of cylinders at the

gaseous diffusion plant, by analysis of a sealed sample withdrawn during the filling operation and by determining that the containers were received in an inviolate condition. The analyses of the UF₆ for uranium and U-235, performed by the Model Plant or by an authorized laboratory acting as an agent, are regarded as verification analyses. Unless significant discrepancies are found at the 95 percent level of confidence, the UF₆ is inputted to the plant using Model Plant receiving weights and the shipper's values, as verified, for percents of uranium and U-235.

Other receipts include samples, SNM standards, and fuel assemblies which occasionally are received for repair. Detailed SNM receiving procedures for these miscellaneous receipts are given in the procedures manual. In all cases (except micro samples), receiving verification procedures are carried out.

Shipper-Receiver Comparisons. The preliminary shipper-receiver comparison is made within 24 hours of receipt of the material. This consists of an item-by-item verification that the items listed on the shipping papers are physically accounted for, that the information on packing labels is in agreement with that on the shipping papers, that the packages are intact, and that the seals provide no indication of tampering. The statistical analysis is performed upon completion of the weighing and analytical operations. In testing for statistical significance of the shipper-receiver difference (SRD), the measurement variances assigned by the shipper and the receiver are normally used. These include the effects of systematic errors. If the shipper's measurement variances are not given, the shipper is contacted immediately and asked to supply this information. If the information is not available, the uncertainties generally associated with the measurement techniques used by the shipper are used. The variance of the shipper-receiver difference is computed by standard propagation of error techniques.

Acceptance Criteria. On an individual item basis any anomaly that cannot be explained, such as item misidentification, a seal showing evidence of tampering, or a discrepancy that exceeds that attributable to measurement errors at the two standard deviation level of significance, is brought to the immediate attention of the Managers, Materials and Purchasing and Licensing, who will conduct an investigation. The results of the investigation will be reported to the Region V Walnut Creek Office of the U.S. Nuclear Regulatory Commission. When a series of shipments is received from the same supplier, the SRD's are examined in total to extract information on long- and short-term systematic errors. Analysis of variance and related statistical techniques are used and such analyses are performed at least annually as part of the annual measurement review. If persistent biases are found and if these are larger than explainable for the measurement systems employed by both parties, investigative and corrective action will be initiated by the Manager, Licensing.

If corrections are required to shipper or receiver data as the result of investigations of significant differences, corrections to source data can only be made through a revised source data document.

A shipper-receiver difference account is maintained.

Corrections for procedural errors or mistakes can only be corrected by submission of a revised source document. Record posting errors may be corrected with the approval of the Accountant, Nuclear Materials.

Shipments

Product Shipments. Packaged low enriched uranium fuel assemblies are shipped from plant site on trucks. Fuel assemblies are shipped in sealed shipping containers; each container typically holds two fuel assemblies. The number of assemblies in a single shipment will vary widely depending on a number of factors. A typical shipment would be about 32 fuel assemblies.

Each fuel shipment is reported on an NRC/ERDA 741 form. Each fuel assembly is uniquely numbered and a listing of the total U-235 and total uranium in each fuel assembly is attached to the NRC/ERDA 741 form.

Receipt of fuel shipments and inspection of fuel assemblies for item identification by the receiver is in accordance with U.S. regulatory requirements.

Fuel shipments designated for overseas transport are shipped via truck to an overseas air terminal and transported overseas by air freight. All such shipments are in accordance with U.S. regulations on reporting and inspection of overseas shipments.

Waste Shipments. As was noted earlier, waste shipments to an approved burial ground are made by truck. Shipments consist of 5-gallon barrels of waste and filters contained in cardboard boxes. Each item is uniquely numbered and each shipment is reported on an NRC/ERDA 741 form. A separate item listing is also attached to the 741 form. The waste receiver also completes the receiver's part of the 741 form and submits the completed form to the USNRC.

Physical Inventory

Physical inventories are taken for the low enriched uranium plant at the end of March and at the end of September. Procedures are developed for each inventory and those procedures will be made available to the Agency prior to inventory taking. Physical inventories are taken on a "clean plant" basis after equipment cleanouts are complete. A typical inventory listing was given in Table 3. Material container descriptions were given in Tables 5 and 6. Equipment hold-up estimates and typical cleanout procedures were described in Section 23.

Measured Discards and Retained Waste

A general description of measured discards and retained waste was given earlier in Section XVIII. The accounting system used for the accounting of measured discards and retained waste was described in the first part (General) of this section.

Measured discards (filter boxes and solid waste barrels) are accounted for on an individual item measurement. Each waste barrel and filter box is measured, uniquely numbered, and subtracted from the processing MBA on an item-by-item basis, e.g., each item is listed on a transfer document.

Waste barrels retained for later recovery are carried on inventory as items under item control. For each uniquely numbered waste barrel, a listing is maintained of the barrel number, barrel seal number, and uranium and U-235 quantity.

Liquid wastes which are discharged to the lagoon are measured on an individual waste discharge basis (volume times concentration). A running book inventory is maintained on the lagoon system by adding each individually measured transfer to the lagoon book inventory. In addition, periodic and extensive physical inventories of the lagoon system are made to confirm and update the lagoon book inventory.

Operational Records and Accounts

See the first part (General) of this section.

XXVII. FOR EACH KEY MEASUREMENT POINT IDENTIFIED UNDER QUESTIONS 14 AND 23 GIVE THE FOLLOWING

Identification

Key measurement points were identified in Figure 8 and described in Table 1.

Chemical and Physical Forms

Chemical and physical forms of the materials under measurement were described in Tables 1, 2, 3, and 6 and the supporting discussions for those tables.

Sampling Procedures and Equipment Used

The sampling procedures and equipment used for accountability measurements are shown in Table 11.

Measurement/Analytical Method and Equipment Used

Analytical Measurements. Analytical measurements for uranium are performed in-house with the exception noted in Item 1 below. A more detailed description of the analytical techniques, is given in "Analytical Procedures," is available on-site.

1. The gravimetric method is used to determine the weight percents of uranium in UF_6 (outside laboratory), in UO_2 powders and pellets, U_3O_8 , and in scrap. For the powders and pellets, five to ten grams of sample is loaded into an ignited, tared crucible, weighed, and the UO_2 ignited to U_3O_8 in a muffle furnace at $900^\circ \pm 25^\circ C$. The weight percent uranium calculation depends on the sample weights before and after ignition, the

TABLE 11. Model Plant Sampling Methods

Key Measurement Point	Materials	Description
(See Figure 8)		
1 UF ₆ Receipts	UF ₆	Sampled at diffusion plants. See UF ₆ sampling procedures, TID-7029, "Selected Measurement Methods for Plutonium and Uranium in the Nuclear Fuel Cycle," USAEC, 1963.
2, 7 Liquid Waste Lagoon Inventory	Centrifuged Grinder Water Filtrate (Centrate Hold Tanks)	Line sample from transfer line Tank solution mixed by circulating pump and sampled through built-in circulating sampling lines.
3, 12 UO ₂ Green Powder	UO ₂ Powder	Thief or scoop sampled after blending. Three buckets from each lot are sampled and each sample assayed.
11 U ₃ O ₈	U ₃ O ₈	Thief or scoop sampled after blending. Three buckets from each lot are sampled and each sample assayed.
8 Sintered Pellets UO ₂ Product	UO ₂ Pellets	Random samples of whole pellets are taken for U assay and U-235 verification. Five pellets per lot are taken for U assay and two for percent U-235 verification.
10 Scrap Inventory	Grinder Sludge, ADU, Dirty Powder, U ₃ O ₈	All scrap is sampled by scoop after mixing of container (5-gallon cans) contents by mechanical stirring or by tumbling the container.

impurity content as determined from the spectrographic analysis, and the calculated U₃O₈ to U gravimetric factor.

2. The titration method may be used to determine the percents of uranium for grinder sludge and dirty powder. An excess of ferrous sulfate is used to reduce U(VI) to U(IV) in a phosphoric acid medium containing sulfuric acid. Excess ferrous ion is

destroyed with nitric acid using Mo(VI) as a catalyst. The titration is made potentiometrically with standard potassium dichromate in a sulfuric acid solution. The primary variables used in the calculation include the weight and normality of $K_2Cr_2O_7$, the volume of the titrant, the equivalent weight of U, the sample weight, and the effective oxidation of NBS $K_2Cr_2O_7$.

3. The mass spectrometer is used to determine isotopic composition (percent U-235). A solid sample deposited on a filament is thermally ionized. The ions travel through electrical and magnetic fields that accelerate and separate the ions into beams, each beam consisting of ions having the same mass-to-charge ratio. Separation of the ions is explained by an equation expressing the mass-to-charge ratio as a function of the magnetic field strength, the radius of curvature of the ion path, and the accelerating voltage. The magnetic field is varied to focus a specific ion on the detector. The detector output is recorded on a strip chart and isotopic content is calculated from the voltages of the ion beams.

4. Analysis of liquid wastes for uranium concentration is performed using the fluorometric technique. Samples are fused with NaF-LiF and the amount of uranium determined by measuring the amount of fluorescence when activated with ultraviolet radiation. Samples are purified via solvent extraction where interfering materials are present.

Nondestructive Assay Measurements. Uranium in 55-gallon drums of solid wastes is measured by an NDA system consisting of four sodium iodide (NaI) detectors and associated electronics and a barrel rotating fixture. The barrel is rotated at about 5 rpm to provide an average count from the barrel independent of the radial location of the uranium. Lead shields around the detectors provide vertical and horizontal collimation to flatten out the system response due to variations in source location in the vertical direction.

Uranium retained in HEPA filters after they have been shaken to remove loosely adhered particles is measured by the same NDA system as described above. The filters are packaged in boxes about one foot by two feet by two feet in size during the measurement operation.

The analytical methods are summarized in Table 12.

Volume Measurements. The volumes of liquid wastes transferred to the lagoons are measured as follows:

1. Filtrate (Centrate waste from conversion and scrap recovery). Volumes are measured by a liquid level (full) sensor for each batch transfer to the lagoon system. A typical batch transfer is about 500 gallons.

2. Centrifuged Grinder Water. Volumes are estimated visually from the liquid level markings on the 15-gallon tanks.

TABLE 12. Summary of Uranium Methods

Measurement Point	Analytical Method	
	Element	Isotope
(See Figure 8)		
1 UF ₆	Gravimetric	Mass Spectrometer
2 Liquid Waste	Fluorimetric, Titration	Factor
3, 12 UO ₂ Powder	Gravimetric	Mass Spectrometer
8 UO ₂ Pellets	Gravimetric	Mass Spectrometer
10 Dirty Powder, ADU	Gravimetric or Titration	Factor
10 U ₃ O ₈	Gravimetric	Mass Spectrometer
10 Grinder Sludge	Gravimetric or Titration	Factor
9 Solid Waste	Factor	NDA

Lagoon Inventory. Periodically, a physical inventory of the lagoon system is carried out by taking liquid and sludge measurements over the entire area and depth of the lagoons.

Mass Measurements. Reference is made to the measurement points (MP) identified in Table 1. Scales of equivalent ranges, accuracies, and precisions may be substituted for those given below.

- MP-1: Cardinal UF₆ Cylinder Scale (4000 kg capacity)
- MP-3: Digiflex (50 kg capacity)
- MP-4, 5, 6, 7: Digiflex (50 kg capacity)
- MP-8: Tridyne Scales (5 kg capacity)
- MP-10, 11, 12: Digiflex (50 kg capacity)

Source and Level of Random and Systematic Errors

Measurement errors are estimated from measurement control program data, special experimental tests, calibration data, and shipper-receiver measurement data. Measurement error estimates for the random and systematic errors associated with weighing, sampling, analytical, and volume measurements are reviewed and updated at least once each material balance period. A current set of error parameter values is shown in Table 13. The measurement control program from which the error parameters are derived is described later in Section XXVII.

TABLE 13. Error Parameter Values for Model Plant Uranium Material Balance

Measurement Method	Description	Method No.	Material Balance Component and Class (b)	σ , % RSD U (or as noted) (a)		
				Random	S.T. Syst.	L.T. Syst.
Weighing	Scale 1 UF ₆ Scale	W ₁	Additions - UF ₆ Full Cylinders, Class 1 Removals - UF ₆ Heels, Class 2e	0.40 kg	0.60 ka	0.15 kg
Weighing	Scales 2-13	W ₂ -W ₁₃	Inventory - Class 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i	8 gm	---	6 gm
Weighing	Scales 14,15	W ₁₄ -W ₁₅	Removals - Rods, Class 3a	0.30 gm	---	0.20 gm
Sampling	Sampling by Scoop or by Thief	S ₁	Inventory - Scrap, Class 3g, ADU	6.0	---	3.0
Sampling	Sampling by Scoop or by Thief	S ₂	Inventory - Scrap, Class 3h, Grinder Sludge	3.0	---	2.0
Sampling	Sampling by Scoop or by Thief	S ₃	Inventory - Scrap, Class 3i, Dirty Powder	3.0	---	0.5
Sampling	Circulating Sample	S ₄	Removals - Liquid Waste, Class 2d	5.0	---	15.0
Volume	Liquid Level Constant Volume Discharge	V ₁ ,V ₂ , V ₃	Removals - Liquid Waste Class 2d	5.0	---	3.0(c)

TABLE 13. (Continued)

Measurement Method	Description	Method No.	Material Balance Component and Class (b)	σ , % RSD U (or as noted) (a)		
				Random	S.T. Svst.	L.T. Syst.
U-Factor	Gravimetric	U1	Receipts - UF ₆ Input, Class 1 Removals - UF ₆ Heels, Class 2e	0.013	---	0.005
U-Assay	Gravimetric	U2	Removals - Class 2a	0.02	---	0.015
U-Factor	Gravimetric	U3	Inventory - Class 3a, 3b	---	0.30	0.015
U-Factor	Gravimetric	U4	Inventory - Class 3c, 3d, 3f	---	0.030	0.015
U-Factor	Gravimetric	U5	Inventory - Class 3e-U ₃ O ₈	---	0.10	0.10
U-Assay	Gravimetric	U6-U8	Inventory - Scrap Class 3g, 3h, 3i	0.04	---	0.10
U-235 Assay	Passive NDA	U-235 ₁	Removals - Waste, Class 2b, 2c, Barrels and Filers	15.0	---	20.0 (d)
U-Assay	Fluorimetric	U9	Removals - Liquid waste, Class 2d	10	---	8

- (a) RSD denotes relative standard deviation. S.T. Syst. and L.T. Svst. denote short-term and long-term systematic errors. Weighing errors for UF₆ cylinders are given as absolute standard deviations for gross weights of uranium. The tare is assumed to be constant. The other weighing errors are given as absolute standard deviations for net uranium weight.
- (b) The material classes correspond to those given in Table 1.
- (c) Combined systematic error for 2 banks of identical tanks for each discharge point, e.g., Line 1, Line 2, and Scrap Recovery.
- (d) Illustrative composite value. Actual NDA's are calculated for each Class 2b and 2c from calibration error equations.

Methods of Converting Source Data to Batch Data

The basic source data for the uranium plant consists of net weights in kilograms (except UF_6 in pounds); uranium concentration in weight percent and in parts per million (for liquid wastes); net U-235 counts for solid wastes; volumes of liquid wastes in gallons; and enrichment in weight percent U-235. The calculational methods for converting source data to item data are shown in Table 14.

The uranium percentage factors (U-factors) shown in Table 14 are based on measurement data accumulated for each material type. Current factors for each material type are maintained in the detailed procedures manual. U-factors tend to remain fairly constant over time and are changed only when a statistically significant change is observed. Cusum plots are maintained on all U-factor data.

The enrichment factors (E-factors) shown in Table 14 generally correspond to the weighted average enrichment of each enrichment account. The weighted average enrichment of each enrichment account is computed from the weighted average of the enrichment of all UF_6 cylinders (of the same nominal enrichment) making up the carting material for that account. When enrichment blending takes place or when material of a mixed enrichment is removed from process equipment, the enrichment factor is determined by mass spectrometry or nondestructive analysis. This case is shown in Table 14 by the notation "E-assay."

Conversion of gallons and pounds to metric units is done using standard conversion factors.

Calculative and Error Propagation Technique

The method of calculating sigma MUF and the error propagation technique used are described in Section XXVIII.

(viii) Techniques and Frequency of Calibration of Equipment Used

See Section XXVII - Measurement Control Program.

(xi) Program for the Continuing Appraisal of the Accuracy, Weight, Volume, Sampling, and Analytical Techniques and Measurement Methods

See Section XXVII - Measurement Control Program.

Program for Statistical Evaluation of Data From (viii and ix)

See Section XXVII - Measurement Control Program.

TABLE 14. Calculational Methods

Material Balance Stratum	Calculation Methods	
	Weight U	Weight U-235
1. Receipts		
UF ₆	Net weight x U-assay	Weight U x E-assay
UO ₂	New weight x U-assay	Weight U x E-assay
2. Inventory		
UO Powders	Net weight x U-factor (separate factor for each powder type)	Weight U x E-factor
Pellets (Inventory)	Net weight x U-factor (separate factor for green and sintered pellets)	Weight U x E-factor
Scrap		
Dirty Powder, Grinder Sludge, ADU	Net weight x U-assay	Weight U x E-factor or assay
3. Product		
Rods	Net weight x U-assay	Weight U x E-factor
Assemblies	Sum of rod U weights	Sum of rod U-235 weights
4. Waste		
Barrels and Filters	U-235 grams divided by nominal E-factor	Grams U-235 per item-- net U-235 counts and calibration curve or fitted equation
Liquid Waste	Volume x con- centration	Weight U x average E-factor

TABLE 15. Measurements for Model Plant Six Month Uranium Material Balance

Measurement	Material	Class	Method Number	Batch Size Kgs U	Total Kgs. U by Method	Measurements by Method		Total Affected by L.T. Syst. Error
						Random	S.T. Syst.	
Weighing	UF ₆	1	W ₁	1,400	117,600	84	17 (a)	84 Items
Weighing	UF ₆ Heels	2e	W ₁	2.0	164	84	17	84 Items
Weighing	Pellet Columns (Rods)	2a	W ₁₄	2.5	58,500	23,400	--	23,400 Items
Weighing	Pellet Columns (Rods)	2a	W ₁₅	2.5	58,500	23,400	--	23,400 Items
Weighing	Green Powder	3a	W ₂	17	4,590	270	--	135 Items (b)
Weighing	Hard Scrap	3f	W ₂	21	420	20	--	10 Items (b)
Weighing	ADU	3g	W ₂	10	400	40	--	20 Items (b)
Weighing	Dirty Powder	3i	W ₂	17	340	20	--	10 Items (b)
								W ₂ = <u>175 Items (b)</u>
Weighing	Green Powder	3a	W ₃	17	4,590	270	--	135 Items (b)
Weighing	Hard Scrap	3f	W ₃	21	420	20	--	10 Items (b)
Weighing	ADU	3g	W ₃	10	400	40	--	20 Items (b)
Weighing	Dirty Powder	3i	W ₃	17	340	20	--	10 Items (b)
								W ₃ = <u>175 Items (b)</u>
Weighing	Green Powder (Scrap Recovery)	3a	W ₁₀	17	1,020	60	--	30 Items (b)

TABLE 15. (Continued)

<u>Measurement</u>	<u>Material</u>	<u>Class</u>	<u>Method Number</u>	<u>Batch Size Kgs U</u>	<u>Total Kgs. U by Method</u>	<u>Measurements by Method</u>		<u>Total Affected by L.T. Syst. Error</u>
						<u>Random</u>	<u>S.T. Syst.</u>	
Weighing	Green Pellets	3b	W4	18	360	20	--	10 Items (b)
Weighing	Green Pellets	3b	W5	18	360	20	--	10 Items (b)
Weighing	Sintered Pellets (On Trays)	3c	W6	6	6,000	1,000	--	500 Items (b)
Weighing	Sintered Pellets (On Trays)	3c	W7	6	6,000	1,000	--	500 Items (b)
Weighing	Sintered Pellets (In Boats)	3d	W8	18	360	20	--	10 Items (b)
Weighing	Sintered Pellets (In Boats)	3d	W9	18	360	20	--	10 Items (b)
Weighing	Grinder Sludge	3h	W11	12	240	20	--	10 Items (b)
Weighing	Grinder Sludge	3h	W12	12	240	20	--	10 Items (b)
Weighing	U ₃ O ₈	3e	W13	17	8,500	500	--	250 Items (b)
Sampling	ADU	3g	S1	10	800	80	--	--
Sampling	Grinder Sludge	3h	S2	12	480	40	--	--
Sampling	Dirty Powder	3i	S3	17	680	40	--	--
Sampling	Liquid Waste	2d	S4	2.0	352	176	--	352 Kgs

37c-47

TABLE 15. (Continued)

Measurement	Material	Class	Method Number	Batch Size Kgs U	Total Kgs. U by Method	Measurements by Method		Total Affected by L.T. Syst. Error
						Random	S.T. Syst.	
Volume	Liquid Waste (Line 1)	2d	V ₁	2.0	158	1,659	--	158 Kgs
Volume	Liquid Waste (Line 2)	2d	V ₂	2.0	158	1,659	--	158 Kgs
Volume	Liquid Waste	2d	V ₃	2.0	36	378	--	36 Kgs
U-Assay	UF ₆	1	U ₁	1,400	117,600	17	} (Full-Heels)	117,432 Kgs
U-Assay	UF ₆ Heels	2e	U ₁	2.0	164	17		
U-Assay	UO ₂ in Rods	2a	U ₂	1,200	117,000	488	--	117,000 Kgs
U-Factor	UO ₂ Unsintered	3a, 3b	U ₃	1,200	10,920	--	0 (Lot-to-Lot) (Variation)	--
U-Factor	UO ₂ Sintered on Inventory	3c, 3d	U ₄	1,200	14,400	--	12 (Lot-to-Lot) (Variation)	--
U-Factor	U ₃ O ₈	3e	U ₅	500	8,500	--	17 (Lot-to-Lot) (Variation)	--
U-Assay	ADU	3g	U ₆	10	800	80	--	--
U-Assay	Grinder Sludge	3h	U ₇	12	480	40	--	--
U-Assay	Dirty Powder	3i	U ₈	17	680	40	--	--

TABLE 15. (Continued)

<u>Measurement</u>	<u>Material</u>	<u>Class</u>	<u>Method Number</u>	<u>Batch Size Kgs U</u>	<u>Total Kgs. U by Method</u>	<u>Measurements by Method</u>		<u>Total Affected by I.T. Svst. Error</u>
						<u>Random</u>	<u>S.T. Svst.</u>	
U-235 Assay	Waste Barrels	2b	U-235 ₁	0.4	188	470	--	188 Kgs
U-235 Assay	Filters	2c	U-235 ₁	0.2	48	240	--	48 Kgs
U-Assay	Liquid Waste	2d	U ₉	2.0	352	176	--	352 Kgs

(a) The short term systematic error for UF₆ cylinder weighing is assumed to affect all cylinders weighed on a given day. For the 84 cylinders and heels, 5 cylinders are weighed per day for 16 days and 4 cylinders weighed during one day.

XXVIII. OVERALL LIMIT OF ERROR

S/R Differences

The statistical method for determining the limit of error for S/R differences was described previously in Section XXVI, "Receipts." In that method, the random and systematic errors of measurement of both the shipper and receiver are used to compute the variance of the S/R difference for each shipment. The computed variance forms the basis for the test of statistical significance.

When a series of shipments is received from the same supplier, the S/R differences are examined in total to extract information on long- and short-term systematic errors. Analysis of variance and related statistical techniques are used and such analyses are performed at least annually as part of the annual measurement review. If persistent biases are found and if these are larger than explainable for the measurement systems employed by both parties, investigating and corrective action is initiated.

Book Inventory

The measurement uncertainty of the book inventory is generally not computed as a separate item. However, at the end of each material balance period (six months), the limit of error ($2 \sigma_{MUF} = LEMUF$) of MUF is computed for the uranium plant.

Physical Inventory

The measurement uncertainty or limit of error for the plant physical inventory is also not generally computed. For verification purposes, limit of error estimates are maintained for each class of items in the physical inventory.

MUF

The limit of error (LEMUF) for the uranium plant MUF is computed at the end of each material balance period. The LEMUF is computed using current estimates of measurement error parameters (see Table 13) and conventional methods of error propagation. The methods of error propagation are described in TID-26298, "Statistical Methods in Nuclear Material Control." The LEMUF calculations are done using data from the computer-based data system described in Section XXVI and current error parameter values.

The error propagation approach is based on propagating measurement errors by method (or source of error) for all items which contribute to the overall plant MUF for the accounting period. The computer-based data system is used to enter only those items which can contribute to MUF (and hence the variance of MUF) into the calculation. The calculational method takes into account the MUF equation in combining systematic error variances of common measurements which are made on items from different components of the material balance.

Example LEMUF Calculation

An example uranium LEMUF calculation is illustrated in Table 16. The basis for the calculation is shown first in Table 15 which lists the items, quantities, and measurements involved in a typical six-month material balance period. The measurement methods and error parameter values used in the example calculation were shown previously in Table 13.

The example uranium LEMUF calculation shown in Table 16 is included to illustrate the methods of error propagation. Although the example closely represents an actual LEMUF calculation and the actual plant LEMUF, it differs from an actual calculation in several respects. First, the error propagation for the NDA U-235 assay on barrels and filters is combined in the example for both types of items assuming mean values. In actual practice, barrel NDA assays and filter assay errors are computed from separate error propagation equations which are derived from the calibration equations. Secondly, the short-term systematic errors for weighing UF₆ cylinders and errors for the U-assay of cylinders are shown as applying to typical groups. The actual computation is based on weighing dates and the number of cylinders included in each U-assay. The actual calculational procedures are available on-site for Agency review.

The following explanatory notes are given to aid the reader in following the example LEMUF calculation given in Table 16.

1. The measurement errors arising from the measurement of each item which contributes to LEMUF are propagated by measurement method. The measurement error variances arising from each different method are summed by error type (random, short-term systematic, long-term systematic error variances) to yield the variance of MUF by each error type and by each error source (sampling, weighing, volume, analytical). The summation of the variances yields the variance of MUF (σ^2 MUF). By convention, LEMUF is taken as twice the standard deviation of MUF:

$$\text{LEMUF} = 2\sigma\text{MUF}$$

2. The numerical values shown in Table 16 are computed by using the batch sizes and number of measurements per class shown in Table 15 and the error parameter values in Table 13. For example, the random error variance for weighing of UF₆ receipts is based on weighing 84 cylinders with an absolute standard deviation of 0.40 kilograms U, e.g.,

$$84(0.40 \text{ kgs U})^2 = 13.44.$$

3. Long term systematic weighing errors for the UF₆ scale are assumed to be of the same magnitude and direction for both full cylinders and heels, e.g., they cancel. For scales used to establish inventory weights, the long term systematic weighing errors of beginning inventory and ending inventory items are assumed to be of the same magnitude but a different and unknown direction, e.g., independent. Long term systematic errors for

TABLE 16. Example Calculation of Uranium Sigma MUF for a Six-Month Material Balance

Measurement	Material	Class	Method Number	Items or Quantities Affected ^(a) By Types Of Error			σ ^(b)			σ^2 Kgs ² U By Method		
				Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.
Weighing	UF ₆	1	W ₁	84	17	84						
Weighing	UF ₆ Heels	2e	W ₁	84	17	84	0.40 Kg	0.60 Kg	0.15 Kg	13.44	149.76	158.76
Weighing	Sintered Pellets (Rods)	2a	W ₁₄	23,400	--	23,400	0.30 gm	--	0.20 gm	0.0002	--	21.90
Weighing	Sintered Pellets (Rods)	2a	W ₁₅	23,400	--	23,400	0.30	--	0.20 gm	0.002	--	21.90
Weighing	Green Powder	3a	W ₂	270	--	135(2)	8 gm	--	6 gm	Variance Computed		
Weighing	Hard Scrap	3c	W ₂	20	--	10(2)				For Total Weighing		
Weighing	ADU	3g	W ₂	40	--	20(2)	8 gm	--	6 gm	On Scale 2		
Weighing	Dirty Powder	3i	W ₂	20	--	10(2)	8 gm	--	6 gm			
				350		175(2)				0.023		2.21
Weighing	Green Powder	3a	W ₃	270	--	135(2)	8 gm	--	6 gm			
Weighing	Hard Scrap	3f	W ₃	20	--	10(2)	8 gm	--	6 gm	Variance Computed		
Weighing	ADU	3g	W ₃	40	--	20(2)	8 gm	--	6 gm	For Total Weighing		
Weighing	Dirty Powder	3i	W ₃	20	--	10(2)	8 gm	--	6 gm	On Scale 3		
				350		175(2)				0.023		2.21
Weighing	Green Powder (Scrap Recovery)	3a	W ₁₀	60	--	30(2)	8 gm	--	6 gm	0.004	--	0.065
Weighing	Green Pellets	3b	W ₄	20	--	10(2)	8 gm	-- E	6 gm	0.001	--	0.007
Weighing	Green Pellets	3b	W ₅	20	--	10(2)	8 gm	--	6 gm	0.001	--	0.007
Weighing	Sintered Pellets (On Trays)	3c	W ₆	1,000	--	500(2)	8 gm	--	6 gm	0.064	--	18.00
Weighing	Sintered Pellets (On Trays)	3c	W ₇	1,000	--	500(2)	8 gm	--	6 gm	0.064	--	18.00
Weighing	Sintered Pellets (In Boats)	3d	W ₈	20	--	10(2)	8 gm	--	6 gm	0.001	--	0.004
Weighing	Sintered Pellets (In Boats)	3d	W ₉	20	--	10(2)	8 gm	--	6 gm	0.001	--	0.004

TABLE 16. (Continued)

Measurement	Material	Class	Method Number	Items or Quantities Affected ^(a)			σ ^(b)			σ^2 Kgs ² U By Method					
				By Types Of Error			Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.
				Random	S.T. Syst.	L.T. Syst.									
Weighing	Grinder Sludge	3h	W11	20	--	10 ⁽²⁾	8 gm	--	6 gm	0.001	--	0.004			
Weighing	Grinder Sludge	3h	W12	20	--	10 ⁽²⁾	8 gm	--	6 gm	0.001	--	0.004			
Weighing	U ₃ O ₈	3c	W13	500	--	250 ⁽²⁾	8 gm	--	6 gm	0.032	--	4.50			
Total Weighing										27.100	299.52	116.815			
Sampling	ADU	3g	S1	80	--	--	6%	--	(3.0%)(c)	28.80	--	--			
Sampling	Grinder Sludge	3h	S2	40	--	--	3%	--	(2.0%)(c)	5.184	--	--			
Sampling	Dirty Powder	3i	S3	40	--	--	3%	--	(0.5%)(c)	10.404	--	--			
Sampling	Liquid	2d	S4	176	--	--	5%	--	15%	1.76	--	2787.84			
Total Sampling										46.148	--	2787.84			
Volume	Liquid Waste (Line 1)	2d	V1	1,659	--	158 Kg	5%	--	3.0%	0.0376	--	22.468			
Volume	Liquid Waste (Line 2)	2d	V2	1,659	--	158 Kg	5%	--	3.0%	0.0376	--	22.468			
Volume	Liquid Waste (Scrap Recovery)	2d	V3	378	--	36 Kg	5%	--	3.0%	0.009	--	1.166			
Total Volume										0.0842	--	46.102			
U-Assay	UF ₆	1	U1	17	--	117,432 Kg (Full Heels)	0.013%	--	0.005%	13.74	--	34.475			
U-Assay	UF ₆ Heels	2c	U1	17	--	--	0.013%	--	0.005%	--	--	--			
U-Assay	Sintered UO ₂ (In Rods)	2a	U2	488	--	117,000 Kg	0.02%	--	0.015%	1.122	--	308.00			
U-Factor	Unsintered UO ₂	3a, 3b	U3	--	10,920 kg (9 Lots)		--	0.30	--	--	119.246	--			
U-Factor	Sintered UO ₂ (In Inventory)	3c, 3d, 3f	U4	--	14,400 kg (12 Lots)		--	0.030%	--	--	1.555	--			
U-Factor	U ₃ O ₈	3e	U5	--	8,500 kg (17 Lots)		--	0.10%	--	--	4.25	--			
U-Assay	ADU	3g	U6	80	--	--	0.04%	--	(0.10)(c)	0.001	--	--			
U-Assay	Grinder Sludge	3h	U7	40	--	--	0.04%	--	(0.10)(c)	0.001	--	--			

TABLE 16. (Continued)

Measurement	Material	Class	Method Number	Items or Quantities Affected ^(a) By Types Of Error			σ ^(b)			σ^2 Kgs ² U By Method		
				Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.	Random	S.T. Syst.	L.T. Syst.
U-Assay	Dirty Powder	3i	Ug	40	--	--	0.04%	--	(0.10) ^(c)	0.002	--	--
U-Assay	Waste Barrels	2b	U-235 ₁	470	--	188 kg	15%	--	20%	1.692	--	Total by Method
U-Assay	Filters	2c	U-235 ₁	240	--	48 kg	15%	--	20%	0.216	--	2227.840
U-Assay	Liquid Waste	2d	Ug	176	--	352 kg	10%	--	8%	<u>7.04</u>	--	<u>792.986</u>
Total U-Assay										23.814	125.051	3363.301
Total All Methods										Random	S.T. Syst.	L.T. Syst.
Weighing										27.100	299.52	116.815
Sampling										46.148		2787.84
Volume										0.0842		46.102
U-Assay										23.813	125.051	3363.301
Subtotal										<u>97.145</u>	<u>424.571</u>	<u>6314.058</u>
Total σ^2 MUF =										6835.774 Kg ² U		
Total σ MUF =										82.679 Kg U		

(a) Unless specified as kilogram quantities the numbers shown refer to the number of items affected by random or short term systematic errors.

(b) Percent errors are in units of relative standard deviations.

(c) Long term systematic sampling and analytical errors are assumed to cancel when the quantities in the beginning and ending are identical.

sampling and analytical measurements are assumed to be constant throughout the accounting period. Since the model material balance has identical quantities in the beginning and ending inventory, those errors are self-cancelling in the example. The example errors and subsequent σ_{MUF} give high emphasis to the potential systematic errors associated with sampling liquid waste and in assaying solid waste. It should be noted that the combination of an equilibrium inventory model and the conversion of difficult to measure material such as ADU to U_3O_8 , results in a very low σ_{MUF} . For example, if the inventory quantity of U_3O_8 shown in the model were a quantity of ADU or grinder sludge accumulated during the accounting period, the σ_{MUF} would be about 2 times larger due to the systematic sampling errors for those materials.

4. The U-factor variance is treated as consisting of two main components. One is the short-term systematic variance representing the lot-to-lot variation in the true percent uranium. The other is the long-term systematic variance of the factor itself which is approximated by the long-term analytical systematic error variance. Items in the beginning and ending inventory which have the same U-factor are treated as having a common long-term systematic error. The lot-to-lot variance of the true percent uranium is propagated as a short-term systematic error variance applying to each different lot of material appearing in inventory.

Enrichment Control and U-235 LEMUF

When enrichment combining does not take place, the uranium element LEMUF may be directly converted to the U-235 LEMUF by multiplying the uranium element LEMUF by the average enrichment fraction (e.g., 0.03 wt. fraction U-235). The direct conversion is possible since almost all of the U-235 LEMUF arises from measurements associated with uranium element. The enrichment assigned to each production project is based on the enrichment of the starting UF_6 . Unless enrichment combining takes place, each project and all of its associated parts are maintained under that original enrichment on a perpetual basis.

To assure that enrichment factors are valid, an extensive enrichment verification measurement program is carried out, including mass spectrometer measurements of all powder and pellet lots, NDA enrichment measurements on all powder and scrap buckets, and an active nuclear assay of each rod. In addition, a high degree of physical segregation and enrichment identification is employed. Each item is identified by enrichment, including an enrichment mark on each pellet.

The verification measurements for enrichments which are made on powder and pellet lots are not entered into the accounting records

unless the data indicate that enrichment mixing has occurred. Unless an actual change has occurred, such a practice would create an artificial U-235 uncertainty.

Enrichment combining takes place when lots of scrap recovery UO₂ are combined under a single project enrichment factor with virgin UO₂ lots of the same enrichment. (Physical mixing is not done.) The enrichment of the total project is based on the weighted average of the (UF₆) enrichment of virgin lots and the enrichment of scrap recovery lots.

In this case, the mass spectrometer measurements made on scrap recovery product are entered into the accounting records. Those enrichment measurement variances and the corresponding scrap recovery feed enrichment variances contribute to the U-235 LEMUF. A separate U-235 LEMUF calculation is done to take this into account. The effect is equivalent to making the relative U-235 LEMUF slightly larger than the relative uranium LEMUF. The error propagation procedure for the case of enrichment combining is available on-site and referenced in Chapter 6, Section 6.5 of IAEA-174, Part F, "Statistical Concepts and Techniques."

XXIX. OPTIONAL INFORMATION

Safeguards Manuals

Copies of the safeguards procedures manuals and descriptions are available on-site. These are:

1. MP-2, "Nuclear Materials Safeguards Procedures Description for the Fuel Fabrication Plant"
2. MP-3, "Nuclear Materials Safeguards Procedures"
3. MP-4, "Analytical Procedures"

Measurement Control Program

Because of its importance in safeguards materials accounting, the general features of the uranium measurement control program are outlined in this section. (See, "A Measurement Control Program for a Conversion-Fabrication Plant," Session: July 31, 1979, Tuesday, 3:00-5:00 P.M.).

**INTERNATIONAL ATOMIC ENERGY AGENCY
DEPARTMENT OF SAFEGUARDS AND INSPECTION**

**DESIGN INFORMATION
QUESTIONNAIRE ***

IAEA USE ONLY

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The purpose of this document is to obtain the facility design information required by the Agency in order to discharge its safeguards responsibilities. It will also serve as a check list for examination of design information by Agency inspector(s). If, in any area, insufficient space is available add further sheets to the extent necessary.

IAEA USE ONLY	
COUNTRY	
COUNTRY OFFICER	
TYPE	
DATE OF INITIAL DATA	
VERIFICATION	
LAST REVIEW AND UPDATING	

* Questions which are not applicable may be left unanswered.

ALL FACILITIES.

GENERAL INFORMATION			
1 NAME OF THE FACILITY (incl. usual abbreviation)			
2 LOCATION AND POSTAL ADDRESS			
3 OWNER (legally responsible)			
4 OPERATOR (legally responsible)			
5 DESCRIPTION (main features only)			
6 PURPOSE			
7 STATUS (planned; under construction; in operation)			
8 CONSTRUCTION SCHEDULE DATES (if not in operation)	Start of Construction	Commissioning	Operation
9 NORMAL OPERATING MODE (days only, two-shift, three shift; number of days/annum, etc.)			
10 FACILITY LAYOUT (structural containment, fences, access, nuclear material storage areas, laboratories, waste disposal areas, routes followed by nuclear material, experimental and test areas, etc.)	DRAWING(S) ATTACHED UNDER REF. Nos.		
11 SITE LAYOUT (site plan showing in sufficient detail; location, premises and perimeter of facility, other buildings, roads, railways, rivers, etc.)	DRAWING(S) AND/OR MAPS ATTACHED UNDER REF. Nos.		
12 NAMES AND/OR TITLE AND ADDRESS OF RESPONSIBLE OFFICERS (for nuclear material accountability and control and contact with the Agency. If possible attach organization charts showing position of officers)			

CONVERSION AND/OR FUEL FABRICATION PLANTS

OVERALL PROCESS PARAMETERS			
13. FACILITY DESCRIPTION <i>(indicating all process stages, storage areas and feed, product and waste points)</i>	GENERAL FLOW DIAGRAM(S) ATTACHED UNDER REF. Nos.		
14. PROCESS DESCRIPTION <i>(identifying sampling and key measurement points: MBAs, inventory locations)</i>	FLOWSHEET(S) FOR NORMAL OPERATION ATTACHED UNDER REF. Nos.		
15. DESIGN CAPACITY <i>(in weight and numbers of product units per annum)</i>			
16. ANTICIPATED THROUGHPUT <i>(in the form of a forward programme indicating the proportion of various feeds and products)</i>			
NUCLEAR MATERIAL DESCRIPTION AND FLOW			
17. MAIN MATERIAL DESCRIPTION	FEED	INTERMEDIATE PRODUCT (1)	PRODUCT
i) Chemical and Physical Form <i>(for fuel element/assembly products attach drawings)</i>			
ii) Throughput, Enrichment Ranges and Pu contents <i>(for normal flowsheet operation indicating if blending and/or recycling takes place)</i>			
iii) Batch Size and Campaign Period			
iv) Storage Inventory <i>(indicating any change with throughput)</i>			
v) Frequency of Receipt or Shipment			
(1) For example powder, pellets, etc. separately stored or shipped.			

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL DESCRIPTION AND FLOW	
<p>18. WASTE MATERIAL</p> <p>i) <i>Source and Form</i> (indicating major contributors; liquid or solid; range of constituents; enrichment range and Pu content, include contaminated equipment)</p> <p>ii) <i>Storage Inventory Range, Method and Frequency of Recovery/Disposal</i></p>	
<p>19. CONTAINERS, PACKAGING AND STORAGE AREA DESCRIPTIONS</p>	<p>SEPARATE NOTE TO BE ATTACHED describing for feeds, products and wastes the type and size of containers & packaging used; method of storage; any special identification features</p>
<p>20. RECYCLE PROCESSES (briefly describe any such processes giving source and form of material, method of storage, normal inventory, frequency of processing)</p>	
<p>21. MEASURED DISCARDS AND RETAINED WASTE</p> <p>i) <i>As % of input</i></p>	

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL DESCRIPTION AND FLOW	
<p>22. INVENTORY</p> <p>i) <i>In-Process</i> (within plant and equipment during normal operation; indicate quantity, form and main locations and any significant change with time or throughput)</p> <p>ii) <i>Other locations</i> (quantity, form and location of inventory not already specified)</p>	
PLANT MAINTENANCE	
<p>23. MAINTENANCE, DECONTAMINATION, CLEAN-OUT</p>	<p>SEPARATE NOTE TO BE ATTACHED describing plans and procedures and defining all sampling and key measurement points associated with:</p> <p>i) normal plant maintenance</p> <p>ii) plant and equipment decontamination and subsequent nuclear material recovery;</p> <p>iii) plant and equipment clean-out.</p>
PROTECTION AND SAFETY MEASURES	
<p>24. BASIC MEASURES FOR PHYSICAL PROTECTION OF NUCLEAR MATERIAL</p>	
<p>25. SPECIFIC HEALTH AND SAFETY RULES FOR INSPECTOR COMPLIANCE (if extensive, attach separately)</p>	

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
<p>26. SYSTEM DESCRIPTION <i>Give a description of the nuclear material accountancy system, the method of recording and reporting accountancy data and establishing material balances, frequency of material balances, procedures for account adjustment after plant inventory, mistakes, etc., under the following headings.</i></p> <p>i) General</p>	<p>SPECIMEN FORMS USED IN ALL PROCEDURES ATTACHED UNDER REF. NO.</p>

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
<p>SYSTEM DESCRIPTION CONTINUED</p> <p>ii) Receipts (including method of dealing with shipper/ receiver differences and subsequent account corrections)</p>	
<p>iii) Shipments (product and waste)</p>	

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
SYSTEM DESCRIPTION CONTINUED iv) Physical Inventory (frequency, procedures, estimated distribution)	LIST OF MAJOR ITEMS OF EQUIPMENT REGARDED AS NUCLEAR MATERIAL CONTAINERS ATTACHED UNDER REF. NO.
vi) Measured Discards and Retained Waste	
vi) Operational Records and Accounts (including method of adjustment or correction and place of preservation and language)	

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
vii) Calculative and Error Propagation Technique	
viii) Technique and Frequency of Calibration of Equipment Used	
ix) Programme for the Continuing Appraisal of the Accuracy, Weight, Volume, Sampling and Analytical Techniques and Measurement Methods	
xi) Programme for Statistical Evaluation of Data from (viii) and (ix)	

FILL IN A PAGE 8 AND A PAGE 9 FOR EACH KMP

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
<p>27. FOR EACH KEY MEASUREMENT POINT IDENTIFIED UNDER Q'S 14,23 GIVE THE FOLLOWING:</p> <p>i) Identification</p>	
<p>ii) Chemical and Physical Form of Material</p>	
<p>iii) Sampling Procedures and Equipment Used</p>	
<p>iv) Measurement/Analytical Method and Equipment Used</p>	
<p>v) Source and Level of Random and Systematic Errors (weighing, volume, sampling, analytical)</p>	
<p>vi) Method of Converting Source Data to Batch Data (standard calculative procedures, constants used, empirical relationships, etc.)</p>	

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY	
<p>28. OVERALL LIMIT OF ERROR Describe procedures to combine individual measurement error measurements to obtain the overall limit of error for:</p> <ul style="list-style-type: none">i) S/R Differencesii) Book Inventoryiii) Physical Inventoryiv) MUF	
OPTIONAL INFORMATION	
<p>27. OPTIONAL INFORMATION (that the operator considers relevant to safeguarding the facility)</p>	

Signature of Responsible Officer



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 38: MC&A SYSTEM DESIGN WORKSHOP

The workshop has as its goal the development of a Material Control and Accounting (MC&A) system for a low enriched uranium fuel fabrication plant. The participants will be divided into four groups and will make recommendations on the key elements of the system. Each group will select a rapporteur to present its results.

To assist the participants in their design work, the factors to be considered for each of the ten key elements of the safeguards (MC&A) are presented in the text for the session. A set of worksheets for recording results will also be provided. Each group will also complete a questionnaire which summarizes its results. The workshop text, worksheets, and questionnaire were introduced in the previous session.

Following the workshop (Session 39), the rapporteur for each group will present the MC&A system recommended by his group and the results will be discussed. In addition, an evaluation and comparison of results will be made by the course instructors.

After these sessions, the participants will be able to:

1. construct a MC&A system for a similar type plant, and
2. understand the key features of a MC&A system for any generic plant.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 38: MC&A SYSTEM DESIGN WORKSHOP

R. A. Schneider, Exxon Nuclear and
N. L. Harms, Pacific Northwest Laboratory

I. INTRODUCTION

The purpose of the workshop is to provide the participants with an opportunity to design the main features of the material control and accounting system for a low enriched uranium fuel fabrication plant. The information presented in the previous session for the Reference or Model Plant and for the Preparation of a FNMC Plan and a DIQ is to be used as the basis for the design.

The participants will be divided into four groups with each group independently developing an outline of the key features that they recommend for the material control and accounting system. The outline should address the following main elements of a MC&A system:

- A. Organization;
- B. Material Control Areas;
- C. Measurements;
- D. Measurement Control Program;
- E. Physical Inventory;
- F. Material Accounting System;
- G. Internal Controls;
- H. Management;
- I. Effectiveness; and
- J. Design for IAEA Safeguards.

The students are to prepare a brief outline of the key features of the material control and accounting system that they recommend for each of the above topics. To aid in the preparation of the outline, suggested features to be considered for each of the ten subject areas are discussed next. Worksheets for recording results are provided to each participant. They are also included at the end of this text.

II. SAFEGUARDS SYSTEM DESIGN TOPICS

A. Organization

1. Show location in organization of the custodial, accounting, auditing and measuring functions. Some of those functions should be in different organizational components.

2. Give minimum qualifications for key safeguards positions.

- a. Manager, Analytical Laboratories
- b. Nuclear Materials Accountant
- c. Safeguards Specialist
- d. Measurement Control Program Coordinator
- e. Accountability Coordinator

3. Describe the Company Safeguards Policy you would recommend for complying with National and International Safeguards requirements.

Reference pages 3-10 of text for Session 37b, "Preparation of a Fundamental Nuclear Material Control Plan".

B. Material Control Areas

1. Show the division of the plant site into material control zones to facilitate local control if such localization is deemed important. Show mass balance areas as MBA's and item control areas as ICA's.
2. Give your reasons for dividing the site into several or more material control areas and the rationale for selecting the particular arrangement chosen.

Reference pages 4, 7 and 11 of text for Session 37b, "Preparation of a Fundamental Material Control Plan".

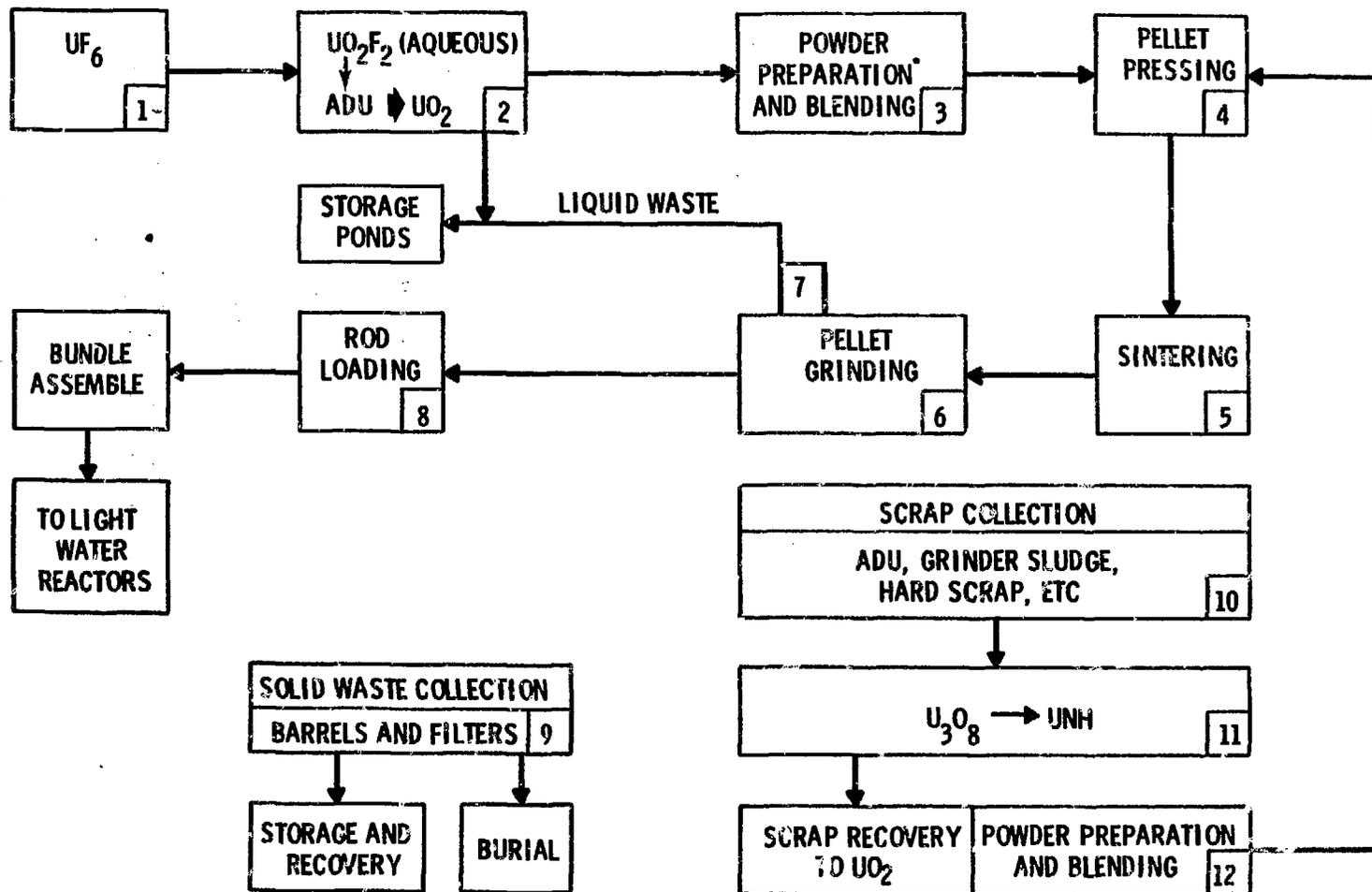
C. Measurements

1. Identify on a process flow diagram or plant site layout each key measurement point. Use Figure 1 and/or Figure 2 of this text for a layout sketch.
2. Describe briefly the materials present and measurements made at each point.
3. Describe briefly each measurement; e.g., volume, analytical, sampling, weighing, and NDA.

Reference see text for Session 37a, "Description of Reference (Model) Plant", pages 3-16.

4. Give the expected random and systematic error for each measurement method selected for use. Note the group may choose other measurement methods than the ones listed in the Reference (Model) Plant.

PROCESS FLOW DIAGRAM FOR MODEL PLANT



38-3

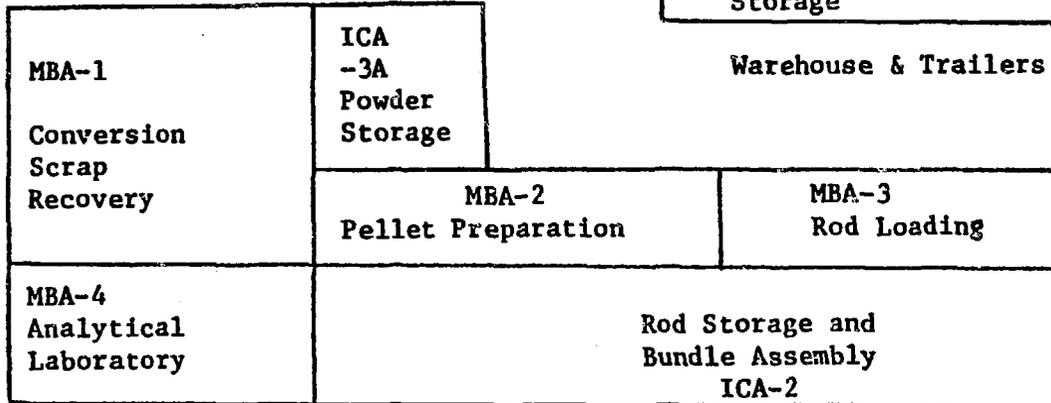
□ KEY MEASUREMENT POINTS

FIGURE 1. Process Flow Diagram for Model Plant

ICA-1
Shipping-Receiving

ICA-3K
Waste
Barrel
Storage

ICA-3B-H
Storage



UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

PHYSICAL COUNT LOCATIONS

FIGURE 2. Model Plant Material Control Areas

The group should state its reasons for selecting other measurements methods; e.g., more accurate or more cost-effective.

D. Measurement Control Program

1. Describe the type of standard that you recommend for each measurement method.
2. Describe in shorthand form the calibration approaches you recommend for those measurement methods that you believe require calibration and the frequency of recalibration.
3. State the frequency you recommend for recertifying standard weights.
4. Describe those aspects of the Measurement Control Program which you believe should involve statistical applications.
5. Describe the type of records and reports that you believe the Measurement Control Program should generate.

Reference see text of Session 28, "Measurement Control Program".

E. Physical Inventory

1. Describe in shorthand form your recommended procedure for taking the physical inventory and the recommended frequency for taking physical inventories.
2. Consider your material control area and measurement approaches in preparing your physical inventory approach.
3. Use Table I (next) to assist you in deciding the key features of your recommended inventory taking procedure.

F. Material Accounting System

1. Describe in shorthand form the accounting system you recommend for use.
2. Use Table II to assist you in deciding those features which you wish to include in your recommended system.

G. Internal controls

1. Describe in shorthand form the internal controls you recommend for the material control and accounting system.

TABLE I
PHYSICAL INVENTORY TOPICS

<u>Discussion Topic</u>	<u>Example</u>
1. Basic Approach	1. Cleanout inventory, all material converted to measured items.
2. Schedule	2. Physical inventory every six months.
3. Organization	3. Two party teams of accounting and custodial personnel.
4. Procedures	4. Written inventory procedures prepared & discussed in advance.
5. Source Data	5. Described in written procedures.
6. Form Control	6. Physical count sheets controlled by two party teams.
7. Typical Inventory Composition	7. A table of typical inventories is given in Table V.
8. Prelisting of Inventory	8. ICA listings, rod printout prior to inventory.
9. Cut-off Procedures	9. Written instructions for each area.

TABLE I (Continued)PHYSICAL INVENTORY TOPICS

<u>Discussion Topic</u>	<u>Example</u>
10. Special Processing	10. Written cleanout and equipment shutdown schedule.
11. Inventory Reduction	11. Not applicable.
12. Current Measurements	12. All materials present as measureable or pre-measured items.
13. Item Inventories	13. Written inventory instructions including reconcillation of ICA's and MBA's.
14. Prior Measurements	14. Only tamper-safed items accepted on basis of prior measurement.
15. Use of Factors	15. Use of element and isotopic factor explained in Section 3.1-1.
16. Residual Holdup	16. Estimated holdup in ducts, plenums, and processing equipment is estimated to be less than 20 kilograms of uranium element by visual inspection and previous measurements of material removed by cleaning specific items.

TABLE IIMATERIAL ACCOUNTING TOPICS

<u>Discussion Topic</u>	<u>Example</u>
1. System Description	1. A centralized double-entry computer based bookkeeping system is maintained by the Controller.
2. Account Structure	2. Accounts are: Plant Location - MBA or ICA Material Type - Depleted U - Enriched U - Natural U Project - Reactor Load Enrichment - Each nominal U-235.
3. Accounting Forms	3. NRC/DOE 741 o Receipt-Shipment o Location Transfer o Physical Inventory Recording Form
4. Flow Chart	4. See Table 8 page 33 of Model Plant DIQ, Session 37c.
5. Accounting Procedures	5. The Nuclear Safeguards Procedures Manual MP-3 includes nuclear material accounting procedures.
6. Source Data	6. The data elements for each material transfer (external and internal) and physical inventory are recorded on the form.

TABLE II (Continued)MATERIAL ACCOUNTING TOPICS

<u>Discussion Topic</u>	<u>Example</u>
7. Adjustments to Records	7. Adjustments to records can only be made through a revised document.
8. Bias Adjustment	8. A separate bias account is maintained.
9. Inventory Reconciliation	9. See page 25, DIQ.
10. Account Reconciliation	10. All accounts reconciled to physical inventory. Plant MUF and sum of MBA MUF's reconciled at end of each accounting period.
11. Location and Identify of Records	11. See page 27-28 of DIQ.
12. Electronic Data Processing	12. Computer services are procured from offsite.
13. Record and Reports	13. See page 26 of DIQ and pages 27-28 for retention of records and storage.
14. Audits	14. Internal audits are performed by three groups - President's Committee, Internal Auditor, and Licensing Department.

2. Use Table III to assist you in deciding the main features you wish to include in your internal control system.

H. Management

1. Describe the key topics and performance indices that management should monitor and take action.
2. Use Table IV to assist you in your selection of the key features your group recommends for inclusion in your material control and accounting system.

I. Effectiveness

1. State your estimate of the effectiveness of your recommended systems in the following respects:
 - a. The minimum time in which the loss of a discrete item would be detected;
 - b. The maximum time in which the loss of a discrete item would be detected;
 - c. The extent to which a MUF loss can be localized to a process step or mass balance accounting area and your estimate of how large a loss the system can isolate with a high probability (> 90%); and
 - d. Your approximate estimate of the uranium element sigma MUF (σ_{MUF}) for your measurement system for the plant material balance shown in Table V. Use your own estimates of the random and systematic errors of measurement or those given for the Reference (Model) Plant if they are applicable to your measurement and accountability system. Use whichever of the error propagation techniques that best fits your group; e.g., the one shown on pages 10-18 of the Reference (Model) Plant Description, or presented in Session 30, or shown in the relative error propagation example on page 6 of Session 17a. Report your sigma MUF as a percent of plant input as given in Table V.

J. Design for IAEA Safeguards

1. Describe any features you would design into your material control and accounting system which would facilitate the implementation of IAEA safeguards at your plant. Assume that the IAEA will 1) verify flow and inventory quantities by independent measurement of item selected by random sample plans, 2) conduct records audits, require advance notification of imports and exports, and 3) require the reporting of flows and inventory quantities by batches.

TABLE III
INTERNAL CONTROL TOPICS

<u>Discussion Topic</u>	<u>Example</u>
1. Receiving Procedure	1. See pages 28 and 29 of DIQ.
2. Shipper-Receiver Comparisons	2. See page 29 of DIQ.
3. Acceptance Criteria	3. See page 29 of DIQ.
4. Conditions for Transfer	4. UF ₆ cylinders may be transferred to process after weight measurement and weight verification are complete.
5. Records	5. Shipper-Receiver difference evaluations and shipper-receiver records are kept for five (5) years.
6. Timeliness of Internal Transfers	6. Transfer forms are executed at time of transfer and processed daily.
7. Storage Program	7. All items are covered such as UF ₆ cylinders and heels, UO ₂ powder buckets, boats and trays of pellets, buckets of ADU, dirty powder, and grinder sludge.
8. Identification	8. Each item is uniquely identified. UF ₆ cylinders have unique number identifications. Buckets of powder and scrap items have pre-printed, sequenced numbers attached to the lid and the body. Pellet boats and trays are all pre-numbered. Fuel rods are all uniquely numbered. Each barrel of solid waste is numbered in sequence.

TABLE III (Continued)INTERNAL CONTROL TOPICS

<u>Discussion Topic</u>	<u>Example</u>
9. Quantity Determination	9. Each item measured by procedures described in DIQ pages 31-38.
10. Tamper-Safing Program	10. See page 40 of Model or Reference Plant used for Session 37a.
11. Scrap and Waste Control	
a. Location	a. Scrap generated in all processing areas is collected on a current basis, converted to U_3O_8 , dissolved and recovered as prepared UO_2 for pressing.
b. Processing and Storage	b. Typical scrap inventories are shown on Table V. Scrap generated and recovered at rate of 15 percent of main product flow. Solid wastes, barrels and filters measured and stored on site for later recovery.
c. Measurement	c. Waste measurements are described on page 516 of Session 37a. At inventory time about 400 kilograms of ADU will be present with a total (2 sigma) limit of error of about 25.2 kilograms of uranium or about 6.3%.

(1) Shipping and Receiving Custodians both sign transfer form.

TABLE IV
MANAGEMENT TOPICS

<u>Discussion Topic</u>	<u>Example</u>
1. Procedures	1. The authorship and approval responsibilities for each procedure that appears in this manual are given in the safeguards manual.
2. Management Review	2a. Management review is conducted annually by the President's Safeguards Committee.
b. Report	b. The management review is reported to the President and copies retained for 5 years.
c. Action	c. The President reviews the report, extracts action, and sends that information to responsible individuals for action.
3. Measurement Controls	3. The Manager of Licensing is responsible for reviewing measurement data to assure the measurement performance remains within limits. If an out-of-control situation is detected he is responsible for initiating action and assuring that the problem is resolved.

TABLE IV (continued)MANAGEMENT TOPICS

<u>Discussion Topic</u>	<u>Example</u>
4. Shipper-Differences	4. The Manager of Licensing is responsible for the evaluation of shipper-receiver differences. When a significant difference is detected this is brought to the attention of the affected MBA and ICA custodians plus others who generated the data used in the SRD analysis. The Manager of Licensing conducts an investigation to reconcile the significant SRD and recommends appropriate action to reduce the probability of future occurrences of significant SRD's. If the nature of the SRD provides evidence of a diversion, e.g., if a container is missing, the Manager of Licensing shall promptly notify the Region V Walnut Creek Office of the NRC.
5. Material Balance Discrepancies	5. The Manager of Licensing is responsible for the MUF and LEMUF evaluation. When the MUF exceeds its approved limits, he is responsible for reporting this to the NRC and to the affected custodians and for conducting an investigation into the cause of the excessive MUF. He has the authority to require that another inventory be taken if necessary. Results of his investigation plus corrective action are reported by him to the Company President, to the NRC and to affected plant personnel.

TABLE IV (continued)MANAGEMENT TOPICS

<u>Discussion Topic</u>	<u>Example</u>
6. Item Discrepancies	6. An apparent loss of a discrete item or container of SNM that cannot be resolved by an immediate investigation is reported to the Manager of Licensing who promptly notifies NRC in accordance with the requirements of 10 CFR 70.52 and conducts an investigation of the apparent loss. The results of the investigation are reported to the Company President and to the Region V Walnut Creek Office of the NRC.

TABLE V
SIX MONTH URANIUM MATERIAL BALANCE
MODEL FOR EXAMPLE PLANT

<u>Material Balance Component</u>	<u>Percent Uranium</u>	<u>Number of Items</u>	<u>Kgs. U per Item</u>	<u>Total per Typ</u>
<u>Additions</u>				
UF ₆	67.60	84	1,400	117,600
<u>Removals</u>				
Rods (UO ₂ pellets)	88.10	46,800	2.5	117,000
Waste Barrels	--	470	0.4	188
Filters	--	240	0.2	48
Liquid Wastes	50 ppm	176 (21)	2.0	352
UF ₆ Heels	67.60	84	2.0	168
<u>Inventory (a)</u>				
Green Powder	87.6	300	17	5,100
Green Pellets	87.6	20	18	360
Sintered Pellets (on trays)	88.10	1,000	6	6,000
Sintered Pellets (in boats)	88.10	20	18	4,250
U ₃ O ₈ Powder	84.5	250	17	4,250
Hard Scrap	88.10	40	21	840
ADU	60.0	40	10	400
Grinder Sludge	80.0	20	12	240
Dirty Powder	86.0	20	17	340

(a) Quantities present for both beginning and ending inventory.

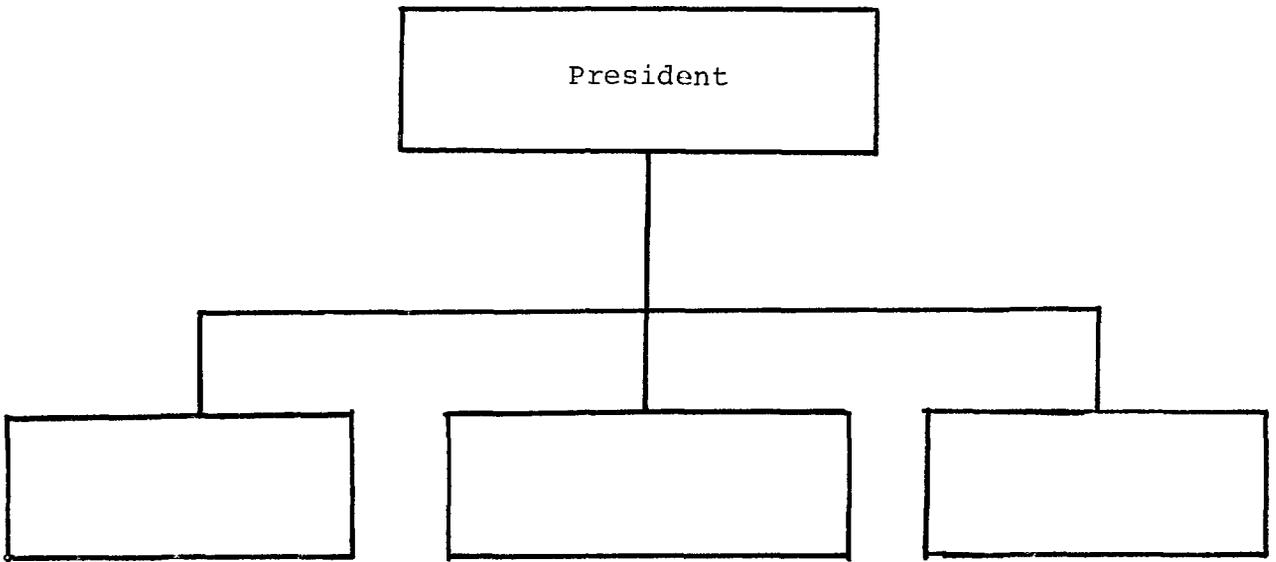
2. Describe any special structural, process, or measurement features that you would include in the design of new LEU fuel fabrication plant to facilitate IAEA safeguards.
3. Describe (or list) the key factors that you consider in developing with your IAEA inspectors plans for physical inventory verification. Assume that the inspectors are going to apply fractional (random) sampling plans to test your statements regarding 1) the total number of items in a stratum and 2) the content of individual items. Assume that your overall goal is to provide the following:
 - a. An accurate physical inventory for plant accounting purposes;
 - b. conditions which meet IAEA requirements for effectiveness, e.g., randomness; and
 - c. Procedures and schedules which minimize or eliminate lost production time.

38-18

COURSE WORKSHEETS

WORKSHEET A

1. Complete the organization chart.



WORKSHEET A (Continued)

2) Minimum Qualifications

- a. Manager, Analytical Laboratories:
- b. Nuclear Materials Accountant:
- c. Safeguards Specialist:
- d. Measurement Control Program Coordinator:
- e. Accountability Coordinator:

3) Company Safeguards Policy

WORKSHEET B: MATERIAL CONTROL AREAS

SOLAR EVAPORATION PONDS
MBA-1

Shipping-Receiving

Waste
Barrel
Storage

Storage

Warehouse & Trailers

Powder
Storage

Conversion
Scrap
Recovery

Pellet Preparation

Rod Loading

Rod Storage and
Bundle Assembly

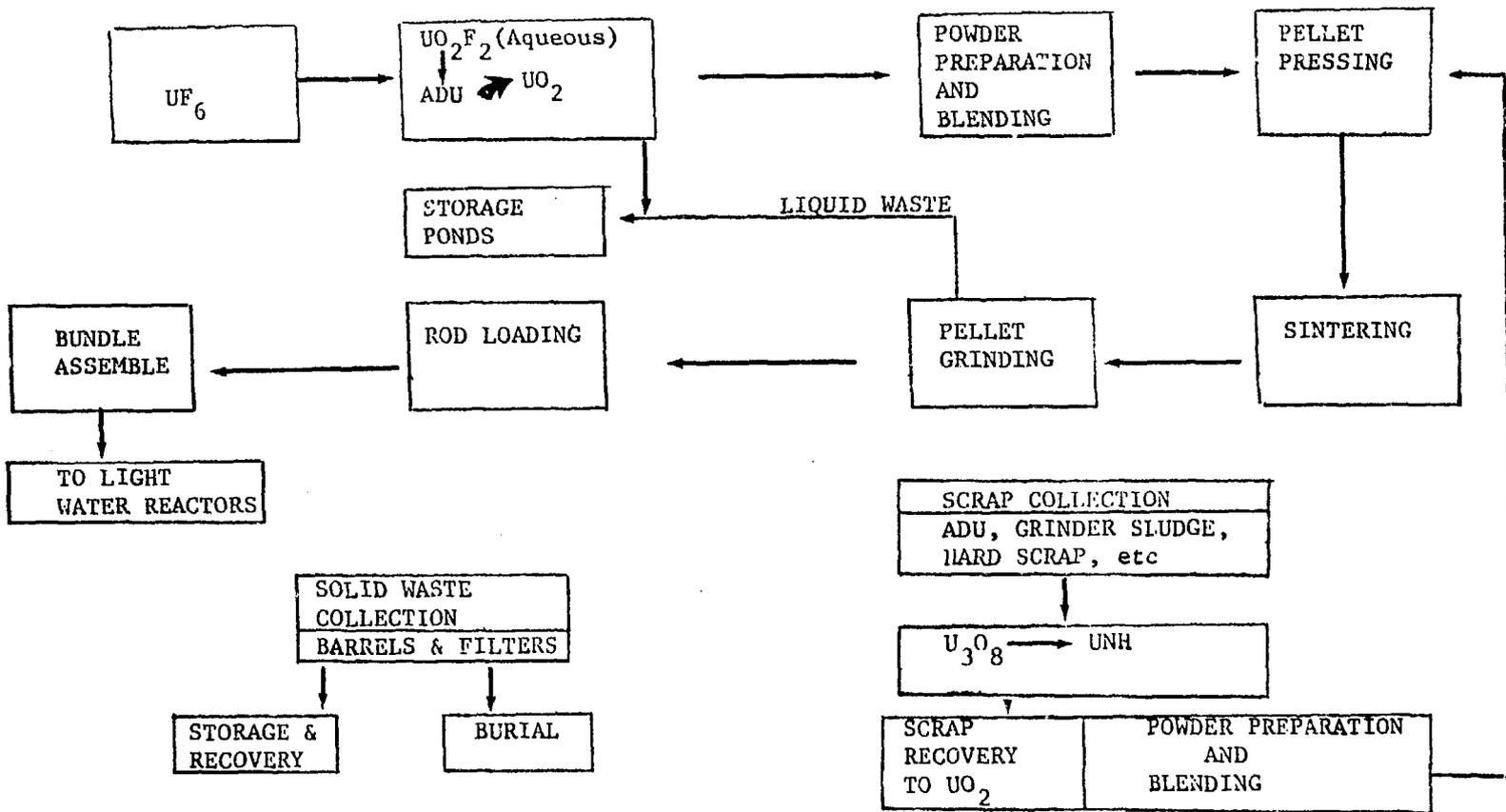
Analytical
Laboratory

UO₂ PLANT

Shipping-Receiving

WAREHOUSE

WORKSHEET B: MATERIAL CONTROL AREAS



WORKSHEET C

38-22

PROCESS FLOW DIAGRAM FOR MODEL PLANT

WORKSHEET C

WORKSHEET D: MEASUREMENT CONTROL PROGRAM

1. Standards

Recertification

a)

b)

c)

2. Calibration Approaches

a)

b)

c)

WORKSHEET E: PHYSICAL INVENTORY

List and describe important features of a physical inventory.
(See pages 6-7 of this text.)

WORKSHEET F: MATERIAL ACCOUNTING SYSTEM

List and describe important features of the material accounting system.
(See pages 8-9 of this text.)

WORKSHEET G: INTERNAL CONTROLS

List and describe internal plant controls important to the safeguards program. (See pages 11-12 of this text.)

WORKSHEET H: MANAGEMENT

Outline authority and responsibility of management positions related to safeguards and describe management reviews. (See pages 13-15 of this text.)

WORKSHEET I: EFFECTIVENESS

Estimate the effectiveness of your recommended system(s) in terms of timeliness, localization, and quantity of uranium. (See page 10 of this text.)

WORKSHEET J: DESIGN FOR IAEA SAFEGUARDS

Describe features of your MC&A system that will facilitate IAEA safeguards. Consider verification activities and reporting requirements. (See page 17 of this text.)



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 39: REPORTS OF MC&A SYSTEM DESIGN WORKSHOP SUBGROUPS

A member of each subgroup will present a brief report on safeguards system design characteristics recommended by each subgroup. The results will be discussed at this plenary session by the participants and course instructors. The course instructors will then present the design features which they recommend for the safeguards MC&A system and compare their results with those of the students.



Subgroup I



Subgroup II



Subgroup III



Subgroup IV



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
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October 17-November 4, 1983

SESSION 39: REPORTS OF MC&A SYSTEM
DESIGN WORKSHOP SUBGROUPS

Compiled by C. R. Hatcher

Participants were divided into four subgroups for the MC&A workshop, as indicated in Table I. Subgroup members were selected to provide a balance of experience in nuclear technology, management, public speaking, and safeguards at the state and facility levels. Each of the subgroups were assigned an advisor who stayed with the subgroup throughout the workshop. It was suggested that each subgroup choose a rapporteur, work through the instructions in Session 38, and answer the MC&A System Design Questionnaire, included as Appendix I.

TABLE I
SUBGROUP ASSIGNMENTS FOR MC&A SYSTEM DESIGN WORKSHOP

<u>Subgroup 1</u>	<u>Subgroup 2</u>	<u>Subgroup 3</u>	<u>Subgroup 4</u>
A. Bin Ali	K. Awal*	S. Ahmed	A. Abou-Zahra
S. Bezak	E. Bantog	B. Beaudin*	G. Dahlin
N. Harms+	A. Hakkila+	Y. Chu	S. Gandikota
J. Hill*	S. Johnson	A. El-Wafi	M. Marzo*
A. Jimenez	J. Kwan	E. Melo	M. Schnaible+
J. Lee	J. Maritz	A. Nabi	P. Roceles
N. Lee	A. Ramakrishna	P. Suksawang	R. Zarucki
M. Qureshi	I. Siemasko	W. Theis+	

+ Advisors

* Rapporteurs

The subgroups met for approximately 2-1/2 hours on November 2, and for 8 hours on November 3, 1983. The final day of the course (November 4) began with each rapporteur presenting the MC&A system design that was developed by their subgroup. After the presentations by rapporteurs, Neil Harms summarized the responses to the MC&A Design Questionnaire. The responses are noted in parenthesis in Appendix I, with numbers "1, 2, 3, and 4" corresponding to the four subgroup responses, and "A" corresponding to the response of a fifth subgroup composed of the workshop advisors, including course coordinator, Dick Schneider. Harms pointed out that the main purpose of the MC&A System Design Questionnaire was to provide a quantitative comparison between approaches taken by the subgroups. He also indicated that the responses to the questionnaire given by the

workshop advisors are not necessarily the "correct" answers because there are a variety of possible approaches that will lead to a good MC&A system design.

APPENDIX I

MC&A SYSTEM DESIGN QUESTIONNAIRE

Please select the condition(s) that best represent the findings of your subgroup. Indicate your answer(s) by circling the appropriate letter or number.

I. SAFEGUARDS ORGANIZATION AND MANAGEMENT

Your organization chart describes a management structure that

- (1,2,4,A)*A. Indicates independence of the MC&A organization from the production oriented organizations.
- B. Makes no separation between production and MC&A organizations in the management structure, although opportunities for frequent communication exist between the two components to resolve differences that may arise from conflicting goals.
- (2,3,)C. Identifies the organizational relationships of staff who perform key MC&A functions, and summarizes the essential MC&A procedures including review and management approval.

II. MATERIAL CONTROL AND ACCOUNTING SYSTEM

The facility material control is structured in

- (A)A. A single MBA for the entire facility.
- (3)B. Three MBAs to account for feed, in-progress and product material.
- (1,2,4)C. Multiple MCAs that parallel operating control units.
- D. Other (describe).

III. MEASUREMENTS

The preferred method for analysis of low-level liquid waste is

- | | | |
|-------------|-----------------------|--------------------|
| (1,2,3,4,A) | A. Fluorometric | D. Non-destructive |
| | B. Gravimetric | assay |
| | C. Spectrophotometric | E. Titrimetric |

**Numbers in parenthesis indicate a preference for a particular response by subgroup 1, 2, 3, or 4. An "A" in parenthesis indicates a preference for a response by the workshop advisors. Occasionally, a subgroup would express more than one preference.*

The preferred method for analysis of UO_2 powder is

- | | | |
|---|-------------|----------------|
| A. Nondestructive assay | (1,2,3,4,A) | D. Gravimetric |
| B. Weighing and appli-
cation of factors | | E. Titrimetric |
| C. Spectrometric | | |

IV. MEASUREMENT CONTROL PROGRAM

A. The preferred frequency of measuring the following types of standards is as follows:

1. Standard weights (≥ 1 kg):

- | | | |
|---|--|--|
| (1,3,A)a. once/shift | | e. when IAEA in-
specter verifies
measurements |
| (4)b. once/day | | |
| c. once/3 days | | (2)f. once/18 months |
| d. a minimum of 15
measurements/material
balance period | | |

2. Chemical standards for U (e.g. NBS U_3O_8 standards):

- | | | |
|------------------|-----------|---|
| a. once/analysis | (1,2,4,A) | e. twice/week |
| (3)b. once/shift | | f. a minimum of 15
measurements/
material bal-
ance period |
| (1)c. once/day | | |
| d. once/week | | |

3. Mass spectrometer standards:

- | | | |
|------------------------|-----|--|
| a. once/analysis | (4) | e. twice/week |
| b. once/4 analyses | | f. a minimum of 15
measurements/ma-
terial balance
period |
| (1,2,3,A)c. once/shift | | |
| d. once/day | | |

B. The preferred frequency of analysis of replicate process samples is as follows:

- | | | |
|--|-----------|--------------------|
| (2)a. once/shift | | e. every fifth lot |
| b. once/day | (1,3,4,A) | f. 5/lot |
| c. once/3 days | | |
| d. based on a minimum of 15
measurements/material
balance period | | |

C. Traceability of standards can be shown to:

- (1, 3, A) 1. National measurement systems.
 (1, 2, 3, 4, A) 2. U.S. National Bureau of Standards (NBS).
 3. Working (secondary) standards prepared from production materials.
 4. Euratom standards laboratory (Geel, Belgium).

V. PHYSICAL INVENTORY

A. Physical inventory procedures for the facility include the following:

- (1, 2, 3, 4, A) 1. Indication of adequate cleanout.
 (1, 2, 3, A) 2. Confirmation that all material has been converted to measurable items.
 (1, 2, 4, A) 3. Methods to confirm item identities.
 (1, 2, 3, 4, A) 4. Remeasurement of unsealed items.
 (1, 2, 4, A) 5. Accessibility to verify items in storage.
 (1, 3) 6. Listing which materials are directly measured and which are based on or derived from other measurements.
 (1, 4, A) 7. How the book inventory is reconciled and adjusted to the physical inventory.
 (1, 2, 3, 4, A) 8. Estimation of σ MUF and Σ MUF.

B. Which of the following values of plant MUF would prompt an investigation at your facility? Assume a 6-month material balance period.

- | | |
|------------------------------------|------------------------|
| 1. 0.1% of throughput | 5. 100 Kg. U |
| (1) 2. 0.3% of throughput | (2, A) 6. 400 Kg. U |
| (2, 3, 4, A) 3. 0.5% of throughput | (2, A) 7. 12 Kg. U-235 |
| 4. 10 Kg U | (2, 3) 8. 75 Kg. U-235 |

C. The preferred frequency of physical inventory taking and verification is:

- | <u>Taking</u> | <u>Verification</u> |
|----------------------------|------------------------|
| 1. once/year | (2, 4, A) 1. once/year |
| (1, 2, 3, 4) 2. twice/year | (1, 3) 2. twice/year |
| (3) 3. every three months | 3. every three months |

VI. SAFEGUARDS EFFECTIVENESS

A. The maximum time to detect the loss of a 5 gal. bucket of UO₂, serial no. 3250, from the long-term storage would be:

- | | |
|--------------|-------------------------------|
| 1. one week | (1, 2, 3, 4, A) 3. six months |
| 2. one month | 4. never |

B. Same as (A) above, only from the in-process area:

- | | |
|--------------------|------------------|
| (1,3,A) 1. one day | (A) 3. one month |
| (2) 2. one week | (4) 4. never |

C. Select the quantity of MUF that your system could detect in each of the following material balance or item control areas.

1. Conversion/scrap recovery
- | | | |
|----------------------|-------------------|------------------|
| (1,3,A) a. 100 Kg. U | (4,A) b. 300 Kg U | (2) c. 800 Kg. U |
|----------------------|-------------------|------------------|

2. Pellet Preparation
- | | | |
|------------------------|----------------------|------------------|
| (1,2,3,A) a. 100 Kg. U | (2,4,A) b. 300 Kg. U | (2) c. 500 Kg. U |
|------------------------|----------------------|------------------|

3. Shipping and receiving
- | | | |
|------------------|---------------------|--------------|
| (3) a. 100 Kg. U | (1,2,4,A) b. 1 item | c. 500 Kg. U |
|------------------|---------------------|--------------|

VII. DESIGN OF IAEA SAFEGUARDS SYSTEM

Select the appropriate topics addressed in your facility plan that satisfy IAEA safeguards system design, inspection and reporting guidelines.

- (1,2,4) A. Conformance with Part F (Statistics) of the Safeguards Technical Manual (IAEA-174).
- (4) B. Physical protection plan.
- (1,2,4) C. Containment and surveillance procedures.
- (1,2,3,A) D. Design information questionnaire (DIQ) completed by facility.
- E. The use of cost free experts for procedure development.
- (2,3,4) F. International training courses on State System of Accounting for and Control of Nuclear Materials.
- (1,2,3,4) G. Adherence to INFCIRC/153.
- (1,3,4,A) H. Written procedures for taking a physical inventory.
- (2,4) I. Method for comparing analytical results of the facility and the IAEA.
- (1) J. Cost effectiveness of IAEA inspections.
- (1,2,3,A) K. A safeguards approach that follows IAEA detection goal quantity guidelines.
- (1,3,A) L. Procedures that permit accurate estimation of holdup of nuclear material.
- (1,2,3,4,A) M. Maintaining facility accounting records.
- (1,2,3,4,A) N. Reporting material transfers to the IAEA through the SSAC.

III. POLICY

Your "company's" policy is to:

- (1) A. Do the minimum required by national law--adopting a strictly legalistic approach.

- (3,4) B. Perform in a cooperative, but passive approach; complying with the regulations, but taking no leadership role in safeguards.
- (2,A) C. Take the initiative by assuming a positive, cooperative leadership role as well as meeting the regulatory requirements.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

Session Objectives

SESSION 40: COURSE EVALUATION, DISCUSSION, AND WRAP-UP

In the final session, attendees will be asked to complete a detailed course evaluation form that provides feedback on the effectiveness and value of the overall course, evaluation of individual sessions, and suggestions for improving follow-on courses. Time will be allocated for general discussion of questions and comments from course attendees. Provision will also be made for informal discussions, individual consultation, and follow-up on special problems, as appropriate, between individual attendees, course staff, and technical specialists from the Los Alamos and Richland areas.

The Course will conclude with a summary and closing remarks by Course sponsors and participating organizations.



INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION
OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS



October 17-November 4, 1983

SESSION 40: COURSE EVALUATION,
DISCUSSION, AND WRAP-UP

Compiled by C. R. Hatcher
and Linda Robinson

Evaluation forms were completed by 26 of the 28 1983 SSAC course participants. Both numerical responses and written comments are summarized on the evaluation form included at the end of this document. Numerical responses show an upward trend for the SSAC courses offered in the U.S. in 1981, 1982, and 1983, as indicated in Table I. This trend may be explained by evolutionary changes in the SSAC courses, made in response to the evaluation of previous courses.

TABLE I
SUMMARY OF PREVIOUS SSAC COURSE EVALUATIONS

	% of Maximum Possible Score		
	<u>1981</u>	<u>1982</u>	<u>1983</u>
A. Overall Course Content	78	81	82
B. Technical Level/Content	73	78	81
C. Course Organization, Format	74	85	89
D. Facilities and Accommodations	83	90	89
E. Workshop and Panel Discussion	NA	NA	78
F. NDA Demonstration at Los Alamos	72	80	88
G. Off-Site Tour and Demonstrations	72	72	82
H. MC&A System Design Workshop	74	74	83
I. Communication and Understanding	77	81	86
J. Course Applicability, Usefulness	78	78	77

Following completion of evaluation forms, a discussion was held at the end of the final session concerning suggestions for improving future SSAC courses. The following points were made:

1. Participants from countries with small nuclear programs want more information about safeguarding reactor facilities than was offered in the 1983 course, which emphasized LEU fuel fabrication plants. They suggest that a course with primary emphasis on item facility safeguards and secondary emphasis on bulk facility safeguards should be offered essentially every year.
2. Some participants were confused by the organization of the model plant into mass balance areas (MBAs) and item control areas (ICAs). They felt that greater care should be taken in explaining (or avoiding) differences between safeguards terminology used in the U.S. and at the IAEA.

3. Participants indicated that the lectures on statistics were too theoretical. Most students would prefer to have statistics treated on a lower technical level and in a way that involves more examples.
4. A few participants suggested that more time be devoted to NDA measurements. Some would like to have several hours to perform measurements with a single instrument of particular interest.
5. A few participants would like more information included on technical approaches used in physical protection. One additional lecture on physical protection was suggested.
6. Participants felt that some of the introductory lectures during the first week of the course could be shortened or possibly eliminated.
7. Participants felt that it was a mistake, during the latter part of the course, to schedule sessions of two hours duration without a break.
8. Participants indicated that the tour of the WPPS reactor control room simulator was of questionable value.



At the end of the final session, suggestions were made for improving future SSAC courses.

SUMMARY OF PARTICIPANT RESPONSES

INTERNATIONAL TRAINING COURSE ON IMPLEMENTATION OF STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS

October 17 - November 4, 1983

Santa Fe/Los Alamos, New Mexico and Richland, Washington

TRAINING COURSE EVALUATION
PARTICIPANTS' COMMENT AND CRITIQUE FORM

Your response to the following questions will help us identify the strengths and weaknesses of this year's International Training Course on Implementation of State Systems of Accounting for and Control of Nuclear Materials. The results will be evaluated and factored into the design of subsequent courses. Your assistance in this evaluation is greatly appreciated.

INSTRUCTIONS: Please circle the number that indicates your response to each question.

	EVALUATION				
	Very Low	Low	Aver- age	High	Very High
A. OVERALL COURSE CONTENT 82%*					
1. Degree to which course met stated objectives	1	2	3(1)	4 (16)	5 (9)+
2. Degree to which course met your needs	1	2	3(9)	4 (14)	5 (3)
3. Your satisfaction with course emphasis	1	2	3(2)	4 (16)	5 (3)

What changes would you suggest in overall course content? None (7). Cover both item and bulk facility safeguards in one course (3). More on measurements (2). More on reprocessing plant safeguards (1). More workshops (1). Add another lecture on physical protection (1). Maybe a bit long (1). Ax lectures on physical protection and power reactor safeguards (1).

B. TECHNICAL LEVEL/CONTENT 81%

1. Degree to which technical level of material met your needs	1	2	3(4)	4 (13)	5 (8)
2. Your understanding of technical presentations	1	2	3(6)	4 (15)	5 (4)
3. Estimated practical value of technical presentations	1	2	3(5)	4 (15)	5 (5)

Should the course have greater technical content? If so, in what areas? No (?). NDA (3). More time on statistics (1). More time or less detail on statistics (1). More on assessment of MC&A effectiveness at facility level (1). Add case study of another fuel fabrication plant (1). More on power reactor safeguards (1).

* Per cent of maximum possible score.

+ Numbers in parenthesis indicate the number of course participants who gave a particular response.

C. COURSE ORGANIZATION, FORMAT, AND SCHEDULE 89%

1. Your satisfaction with course format and schedule	1	2	3 (1)	4 (9)	5 (16)
2. Satisfaction with amount of discussion allowed after lectures	1	2	3 (1)	4 (15)	5 (10)
3. Satisfaction with planning for free time and independent study	1	2	3 (3)	4 (10)	5 (13)

What changes in course schedule and organization would you recommend? None (8). Limit lectures to one hour (2). Schedule too tight (1). Start course at 9 a.m. (1). Avoid repetition between lecturers (1). Hold small group or panel discussions after each lecture (1). Course should be one month in duration (1).

D. FACILITIES AND ACCOMMODATIONS 89%

1. General helpfulness/cooperation of course staff	1	2	3	4 (5)	5 (21)
2. Satisfaction with planned social activities	1	2	3 (2)	4 (7)	5 (17)
3. Satisfaction with Santa Fe Hilton hotel accommodations, personnel, services, etc.	1	2	3 (7)	4 (12)	5 (7)
4. Satisfaction with Rivershore hotel accommodations, personnel, services, etc.	1	2	3 (1)	4 (12)	5 (13)

Explanation/Comments: Course staff superb (3). Rivershore too far from center of town (2). Social activities well planned (1). Suggest weekend picnic (1). Santa Fe Hilton too expensive (1). Santa Fe atmosphere too dry (1). Enjoyed Rivershore (1). Driver not available at Rivershore morning of Saturday, October 29 (1).

E. WORKSHOP AND PANEL DISCUSSION ON OCTOBER 19, 1983 78%

1. Value of presentations by course attendees	1	2	3 (8)	4 (16)	5 (2)
2. Value of subgroup discussion prior to panel	1	2	3 (4)	4 (18)	5 (4)
3. Value of panel discussion	1	2 (1)	3 (5)	4 (15)	5 (7)

Explanation/Comments: Presentations by attendees of value (3). Subgroup discussions rewarding (2). More time needed for subgroup discussions (1). Panel discussion useful to my work (1). Little discussion between panel members; questions answered were matters of fact (1). Too political (1). Increase length and frequency of workshops (1). Schedule another at conclusion of course (1).

F. SAFEGUARDS EQUIPMENT TOURS AND DEMONSTRATIONS AT LOS ALAMOS, NM 88%

- | | | | | | |
|--|---|---|-------|--------|--------|
| 1. Value to you of hands-on equipment demonstration | 1 | 2 | 3 (2) | 4 (8) | 5 (16) |
| 2. Value of NDA workshop on second day at Los Alamos | 1 | 2 | 3 (5) | 4 (10) | 5 (11) |
| 3. Value of dialogue with Los Alamos technical staff | 1 | 2 | 3 | 4 (15) | 5 (10) |

Explanation/Comments: Tours were of significant value (7). Need more time (4). Los Alamos staff helpful (3). First time I have used such equipment (2). Tours more effective than lectures (1). Would like NDA training courses on video tape (1).

G. TOURS AND DEMONSTRATIONS IN RICHLAND, WA 82%

- | | | | | | |
|--|---|-------|-------|--------|--------|
| 1. Value of first Exxon plant tour and process demonstration | 1 | 2 | 3 (5) | 4 (7) | 5 (13) |
| 2. Value of second Exxon plant tour and demonstration of measurement methods | 1 | 2 (1) | 3 (1) | 4 (7) | 5 (15) |
| 3. Value of tour of Battelle NDA equipment van | 1 | 2 (3) | 3 (8) | 4 (8) | 5 (6) |
| 4. Value of tour of WNP reactor and FFTF visitor center | 1 | 2 (1) | 3 (8) | 4 (10) | 5 (6) |

Explanation/Comments: All Richland tours worthwhile (5). Exxon tours too short (4). Exxon tours valuable (3). Tour groups at Exxon too large (2). Exxon tour guide not sufficiently conversant with plant (1). Not much gained by tour of Battelle van (1). WNP reactor interesting, but WNP simulator not (1).

H. MC&A SYSTEM DESIGN WORKSHOP ON NOVEMBER 3-4, 1983 83%

- | | | | | | |
|---|---|-------|-------|--------|--------|
| 1. Overall effectiveness of workshop--methods and results | 1 | 2 | 3 (3) | 4 (12) | 5 (10) |
| 2. Estimated value of workshop to you professionally | 1 | 2 | 3 (5) | 4 (13) | 5 (6) |
| 3. Satisfaction with discussion of workshop results | 1 | 2 (1) | 3 (4) | 4 (11) | 5 (9) |

What changes, if any, in the workshop would you suggest? Time too short (5). Divide workshop into two parts (4). No change (3). Valuable exercise (3). Too much material in too short a time (1). A recapitulation of everything in the course (1). Made us think (1). A chance to evaluate what this course contributed to one's knowledge (1). Group discussions useful, but presentations were a mindless recitation of what one heard a few days previously; problems for discussion should be carefully chosen so that participants must use what they have learned, but also make original input (1).

I. COMMUNICATION AND UNDERSTANDING 86%

1. Your understanding of spoken language during course	1	2	3 (5)	4 (11)	5 (8)
2. Effectiveness of communication between instructors and attendees	1	2	3 (2)	4 (13)	5 (10)
3. How well your questions about course material were answered	1	2	3 (3)	4 (14)	5 (8)
4. Usefulness of visual aids in aiding your understanding	1	2	3 (2)	4 (9)	5 (13)

How could we improve communication between instructors and attendees? Communication was excellent (4).
Encourage some lecturers to speak more slowly and clearly (3).

J. COURSE APPLICABILITY, USEFULNESS 77%

1. Applicability of course material to your work	1	2 (1)	3 (6)	4 (11)	5 (8)
2. Applicability to your nation's safeguards system	1	2 (2)	3 (8)	4 (7)	5 (7)
3. Usefulness of course material to colleagues in your country	1	2 (1)	3 (11)	4 (7)	5 (6)

How could the course material be made more useful to you? Provide more research reactor safeguards (2).
Provide future correspondence (2). More handouts, books, articles, etc. (1). Schedule participant discussion of how
MC&A can best serve their country (1). Substitute, for introductory material, lectures on safeguarding reprocessing
enrichment, and MCX fabrication plants (1). Course material went beyond current needs (1).

K. GENERAL SUGGESTIONS, CRITICISMS, COMMENTS

1. Which parts of the course were of greatest value to you? Los Alamos NDA tours (7). Exxon tours (7).
All parts (4). Introduction to IAEA/SG, Buechler (4). IAEA/SG Information Systems, Nardi (4). Physical Protection,
Sonnier (3). Safeguarding Nuclear Power Stations, Whan (3). NDA For LEU Fuel Fabrication Plants, Augustson (3). De-
scription of Model Plant MC&A Systems, Schneider (3). NDA Methods at Model Facility, Johnson (3). Typical IAEA Pro-
cedures for Model Power Plants, Theis (3). MC&A Workshop (3). NDA (3). Off-hour consultations with IAEA and NRC
staff (2). Gaining an appreciation of plant operator effort necessary to establish good MC&A (1).

K. GENERAL SUGGESTIONS, CRITICISMS, COMMENTS Cont'd. **

2. Which parts of the course should be expanded? Subgroup discussions (6). Los Alamos tour and NDA Workshop (4). NDA (2). Statistics (3). Item facility safeguards (3). Workshops (3). None (2). All (1). First part (1). Exxon tours (1). MCSA Workshop (1). Cost of equipment, operations, etc. (1). Tours of different facilities (1). Computer systems (1). Advanced bulk-handling facilities (1). IAEA Inspections at model plant (1). Examples of national systems to include non-NPT countries (1).

3. Which parts of the course should be shortened (or omitted)? None (6). Shorten statistics (3). Shorten preliminary sessions (2). Sessions 7, 13, and 29 (1).

4. Overall course length was too long 1 too short 1 about right 20 No Answer (1)

5. In your opinion should the training course be offered again? Yes (22) No Answer (1)

6. What changes in the course would you suggest in order to make it more useful? In statistics, give simple exercises to be performed by attendees (6). Less theoretical approach to statistics (2). Combine item and bulk facilities into one course (3). Describe model plant using IAEA, MPA, and KMP structures, rather than NRC, ICA, and Mass BA structure (2). Simplify model plant (1). Give more case studies (1). Give a slightly less detailed course for countries in the early stages of planning their fuel cycle (1).

7. General comments/observations not covered above. Excellent organization (7). Good selection of lecturers (3). Effectiveness of workshop methods wonderful (1). Keep course emphasis on SSAC (1). Furnish attendees with announcements of future SSAC courses (1). Provide video tapes so countries can use them in their training programs (1). Change course to summer (1). Advise attendees to bring a songbook - especially the French (1).

Name _____

** The written responses on this page sometimes answered question 'X' using space under question 'Y'. In summarizing responses, all answers were combined.