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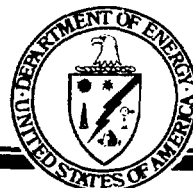
ADVANCED INTERNATIONAL TRAINING COURSE ON STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS

April 27-May 12, 1981

Santa Fe, New Mexico and Richland, Washington



PROCEEDINGS



LA--8901-C

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



April 27-May 12, 1981

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D. Smith, Los Alamos



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



April 27-May 12, 1981

FOREWORD

This Advanced International Training Course on State Systems of Accounting for and Control of Nuclear Materials was developed "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 IAEA international safeguards objectives." The course was conducted by the University of California's Los Alamos National Laboratory, the Battelle Pacific Northwest Laboratory, and the Exxon Nuclear Company, Inc. The course is part of the ongoing series of safeguards training courses sponsored by the US Department of Energy in cooperation with the International Atomic Energy Agency.

A total of some 70 participants (including course attendees, lecturers, and equipment demonstrators) took part in the 16-day course. Nations represented included Belgium, Brazil, Canada, Egypt, France, India, Iraq, Israel, Italy, Japan, Korea, Luxembourg, Malaysia, Mexico, Pakistan, Poland, Sweden, Switzerland, Taiwan, Turkey, and Yugoslavia. Participants also came from the cosponsoring organization--the IAEA in Vienna, Austria--and from the Euratom Organization of the Commission of the European Communities in Luxembourg.

Major emphasis in the course was placed on the principles and practical methods used in establishing and operating nuclear material accounting and control systems at bulk-handling facilities -- particularly low-enriched uranium (LEU) conversion and fuel-fabrication plants. Emphasis was also placed on the interaction between (1) facility safeguards, (2) national system (SSAC) safeguards, and (3) international (IAEA) safeguards.

Course attendees hold positions of major responsibility in technical research, operations, and technical management in nuclear materials accounting and control organizations at both the facility and national levels in their respective countries. Many attendees had attended one or more of the basic SSAC courses previously offered by the International Atomic Energy Agency in 1976 and 1977 in Vienna, in 1978 in the USSR, and in 1980 in Santa Fe, New Mexico.

The course lecture staff included safeguards experts from the IAEA, US Department of Energy, US Nuclear Regulatory Commission, US Department of State, Los Alamos National Laboratory, Battelle Pacific Northwest Laboratory, Exxon Nuclear Company, Inc., and Allied General Nuclear Services.

In addition to the formal lecture presentations, panel discussions, and the safeguards design workshop, the course featured a tour and demonstration of state-of-the-art nondestructive assay instruments and methods at the Los Alamos National Laboratory and extensive tours and demonstrations of safeguards equipment, methods, and plant accounting systems at the Exxon Nuclear Fuel-Fabrication Plant at Richland, Washington.

The course culminated in a two-day workshop on safeguards system design for a fuel-fabrication plant. Based on data provided for a model LEU fuel-conversion/fabrication plant, students in the workshop developed a FNMC plan for the model plant and made recommendations for establishing and implementing an appropriate measurement and accountability system. The resulting system designs were then reviewed and evaluated in an informal panel discussion involving participation of both attendees and course instructors.

In addition to the formal material presented, participants were able to exchange information and ideas with each other concerning the actual practice of safeguards in the different countries and organizations represented. These informal exchanges and contacts among responsible safeguards personnel from differing professional and cultural backgrounds provided significant additional benefit to both lecturers and participants. These interactions should prove of considerable value to participants in their task of implementing effective safeguards in their own individual countries.

These published proceedings of the 1981 advanced course, including the full text of all lecture presentations, are available from the US Department of Energy, Office of Safeguards and Security, or from any of the participating organizations.

G. Robert Keepin
NNPA Course Director
Los Alamos, New Mexico
25 August, 1981



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



April 27-May 12, 1981

ABSTRACT

This report incorporates all lectures and presentations at the Advanced International Training Course on State Systems of Accounting for and Control of Nuclear Material held April 27 through May 12, 1981 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. Major emphasis for the 1981 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, the Battelle Pacific Northwest Laboratory, and Exxon Nuclear Company, Inc. Tours and demonstrations were arranged at both the Los Alamos National Laboratory, Los Alamos, New Mexico and the Exxon Nuclear fuel fabrication plant, Richland, Washington.



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



April 27-May 12, 1981

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S. Thorstensen, IAEA
R. Nilson, Exxon

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R. Keepin, Los Alamos

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IN NUCLEAR SAFEGUARDS
J. Boright, US Department of State

Session 3: IAEA GUIDELINES FOR STATE SYSTEMS OF AC-
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Session 5: NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS
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C. Buchler and S. Thorstensen, IAEA;
J. Foley, Los Alamos; R. Nilson, Exxon;
C. Smith, US NRC; G. Weisz, US DOE/OSS

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Los Alamos

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- Session 42: COURSE EVALUATION, DISCUSSION, AND WRAP-UP
Course Staff and Attendees



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



April 27-May 12, 1981

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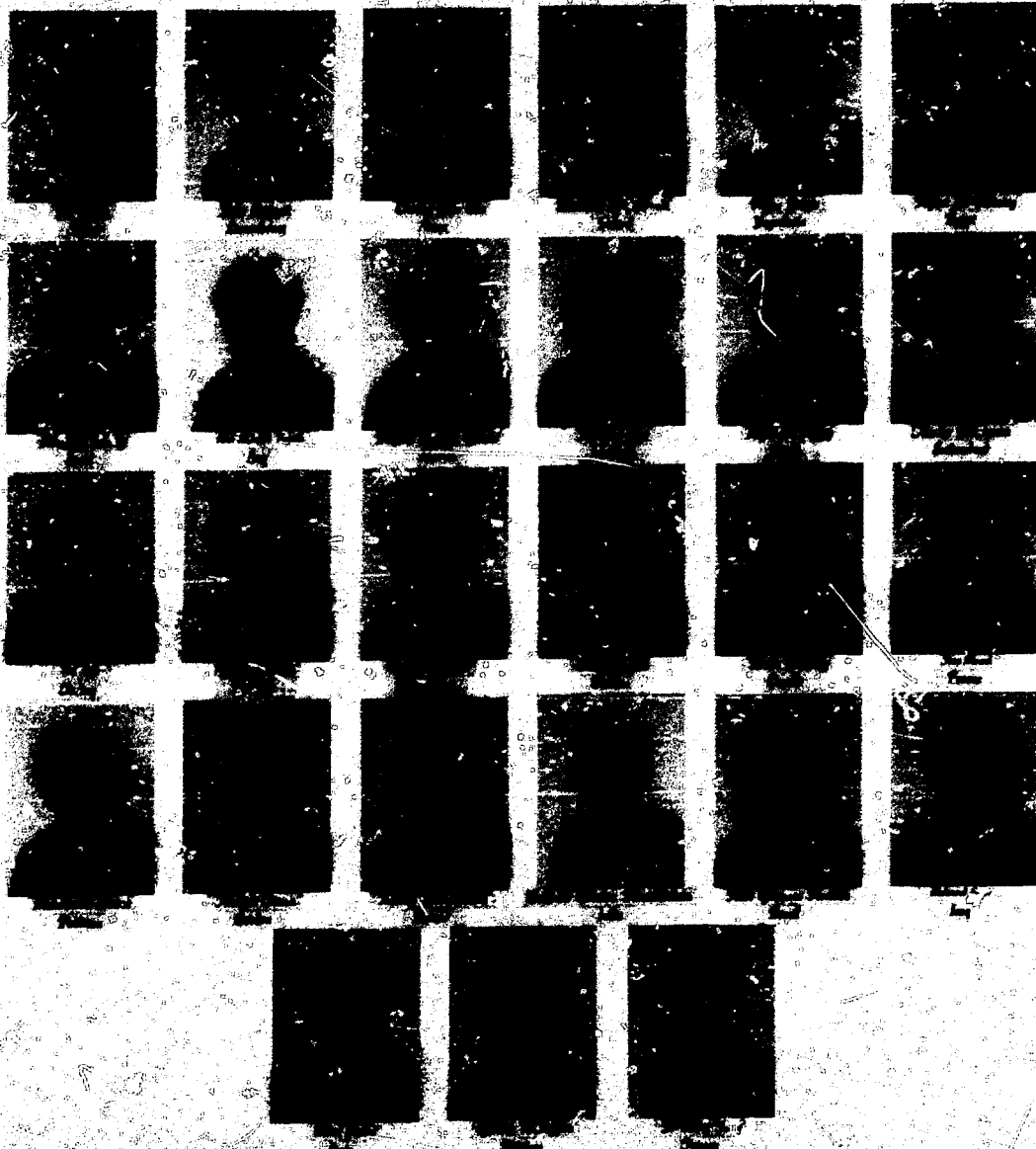
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**ADVANCED INTERNATIONAL TRAINING COURSE
ON STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



April 27-May 12, 1981





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

April 27-May 12, 1981



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Mr. [Name]



Mr. [Name]



Mr. [Name]



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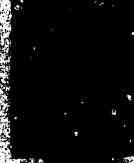
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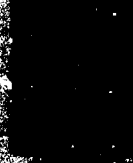
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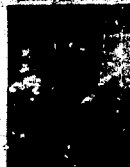
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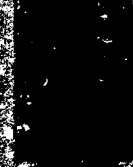
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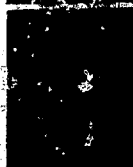
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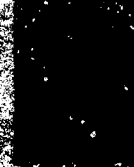
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Mr. [Name]



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



April 27-May 12, 1981

Los Alamos/Santa Fe, New Mexico, April 27-May 1, 1981
Battelle/Exxon, Richland, Washington, May 4-12, 1981

COURSE SYLLABUS

SUNDAY, APRIL 26, 1981, 4:00-6:00 PM - REGISTRATION

MONDAY, APRIL 27, 1981

AM

WELCOME AND ORIENTATION

DOE
IAEA
LOS ALAMOS
BATTELLE/EXXON

Session 1: INTRODUCTION TO ADVANCED SSAC TRAINING COURSE

Course Structure
Course Components
Course Materials and Facilities
Administrative Details/Announcements

Session 2. HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS

Development of International Safeguards, 1945-1980
NNPA
US-IAEA Agreement
Current Trends in International Safeguards

STATE SAFEGUARDS SYSTEMS AND THE INTERNATIONAL INTERFACE

PM

Session 3: IAEA GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL

History and Development of IAEA Safeguards
Establishment of Authority and Responsibility (Requirements)
Establishment of Requirements of Nuclear Materials Accounting and Control
Categorization of Nuclear Materials
Material Balance Areas (MBAs) and Key Measurement Points (KMPs)
Measurement System
Nuclear Material Flow
Physical Inventory Taking
Records and Reports

COURSE SYLLABUS

Session 4: IAEA SAFEGUARDS OPERATIONS AT A BULK FACILITY

- Facility Attachments (based on DIQ for Facility)
- Review of Material Balance Areas and Key Measurement Points
- IAEA Inspection Procedures; Sampling Plans
- Physical Inventory Taking
- Independent Verification Measurements
- Measurement Controls
- Material Balance Closing for Plant MBAs
- Audit/Verification of Inventory Listings, Records
- Data Evaluation and Assessment
- Preparation of Reports

TUESDAY, APRIL 28, 1981

AM

Session 5: NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS

- General Features of US Safeguards Requirements (Importance of Centralized Authority, etc.)
- Basic Materials Accounting and Control Requirements
- Basic Nuclear Material Control Program
- General Provisions for Low-Enriched Uranium
- US/IAEA International Safeguards Agreement

Session 6: NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY

- Review of National MC&A Regulations (10 CFR Part 70)
- Discussion of the Basic Elements of MC&A
- FNMC (Fundamental Nuclear Material Control) Plan
- Guidance Information to Generate FNMC Plan
- Relationships of 10 CFR Part 70, 75, and INFCIRC-153
- Review of 10 CFR Part 75 to Implement US-IAEA Safeguards Agreement

PM

Session 7: PANEL: IAEA - STATE SYSTEM INTERFACE

Panel members will be drawn from IAEA and Course Lecture Staff (DOE, NRC, Los Alamos, Battelle/Exxon), and will be structured to encourage maximum participation by Course Attendees. Emphasis will be placed on bulk facilities such as fuel-fabrication plants. Questions and problem areas that may have arisen during the preceding lectures 1-6 will be addressed. Typical topics:

- Negotiation of Subsidiary Arrangements
- Use of Design Information Questionnaires (DIQs)
- Negotiation of Facility Attachments

COURSE SYLLABUS

IAEA Inspection and Verification (maximize parallels with SSAC requirements)
Complementary Roles of Materials Accounting and Containment and Surveillance
Format of Records and Reports for IAEA and State Inspections
Evaluation/Assessment of Inspection Results (e.g., Safeguards Implementation Reports)
Discussion of Institutional Arrangements (e.g., future IPS, Fuel-Cycle Centers, etc.)

WEDNESDAY, APRIL 29, 1981

SAFEGUARDS MEASUREMENT TECHNOLOGY AND APPLICATIONS

AM

Session 8: SURVEY OF CHEMICAL AND DESTRUCTIVE ANALYSIS METHODS

Gravimetric Methods
Titrimetric Methods
Spectrophotometric and Fluorimetric Techniques
Isotopic Assay
 Gamma and Alpha Spectrometry
 Mass Spectrometry
Concentration Measurement Methods
 Isotope Dilution Mass Spectrometry
 X-Ray Absorption and Fluorescence Methods
Sampling Problems and Techniques
Measurement Uncertainties; Precision and Accuracy

Session 9: SURVEY OF BULK-MEASUREMENT TECHNOLOGY AND MEASUREMENT STANDARDS

Introduction to Bulk Measurement
Volume, Density, and Mass Measurements
Sampling and Analytical Measurements
Data Collection and Computation
Calibrations and Measurement Standards
An Example of Bulk-Measurement Capability
Videotape Demonstration of a Tank-Calibration Procedure

PM

Session 10: ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY

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

COURSE SYLLABUS

Session 11: ELEMENTS OF IN-PLANT NONDESTRUCTIVE ASSAY INSTRUMENTATION DESIGN AND IMPLEMENTATION

- Instrument Classification
- Sample-Sensor Measurement Configuration
- Information Processing
- Measurement Integrity
- Instrument-User Interface
- Safeguards and Process Control Systems Interfaces

THURSDAY, APRIL 30, 1981

Sessions 12-13: DEMONSTRATION OF NDA INSTRUMENTS AND METHODS AT LOS ALAMOS

AM Tour of Los Alamos Safeguards Laboratories

- X-Ray Absorption Edge Densitometers
- Gamma-Ray Spectroscopy Systems
- Segmented Gamma Scanner
- High-Level Neutron Coincidence Counter
- Active Well Counter
- Californium Shuffler
- Portable Multi-channel Analyzer

PM Demonstration of Spent-Fuel Assay Instrumentation at Omega
West Reactor

- Cerenkov Detector
- Gamma-Ray Spectroscopy
- Passive Neutron Counting

Visits to Los Alamos Meson Facility and Science Museum

FRIDAY, MAY 1, 1981

SAFEGUARDS SYSTEMS -- DESIGN AND IMPLEMENTATION

AM

Session 14: PRINCIPLES OF NEAR-REAL-TIME MATERIAL ACCOUNTING AND CONTROL SYSTEMS

- Approaches to Systems Design
- Automated In-Plant Accounting Systems
- Integrated Systems (projected role in large-scale facilities)
- Performance Criteria and Effectiveness Evaluation
- Verification by National and International Safeguards Authorities

COURSE SYLLABUS

Session 15: EXAMPLE OF AN IN-PLANT NEAR-REAL-TIME ACCOUNTANCY/PROCESS CONTROL SYSTEM

- Introduction to CNMCAS
- General Description
- Process Measurement Instruments
- On-Line Analytical Instrumentation - Application and Calibration
- Analytical Laboratory Computer System
- CNMCAS Function
- Benefits of Computerized Accounting
- Videotape Tour of a Reprocessing Facility

PM

Session 16: PERFORMANCE EVALUATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS

- Description of AGNS Miniruns (including videotape)
- Evaluation of Minirun Data
- Improvements in System Performance
- Los Alamos-Plutonium Facility (DYMAC system)
 - Brief Facility Description
 - Videotape Tour
 - Operating Experience - Problems and Benefits
 - Overall Effectiveness Evaluation

Session 17: REVIEW, DISCUSSION, AND CONSULTATION WITH TECHNICAL EXPERTS

This session will be opened to general discussion and answering of questions and comments from course attendees on the material presented in Sessions 1-16. Specific problem areas will be reviewed and explained as required. Technical experts in various areas of safeguards technology and practical implementation will be available for individual consultation and follow up on special problems that individual attendees may have.

COURSE SYLLABUS

Exxon Nuclear Company, Inc.
Battelle Pacific Northwest Laboratory
Richland, Washington

SUNDAY, MAY 3, 1981, 6:00-7:30 PM - REGISTRATION (At Hotel)

MONDAY, MAY 4, 1981

MATERIAL ACCOUNTING AND CONTROL AT AN OPERATING FUEL-FABRICATION PLANT

AM WELCOME, GENERAL INTRODUCTION, ANNOUNCEMENTS

Session 18: BRIEF DESCRIPTION OF EXXON FUEL-FABRICATION PLANT

Session 19: GENERAL PLANT TOUR

PM

Session 20: MODEL PLANT KEY MEASUREMENT POINTS (KMPS)

Flow KMPS

Inventory KMPS

Session 21a: BASIS OF PLANT ACCOUNTING SYSTEMS

General Safeguards Criteria

Design Consideration

National System Requirements

Session 21b: MODEL PLANT ACCOUNTING SYSTEM

Principles of System

Projects, Enrichments, and Locations

Mass Balance and Item Control

Responsibilities and Authorities

TUESDAY, MAY 5, 1981

AM

Session 22: TOUR OF CONVERSION AREA

Green Powder Weighing

U₃O₈ Burnback

Sampling

Liquid Waste Tanks

Solid Waste Assay Demonstration

COURSE SYLLABUS

Session 21c: MODEL PLANT ACCOUNTING SYSTEM (Continued)

- Description of Computer-based System
- Description and Example of Records, Reports, and Forms
- Assignment of Element and Isotope Factors

PM

Session 23: MEASUREMENT METHODS USED AT THE PLANT

23a: Bulk Measurements

- Weighing and Sampling

23b: Analytical Methods

- Gravimetric Assay
- Fluorometric - Low-Level Assay
- Mass Spectrometry
- Emission Spectrometry
- Standards

23c: NDA METHODS

- Waste Assay Counter
- Enrichment Meter - SAM-II
- Fuel Rod Scanner as Quality Control Check and NRC License Requirement

Session 24: PROCESS MONITORING

WEDNESDAY, MAY 6, 1981

AM

Session 25: DEMONSTRATION OF MEASUREMENT TECHNIQUES

- Analytical Methods: Gravimetric, Fluorometric, and Davies-Gray
- SAM-2 Enrichment Meter and Rod Assay Unit (Near Rail and Cold Zone)
- Pellet Weighing and Sampling; Pellet Column Weighing
- (Divide Attendees into Two Groups)

Session 26: PROCEDURE FOR TAKING PHYSICAL INVENTORIES

- Requirements and Procedures
- Plant Cleanout and Conversion of All Inventory to Measured Items
- Administration Procedures
- Verification and Treatment of Tamper-Safed Previously Measured Items
- Reconciliation and Calculation of MUF

COURSE SYLLABUS

PM

Session 27: MATERIALS CONTROL

Seal Controls and Procurement Program
Application of Paper and Metal Seals -- Class Participation

Session 28: MEASUREMENT CONTROL PROGRAM

Technical Requirements - Standards
Application to Measurement Elements
Special Experiments
Statistical Aspects
Documentation

THURSDAY, MAY 7, 1981

AM

Session 29: PREPARATION OF FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN (FNMC) AND DIQ FOR FUEL FABRICATION PLANT

Session 30: DESCRIPTION OF TYPICAL NRC INSPECTION PROCEDURES FOR MODEL LEU FUEL FABRICATION PLANT

A summary of NRC inspection procedures. Procedures and methods for combining inventory data, seals, measurement techniques, and statistical analysis will be emphasized. Questions from participants will be encouraged and answered.

PM

Session 31: DEMONSTRATION OF MOBILE NDA SAFEGUARDS MEASUREMENT SYSTEM

General Description; Functions & Capabilities
Demonstration and Operation of Equipment
Questions and Discussion

FRIDAY, MAY 8, 1981

AM

Session 32: CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES (ERROR PROPAGATION)

Sources and Types of Measurement Error
Calculation of the Variance of MUF
Random
Systematic
Total

COURSE SYLLABUS

Session 33: CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC

Shipper/Receiver Data
Inspection Data

PM

Session 34: ESTIMATION OF MEASUREMENT VARIANCES

Systematic Errors
Random Errors
Fluctuating Bias

Session 35: STATISTICAL SAMPLE PLANS

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

SATURDAY, MAY 9, 1981

AM and PM

Sessions 36 & 37: MEASUREMENT AND MATERIAL CONTROL DEMONSTRATION AND STUDENT PARTICIPATION AT EXXON NUCLEAR PLANT

Students will be divided into four groups with approximately 1.5 hours for each activity. An ENC instructor will be assigned to escort and assist each group.

UF₆ Cylinder Weighing
SAM-2 Enrichment Meter and Scales in Warehouse
Analytical Chemistry
Student Participation in Analytical Techniques.
Tour of Mass Spectrometer and Quantometer Labs.
Completion of Transfer Forms, Material Record Cards, Inventory Sheets, Illustration of Bunco Decks, and Application of Seals to Barrels, Filters, and Buckets. (UO₂ Training Trailer.)

MONDAY, MAY 11, 1981

AM and PM

Sessions 38 and 39: WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR A FUEL-FABRICATION PLANT

Data will be provided on reference LEU fuel conversion/fabrication facility
Attendees will be divided into approximately four subgroups for safeguards design Workshop

COURSE SYLLABUS

Workshop Goals:

- Development of an FNMC Plan
- Make Recommendations, such as:
 - Measurement and Accountability System
 - Inventory-taking Procedure
 - Data Analysis and Reporting
 - Evaluation of Effectiveness
- Example Problems

TUESDAY, MAY 12, 1981

AM

Session 40: REPORTS OF DESIGN WORKSHOP SUBGROUPS - PLENARY SESSION

A member of each subgroup will present a brief report on safeguards system design characteristics recommended by each subgroup.

PM

Session 41: PANEL DISCUSSION: COMPARISON/CRITIQUE OF SUBGROUP REPORTS

Panel will consist of approximately six attendees, with an instructor acting as moderator. Moderator will later open discussion to comments and questions from the floor, and encourage maximum attendee participation and feedback.

Session 42: 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 followup 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 - DOE, IAEA, Los Alamos, NRC, Battelle/Exxon.



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



REGISTRATION
SUNDAY 3 MAY
1800 - 2000

April 27-May 12, 1981

TIME	MONDAY 4 MAY	TUESDAY 5 MAY	WEDNESDAY 6 MAY	THURSDAY 7 MAY	FRIDAY 8 MAY	SATURDAY 9 MAY	SUNDAY 10 MAY	MONDAY 11 MAY	TUESDAY 12 MAY
0900	WELCOME, INTRODUCTION, ANNOUNCEMENTS (SORENSEN, SCHNEIDER)	22. TOUR OF CONVERSION AREA (GALBRAITH)	25. DEMON- STRATION OF MEASURE- MENT TECHNIQUES (WING, JOHNSON, SHARP, KEY)	29. PREPARATION OF FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN AND DQ FOR FUEL FABRICATION PLANT (SCHNEIDER)	32. CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES (ERROR PROPAGATION) (JAECH)	36. MEASUREMENT AND MATERIAL CONTROL DEMONSTRATION AND STUDENT PARTICIPATION AT EXXON NUCLEAR PLANT (GALBRAITH, SCHNEIDER, MULLIGAN, JOHNSON, WING)	TOURS TO MT. RANIER AND OTHER POINTS OF INTEREST (TO BE ARRANGED)	38. WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR A FUEL FABRICATION PLANT (SCHNEIDER AND SMITH - WORKSHOP COORDINATORS)	40. REPORT OF DESIGN WORKSHOP SUBGROUPS (DESIGNATED WORKSHOP RAPPORTEURS)
0930	18. BRIEF PLANT DESCRIPTION (GALBRAITH)	21. WASTE ASSAY DEMON- STRATION (JOHNSON)							
1000	BREAK								
1030	19. GENERAL PLANT TOUR (GALBRAITH, SCHNEIDER)	BREAK	BREAK	BREAK	BREAK				
1100		21c. MODEL PLANT ACCOUNTING SYSTEM, CONTINUED (KRAFT, McGINNES, HERZ)	26. PROCEDURE FOR TAKING PHYSICAL INVENTORIES (McGINNES)	30. DESCRIPTION OF TYPICAL NRC INSPECTION PROCEDURES FOR MODEL LEU FUEL FABRICATION PLANT (BLAYLOCK)	33. CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC (JAECH)				
1200									
1225 1230	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH		LUNCH	LUNCH
1300									
1330									41. PANEL DISCUSSION: COMPARISON/ CRITIQUE OF SUBGROUP REPORTS (SORENSEN - MODERATOR)
1400	20. MODEL PLANT KEY MEASUREMENT POINTS (SCHNEIDER)	23. MEASUREMENT METHODS USED AT PLANT (SCHNEIDER, WING)	27. MATERIAL CONTROL (HERZ, SHARP)	31. DEMON- STRATION OF MOBILE NDA SAFE- GUARDS MEASUREMENT SYSTEM (SMITH)	34. ESTIMATION OF MEASUREMENT VARIANCES (JAECH)	37. DEMON- STRATION AT EXXON NUCLEAR PLANT, CONTINUED (GALBRAITH, SCHNEIDER, LOGSTON, SHARP)	39. SAFEGUARDS SYSTEM DESIGN WORKSHOP, CONTINUED (SCHNEIDER AND SMITH - WORKSHOP COORDINATORS)		
1445	BREAK	BREAK							BREAK
1500									
1515	21a. BASIS OF ACCOUNTABILITY SYSTEM (SCHNEIDER)	23. MEASUREMENT METHODS USED AT PLANT, CONTINUED (JOHNSON)	BREAK		BREAK				
1530									
1545	21b. MODEL PLANT ACCOUNTING SYSTEM (SCHNAIBLE)		28. MEASUREMENT CONTROL PROGRAM (SCHNEIDER)		35. STATISTICAL SAMPLE PLANS (JAECH)				42. COURSE EVALUATION, DISCUSSION, AND WRAP-UP
1600									
1630		24. PROCESS MONITORING (BROUNS)							
1645									
1700									
1715 1830							RECEPTION, BANQUET AND PRESENTATION OF DIPLOMAS		



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



REGISTRATION
SUNDAY 28 APRIL
1600 - 1800

April 27-May 12, 1981

	MONDAY 27 APRIL	TUESDAY 28 APRIL	WEDNESDAY 29 APRIL	THURSDAY 30 APRIL	FRIDAY 1 MAY	SATURDAY 2 MAY	SUNDAY 3 MAY
0730							
	LATE REGISTRATION			BUS TO LOS ALAMOS			
0830							
0900	WELCOME AND ORIENTATION (KERR, WEISZ, THORETENSEN, NILSON)	5. NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS (SMITH)	8. SURVEY OF CHEMICAL AND DESTRUCTIVE ANALYSIS METHODS (HAKKILA)	12-13. DEMONSTRATION OF NDA INSTRUMENTS AND METHODS AT LOS ALAMOS TOUR OF SAFEGUARDS LABORATORIES (REILLY, HATCHER)	14. PRINCIPLES OF NEAR-REAL-TIME MATERIALS ACCOUNTING AND CONTROL SYSTEMS (SHIPLEY)		BUS TO ALBUQUERQUE AIRPORT
0930							
1000	1. INTRODUCTION TO ADVANCED ISAC TRAINING COURSE (KEEPIN)					OPTIONAL TOUR OF INDIAN AND SPANISH TOWNS IN NORTHERN NEW MEXICO	
1030		BREAK	BREAK		BREAK		
1045	BREAK						
1100		6. NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY (SMITH AND SANDERS)	9. SURVEY OF BULK MEASUREMENT TECHNOLOGY AND MEASUREMENT STANDARDS (ELLIS)		15. EXAMPLE OF AN IN-PLANT NEAR-REAL-TIME ACCOUNTANCY/PROCESS CONTROL SYSTEM (ELLIS)		CONTINENTAL FLIGHT 253 TO SEATTLE, WASHINGTON
1130	2. HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS (BORIGHT)						
1200							
1230							
1245	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH		
1300							
1330				MEBON PHYSICS FACILITY TOUR			
1400							
1415	3. IAEA GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL (BUCHLER, HOUGH)	7. PANEL: IAEA-STATE SYSTEM INTERFACE	10. ELEMENTS OF NON-DESTRUCTIVE ASSAY (NDA) TECHNOLOGY (HATCHER)		16. PERFORMANCE EVALUATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS (COBB, MALANIFY, ELLIS)		
1430				SAFEGUARDS DEMONSTRATION AT OMEGA WEST REACTOR			
1500							
1530		BREAK	BREAK		BREAK		
1545	BREAK						
1600		7. PANEL: IAEA-STATE SYSTEM INTERFACE, CONTINUED	11. ELEMENTS OF IN-PLANT NDA INSTRUMENTATION DESIGN AND IMPLEMENTATION (CANADA)	SCIENCE MUSEUM TOUR	17. REVIEW DISCUSSION, AND CONSULTATION WITH TECHNICAL EXPERTS		REPUBLIC FLIGHT 727 TO PASCO, WASHINGTON
1700	4. IAEA SAFEGUARDS OPERATIONS AT A BULK FACILITY (THORETENSEN)						
1730				RECEPTION AT STUDY CENTER			
1800	BREAK						
1815	IAEA RECEPTION			DINNER AT CASA DEL MIRADOR			REGISTRATION AT HOTEL IN RICHLAND, WASHINGTON
1930							
2000							
2100				BUS TO SANTA FE			



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



April 27-May 12, 1981

WELCOME

Donald M. Kerr
Director, Los Alamos National Laboratory

It is indeed a pleasure to welcome you to New Mexico and to the historic and beautiful Los Alamos-Santa Fe area for this US DOE-IAEA Advanced International training course in the vital field of nuclear safeguards. Our fair state of New Mexico -- also known as "The Land of Enchantment" -- is richly endowed, not only with majestic mountains, canyons, and mesas, but it is also rich in energy resources including the basic nuclear energy resource -- uranium. In fact, New Mexico is the leading uranium-producing state in the United States. As all of you are keenly aware, the future of the nuclear energy option worldwide may well depend on how effectively all of us, working together, can safeguard and control the strategic nuclear materials that fuel nuclear power reactors. The Los Alamos National Laboratory is making significant contributions to all three of the major problems facing the nuclear industry: reactor safety, acceptable waste disposal, and effective nuclear safeguards.

We are proud of the leadership role we have played in pioneering modern safeguards R&D and in applying the results of this new technology to plants and facilities throughout the nuclear fuel cycle. As the US Department of Energy's lead laboratory for research and development in nuclear material accountability and control, Los Alamos has developed innovative nondestructive assay instrumentation for accurate and timely measurement of sensitive nuclear materials in all stages of processing. Building on this new measurement technology, we have designed advanced "near-real-time" material control and accountability systems for test, evaluation, and implementation in existing and future nuclear fuel-cycle facilities, including reprocessing plants.

This Advanced International Training Course on State Systems of Accountability for and Control of Nuclear Materials, sponsored by the US Department of Energy in cooperation with the International Atomic Energy Agency, builds on the highly successful Introductory Course on Nuclear Materials Safeguards that was held here in Santa Fe just one year ago. The technical subject matter and thrust of this year's advanced course is especially timely and relevant in view of the first IAEA inspection earlier this month of a US commercial nuclear facility under the terms of the new US-IAEA Safeguards Agreement that came into force just last December 8.

I would make one further observation concerning the "student body" for this rather unique advanced safeguards course. Your course Director, Bob Keepin, has called my attention to the very broadly based international participation that your presence here represents, and to your respective professional backgrounds and experience specifically in the nuclear materials management, safeguards and security area. It is indeed most gratifying to have the participation of so many highly qualified technical experts in the safeguards field representing some 23 countries and two international organizations. I am confident that your technical discussions and deliberations here will contribute significantly to more effective nuclear safeguards on both the national and the international level. I wish you every success as you proceed in this important undertaking.

In looking over your very full course schedule, I'm pleased to see that you'll be visiting Los Alamos on Thursday, April 30. I look forward to joining you for the reception at the Los Alamos Study Center and for dinner beside the Rio Grande that evening.



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



April 27-May 12, 1981

WELCOME AND ORIENTATION

George Weisz
Director, Office of Safeguards and Security
U.S. Department of Energy

Good morning. On behalf of the Office of Safeguards and Security of the U.S. Department of Energy (DOE), it gives me great pleasure to welcome you. As you may know, we sponsor this training course in cooperation with the International Atomic Energy Agency (IAEA) and the U.S. Nuclear Regulatory Commission (NRC). We are anxious to share with you our most recent developments in nuclear materials accountancy and control and to provide a forum for the IAEA and other countries to do likewise. We hope that your experience during the next two and a half weeks will stimulate and enhance the spirit of international cooperation and collaboration on this subject.

I should emphasize that we consider your presence here an opportunity for dialogue. While we are pleased to have this opportunity to make our technology and methodology available for use in your own countries and trust this will help your own program of safeguarding your peaceful nuclear activities, we are most interested to hear your views. Experience with other courses we have sponsored reflects considerable benefit flowing from the participants through a free exchange of views.

We know that the Los Alamos, Battelle, and Exxon personnel who have played a key role in arranging the program for this course, as well as we in DOE, are anxious to have you take part in an exchange of information and ideas. We encourage your questions and comments as the program proceeds, and ask you to feel free to make suggestions about it at the conclusion of the course so that we may improve on it for future offerings.

This course focuses on an important aspect of non-proliferation; a goal of fundamental importance to the United States and to the international community as well as the IAEA. In fact, this course is mandated by the U.S. Nuclear Non-Proliferation Act (NNPA) of 1978, which recognizes safeguards to be one of the pillars of non-proliferation. Section 202 of that Act calls for making training available to the international community in both physical security and in safeguards. Three courses in physical security have been conducted to date, the latest one concluding just a few months ago. Today begins the second NNPA course on nuclear material accountancy and control, not only for national purposes but for IAEA safeguards purposes as well.

One year ago we conducted our first NNPA course in basic nuclear material accountancy and control. That course, which some of you attended, concentrated on the institutional and operational concepts and technology to establish and operate nuclear material accountability programs to meet national safeguards objectives and the international

objective of facilitating effective IAEA safeguards. The present advanced course is designed to be a follow-on to the basic course by providing practical training in the implementation and operation of a national accountability system for bulk handling facilities with emphasis on low enriched uranium (LEU) conversion and fabrication plants.

To accomplish this, the first week of the course will be spent here in Santa Fe with a one day visit to the Los Alamos National Laboratory. During this time, the latest state-of-the-art technology and methodology for measuring, accounting for and controlling nuclear materials will be discussed in detail. The one-day visit to Los Alamos then will enable you to see, first hand, nondestructive assay (NDA) equipment and software in a working environment. To complement this research and development atmosphere, the course will then reconvene in Richland, Washington where the staff at Battelle, Pacific Northwest Laboratory and the Exxon Nuclear Company, Inc. will present their views and ideas on accountability systems at the Exxon facility and the considerations associated with integrating into modern process facilities the latest safeguards technology such as the NDA equipment demonstrated at Los Alamos.

On Saturday, May 9, you will all have the opportunity to visit the Exxon facility for a measurement and material control demonstration. This will provide an excellent opportunity for you to witness some of the basic operations in a modern fuel fabrication facility, to see NDA equipment in actual plant use, and to participate in measurements and demonstrations of modern equipment and analytical techniques for determining nuclear material content. This is indeed a rather unique opportunity, and I believe we owe Mr. Sorenson and Mr. Schneider a special note of thanks for arranging this for us.

That's all I'll say now on the course itself. Dr. Keepin, your Course Director, will provide an overview of the course and further details in Session 1 this morning, and subsequently as the course proceeds. I will now discuss briefly some of our other related programs.

As I mentioned earlier, we view safeguards as a keystone of non-proliferation. However, the NNPA training program is but one of a number of U.S. technical initiatives in support of international safeguards. We are currently entering our fifth year of a special Program of Technical Assistance to IAEA. Since its inception in 1977, 171 specific tasks requested by the IAEA Director General have been completed and another 83 are underway at a cost of almost \$23 million U.S. dollars. The Program has provided assistance in such areas as material measurement, containment and surveillance, inspector operations and information treatment and has been acknowledged by the Director General and other senior officials of the IAEA to have impacted markedly on the effectiveness of their safeguards operations. I should be quick to mention that other IAEA Member States are providing technical assistance to IAEA safeguards. Indeed, the future effectiveness of IAEA safeguards is highly dependent on such continuing voluntary support by the Member States. I'm sure

you realize by the magnitude and scope of our activities in support of international safeguards that the U.S. has a serious commitment to IAEA safeguards effectiveness and non-proliferation.

Allied with this have been research and development activities devoted to improving safeguards for enrichment, fuel fabrication, reprocessing, and storage facilities. The results of the International Nuclear Fuel Cycle Evaluation Program (INFCE) pointed out that various facilities and technologies such as these are subject to being misused and for this reason it is important to plan future fuel cycles and facilities with careful attention to proliferation risks. There is need for us to ensure that new safeguards-related developments are completed and incorporated in the early stages of design of future fuel cycle facilities. In order to maintain acceptability of nuclear power in the political and international arena, we will need to demonstrate that future large-scale facilities and their special nuclear material can be accounted for and independently verified by IAEA.

Lastly, I am happy to be able to state that last December the U.S.-IAEA Safeguards Agreement entered into force and now all U.S. nuclear activities are eligible for IAEA safeguards except those of direct national security significance. Just a few months ago, the IAEA made their first selection of the U.S. facilities to be placed under safeguards. One of the selected facilities is the Exxon plant which you will visit. It's a real coincidence the way things turned out because when we selected Exxon to be one of the organizations to conduct this course, we did not know that it would be one of the facilities selected for IAEA safeguards. In any event, your visit to the Exxon facility was scheduled because it is especially appropriate for this course and your interests in nuclear power.

We sincerely hope you find this course rewarding and that you will be stimulated to interact freely with guest speakers, course instructors, fellow students, and others with whom you come in contact. We welcome your criticisms, suggestions, and any other comments you may care to make throughout the period of the program and certainly during the special sessions that will be devoted to your critique of this course.

The Department of Energy will have a representative on hand for the latter portion of your stay in Richland and will be available to assist you in any way necessary to make your stay in the U.S. productive and pleasant. Please don't hesitate to call upon him for assistance.

Let me conclude by saying that we all need to dedicate ourselves to face the safeguards problems of the future in a spirit of enlightened self interest and with full realization of the security benefits to our respective nations. It is hoped that your experience here will strengthen your foundation of knowledge for addressing safeguards issues in the context of your country's nuclear energy needs.



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



April 27-May 12, 1981

WELCOME

Svein E. Thorstensen
International Atomic Energy Agency

On behalf of the International Atomic Energy Agency I welcome you to this Advanced International Training Course on State Systems of Accounting For and Control of Nuclear Material. It is also my pleasure to extend to you the personal greetings of Dr. Eklund, our Director General, and Professor Gruemm, Head of the Department of Safeguards, with the wish that the work to be carried out in the coming two weeks will be useful to you, to your country, and to the sponsoring organizations in the interest of nonproliferation.

In his opening address to the first International Training Course on Nuclear Materials Accountability for Safeguards Purposes held here almost a year ago, Dr. Kerr pointed out that the future of the nuclear energy option might well depend on how effectively industry, state authorities, and the inspectorates can work together with the objective of achieving effective safeguards. While there are still many problems to be solved, it has been our experience over the past year that there is a growing awareness by the parties concerned of the need for, and a common interest in, improved safeguards. It has been possible to come to better understandings between industry, state authorities and the inspectorates; and safeguards effectiveness has increased. It has equally well been our experience that this improvement must continue and that there is still a long way to go. It is our sincere hope that the present training course will help to speed up this improvement. Needless to say, in a new field, which safeguards is still considered to be, there will always be a number of new ideas and at times even conflicting views. As long as we, in our work, from time to time sit back and ask ourselves if what we are doing is likely to lead to improved cooperation between the industry, the state authorities, and the inspectorates in the interest of improved safeguards, we can only hope that the progress achieved will be continued.

Last, but not least, let me thank our American hosts for making it possible for us once more to get together in such a place so ideally suited for a training course of this nature. Thank you.



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



April 27-May 12, 1981

WELCOME

Roy Nilson
Exxon Nuclear Company, Inc.

On behalf of the Pacific Northwest Laboratory of Battelle Memorial Institute and the Exxon Nuclear Company, it is with great pleasure that I welcome you in advance to Richland, Washington. Richland is located in the southeastern part of the state of Washington. It is an important nuclear area, having been both the site of the war time Hanford project and now the site of a large complex of nuclear facilities, including research centers, fuel fabrication, a fast breeder test reactor, power reactors, and fuel reprocessing.

Battelle is a multi-national, public-purpose organization. In 1964 it assumed operation of the original Hanford Laboratories (renamed the Pacific Northwest Laboratories). A major objective of Battelle is the advancement and use of science for the benefit of mankind through technological innovations, covering a broad range of research, educational and industrial development activities. Among these is a strong program of international safeguards.

Exxon Nuclear Company, a daughter of Exxon Corporation (ESSO), is a supplier of fabricated fuel and uranium for light-water reactors in the U.S., Western Europe, and the Far East. Headquartered in Bellevue, Washington (near Seattle), Exxon Nuclear has nuclear fuel manufacturing facilities in Richland and Lingen, West Germany. Research and technology facilities are also located in Richland. Exxon Nuclear's Lingen plant is under IAEA safeguards and its Richland plant was recently chosen as one of three U.S. facilities to come under IAEA inspection.

In addition to heavy nuclear involvement at Richland, you will find that the area is an important agricultural area for the growing of fruit, wheat, mint, alfalfa, wine grapes, potatoes, asparagus, cattle, etc. on land watered by vast irrigation systems furnished by the Columbia River and other streams. The Tri-Cities, which include Pasco, Richland, and Kennewick, is one of the fastest growing communities in the U.S., and one can virtually see its progress marching across the desert hills. Washington State offers much to the visitor, from the rainy warm green forests of the western part to the arid fertile desert of the east. Seattle, home of the Boeing Airplane Company, is a beautiful modern city which has nevertheless preserved its past and is strikingly set between mountain ranges to the west and east and surrounded by beautiful lakes and bays. In

the agricultural eastern part of the state, one finds massive billion watt hydroelectric dams harnessing the flow of the Columbia River and still allowing ocean salmon to migrate upstream to their spawning ground over ingenious fish ladders.

I am sorry I won't be in Richland to greet you again, but I will be at the ESARDA conference in Karlsruhe. Nevertheless, the staff of both Battelle and Exxon Nuclear have prepared amply for your visit, and I promise you an educational as well as pleasurable stay with an opportunity to make new friends in an exciting community. So, again, I say welcome.



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



April 27-May 12, 1981

Session Objectives

SESSION 1: INTRODUCTION TO TRAINING COURSE

The overall structure and format of the course will be presented together with a brief survey of the entire course curriculum.

The major components, including lecture presentations, panel discussions, hands-on equipment demonstrations, and workshop sessions will be described and participants' questions answered. Similarly, the various course materials and facilities to be used will be described and discussed.

This introduction and broad overview of the course is intended to provide participants with a perspective and general understanding of the overall objective and nature of the course from both the national and the international standpoint.



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



April 27-May 12, 1981

SESSION 1: INTRODUCTION TO ADVANCED SSAC COURSE

G. Robert Keepin
Los Alamos National Laboratory

I. INTRODUCTION

In addition to the warm welcome already extended by Don Kerr, George Weisz, Svein Thorstensen, and Roy Nilson, I'd like to add my own greetings and welcome on behalf of the training course lecturers and the course staff.

We are genuinely pleased and honored to have so many highly qualified participants in this advanced SSAC Course who are directly engaged in technical research, operations, and technical management positions in nuclear material accounting and control organizations at both the facility and national levels in your respective countries. Such excellent participation from throughout the worldwide nuclear community certainly promises a most challenging and professionally rewarding learning experience for us all during the next 16 days here in Santa Fe and in Richland, Washington.

It is abundantly clear to all of us that nuclear energy has a key role to play in supplying the growing energy needs of an increasing number of countries of the world. At the same time, we also are only too aware that nuclear fission energy is frequently under criticism and attack, usually based more on emotion than on fact. Certainly the impact of Three-Mile Island has been felt everywhere, and in its wake many have expressed pessimism about the future of fission energy. With this in mind, I'd like to open this training course on a positive note concerning the future of nuclear energy.

In a recent address, Dr. Alvin Weinberg -- long time Director of Oak Ridge National Laboratory and a well-known world leader in energy technology -- observed that "in many ways nuclear energy is a fantastic success: it is a completely new source of energy now producing, or soon scheduled to produce, about 20 exajoules per year or almost 10 percent of all the energy man now produces. This energy will come from some 500 large reactors in 36 countries. These reactors, if replaced by oil-fired plants, would require about 10^7 barrels of oil per day -- that is about one seventh of all the oil produced in the world." Weinberg also cites recent projections of a world population 50 years hence of 8×10^9 people using three to four times as much energy in 2030 as we use now. If this were to come from coal, 25×10^{10} tons of coal would have to be mined each year -- 10 times the worldwide annual rate mined at present. This Weinberg deems to be "incredible," and he adds that "the dangers of nuclear energy would pale by comparison." He quickly adds that not only coal and nuclear, but all other energy options are beset with difficulties familiar to all of us, and the hard fact is that we really cannot count on any of them with absolute certainty.

Speaking directly to the nuclear technical community, Weinberg concludes that "our responsibility as scientists and engineers is to perfect the fission system so that it remains an available, politically acceptable energy option." And as this audience is keenly aware, one very important aspect of making the nuclear energy option acceptable is effectively safeguarding the strategic nuclear materials that fuel nuclear power reactors around the world.

During the past decade of the 70s, the US, and other countries, have developed a broad safeguards technology base that was considered a necessary prerequisite to meeting the increasingly stringent requirements of safeguards and nuclear materials controls that were foreseen for the decade of the 80s. Thus the time is clearly at hand for proven new safeguards techniques and instrumentation that were developed in the 70s to be applied and implemented in facilities throughout the nuclear fuel cycle. This is, in fact, one of the major reasons for the present advanced safeguards training course and more generally for the ongoing series of international training courses on state systems of accountancy and control of nuclear materials.

As you are undoubtedly already well aware, safeguards viewpoints and concerns can differ widely between plant people on the one hand and safeguards people -- both national and international -- on the other. Recognizing this important "fact of life" in the safeguards world, we have placed considerable emphasis in this course on the interaction between 1) facility safeguards, 2) national system (SSAC) safeguards, and 3) international (IAEA) safeguards.

Now I'd like to give you a brief statement of the purpose of the course, followed by a preview of the course curriculum, so you'll know generally what to expect during the next 16 days.

II. PURPOSE AND EMPHASIS

The purpose of this advanced SSAC course can be stated very simply as follows: 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 IAEA international safeguards objectives. (See vugraph 1)

To this should be added a corollary statement that major emphasis in the course 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 LEU (low-enriched uranium) conversion and fuel fabrication plants.

By way of a general comment on the course content and level, we are well aware that most, if not all, of you have had extensive background and experience in the nuclear materials accountancy and control field, and that many of you have attended one or more of the basic SSAC courses previously offered in Vienna, in the USSR, and last year here in Santa Fe in the USA. With this in mind, we have sought to gauge this course at an appropriately high technical level. As the course proceeds, any comments, suggestions, and feedback that you may have concerning the subject matter, technical level,

mode of presentation, or effectiveness of communications will be greatly appreciated and implemented insofar as possible. In short, we want to be as responsive as we can to your needs and areas of professional interest.

III. COURSE STRUCTURE

The basic course structure is outlined as shown in vugraphs 2 - 5. Following a review of historical development and current trends in nuclear safeguards, the first major topic to be addressed is the vital area of "State Safeguards Systems and the International Interface." IAEA Safeguards experts will first review the IAEA requirements and guidelines for State Systems of Accounting and Control and then describe the establishment and practical implementation of IAEA safeguards operations at a bulk-handling facility with special emphasis on a fuel fabrication facility. This is then followed by an overview of state system requirements, taking as an example current US requirements and regulations governing nuclear material accountancy and control, as well as recent modifications to US NRC regulations to accommodate the implementation of IAEA safeguards in the United States. The concept and role of the FNNC (Fundamental Nuclear Material Control) plan will be discussed, and typical national safeguards system operations will be described and explained from the standpoint of meeting both national requirements and IAEA international safeguards.

To put in perspective the principles and actual practice of national safeguards systems on the one hand and the overlay of the IAEA international system on the other, a panel discussion entitled "IAEA - State System Interface" will address a wide range of topics from facility Design Information Questionnaires (DIQs) to reporting and assessment of inspection results (e.g. IAEA Safeguards Implementation Report [SIR]) and possible future safeguards agreements and arrangements.

The second major topic area "Safeguards Measurement Technology and Applications" begins with a survey of "traditional" measurement methods (chemistry, mass spectrometry, bulk measurements), and associated measurement standards. This is followed by a review of the newer techniques of nondestructive assay (NDA) and their applications in fuel-cycle facilities. On Thursday, April 30, we will visit the Nuclear Safeguards R&D facilities at Los Alamos for a tour and demonstration of NDA instruments and methods - both portable NDA instruments as used by safeguards inspectors, and the larger in-plant instruments typically used by plant operators and process personnel. The final day at Santa Fe will be devoted to the principles and practice of safeguards systems design and implementation. Modern near-real-time accountancy/process control systems will be described and a specific example of an operating in-plant system given, together with a discussion of methods and criteria for evaluating the performance of advanced materials accountancy and control systems. The Santa Fe portion of the course will conclude with a review, discussion and question-and-answer session covering the material presented during the first week of the course. Experts will be available for technical consultation and follow up on special problem areas or topics of specific interest to individual attendees.

The Richland portion of the course (see vugraphs 4 and 5) opens with a brief description and general plant tour of the Exxon Fuel Fabrication Plant. As already noted, this facility was selected by the IAEA for its first safeguards inspection in the United States under the terms of the recent US/IAEA agreement which entered into force in December 1980.

Following the plant tour, the plant accounting system, key measurement points, safeguards criteria and operating system characteristics are described and discussed. Lectures on the various measurement methods and techniques used at the Exxon plant are alternated with numerous tours and demonstrations of plant measurement equipment--both conventional chemical analysis and nondestructive assay methods. Measurement control, sampling plans and statistical data analysis/treatment methods used at the plant are described, as are typical national system (NRC) inspection procedures for LEU fuel fabrication plants. A mobile NDA safeguards measurement van will be visited and operation of on-board equipment demonstrated. On Saturday, May 9, course attendees will tour the Exxon plant and participate directly in the operation of a variety of in-plant analytical and measurement procedures in key process areas of the plant. To assure effective demonstration of measurement equipment and ample opportunity for individual participation, course attendees will be divided into four groups, with an Exxon instructor assigned to escort and assist each group in the demonstration and operation of in-plant equipment.

The Richland portion of the course will culminate in the workshop on safeguards system design for a fuel fabrication plant. To permit maximum individual participation, students will be divided into four subgroups for the design workshop. Based on data provided for a model LEU fuel conversion/fabrication plant, each subgroup (approximately 7 students) will work on development of a FNMC plan for the model (or reference) plant and make recommendations for establishing and implementing an appropriate measurement and accountability system. Instructors will be available to guide and assist the efforts of each workshop subgroup in system design and in solving assigned example problems. More information on the workshop, its goals and mode of operation will be provided as the course proceeds, so students should be well prepared for the workshop by the time it comes around.

Following the workshop, there will be a plenary session of all attendees in which reports on the work and results of each design subgroup will be presented by a "rapporteur" for each subgroup. The different subgroup designs will then be compared and critiqued in a panel discussion consisting of both attendees and course instructors. The panel will be quite informal and will be open to full discussion and participation from all course attendees.

In the final session of the course, attendees will be asked to complete a course evaluation form that will help gauge the effectiveness and value of the SSAC course, and point up areas where improvements can be made in future course offerings. Also in the final session, time will be allocated for general discussion, 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 the course sponsors and participating organizations.

IV. COURSE COMPONENTS, MATERIALS, AND FACILITIES

Basically, the course consists of two main components: (1) lectures, panel discussion and workshop sessions on the principles and practice of state systems of nuclear materials accounting and control and (2) demonstration, direct observation, and some "hands-on" experience with safeguards measurement instrumentation and methods in an R&D laboratory and in an operating plant environment. In addition, provision is made for consultation and follow up on special problems and specific areas of interest to individual attendees.

The major components, materials, and facilities comprising this advanced course are summarized in vugraph 6. Following the presentation and discussion of course components, mode of operation, materials and facilities, specific questions and concerns of course attendees will be solicited and addressed.

V. SOME GENERAL PERSPECTIVES ON THE COURSE

In any activity such as this involving detailed information transfer and two-way exchange, it is obvious that effective communication is absolutely essential to the success of the entire training course. And we all know that even under the best circumstances, and indeed even when there are no language or cultural differences, the accurate and effective transfer of information -- technical or otherwise -- can sometimes be difficult and frustrating. Knowing from past training course experience that language difficulties can indeed be formidable for some participants, we've asked our lecture staff to be mindful of the language factor and to speak clearly, slowly, and to make maximum use of visual presentations, vugraphs, etc., during their lecture presentations. We've tried to allow ample time for questions and discussion following each lecture, and we urge participants to take full advantage of the question periods for further clarification of session topics. We also encourage direct contact and discussions between students and lecturers (e.g. during "free-time" intervals; during and after lunch and dinner).

It is important to recognize that occasional differences in viewpoint and approach to safeguards issues and problems will sometimes be apparent among different lecturers. Such diversity clearly underscores the great need for consensus, international cooperation, and standardization in the implementation of equitable, effective safeguards on both the national and international level. Indeed, this need is an important underlying factor in the basic thrust and overall purpose of this advanced international training course.

As all of us are only too well aware, there are certain professional biases that can arise quite naturally in the normal course of inspector-inspectee interactions. In contrast to the defensive, at

times even adversary, role that can develop between the "safeguarder" and the "safeguarded" in the course of an inspection or plant inventory campaign, a professional forum such as this training course can focus objectively on the techniques and methods of accomplishing safeguards goals with minimum interference in plant operations and production.

In this connection, it is indeed gratifying that in recent years there has been significant progress in mutual understanding and mutual appreciation between plant people on the one hand and safeguards people on the other. In some US facilities, for example, in-plant test and evaluation programs of new safeguards equipment have led to new awareness on the part of both plant operators and safeguards technologists. With more in-plant test experience, safeguards technologists have acquired a fuller appreciation that the cooperation and understanding of plant people are absolutely essential to effective in-plant implementation of new safeguards techniques and instrumentation. By the same token, many of the plant people who have had involvement with in-plant test and evaluation programs have become increasingly aware of the significant contribution that modern safeguards measurement equipment and systems can make to increased plant operational efficiency and production, and hence to good overall plant economics. These and other practical issues will be further developed and discussed -- pro and con -- as the course proceeds.

Suffice it to say here, we hope this advanced course will provide you not only with the administrative and technical details of modern safeguards, but will help each one of us, through our collective interactions and deliberations, to achieve a deeper insight and basic knowledge with which to undertake the vital task of implementing effective safeguards both in our own individual countries and throughout the international nuclear community.

In closing, I'd like to express the sincere hope that the common concern and professional commitment to effective safeguards that has brought us together here in historic Santa Fe, may provide an overall theme of collegiality and a certain esprit d'corps among all of us who will be participating together in this advanced international training course.



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

April 27-May 12, 1981



PURPOSE OF COURSE

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 IAEA INTERNATIONAL SAFEGUARDS OBJECTIVES.

COURSE EMPHASIS

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 LEU (LOW ENRICHMENT URANIUM) CONVERSION AND FUEL-FABRICATION PLANTS.

Vugraph 1



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

April 27-May 12, 1981



COURSE STRUCTURE **FIRST WEEK — SANTA FE**

INTRODUCTION TO COURSE

HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS

STATE SAFEGUARDS SYSTEMS AND THE INTERNATIONAL INTERFACE

- IAEA GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL
- IAEA SAFEGUARDS OPERATIONS AT A BULK-HANDLING FACILITY
- NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS (U.S. REGULATIONS)
- NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY

PANEL DISCUSSION: IAEA-STATE SYSTEM INTERFACE

Vugraph 2

FIRST WEEK — SANTA FE (CONTINUED)

SAFEGUARDS MEASUREMENT TECHNOLOGY AND APPLICATIONS

- SURVEY OF CHEMICAL AND DESTRUCTIVE ANALYSIS METHODS
- SURVEY OF BULK MEASUREMENT TECHNOLOGY AND MEASUREMENT STANDARDS
- ELEMENTS OF NONDESTRUCTIVE ASSAY (NDA) TECHNOLOGY
- ELEMENTS OF IN-PLANT NDA INSTRUMENTATION DESIGN AND IMPLEMENTATION

DEMONSTRATION OF NDA INSTRUMENTS AND METHODS AT LOS ALAMOS

- PORTABLE/TRANSPORTABLE NDA INSTRUMENTS
- NDA INSTRUMENTS DEVELOPED FOR IN-PLANT USE

SAFEGUARDS SYSTEMS — DESIGN AND IMPLEMENTATION

- PRINCIPLES OF NEAR-REAL-TIME ACCOUNTING AND CONTROL SYSTEMS
- EXAMPLE OF AN IN-PLANT ACCOUNTANCY/PROCESS CONTROL SYSTEM
- PERFORMANCE EVALUATION OF NEAR-REAL-TIME ACCOUNTANCY SYSTEMS

REVIEW, DISCUSSION, AND CONSULTATION WITH TECHNICAL EXPERTS

Vugraph 3



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



April 27-May 12, 1981

COURSE STRUCTURE **SECOND WEEK — RICHLAND**

MATERIAL ACCOUNTING AND CONTROL AT AN OPERATING FUEL FABRICATION PLANT

- BRIEF DESCRIPTION OF EXXON FUEL-FABRICATION PLANT
- GENERAL PLANT TOUR
- MODEL PLANT KEY MEASUREMENT POINTS (KMPs)
- BASIS OF PLANT ACCOUNTING SYSTEM
- MODEL PLANT ACCOUNTING SYSTEMS
- TOUR OF UF_6 CONVERSION AREA
- MODEL PLANT ACCOUNTING SYSTEMS (CONTINUED)

MEASUREMENT METHODS USED AT THE EXXON PLANT

- BULK MEASUREMENTS (MASS, VOLUME, DENSITY, ETC.)
- ANALYTICAL METHODS (CHEMISTRY, MASS SPECTROMETRY, ETC.)
- NONDESTRUCTIVE ASSAY (NDA) METHODS
- PROCESS MONITORING
- DEMONSTRATION OF MEASUREMENT TECHNIQUES

PROCEDURE FOR TAKING PHYSICAL INVENTORIES

Vugraph 4

SECOND WEEK — RICHLAND (CONTINUED)

MATERIALS CONTROL — SEALS

MEASUREMENT CONTROL PROGRAM

PREPARATION OF FNMC PLAN AND DIQ FOR FUEL-FABRICATION PLANT

STATISTICAL ASPECTS OF MATERIALS ACCOUNTING AND CONTROL

- CALCULATING UNCERTAINTIES OF SAFEGUARDS INDICES (ERROR PROPAGATION)
- CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC
- ESTIMATION OF MEASUREMENT VARIANCES
- STATISTICAL SAMPLE PLANS

INSPECTION PROCEDURES (NRC) AND MOBILE NDA SYSTEM

MEASUREMENT DEMONSTRATIONS/STUDENT PARTICIPATION AT EXXON PLANT

WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR A FUEL FABRICATION PLANT

- WORKSHOP SESSIONS — 4 DESIGN SUBGROUPS
- REPORTS OF WORKSHOP DESIGN SUBGROUPS — PLENARY SESSION
- COMPARISON/CRITIQUE OF DESIGN SUBGROUP REPORTS

COURSE EVALUATION, DISCUSSION, AND WRAP UP

Vugraph 5



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



April 27-May 12, 1981

COURSE COMPONENTS, MATERIALS, AND FACILITIES

COURSE MANUAL/SESSION LECTURE TEXTS

- TABLE OF CONTENTS (INCLUDING LECTURERS)
- LIST OF ATTENDEES
- COURSE SYLLABUS
- COURSE SCHEDULE
- SESSION OBJECTIVES
- SESSION LECTURE TEXTS

TOUR/DEMONSTRATIONS OF SAFEGUARDS EQUIPMENT/FACILITIES

- LOS ALAMOS SAFEGUARDS R&D LABORATORY/NDA INSTRUMENTATION
- OMEGA WEST REACTOR/LAMPF FACILITY
- EXXON FUEL-FABRICATION PLANT/MEASUREMENT SYSTEMS
- MOBILE NDA SAFEGUARDS MEASUREMENT VAN

RESOURCE MATERIALS

- LECTURE REFERENCE MATERIALS
- VIDEO TAPE LIBRARY
- TV MONITORS (3)
- DOCUMENTS AND REPORTS

PANEL DISCUSSIONS/INDIVIDUAL CONSULTATION

PROFESSIONAL AND SOCIAL INTERACTIONS

ADMINISTRATIVE/TRAVEL ASSISTANCE

Vugraph 6



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



April 27-May 12, 1981

Session Objectives

SESSION 2: HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS

The historical need for and development of both national and international nuclear materials safeguards systems will be presented. Emphasis will be placed on the role and interaction of political, economic, and technical factors and the interrelation of national (state) and international systems. Current political, institutional, and technical trends will be discussed and their impact on nuclear safeguards systems considered.

After the session, participants will be able to:

1. outline the need and rationale for both national and international nuclear safeguards systems, and the need for coordination,
2. trace the development of international safeguards and the role of the IAEA in implementing international safeguards inspection and verification,
3. describe the interdependence of technology, institutional arrangements (including treaties), and national policy in international cooperation and achievement of safeguards and non-proliferation goals.



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



April 27-May 12, 1981

SESSION 2. HISTORICAL DEVELOPMENT AND CURRENT TRENDS IN NUCLEAR SAFEGUARDS

John P. Boright
State Department

I. INTRODUCTION

We have, in the United States, a saying which goes "No news is good news." With regard to public and press attention, this can be turned around to read "good news is no news." This saying is relevant to the political and public context for peaceful nuclear development and safeguards. In fact, the importance and uniqueness of the international framework for cooperation in peaceful nuclear energy is greatly underestimated. Judged relative to other efforts of the international community, this framework for cooperation is remarkably successful. The measure of this importance and success is to a large extent the fact that there has been remarkably little "news" i.e. bad news, either in the reactor safety area, or in theft/terrorist action, or diversion. Maintenance of that good record is enormously important for the continued health of international cooperation in nuclear power. In a narrower sense, "no news is good news" is an accurate description of the reporting function of IAEA safeguards. This presentation will briefly review the historical and political context of the IAEA safeguards system, its principal features, and recent developments and trends.

II. EARLY DEVELOPMENT

From the beginning, those involved in developing the use of nuclear power agonized over the apparently enormous threat of military use, and the enormous potential for peaceful benefits. Attempts to deal with this issue involved several elements, and over time the relative emphasis on these elements has undergone several changes.

Immediately following the second World War, the need for international control was stressed by several governments, and the effort at definition of such international control was launched. Already in 1946, the United States proposed an ambitious plan for international ownership or management of nuclear activities - the Baruch Plan. This plan had the advantage of being fundamentally non-discriminatory: the military use of nuclear energy was to be completely banned. The concept of international inspection was included, as was the promotion of peaceful uses of nuclear energy. This plan was not accepted, and the long laborious international process of defining and implementing some related (but more modest) steps started again.

The world has never returned to the concept of international safeguards involving physical control, ownership, and management by an international agency. "Safeguards" has ever since been a much more limited idea of monitoring and reporting.

For a period of several years, little progress was made, and tight classification was maintained on nuclear science and technology. Then in 1953 President Eisenhower proposed the Atom for Peace program. The basic approach envisaged cooperation and trade in nuclear training, materials, and technology, combined with creation of an international agency which would apply international control to nuclear material and activities.

In the United States, the legal basis for private civil nuclear activities and for cooperation with other countries is the Atomic Energy Act, passed in 1954 as a result of the Atoms for Peace initiative. Civil nuclear facilities moved rapidly. For example, the Shippingport reactor was already in operation in 1957. Hopes and projections for nuclear power, of course, grew even faster. Our first agreements for cooperation were concluded in 1955. An ambitious international training program was launched. I am continually impressed with the large number, among my foreign colleagues, of outstanding scientists, program administrators, and policy makers who worked together in the United States in this program. In fact, my review of early developments will stop here partly because I so often find real authorities on it in international groups such as this.

III. THE INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

The Statute of the IAEA sets out, in Article II, two basic objectives:

"The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose."

The international community had chosen its basic route: co-operation in civil nuclear activities, avoidance of use of that cooperation for military purpose, and the use of the IAEA to ensure such peaceful uses. The early history is replete with judgments that the military uses of nuclear weapons could not be avoided, and that widespread development of civil nuclear power would inevitably bring with it widespread nuclear weapons. Nevertheless, the international community had chosen to try.

With regard to safeguards, the Statute says:

"With respect to any...arrangement where the Agency is requested by the parties concerned to apply safeguards, the Agency shall have the following rights and responsibilities...to send into the territory of the recipient

State or States inspectors, designated by the Agency after consultation with the State or States concerned, who shall have access at all times to all places and data and to any person...as necessary to account for source and special fissionable materials..."

By the way, it also provides considerable food for thought with the following language in Article XII A 5:

The Agency shall have the right "to approve the means to be used for the chemical processing of irradiated materials solely to ensure that this chemical processing will not lend itself to diversion of materials for military purposes and will comply with applicable health and safety standards;...and to require deposit with the Agency of any excess of any special fissionable materials recovered or produced as a by-product over what is needed for the above-stated uses in order to prevent stock-piling of these materials, provided that thereafter at the request of the member or members concerned special fissionable materials so deposited with the Agency shall be returned promptly to the member or members concerned for use under the same provisions as stated above;"

This language indicates considerable foresight and concern over the presence of plutonium.

The IAEA safeguards system, fortunately, had time to develop gradually. In the early years of its existence, the job of safeguarding was mainly confined to research reactors, and, to an increasing extent, power reactors. The applicable guidance laid out in document INFCIRC/66/Rev.2, was very general with regard to specific inspection goals and methods. It did, however, provide for IAEA inspection access at all time for large facilities.

IV. THE TREATY FOR THE PROHIBITION OF NUCLEAR WEAPONS IN LATIN AMERICA AND THE NON-PROLIFERATION TREATY

Interest continued in establishment of a treaty basis for nuclear cooperation and peaceful use guarantees. One approach, of a nuclear-free-zone, was used in Latin America, where the Treaty of Tlatelolco was concluded in 1967. Consideration of nuclear-free-zones in other areas has continued. The concept of the nuclear-free-zone is based on the increase of security of States in the area by exclusion of nuclear weapons, and increase of confidence by application of IAEA safeguards to all nuclear activities in States party.

The Non-Proliferation Treaty, which came into force in 1970, is an attempt at a world-wide commitment to non-proliferation of nuclear weapons. Non-Nuclear Weapons States (NNWS) parties to the Treaty have pledged not to acquire or manufacture nuclear weapons. A NNWS party agrees to place all its nuclear activities under safeguards 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 explosive devices."

During the period just prior to entry into force of the NPT, a committee of the whole membership of the IAEA drafted a model safeguards agreement for fulfilling NPT obligations - INFCIRC/153. This model added considerable precision and specificity to concepts and approaches to IAEA safeguards, including a set of guidelines for amount of inspection and a set of protections for the inspected nuclear programs.

The NPT contains other obligations, in particular relating to promoting the fullest possible exchange of equipment, material and technology, and to measures to halt and reverse the nuclear arms race between the nuclear weapon states.

Two Review Conferences of the NPT have been held, in 1975 and 1980. These reviews have underscored the feeling of many parties that more progress must be made in nuclear arms control. The reviews have also strongly supported the importance of IAEA safeguards and stressed the need for continued development and improvement of safeguards.

V. DEVELOPMENTS IN THE MID-1970s

There were a set of interrelated developments in the mid-1970s which influenced attitudes and perceptions of the proliferation problem and of the role of safeguards. One, of course, was the nuclear explosion by India in 1974, and the resulting agonizing review by those whose cooperation or supply somehow contributed to that explosion. I believe, however, that other developments were also important. For example, oversimplified reports of potential US reactor supply to Israel and Egypt triggered considerable re-thinking in the US Congress. The increase in terrorism led naturally to concern over the presence of material which could be used for nuclear weapons. Also, the logic and rhetoric and planning of nuclear programs envisaged early and widespread reprocessing for plutonium use, primarily in breeder reactors. On the other hand, breeder programs themselves move more slowly than predicted, and resulting projections of excess plutonium appeared very ominous. At the same time, nuclear power programs lagged much behind projections, and large uranium deposits were found, also adding to questioning of the immediate need for reprocessing. Finally, increased competition for international sales of reactors and fuel led to an appreciation of the potentially very unfortunate effects of differing safeguards policies.

With regard to safeguards, these developments seemed suddenly to make the need for effectiveness much more immediate. And they led to focus on the question of what constitutes "timely" detection of diversion.

One resulting development was discussions among nuclear suppliers and the announcement by several suppliers of identical export principles. The reason for these discussions was primarily that one major supplier did not have an obligation to require safeguards on its exports. The focus was, therefore, a restatement of that export policy, and an updating of the detailed list of items which, if exported, would require safeguards.

A second development was the passage in the US of the Nuclear Non-Proliferation Act of 1978. That Act amended our basic Atomic Energy Act, making the export process and requirements more specific. It also set out general goals, and strongly supported the IAEA safeguards system.

As is quite predictable, the questioning of long-held assumptions about nuclear developments was very unsettling to people in many countries trying to move forward with nuclear power programs. This was particularly so in cases when the questioning seemed to have a weak technical basis, when cooperative arrangements seemed to be put in doubt, or when it seemed that guidelines were being set in small groups without input from the broad membership of the IAEA.

It became quite clear that we needed an open international examination of the relationship of the nuclear fuel cycle, nuclear supply, proliferation risks, and non-proliferation measures.

VI. THE INTERNATIONAL NUCLEAR FUEL CYCLE EVALUATION

The INFCE was launched in October 1977. The participating governments

"were conscious of the urgent need to meet the world's energy requirements and that nuclear energy for peaceful purposes should be made widely available to that end;

were convinced that effective measures can and should be taken at the national level and through international agreements to minimize the danger of proliferation of nuclear weapons without jeopardizing energy supplies or the development of nuclear energy for peaceful purposes;

recognized that special consideration should be given to the specific needs of and conditions in developing countries."

The magnitude of the study effort was unprecedented. The results were contained in nine volumes of final report. Obviously, all aspects of the questions were addressed in these reports, and by careful selection it can appear that INFCE endorsed just about any view. I believe, however, that an overall reading of the reports would indicate that the following points are a reasonable reflection of the analysis done:

- nuclear power will be of increasing importance in meeting electrical energy needs.

- the role of nuclear power and the fuel cycle choices in individual countries are highly dependent

on specific needs, resource availability, and technical infrastructure.

- no fuel cycle is without some proliferation risk, and there is no single technical approach which fits all needs and minimizes those risks.

- however, special approaches are necessary to minimize or deal with the more sensitive fuel cycle aspects, such as enrichment and reprocessing.

- the IAEA should play a central role in such approaches: in particular, the safeguards system must be supported and improved to deal with large future bulk handling facilities.

Beyond its specific results, the INFCE study was very useful in establishing detailed international dialogue, in removing some misunderstanding and in pointing towards certain follow-on work.

VII. CONCLUSION

This very brief review has only mentioned certain specific developments as they relate to IAEA safeguards. In conclusion, I would like to mention certain current efforts possible and future directions.

At the IAEA, a study of an international Plutonium Storage system, and of its relationship to the IAEA safeguards system, is going forward. This system could add modest but useful aspects to the application of safeguards: the declaration and verification of end use, and the avoidance of national stockpiles of separated excess plutonium.

Also at the IAEA, a Committee on Assurances of Supply is organizing its work, which will relate to safeguards aspects of supply.

The UK, France, and the US are all bringing into effect agreements with the IAEA permitting the application of IAEA safeguards in those countries. These are of considerable importance in achieving near-universal acceptance of IAEA safeguards on civil nuclear facilities.

Finally, in the United States, a new administration has indicated its strong interest in nuclear power and in stable supply relationships. We intend to work actively with the IAEA and other interested states to support its safeguards system and its technical programs of interest to members particularly in such key areas as manpower training and reactor safety.

In fact it is clear that a recurrent theme of the developments I have listed is the repeated reiteration of the importance of the IAEA and its safeguards system, and the necessity of support for improvements in the system. That emphasis will almost

certainly continue as suppliers and consumers become increasingly dependent on nuclear supply relationships.

The one uncertainty with regard to this continued support relates to the possibility of such events as diversion, abrogation, or a serious interference with IAEA safeguards by an inspected state. Such an event would be a major setback. But if the IAEA performs its functions of detection and reporting to its Board of Governors, it is likely to be able to survive such an event.

With regard to the substance of IAEA safeguards implementation, there is the question of the technical standards of IAEA safeguards. Specific requirements, in terms of quantities to be detected, detection times, or confidence in detection, have not been formally set by the Board of Governors. The IAEA has, following discussion in the Standing Advisory Group on Safeguards Implementation, adopted certain goals based on quantities and times of significance for nuclear explosives. It has been emphasized, however, that these are goals and not requirements. In fact, implementation in practice probably often does not achieve these goals. Also, the confidence in detection may not often reach the high levels which are desirable. It seems likely that the goals will be maintained, but will be approached as technical capabilities improve over time.

The application of safeguards is now encountering in practice difficult technical challenges at specific facility types, such as large enrichment, reprocessing, and fuel fabrication plants. Much of the technical development work done on safeguards is now devoted to these facility types. Success will not be easy, and will require considerable resources and dedication. As a related point, the logistics of world-wide application of IAEA safeguards will be an increasing challenge. It seems likely that new approaches to recruiting, training, and field offices may be necessary.

I would like to close with a comment related to the question of recruiting. One political point often made in the IAEA Board of Governors is the desire for some geographical balance in the recruiting of inspectors. I would like to strongly endorse that desire, and to recommend to all of you in an international group such as this that you actively seek out promising people from your own technical organizations who might serve with the IAEA. They will benefit from experience with the IAEA as well as your own organizations. The IAEA will also benefit, most importantly because the application of safeguards worldwide is greatly facilitated by the understanding and experience which its former staff bring to national systems.



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



April 27-May 12, 1981

Session Objectives

SESSION 3: IAEA GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL

This session will emphasize guidelines for the organization and functions of the SSAC with respect to obligations arising from safeguards agreements concluded by a state with the IAEA, including the elements of the system and the performance required from it.

The division among the two lectures is as follows:

- a) history and development of IAEA safeguards; establishment of authority and responsibility (requirements).
- b) establishment of requirements of nuclear material accounting and control; material balance areas and key measurement points; measurement systems; nuclear material flow; physical inventory taking; records and reports.

After the session, participants will be able to:

1. understand the basic objectives of safeguards and the legal basis for their application,
2. identify the three main features of a system of accounting for and control of nuclear material,
3. know who has the responsibility of establishing, implementing and maintaining an SSAC within a State or group of States party to a safeguards agreement with the IAEA,
4. describe the major requirements of nuclear materials accounting and control,
5. identify the organizational and functional elements of SSAC at the State level,
6. describe important elements and functions of nuclear material accounting and control.



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



April 27-May 12, 1981

SESSION 3a: GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL

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 divertors 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 1965⁷ 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 agreement 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 means 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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4. IAEA Statute, Article XII, Item A.6, p. 27.
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6. INFCIRC/26/Add. 1, The Agency's Safeguards, 9 April 1964.
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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.
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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 divertor, 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 divertor 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 divertor may present evidence that the material:

- (a) was never received at the facility in question;
- (b) was shipped to some other facility or facilities;
- (c) was discarded or accidentally lost; or
- (d) is still present at the facility:
 - (i) with complete items missing;
 - (ii) with part of the items missing;
 - (iii) with portions of materials from all items missing;
 - (iv) with a combination of (i), (ii), and (iii);
 - (v) by substituting, for the diverted material, non-nuclear material or material of lesser value to the divertor;
 - (vi) by presenting material for counting more than once;
 - (vii) 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 had previously been included in the records and reports available to the IAEA would presumably involve some falsification of these documents as part of the divertor'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 unsafeguarded 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.

In cases when the facility ships material to facilities which are not subject to IAEA safeguards, the operator may record non-existing transfers. Other possibilities would be to record measured discards in excess of those which occurred or to record shipments as having occurred just prior to the physical inventory taking, but hold the material and ship it 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 correctly a series of numbers and 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 divertor 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 1. The times listed in Table 1 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 1

IMPORTANCE OF DIVERSION*

Required Conversion of Nuclear Material to the Form Suitable for the Manufacture of Nuclear Explosive Devices	Material Form	Approximate Range of Times Required to Convert Nuclear Material to the Form Suitable for Manufacture of Nuclear Explosive Devices
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	Less than one year

*Based on the approximate time required to convert the material suitable to manufacture of nuclear explosive 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 Section 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 safeguard system, the IAEA shall be able to verify, in particular, that:

- (a) 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;
- (b) the quantities of nuclear materials on which safeguards are to be terminated, e.g., exports or consumption, are not overstated by the State; and
- (c) 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) a Safeguards Agreement between the IAEA and the State, including Subsidiary Arrangements and Facility Attachments;
- (b) 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,
- (c) 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 Section 1. 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" 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, e.g., 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:

1. provide the IAEA with information in respect to facility design features and other information relevant to safe-guards;
2. arrange that records are kept in respect of each material balance area; and
3. 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 safe-guards.^{28, 29, 30}

Accordingly, the IAEA's verification process consists of:

1. Examination of the information provided by the State in:
 - (i) design information;³¹
 - (ii) accounting reports;³²
 - (iii) special reports;³³
 - (iv) amplification and clarification of reports;²⁴ and
 - (v) advance notifications of international transfers.^{35, 36}
2. Collection of information by the IAEA in:
 - (i) inspections for verification of design information;³⁷
 - (ii) ad hoc and routine inspections;^{38, 39} and
 - (iii) 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:

1. to identify the features of facilities and nuclear material relevant to the application of safeguards to nuclear material in sufficient detail to facilitate verification;
2. 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;
3. to establish the nominal timing and procedures for taking of physical inventory for IAEA accounting purposes;
4. to establish the records and reports requirements and records evaluation procedures;
5. to establish requirements and procedures for verification of the quantity and location of nuclear material; and
6. 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:

1. 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;
2. to verify the location, identity, quantity and composition of all nuclear material subject to safeguards; and
3. 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:

1. to verify information contained in special reports; and
2. 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:

1. complete in that it covers all nuclear material that has been present in the material balance area;

2. formally correct in terms of being free of mistakes;
3. valid with respect to the actual location, identity, quantity and composition of all nuclear material subject to safeguards; and
4. 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 frequency⁴⁷ 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, i.e., 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 identified in Section 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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5. INFCIRC/153 (Corrected) Article 35
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7. INFCIRC/153 (Corrected) Article 102
8. INFCIRC/153 (Corrected) Article 113
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21. INFCIRC/153 (Corrected) Article 29
22. INFCIRC/153 (Corrected) Articles 42-45; 49-50

23. INFCIRC/153 (Corrected) Articles 51-58
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26. Annex 1 to STM, Part A
27. Annex 2 to STM, Part A
28. INFCIRC/153 (Corrected) Article 72
29. INFCIRC/153 (Corrected) Article 74
30. INFCIRC/153 (Corrected) Article 75
31. INFCIRC/153 (Corrected) Articles 43, 44, 49
32. INFCIRC/153 (Corrected) Articles 62-65, 67
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34. INFCIRC/153 (Corrected) Article 69
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37. INFCIRC/153 (Corrected) Article 48
38. INFCIRC/153 (Corrected) Article 71
39. INFCIRC/153 (Corrected) Article 72
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41. INFCIRC/153 (Corrected) Article 62
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)
46. INFCIRC/153 (Corrected) Articles 76, 77
47. INFCIRC/153 (Corrected) Article 78-81
48. INFCIRC/153 (Corrected) Articles 83-84
49. INFCIRC/153 (Corrected) Article 85

- 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



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



April 27-May 12, 1981

SESSION 3b: GUIDELINES FOR STATE SYSTEMS OF ACCOUNTING AND CONTROL

FEATURES OF SSAC FOR A BULK HANDLING FACILITY

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I. INTRODUCTION

The definition of Nuclear Material Accountancy as formulated in the IAEA Safeguards Glossary¹ provides a fairly concise summary of the features of a safeguards system at the facility, State and IAEA level:

110. Nuclear material accountancy - the practice of nuclear material accounting by the facility operator and the SSAC and, in addition, the verification and evaluation of this accounting system by a safeguards authority (SSAC or IAEA) with subsequent statements of results and conclusions which make it possible to determine the degree of assurance provided by the safeguards measures.

Accountancy includes activities such as:

Facility Level

- Dividing nuclear material operations into material balance areas (MBAs)
- Maintaining records describing the quantities of nuclear material held within each MBA
- Measuring and recording all transactions involving the transfer of nuclear material (international or domestic) from one MBA to another or changes in the amount of nuclear material present due to nuclear production or nuclear loss
- Periodically determining the quantities of nuclear material present within each MBA through the taking of the physical inventory
- Closing the material balance over the time period spanned by two successive physical inventories and computing the material-unaccounted-for (MUF) for that period
- Providing for a measurement control program to determine accuracy of measurements and calibrations, and correctness of recorded source and batch data

- Testing the computed MUF against its limits of error for indications of undetected loss
- Analyzing the accounting data to determine the cause and magnitude of mistakes in recording, unmeasured losses, accidental losses and unmeasured inventory (holdup)

SSAC Level

- Preparing and submitting accounting reports to the IAEA as appropriate
- Ensuring that the accounting procedures and arrangements are correctly adhered to
- Providing for inspector access and coordination arrangements as necessary to enable the IAEA to carry out its verification activities
- Providing for independent verification by the SSAC of facility operator's safeguards performance, as appropriate

IAEA Level

- Independently verifying nuclear material quantities and locations, using inspection methods such as: examination of accounting records and comparison with accounting reports, item counting and identification, independent measurements, verifying the operation and calibration of instruments and other measurement and control equipment, verifying information on possible causes of MUF and of shipper/receiver differences and uncertainties in the book inventory, and carrying out other activities as provided for in the safeguards agreement
- Determining the effectiveness of the SSAC
- Providing statements on the IAEA verification activities to the State
- Providing statements for the annual safeguards implementation report (SIR) for the Board of Governors on the effectiveness of IAEA Safeguards

The IAEA guidelines for States' Systems of Accounting For and Control of Nuclear Materials have been published in Reference 2. This report provides additional information that may be useful in designing an effective SSAC that is responsive to the needs of international safeguards. The information is relevant primarily to a bulk handling facility such as a fuel fabrication plant.

II. DESIGN INFORMATION AND SUBSIDIARY ARRANGEMENTS

The IAEA Design Information Questionnaire (DIQ) provides an outline of the important facility information needed during the discussion of Subsidiary Arrangements, usually before nuclear material is introduced into a new facility.

An example of a completed DIQ for a model LWR fuel fabrication plant is given in Reference 3. Reference 4 provides information on the General Part of the Subsidiary Arrangements. The contents include:

- Code 1. Regular channels of communication
- Code 2. National System of accounting for and control of nuclear material
- Code 3. Provision of information by _____ (State)
- Code 4. Provision of information by the Agency
- Code 5. Publication of information by the Agency
- Code 6. Termination of, exemption from, and reapplication of Safeguards
- Code 7. Advance notifications of international transfers
- Code 8. Model inventory for _____ (State) of nuclear material subject to safeguards
- Code 9. Inspections and Inspectors
- Code 10. Report Forms and explanations for their use

An example of a facility attachment for a model LWR fuel fabrication plant is given in Reference 5. This model facility attachment gives an example of the definition of the material balance areas, key measurement points, and the stratification of the nuclear materials according to material type and location within the facility. Complete definitions of batch data and source data are specified for each type of material and key measurement point. Other details on records, reports, and inspection activities are spelled out.

III. SAFEGUARDS APPROACH

The Safeguards approach provides information on:

- 1. Safeguards objectives and criteria;
- 2. Diversion assumption;
- 3. Material balance areas and strategic points;
- 4. Records and Reports;
- 5. Nuclear Material Verification;
- 6. Safeguards equipment; and
- 7. Inspection activities.

A detailed example for a LWR fuel fabrication plant is given in Reference 6.

IV. MEASUREMENT SYSTEM AND MEASUREMENT CONTROL PROGRAMS

At the present time, very few States have implemented measurement control programs and very few facilities provide information on measurement errors and the uncertainty of MUF.

Specific details of a measurement system for a model fuel fabrication facility is provided in Reference 3. In addition the Agency has published Part F of the Safeguards Technical Manual on Statistical Concepts and Techniques.⁷ A new volume containing improved methods of data evaluation will soon be published.⁸ These manuals provide great detail on methods of estimating measurement errors for use in a facility measurement control program, and for propagation of the errors to determine the limits of accuracy of MUF (σ MUF). Reference 9 describes a useful computer program (NUMSAS) for computing σ MUF that uses information provided in the design information questionnaire (DIQ), inventory change reports (ICR) and physical inventory list (PIL). It can be acquired on magnetic tape at a very low cost by writing to:

EURATOM PROGRAM DISTRIBUTION AGENCY
EUROCOPI - DEPT. A, JRC EURATOM
I-21020 ISPRA, ITALY

Table 1 provides a concise summary of a data acquisition plan for a measurement control program. If the data acquired are analyzed using the methods in References 7 and 8, then the uncertainty of MUF can be determined using computer codes described in Reference 9.

V. STRATIFICATION OF NUCLEAR MATERIALS

An example of stratification for a LWR fuel fabrication plant is given in Table 2. It follows the natural components of the material balance equation as provided in inventory change reports (ICR) and physical inventory listings (PIL). When the inspector carries out an inspection to verify inventory or inventory changes, he examines the facility records to establish the quantities to be verified from listings of items and batches, and sums the number of items and quantities for each stratum. He then selects a random sample of items for verification and carries out an item count to confirm the physical presence of the items in each stratum. The summing of items is very difficult in large facilities involving thousands of items. Therefore, a computerized summary for each stratum as close to the date of inspection as possible is needed before a meaningful verification can be carried out.

This verification activity could be expedited considerably if the lists provided by the facility were pre-stratified by material type and location so as to eliminate the need for manual summation of thousands of items. These needs of the inspector are briefly summarized in Table 3.

TABLE 1

TYPICAL DATA ACQUISITION PLAN FOR A MEASUREMENT CONTROL PROGRAM

Measurement	Measurement Control Procedure	Purpose
Liquid Volume Measurement	Calibration of system and periodic recheck of calibration. Check of specific gravity measurement devices by periodic measurement of process samples in the analytical laboratory. Regular inspection or testing of liquid level gauges. Independent replication of volume measurements of process materials at a frequency consistent with sound statistical practices.	To ensure accuracy and to estimate the standard deviation of the calibration. To ensure proper functioning of the instruments, to ensure accuracy, and to estimate bias. To ensure proper functioning of the instruments. To estimate the random error standard deviation of volume measurements.
Weighing	Scale* calibrations and frequent operator checks with standard weights. Periodic inspection, maintenance, and recalibration of all scales. Independent replication of weighings of process materials at a frequency consistent with sound statistical practice.	To ensure accuracy and to estimate the standard deviation of the calibration. To ensure continued accuracy. To estimate the random error standard deviation for weighing process materials.
Sampling	Mixing and sampling tests. Periodic replication of sampling by independent procedures. Analysis of independent replicate samples at a frequency consistent with sound statistical practices.	To establish operating procedures for bias-free sampling. To test for sampling bias. To estimate the combined random error standard deviation of sampling and analysis (also see Laboratory Analysis).
Laboratory Analysis	Calibration or standardization of instruments and reagents. Analysis of standard samples that simulate process samples. Analysis of independent replicate process samples. Replicate analyses of samples.	To ensure accuracy and to estimate the standard deviation of the calibration. To estimate bias. To estimate the combined random error standard deviation of sampling and analysis. To estimate the random error standard deviation of analysis.
Nondestructive Assay	Calibration of instruments. Frequent operator check of instruments using working standards. Independent replicate measurements of items at a frequency consistent with sound statistical practices. Periodic comparative analysis of items by an accepted reference analytical method.	To ensure accuracy and to estimate the standard deviation of the calibration. To ensure that the instruments are functioning properly and are within accuracy control limits. To estimate the random error standard deviation of analysis. To estimate bias.

*Scales will be used to refer to all weighing devices.

TABLE 2

STRATIFICATION OF A MATERIAL BALANCE
LEU FABRICATION

INSPECTION DATE _____	ITEMS	BATCHES	KILOGRAMS	
			U	U-235
PHYSICAL BEGINNING				
INCREASES:				
UF ₆ CYLINDERS				
UO ₂ POWDER				
DECREASES:				
FUEL ASSEMBLIES				
FUEL RODS				
SOLID WASTE				
SMALL AMOUNTS				
BOOK INVENTORY				
PHYSICAL ENDING:				
POWDER IN DRUMS				
POWDER IN HOPPERS				
UO ₂ PELLET TRAYS				
DRY SCRAP				
WET SCRAP				
SOLID WASTE				
FUEL RODS				
FUEL ASSEMBLIES				
UF ₆ CYLINDERS				
U SOLUTION				

TABLE 3

INSPECTOR NEEDS

PHYSICAL INVENTORY

1. List by Location
2. Stratified by Material Description
3. Subtotals for Material Description and Location

INVENTORY CHANGES

1. List by Location
2. Stratified by Type of IC and Material Description
3. Subtotals by Strata

MATERIAL BALANCE

1. Measurement Method Error Summary (Bulk Facility)
2. Variance of MUF Summary

REFERENCES

1. IAEA Safeguards Glossary, IAEA/SG/INF/1, Vienna 1980.
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3. Design Information Questionnaire for a Model LWR Fuel Fabrication Plant, IAEA/STR-76, Revised October 1977.
4. Subsidiary Arrangements to the Agreement between the Government of [] and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, IAEA, Fifth Revision 1974-03-12.
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ADVANCED INTERNATIONAL TRAINING COURSE ON STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS



April 27-May 12, 1981

Session Objectives

SESSION 4: IAEA SAFEGUARDS OPERATIONS AT A BULK FACILITY.

This session will emphasize the basis for IAEA inspection procedures. It will analyze the performance of IAEA inspections, including independent verification measurements, examination of records, comparison with reports, and collection of necessary data for evaluation and assessment.

Finally, the session will address the preparation of reports, and current problems involved in the various activities performed by the agency inspectorate.

After the session, participants will be able to:

1. understand basic objectives of IAEA operations at a bulk handling facility,
2. identify main features of inspection and evaluation activities.



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



April 27-May 12, 1981

SESSION 4: IAEA SAFEGUARDS OPERATIONS AT A BULK FACILITY

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I. INTRODUCTION

As the title of this session indicates, we are going to consider IAEA safeguards operations at a bulk facility, or to be more specific, mainly at a LEU fuel fabrication plant.

After this session, I hope you will be able to: (a) understand the basic objectives of IAEA operations at such a plant, and (b) identify the main features of the inspection and evaluation activities.

I will now, in sequence, consider:

- the IAEA objective, which is the basis for our activities,
- information about the LEU fuel fabrication plant under consideration,
- the background for and the selection of the basic approach, and
- incorporation of the above in a Facility Attachment (FA).

Before proceeding, I should like to point out that the IAEA is not in a position to reveal information collected during an inspection and actual FA, but only experience from negotiation and implementation of unidentified FAs. I trust you will appreciate that this will necessarily have some restraint on this presentation. I have, however, endeavored to base it on actual practices. Needless to say, there are variations in approaches to different facilities. These are caused by several factors which include:

- different types of safeguards agreements,
- plant specifics, and
- particular wishes of operators and states.

As this is an advanced course, I have made the assumption that, in addition to the information received during Sessions 2 and 3 of this course, all participants are familiar with the content of the proceedings from the "International Training Course on Nuclear Materials Accountability for Safeguards Purposes" held here in Santa Fe in May-June last year. This applies, in particular, to the three

papers presented in Session 8, "IAEA International Safeguards," by Messrs. C. Büchler, G. Hough, and L. Thorne covering the following topics:

- Objectives, Diversion of Nuclear Material, and the IAEA Safeguards Systems,
- Impacts of IAEA Safeguards on State/Facility, Records and Reports Systems, and
- IAEA International Safeguards, Inspection Procedures.

Furthermore, I also assume that the participants have a basic knowledge of LEU fabrication plant technology.

II. OBJECTIVE OF IAEA SAFEGUARDS AT BULK FACILITIES

To start with, we must, of course, define what our task is. The objective of the technical instrument is specified in NPT-type agreements as the "timely detection of diversion of significant quantities of nuclear material;" in connection with the deterrent effect, the "risk of early detection" is mentioned. This purely qualitative specification per se cannot be used to plan systematic safeguards work. It is necessary to translate terms such as "timely," "significant," or "risk" into technical detection goals that can be used to design safeguards approaches, leading, in turn, to inspection goals and to inspection plans for specific nuclear installations or fuel cycles.

This IAEA translation has continuously attracted critical interest from opposite sides, some saying the translation is too weak, others that it is too strong. In order to make the translation more transparent to parties concerned, Professor Gruemm presented a paper on this point, "Designing IAEA Safeguards Approaches," during the INMM annual meeting 1980; copies of which can be made available to those of you who may not be familiar with this paper. I do not intend here to go into a discussion of the size of figures to be adopted, but simply state the figures we use in our working plans and leave possible discussions until Session 7. Briefly, for a LEU fuel fabrication plant, the aim is to detect the diversion of 75 kg or more of contained U-235 within a time not exceeding one year. For HEU plants and mixed plutonium-uranium oxide plants, quite different and more stringent goals apply. For the present, however, we will exclude these plants from our discussion.

It should be emphasized, however, that all detection goals are not requirements, but serve as guidelines for the development of

safeguards approaches applicable to generic types of nuclear facilities; they take into account the design and operating practices of such facilities as well as the technical capabilities of safeguards measures.

Back to our LEU fuel fabrication plant. In order to get a good feeling for what the IAEA target is for a plant with an average enrichment of 2.5%, a simple calculation will show that this is about 3 tons of total uranium or approximately the content of uranium in six BWR assemblies.

III. PLANT INFORMATION

The plant under consideration is a typical medium capacity plant with the following main characteristics:

- It produces assemblies for LWR containing uranium of low enrichment, normally within the range of 2-4%.
- The foreseen annual throughput is about 350 t of uranium.
- The input material is UO_2 powder; conversion from UF_6 to UO_2 is, therefore, not made at this plant.
- Each rod contains uranium of a single level of enrichment.
- The production involves three main steps: preparation of pellets, canning of pellets in rods, and assembling of rods in fuel assemblies.
- There are four main stores: powder, sintered pellets, rods, and assemblies.
- The production is following a strict path "per enrichment;" however, more than one enrichment may be processed in parallel.
- The plant is working 5 days per week in one shift.
- Since its startup the plant has practiced one physical inventory taking (PIT) per year and has operated on a one materials-balance-area (MBA) concept.
- The plant adopted the policy to physically separate, as much as practical and feasible, the nuclear materials of the same enrichment. Furthermore, a rod scanner was installed for enrichment check of each rod.

- Based on past experience, the operator closed his materials balance with an accuracy that met international standards.

The main controls carried out by the operator at the facility boundaries may be summed up as follows:

- Control of receipts: verification of the information contained in the transfer documents by means of weighing and NDA enrichment measurement of each drum of UO_2 entering into the plant. (For each original batch of oxide the quality of the powders is also checked through sampling and analysis carried out at the shipping installation).
- The enrichment of the uranium charged into the fuel assemblies is determined at the pellet level. The continuity of knowledge of this parameter is assured by a strict physical separation of materials of different enrichment. Each rod is examined at the rod-scanner, but this is considered as a test of quality (missing pellets, pellets of different enrichment, etc.) and not of quantity.
- The total amount of UO_2 present in the fuel assemblies is determined by weighing (gross weight minus weight of structural material). The amount of uranium is calculated by using the stoichiometric ratio U/UO_2 (= U factor). The U-235 amount is calculated on the basis of the nominal enrichment verified at pellet stage, as mentioned above.

The physical inventory determination is essentially based on the following set of measurements (not necessarily made at the time of the physical inventory taking, PIT):

- Powders: (i) in input store, as described above; (ii) elsewhere: weighing, sampling, and analyses (particularly for recovered "unknown" material).
- Pellets: item weighing (or use of weight derived from stack length and density measurement), nominal uranium factor, enrichment measurement by sampling, and destructive analysis.
- Rods and Assemblies (before final "acceptance" by the facility quality control): nominal weight and measured enrichment.
- Assemblies (after final "acceptance"): actual weight and enrichment (see above).

IV. SELECTION OF BASIC SAFEGUARDS APPROACH

For bulk facilities in general, the NPT approach foreseen in INFCIRC/153 is that the materials accounting is intended to be used as a safeguards measure of fundamental importance and that the other techniques (containment/surveillance) are implemented as complementary measures to the former. This approach is acceptable as long as the expected (and realized) uncertainty in the materials balance is such that a statement on the significance of the material unaccounted for (MUF) may be made.

Let us first consider what influence this may have on the frequency of the PIT and physical inventory verification (PIV) required per year.

To evaluate the frequency of PIVs, it is assumed that accuracy for closing materials balance by operator σ_{MUF} meets international standards $\sigma = 0.3\%$, namely $\sigma_{\text{MUF}} = \sigma$. Taking into account a goal to detect protracted diversion of 75 kg U-235 per year with a confidence level of 90%, one PIV might be done for the facilities with throughput:

$$T = \frac{75 \times 10^{-3}}{e(3.29 \sigma)}$$

where

e = average enrichment,
 σ = international standard of accuracy mentioned above.

For example, for a fuel fabrication plant using 2.5%-enriched uranium, the cut-off point for choosing one or two PIVs/year would appear to be:

$$T = \frac{75 \times 10^{-3}}{(2.5 \times 10^{-2}) (3.29) (3 \times 10^{-3})} \approx 300 \text{ t U/year.}$$

While this calculation would indicate that our particular plant might require two PIVs per year, it was decided that the advantages obtained to the IAEA were not strong enough to force the operator to deviate from his established practice of carrying out one PIT per year.

Let us now consider the materials balance equation for this facility:

$$MUF = BI + R - S - EI$$

where

MUF = material unaccounted for
 EI = ending physical inventory
 BI = beginning physical inventory
 R = all receipts of nuclear material at the plant during the chosen period of time.

MUF can occur because of: scrap which remains in the process equipment, operator measurement errors, losses during processing, etc. The establishment of a materials balance is necessary for the plant operator primarily from the economic point of view. From the IAEA inspector's point of view, MUF could be an indication of possible diversion.

MUF is calculated by the plant operator with certain error limits and is reported to the Agency. Another figure of MUF should be derived from the verification activities and calculations of the IAEA inspector. This figure also has certain error limits.

The MUF figures calculated by the operator and those drawn from the IAEA inspector verification should be compared for a statement to be made by the Agency as to whether the Agency can accept the operator's materials balance for the period in question.

The use of the MUF as a statistical indicator for safeguards has, of course, only its full significance if all the materials balance entries related to it are verified 100% or randomly selected. A conventional safeguards approach would, therefore, require that such a verification by the IAEA takes place.

For our particular facility there is no problem in the case of PIV. The operator carries out a PIT during the summer holiday period with the plant in cleaned-out and static condition. The PIV is subsequently carried out by the IAEA on the basis of a sample plan.

In the case of flow verification, we do, however, run into problems, in particular for the outputs of finished assemblies from the plant. We have seen above that the operator determines the amount of UO₂ present in fuel assemblies by making various determinations along the process line. It would be easy for IAEA inspectors to verify the operators flow measurements if they were available all the

time when the operator made his determinations. It would likewise be almost impossible to make a quantitative verification if the inspector was not there at the time of the determination, but only at some time after this determination (i.e., no permanency). This would, however, have been possible if bundle monitors had been developed, which is, unfortunately, not the case.

While the operator had no objections to a resident IAEA inspector at the facility, there were other objections to this approach; namely, manpower and equipment resources available to the IAEA. At present, member states of IAEA are prepared to spend annually about 20 million dollars for the safeguards budget, roughly equivalent to the cost of a single military aircraft. Optimal allocation of these very limited financial resources is mandatory. On the one hand, concentration of resources on nuclear materials of strategic value or on sensitive facilities is necessary; on the other hand compromises among the basic detection goals must be made. As far as LEU fuel fabrication plants are concerned, it was judged to be out of the question to use resident inspectors in view of the relative lower strategic value of the feed and product materials. The Director General of IAEA informed the Board that in anticipation of the development of a bundle monitor, the IAEA would, therefore, implement a limited and provisional inspection scheme. This scheme was aimed at full (but qualitative) flow verification of fuel assemblies in particular. While IAEA inspections would initially take place at approximately monthly intervals, the Director General pointed out that the adequacy of the levels of inspection will, in particular, depend upon the cooperation of the plant operators in making arrangements that will permit adequate flow verification. Experience will show whether shortening or lengthening these intervals is necessary.

The above approach would enable the IAEA to count, identify, and seal fuel assemblies before they were sent to the reactors. It would also, to some extent, enable the IAEA to carry out flow verification of receipts. Although the approach would not provide for a quantitative flow verification of assemblies, it was aimed at partly compensating for this by "providing the Agency with a reasonable degree of assurance that undetected changes in level of enrichment of the composition of fuel assemblies were not taking place."

This was done by providing the inspectors with access to operating data and certain "strategic points" in the process area. The fabrication plant under consideration (and in practice all the plants of this type) may be considered as a sequence of "production stages"

inserted between "stores." Very roughly, this may be represented by the following sequence (see also Fig. 4-1):

- input store (UO₂ powders)
- pelletizing area
- pellet (sintered) store
- canning area
- rod store
- assembling area
- assembly store.

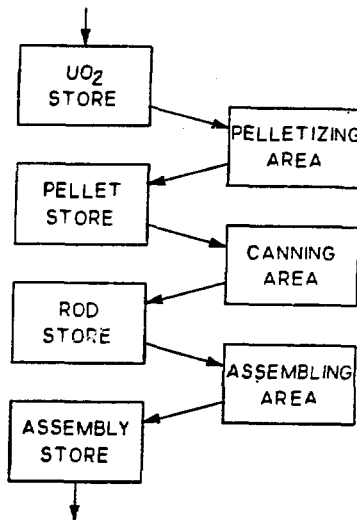


Fig. 4-1. Rough sketch of the production and storage areas sequence of the reference plant considered.

An interesting peculiarity of the production of this factory (making the verification easier) is that each rod contains uranium of a single level of enrichment and that even the assemblies contain a single enrichment. Let us recall the strict rule of physical separation of materials with different enrichments: before a new enrichment enters in a location or production stage, the area is cleaned to avoid any possible physical mixture of different materials.

The safeguards approach foresees that, at about monthly intervals, the inspectors establish the inventories of the four main stores mentioned above of one or more of the enrichment categories

of material. These verifications will enable the inspectors to establish a rough periodic balance "per enrichment" so that the correlation between subsequent situations provides evidence that the correct quality and quantity of nuclear material has been fed into the assemblies produced. The rough balances will not include the nuclear materials which are in the production areas. It is important to note that these quantities, known by the difference between the book inventory and inventories in the stores, do not vary much when the facility is in steady-state conditions. The verified quantities of nuclear material are compared monthly with the book values and checked against the relevant operating data sheets, which are considered as part of the operating records.

By taking samples at the rod loading station and by using the rod scanner, an inspector can obtain information about the quality of the operator's measurement system and some additional assurance "that undetected levels of enrichment of the composition of fuel assemblies were not taking place."

I have discussed above some details of the limited approach selected. In general, when designing a safeguards approach, we first consider in some detail the diversion possibilities and also the associated concealment methods. As a response, it follows that the overall safeguards approach must incorporate appropriate counter-measures. Table 4-1 shows a few typical possibilities which you may wish to study at your leisure. It will be noticed that, in general, the safeguard measures to counter the various concealment methods fall in two categories:

- careful audit procedures to detect falsifications, and
- physical inspection of the material, to confirm presence.

It should also be noted at this stage that we are not evaluating the interconnection of several facilities (i.e., fuel cycle approach) in this presentation.

One more point should also be mentioned in this section; namely, the establishment of the MBA (material balance area) structure. This is a point which has given and will continue to give rise to heated argument. Our guidelines state that in specifying the MBA arrangements for effective safeguards necessary within a facility, the IAEA should use, inter alia, the following criteria:

- the size of the materials balance area should be related to the accuracy with which the materials balance can be established;

TABLE 4-1

Typical examples of diversion possibilities with possible concealment methods and appropriate safeguards measures for a LEU fuel fabrication plant.

<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	Comparison of reports
	Understating amount received	Weighing, sampling, and analysis of random selection of drums received
	Inflation of measurement uncertainty	IAEA standards
	Substitution with natural or depleted uranium (for enriched uranium)	Analysis of SRDs Seals NDA measurements
	Borrowing from other facilities	Simultaneous inspections
Removal of fuel assemblies	Hollow or low-density pellets	Weighing NDA measurements
	Changing serial number of assembly and offering for re-inspection plus substitution with dummies	Seals Verification upon receipt at reactor
	Invention of shipment	Careful checking of records and item counting
	Borrowing from other sites	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)	Thorough checking of records and on-site verification at recovery plant
	Inflation of measurement uncertainty	
	Inflated processing losses	

- in determining the materials balance area advantage should be taken of any opportunity to use containment/surveillance to help ensure the completeness of flow measurements and thereby simplify the application of safeguards and concentrate measurement efforts at key measurement points;....(INFCIRC/153, para. 46(b)).

For the facility in question, a single MBA structure was accepted. The following points should, however, be noted:

- Shipper/receiver differences must be separated from MUF to permit the use of nuclear materials accounting as a safeguards measure in any facility. This separation was done by identifying a flow key measurement point (KMP) for this purpose. Often the designation KMP is used for reporting shipper/receiver differences.
- Also, in the one MBA approach, access rights inside the MBA to source data can be ensured by introducing the following footnote to the specification of strategic points which are KMPs in the FA: "These KMPs include the locations where instrument readings and measurements, relevant to the source data, are made, wherever and whenever those source data are generated."

V. FACILITY ATTACHMENT CONSIDERATIONS

All of you should be aware of the basic structure of an FA. (Copies of a model FA can be made available to those of you who are interested.)

It is not my intention here to go through an entire FA with you, but simply to identify some of the topics referred to under selected codes in the FA, which I have judged to be of particular interest, and to make some comments on these. I expect that you may wish to comment on some of these topics during Session 7.

A. Safeguards Measures, Accountancy (Code 3.1)

1. MBAs and their identification codes:

- The fuel fabrication plant constitutes one MBA, having one MBA identification code

2. Strategic points that are identified as key measurement points (KMPs)¹:

For the determination of nuclear material flow:

- KMP 1 Receipt and shipment on shipper's data of uranium, de-exemption
- KMP 2 Shipment of fuel assemblies, receipt of rejected assemblies (on operator's data)
- KMP 3 Shipment of intermediate products, exemption
- KMP 4 Measured discards, accidental losses
- KMP 5 Shipment for testing and receipt back (on operator's data) of fuel pins and assemblies
- KMP¹ Shipper/receiver difference, rebatching

For the determination of physical inventory:

- KMP A Stores of UO₂ for the material kept on shipper's data
- KMP B Stores of UO₂ and homogeneous scrap or oxide from scrap recovery for the material kept on operator's data only in building no. ____
- KMP C Pelletizing area in building no. ____, including intermediate storage of pellets
- KMP D Stores of pellets for finished pellets ready for loading or shipment
- KMP E Pin loading and inspection stations and adjacent temporary storage of pins
- KMP F Store of pins after quality control
- KMP G Assembling area

¹These KMPs include the locations where instrument reading and measurements, relevant to the source data, are made, wherever and whenever those source data are generated.

- KMP H Stores of assemblies and shipping containers in loading area
- KMP I Stores for the material kept on shipper's data
- KMP J Chemical process area including wet-scrap recovery and temporary storage locations for these materials in building no. ____
- KMP K Stores of uranium in building ____
- KMP L Experimental line in building ____
- KMP M Laboratories in building ____
- KMP N Storage of solid wastes

Comment: Note introduction of KMPs.

B. Safeguards Measures, Physical Inventory Taking (Code 3.1)

1. Nominal frequency: Once a year
2. Timing: Normally at the end of production campaigns or plant shutdowns
3. Procedures:
 - Clean-out of fabrication units, as far as practicable, and transfer of the nuclear material to the inventory KMPs
 - Item counting and identification, weighting, sampling and analyzing, if applicable
 - Proper tagging of all items on inventory
 - Preparation of an itemized list of the nuclear material on inventory grouped by batches with batch data, including number of items, material description, and location

Comment: Note flexibility of PIT to suit operator's production campaign.

C. Safeguards Measures, Containment and Surveillance (Code 3.2)

1. Strategic points for application of containment and surveillance measures:
 - Storage and process areas as appropriate
2. Installed instruments and devices to be applied in accordance with the modalities agreed upon with the operator:
 - Seals on input material until shipper/receiver difference determination
 - Seals on shipping containers of final and intermediate product
 - Seals on sample and standards containers
 - Seals on installed devices, including measuring instruments and surveillance equipment
 - Seals used for physical inventory verification purposes
 - Surveillance equipment (e.g., for detection of unrecorded movements of nuclear material during PIT/PIV)
 - Seals in addition to those above which may be broken by the operator if needed, without advance notification²
 - Seals on nuclear material which could be left sealed up to the next physical inventory verification
 - Seals for fuel assemblies if practicable

Comments: Note extensive use of containment and surveillance.

Note usual modality clause on installation of instrument and devices

²If the operator needs to break the seal or 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 instrument takes place.

D. Safeguards Measures, Strategic Points (SP) in Addition to Flow and Inventory KMPs (Code 3.3)

1. Strategic points for the interim verification of quality and quantity of nuclear material:
 - SP 1 Input powder store
 - SP 2 Main pellet store
 - SP 3 Pin store including pin-scanner
 - SP 4 Assembly weighing station and assembly storage locations
2. Strategic points for the verification of the quality of nuclear material:
 - SP 5 Pin-loading station

Comment: Note basis for limited approach referred to in paragraph 4.

E. Specifications for Strategic Point (SP) Operating Data (Code 4)

- SP 1 operator's lot identification
chemical composition
uranium factor
uranium enrichment
stock ledger
- SP 2 operator's lot identification
uranium factor
uranium enrichment
stock ledger
- SP 3 operator's lot identification
uranium enrichment
uranium factor
pin type
nominal weight of the pins and of the contained pellets
- SP 4 assembly identification
loading scheme
nominal nuclear material content

actual nuclear material content (after weighing) and weight of the structural material ledger of assemblies

- SP 5 operator's lot identification
pellet nuclear material specification

Comment: Note basis for limited approach referred to in paragraph 4.

F. Records System, Specific Provisions for Accounting Data (Code 5)

1. Inventory changes, time of recording:

- Receipts:

KMP 1 Upon receipt, on shipper's data

KMPs 2 and 5 Upon receipt, on operator's data

- Shipments:

KMPs 2, 3 and 5 Upon shipment, on operator's data

KMP 1 Upon shipment, on labeled data

- Measured discards:

KMP 4 Upon discards

- De-exemption (KMP 1), exemption (KMP 3):

Upon transfer of nuclear material out of or into the facility, respectively

- Shipper/receiver difference (KMP 1):

Upon measurements by the operator of the material received on the basis of the shipper's data. If rebatching is done prior to the receiver's measurement, material from more than one shipper should not be mixed

- Rebatching (KMP 1):

Upon rebatching

2. Measurement results used for the determination of the physical inventory, time of recording:

● All physical inventory KMPs:

Upon counting and identification, and weighing and sampling, as possible, of items during the physical inventory taking

Preparation of an itemized list of nuclear material quantities on the inventory as specified above

Adjustment and corrections, time of recording

● MUF:

After a physical inventory has been taken

● Corrections: As a new entry

whenever errors have been found, or

when the results of an improved measurement at a KMP have become available with specific reference to the entry being corrected

Comment: Note reference to shipper/receiver/rebatching KMP 1.

G. Records Systems, Specific Provisions for Operating Records
(Code 5)

1. Operating data used to establish changes in the quantities and composition of nuclear material:

- As described in the design information of the facility, dated _____
- Actual location of each item in the storage area
- Quantities, U factor, and U enrichment for each uranium "lot" in the pelletizing lines
- Pin-loading records, including the specifications of the pins production
- Identification, location, and assembly composition and weighing records

- Information on any accident that resulted in a loss of nuclear material, including date and time of loss and the relevant source data
2. Calibration of tanks and instruments, sampling and analysis, procedures to control the quality of measurements, derived estimates of random and systematic error; in particular for all KMPs:
- Date and method of the calibration and recalibration of NDA equipment and equipment for measuring weight and density, calibration data and the resulting random and systematic error of the measurement procedures, information on malfunctioning of measurement equipment
 - Date, type of material sampled, method of sampling, name or number of batch, identification number and weight (and/or volume) of each sample taken, random and systematic errors of sampling procedure
 - Date and method of the analysis of each sample taken, results of the analysis, and random and systematic errors of the measurements
 - Methods and relevant updated numerical values necessary for the calculation of random and systematic errors for each type of nuclear material measured and described
 - All relevant conversion factors used for the calculation of nuclear material quantities
3. Sequence of the actions taken in preparing for and in taking a physical inventory:
- All inventory KMPs:
- Dates and description of the actions taken and the results obtained, including an itemized list as specified
- Actions taken in order to ascertain the cause and magnitude of any accidental or unmeasured loss
- Dates and description of the actions taken and the results obtained

H. Inspections, General Conditions (Code 7)

The safeguard approach is based on the following assumptions:

- The actual inventory or annual flow (whichever is greater) will not be significantly greater than that indicated in design information.
- The annual physical inventory taken by the operator will be verified by the Agency.
- During all the inspections, verification of the ingoing and outgoing flow is made to the extent possible, using the available technical means; the main objective is full verification of the outflow.
- Inspection schedules will be adapted to the main shipping and receiving dates foreseen by the operator, who should provide early notification of these dates to the IAEA. There should be no undue concentration of inspection in a particular period of the year.
- Checks at the strategic points will be made to verify the consistency of the operating data mentioned in this FA until effective means for the verification of the complete assemblies are available.
- Each pin will contain only one level of enrichment, or category, of uranium; each assembly will contain only pins of the same level of enrichment, or category, of uranium.

Comment: Note reference to basis for limited approach described in paragraph 4 above.

I. Inspections, Routine Verification Activities

1. Evaluation of operator's measurement system:

- Observe the calibration of plant instrumentation and request recalibrations as necessary
- Observe and verify operator's analytical capability and performance
- If necessary, standards of the Agency may be submitted to the plant for measurement

2. Audit activities:

- Examine book inventory using facility data
- Examine records for self-consistency
- Reconcile reports and records

3. At flow KMPs:

- Item counting and identification
- Measurements: weighing, NDA, and sampling and analysis
- Checking integrity of seals on receipt items and application of seals on items to be shipped

4. At inventory KMPs:

The verification will include:

- Checking every line entry in the list of inventory items for existence of the item concerned and for compatibility with the tag values
- Grouping all items in the inventory into strata
- Preparation of sampling plans for the strata
- Implementation of the sampling plans through weighing, NDA, and sampling and analysis
- Application, checking, and removal of seals
- Servicing of surveillance devices

5. At containment and surveillance strategic points:

- Application, checking and removal of seals
- Servicing of surveillance devices

6. At strategic points:

- SP 1 Item identification and counting, weighing and NDA
- SP 2 Item identification and counting, and NDA on trays

- SP 3 Identification by type, counting and NDA of pins
- SP 4 Observation of weighing operations
Identification and counting of assemblies
- SP 5 Sampling of pellets, for destructive and nondestructive assay, from trays before pin-loading

These activities will be carried out periodically and will involve only a limited number of samplings.

Comment: Note impact of limited approach.

J. Agreed Estimates of the Actual Routine Inspection Efforts of the Agency

For LEU fuel fabrication plants these vary in the range 60-140.

Comment: This range is influenced by the type of agreement and plant specifics.

K. Agency Statements

A summary statement (paragraph 90a) will be made on the result of each Agency inspection.

A statement on the conclusions the Agency has drawn from its verification activities in respect of the facility (paragraph 90b) will be made within 60 days after the end of the month in which the Agency has verified a physical inventory. The statement will include, as appropriate, conclusions drawn from:

- Records examination
- Reports to the Agency
- Verification of containment and surveillance measures
- Verification of inventory changes
- Verification of material accountancy
- Verification of the quality and functioning of operator's measurement system

- Activities in respect of MUF, shipper/receiver differences and/or losses

Comment: Due to delays in receipts of physical inventory listings, material balance reports, results of analysis, etc., delays in issuing IAEA statements have been experienced. Efforts are now under way to modify the situation with an anticipated improvement on timeliness of IAEA statements.

VI. CONCLUDING REMARKS

In my welcoming remarks, I pointed out that safeguards is still a relatively new field and that there is always room for new ideas.

I am certain that you have now recognized that in the practical world even simple bulk facilities like LEU fuel fabrication plants present problems. Problems are there to be solved and I am certain with good will and cooperative spirit between industry, state systems and inspectorate, we will continue our progress.



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



April 27-May 12, 1981

Session Objectives

SESSION 5: NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS

This lecture will trace the history of the development of the U. S. national safeguards program over the past 25 years. This development will include a discussion of the changing needs for the safeguards program as well as a discussion of the interrelated roles of material accounting, material control, and physical protection systems as they have been developed to meet safeguards needs. While the lecture will stress the development of the U. S. national program, it will also include a discussion of its compatibility with international safeguards requirements as well as recent modifications that have been made in order to accommodate the implementation of IAEA safeguards in the United States.

After the session, participants will be able to:

1. understand the need for a State System,
2. understand the roles of accountability, material control, physical protection,
3. understand the similarities as well as the differences between national and international safeguards programs.



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



April 27-May 12, 1981

SESSION 5: NATIONAL SAFEGUARDS SYSTEM REQUIREMENTS

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I. INTRODUCTION

During the next two weeks you will be exposed to lectures, discussions, and other training sessions designed to improve and expand your knowledge of systems and methods that can be used to establish a state system of accountability and control over nuclear materials---an SSAC.

I want to emphasize the fact that the establishment of a strong SSAC is essential to the effectiveness of the IAEA in fulfilling its international safeguards role. The individual states, as signers of the Non-Proliferation Treaty, have an obligation to establish SSACs in support of international safeguards. Also, the establishment of a strong SSAC, as an integral part of a comprehensive overall national safeguards program, is in the best interest of the state in protecting the health and safety of its citizens.

In discussing the need for a strong SSAC for both national and international purposes, we will also examine the general features and requirements of a state safeguards system and introduce its basic elements of Material Accounting, Material Control, and Physical Protection.

II. THE NEED FOR NUCLEAR MATERIALS SAFEGUARDS AS A PRUDENT NATIONAL PROGRAM

A. Background

The development of the nuclear industry as part of a nation's energy supply system presents a potential for increasing the risk of harm to the general public from: (1) theft or diversion of special nuclear material (SNM) which can be fabricated into a nuclear explosive device or used for dispersal of radioactivity, and (2) sabotage of nuclear material or facilities leading to dispersal of radioactivity. Actions of either type may appeal to dangerous elements of society. Such elements could include criminals, motivated by personal gain (from sale of SNM or by extortion); extremists, exerting pressure for socio-political or economic change; and disoriented persons seeking revenge for some perceived wrong.

Groups that could in theory take malevolent action against nuclear plants or materials occupy a wide spectrum. For purposes of establishing safeguards controls, two categories of groups

are considered most likely to constitute a threat in the future. These are: (1) a small group of individuals possessing the highest motivation and skill needed to achieve their goals, including a willingness to receive and inflict casualties, and equipped with automatic weapons, and (2) disgruntled employees with access to nuclear fuel industry operations and thus capable of acting covertly.

The nature of special nuclear material, with its potentially high risk to the public, demands that proper safeguards precautions be observed. The general world-wide increase in terrorism has heightened concern over the possibility of attempted sabotage or seizure of nuclear materials for illicit use. Such events have in turn been widely publicized in the media with the result that public awareness and concern is growing because of this increased publicity.

For national purposes, safeguards are defined as those measures employed to deter, detect, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft or diversion, and (2) the sabotage of nuclear materials and facilities. The national safeguards program has the general objective of providing a level of protection against such acts that will insure against significant increase in the overall risk of death, injury, and property damage to the public from other causes beyond the control of the individual. To be acceptable, safeguards must take realistic account of the risks involved and of burdens on the public in terms of civil liberties, institutional, economic, and environmental impacts.

In order to deter, detect, prevent, and respond to sub-national 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 of these systems (particularly in the area of material control and accounting) are similar and complimentary to international safeguards programs that are generally considered to be a part of a State's System of Accounting and Control.

B. Definitions

At this point, I would like to introduce some general definition of the terms Material Control, Material Accounting, and Physical Protection, and discuss the roles that they play in the overall safeguards program. In the U.S. national program, we generally define these terms as follows:

Material Control is 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 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.

Physical Protection is that part of the safeguards program encompassing the equipment, procedures, and physical controls to (1) protect nuclear materials from theft or diversion through the use of access and egress controls and physical barriers, (2) detect attempts at theft or diversion through the use of surveillance measures and alarm systems, and (3) respond to attempts at theft or diversion through the use of on-site security personnel and off-site law enforcement assistance.

In a very general sense, one might look at material control and material accounting as those measures that are applied to ascertain and manage the status of nuclear materials, while physical protection measures are those that are applied to ascertain and manage the status of people.

Given the national safeguards functions of deterrence, detection, prevention, and response to the theft of nuclear materials, let us consider the role that material control and material accounting programs should play in making the overall system work.

Deterrence is the safeguards function that incorporates measures intended to discourage a potential adversary from attempting a malevolent act. Prevention is the safeguards function that consists of measures to impede or stop an adversary from successfully completing a malevolent act or successfully perpetrating a hoax. Response is the safeguards function that provides for loss Detection and assessment and for a predetermined course of action in response to an actual or alleged theft.

One other function, Assurance, can be inferred from the safeguards objective statements. Assurance is the safeguards function that incorporates measures to satisfy the state and the public that the safeguards program is in place, that it can respond effectively to a threat or an attempted malevolent act, and that nuclear materials are present in assigned locations and accounted for.

C. Roles of Material Control and Material Accounting Systems

Having structured the safeguards program into these major functions, the roles that material control and material accounting systems should perform can be described with respect to their contributions to these functions.

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 attempts 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 interruption 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 operation 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.

III. THE NEED FOR A STRONG SSAC IN SUPPORT OF INTERNATIONAL SAFEGUARDS

A. Background

The basic objective of international safeguards, as administered by the IAEA, is the timely detection of diversion of significant quantities of nuclear materials. In the international context of non-proliferation of nuclear weapons, the word "diversion" (as opposed to theft by persons of subnational organizations) is recognized to mean actions by a state to remove materials from commercial, peaceful applications and apply them to use in a weapon or nuclear explosive device. Given the growth in the peaceful uses of nuclear materials throughout the world, both in terms of the quantities of materials utilized as well as the number of nations utilizing nuclear power, the IAEA objective of early detection of diversion represents a significant challenge that is growing with each passing year. Short of utilizing massive financial and personnel resources from the member nations to continuously oversee and

directly measure and account for all aspects of the global use of nuclear materials, the IAEA system must be dependent upon the positive actions and cooperation of participating states if it is to fulfill its objective without unreasonable costs. A nationally administered and supported State System of Accounting and Control, leading to the implementation and maintenance of effective accounting and control procedures by each facility operator can and must provide the basic framework and substance of a system that will allow the IAEA to be successful in its objective in a world of limited financial resources and qualified personnel. When a structured, effective program of accountability has been established at the facility level, and when that program is administered and managed at the state level for all facilities in a comparable manner, only then can the IAEA program of periodic inspections, records examination, material verification, data analysis, and surveillance measures be effective in confidently overseeing peaceful nuclear activities. Each nation which participates in and supports international safeguards cooperation seeks and expects confidence that the IAEA can and is doing its job. Our collective confidence in the IAEA system depends heavily upon the actions of each participating nation in establishing and maintaining a State System of Accounting and Control which supports and enhances IAEA safeguards.

B. Major SSAC Components that Support International Safeguards

Let us now briefly look at the major SSAC components (IAEA-174, IAEA/SG/INF/2) which each state is expected to maintain in support of international safeguards. These overall components include:

- A system of National Regulations that incorporates into law the safeguards programs and procedures to be followed by facility operators.
- A system of Licensing or the equivalent to establish authorized uses of nuclear materials, and to incorporate a mechanism for the state review and approval of local procedures (prepared by individual facilities) to be followed in compliance with the regulations.
- A program of controlling and maintaining Compliance to the regulations and license conditions through state inspections.
- The establishment of an Information System to be used in maintaining knowledge of the status of nuclear materials within the state.
- A program of national Technical Support to provide training programs, assistance to facility operators, and research and development programs for improving material accounting and control in the state's facilities.

C. Accounting and Control

The IAEA's Information Circular #153 contains a summary of the accounting and control measures that should be included in the SSAC's program of regulations and licensing reviews. This document requires that a facility's accounting and control procedures be based upon a structure of Material Balance Areas and should include the following elements:

- 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.

D. Containment and Surveillance

In addition to the above basic elements that constitute a program of material accounting and control, there are two other general elements in the IAEA safeguards program - the elements of Containment and Surveillance. These measures are necessary in order to enable the IAEA, as part of its material control function, to monitor flows, to confirm the identity of stored material, and in general, to indicate when material present in a material balance area or facility is removed without appropriate accounting action.

As used in safeguards, the term containment refers to physical barriers, fences, transport containers, processing tanks, etc., that in some way physically restrict or control the movement of nuclear materials. Containment measures are used by plant operators for a number of reasons, e.g., physical protection of material, safety of personnel, or convenience of operations procedures. In general, containment measures are not provided specifically for international safeguards purposes, but their existence in a facility will simplify the application of surveillance devices by the IAEA. As a simple

example, it is clearly easier to observe the movements of nuclear materials from a building with one exit than from a building with ten exits. The concept of containment may help in defining material balance areas for accounting purposes, but the physical boundaries that confine nuclear material within a facility do not always correspond with boundaries of material accountancy. In other words, the existence of containment barriers is not decisive in delineating such MBA's.

Surveillance means instrumental or human observation to indicate or detect the movement of nuclear material. Surveillance instruments and devices indicate that either no nuclear material has left a certain location or that it has left only via legitimate routes. In their role of independently verifying the effectiveness of containment, surveillance instruments thus indicate whether containment of nuclear material in a location was broken or not during a certain period.

Surveillance as applied or required by the IAEA may include, for example, observation by responsible personnel, the use of tamper-resistant instrumentation or other equipment, seals to ensure that the integrity of containment has not been breached, doorway monitors to detect removal of nuclear material, closed circuit television surveillance equipment in combination with a video recorder, or film cameras, to take and store pictures for subsequent review.

In IAEA safeguards procedures, surveillance is recognized as an important measure to complement nuclear material accountancy. Surveillance is greatly assisted by the provision of containment measures, but in using surveillance devices for IAEA safeguards purposes it is recognized that:

- Their installation must be agreed to in detail with the plant operator taking due cognizance of any legal, personnel or operational requirements;
- They are designed to give information relating only to the movements of materials, to reactor operational history, etc., for IAEA safeguards purposes; and
- They are not installed for the direct observation or monitoring of plant operator's staff.

IV. SUMMARY OF AN SSAC RELATIVE TO INTERNATIONAL AND NATIONAL SAFEGUARDS

Let us now summarize the safeguards elements that have been introduced in describing an SSAC. Keeping in mind the idea that an effective SSAC is needed for both international and national purposes, we have addressed the following points.

For Both National and International Safeguards: The SSAC should include programs for Regulations, Licensing, Compliance, Information Systems, and Technical Support.

For National Safeguards: In order to deter, detect, prevent and respond to the theft of nuclear material by persons or subnational groups, the national safeguards program should include a physical protection system and SSAC regulations requiring material accounting and control measures.

For International Safeguards: In order to support the IAEA objective of timely detection of diversion of significant quantities of nuclear material, the international safeguards program should include SSAC regulations requiring material accounting and control measures. Also, the SSAC should make provisions for IAEA material accountancy and containment and surveillance measures to be applied at the facility.

V. THE SAFEGUARDS PROGRAM IN THE U.S. LICENSED SECTOR

A. Background

As a final segment of this paper, I would like to very briefly describe the U.S. licensed sector national safeguards program that we have today. But first, some background and history might be appropriate.

Prior to 1954, all special nuclear materials in the United States were owned by the U.S. Government. Only relatively small quantities of these materials existed at that time and they were protected largely in the interest of maintaining nuclear secrecy. The development of a private nuclear industry began in 1954, when nuclear materials were made available to private individuals and organizations for peaceful uses. These materials were still owned by the U.S. Government and it was not until 1964 that Congress enacted legislation authorizing private ownership of special nuclear materials.

In the mid 1960's it became apparent that development of economically attractive nuclear commercial applications would result in increasing quantities of nuclear materials in the licensed, private sector. Furthermore, these increased quantities of nuclear materials, together with the accompanying growth of nuclear fuel facilities and the spread of nuclear technology, could contribute to increased opportunities for malevolent acts involving nuclear materials unless appropriate safeguards measures were implemented. Accordingly, in July 1966, the U.S. Atomic Energy Commission established an Advisory Panel headed by R. F. Lumb, charged to conduct an independent review and appraisal of U.S. safeguards policies and procedures.

The work of that panel was reported in early 1967 and had a significant effect on U.S. safeguards policy. Previously, the scope of safeguards policy was limited, by and large, to material accountability. Prior to this time, it had been assumed that adequate control and accountability of nuclear materials would be maintained by licensed, commercial facilities because of the intrinsic value of the nuclear materials. But the Lumb report raised the issue of safeguards against subnational threats posed by criminals and terrorists. Thus, the report,

reinforced by the social turmoil and terrorism that had erupted toward the end of the 1960's, set the stage for greatly increased attention to the physical security of nuclear materials held in the licensed sector.

During the ensuing three year period between 1967 and 1970, the Atomic Energy Commission issued regulations requiring more comprehensive material control and accounting programs and establishing requirements for the physical protection of significant quantities of nuclear materials, both in transit and at fixed sites. During this same period, the U.S. national safeguards program began to develop the major components of an SSAC which were discussed earlier; a system of national regulations, licensing, compliance oversight, information systems, and technical support.

B. Present and Future Status

Today the U.S. Nuclear Regulatory Commission (NRC) is responsible for administering the safeguards program for licensed, commercial facilities. For safeguards, as well as for the other aspects of nuclear safety, the NRC has developed major program offices to administer each of the basic components. The Directors of these offices report directly to the NRC's Commissioners through an Executive Director for Operations. Safeguards regulations are developed by the Office of Nuclear Regulatory Research in close cooperation with the Office of Nuclear Material Safety and Safeguards. The licensing process is conducted by the Office of Nuclear Material Safety and Safeguards. Compliance inspections are conducted by the Office of Inspection and Enforcement, that includes five regional offices in addition to the Washington headquarters. Technical support and guidance is provided by the Office of Nuclear Regulatory Research. Additionally, technical support as well as the administration of a national information system for nuclear materials is provided by the U.S. Department of Energy in coordination with the major NRC program offices.

Although the development of a comprehensive U.S. national safeguards program (our SSAC plus physical protection system) began well over ten years ago, the program is still developing and changing. Today, we are seeking to establish a graded system of safeguards. By "graded" safeguards, I mean the application of an appropriate level of protection and an appropriate mix of physical protection and material accounting and control that recognizes the differences in the potential misuse of source materials, slightly enriched uranium, highly enriched uranium, and plutonium, both at fixed sites and during transit.

In addition to our continuing efforts to improve the national safeguards program, the U.S. is also now preparing to implement IAEA safeguards at eligible facilities in both the commercial and government sectors of the nuclear industry. The U.S. Senate ratified the treaty in July 1980 and the U.S./IAEA Agreement was implemented in December 1980. A new set of regulations for implementation of IAEA safeguards became effective in December 1980. Accounting and control measures, mainly as specified in the Facility Attachment, will be incorporated as

a condition of the license which is required for each licensed, commercial holder of nuclear materials. Facility operator compliance with procedures that support IAEA safeguards will be monitored by the NRC Office of Inspection and Enforcement. Whenever possible, NRC safeguards inspectors will accompany the IAEA during their inspections. Our national nuclear materials information system is now being modified to accommodate the reporting of accounting information to the IAEA. Technical support for facility operators who will be subject to IAEA safeguards is and will continue to be provided through site visits by NRC personnel and through our regular program of distribution of technical reports and guidance.

In summary, the U.S. experience to date has been that a well-developed State System of Accounting and Control, in addition to its original purpose for national safeguards, is serving as an excellent foundation upon which a program of international safeguards support can be efficiently and effectively added.



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



April 27-May 12, 1981

Session Objectives

SESSION 6: NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY

The presentation will center on the State System of Accounting and Control (SSAC) for bulk-handling facilities in the licenses sector of the U. S. nuclear community. Details of those material control and accounting measures dealing with the national safeguards program will be discussed in Session 6a. The concept and role of the Fundamental Nuclear Material Control (FNMC) Plan will be discussed with the participants. In Session 6b, the lecture will focus on the international safeguards program of the U. S. SSAC. The relationship of the national and international requirements will be discussed as they relate to the IAEA INFCIRC/153 document.

After the session, participants will be able to:

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



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



April 27-May 12, 1981

SESSION 6a: NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY

DETAILS OF A NATIONAL MATERIAL CONTROL AND ACCOUNTING PROGRAM

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I. INTRODUCTION

The purpose of Session 6 is to provide the course participants with details of the U.S. national and international material control and accounting (MC&A) programs, building upon the general information and framework presented in Session 5. Each of the basic elements of the national MC&A program will be discussed in some detail in this paper (Session 6a). 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 international MC&A program will be discussed in Session 6b.

Two handouts will be utilized in Session 6a to aid the course participants in understanding the U.S. national MC&A program. 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

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 even 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 program 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 FNNC 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 of 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, (> 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.

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 details 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 detailed measures proposed by each facility operator in order to assure that the facility's MC&A measures meet the MC&A requirements in the regulations. When all of the MC&A measures of 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. The facility must follow 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. This inspection program will be discussed in detail in Session 34 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 the Regulatory Guide 5.45, there are many other NRC regulatory guides which provide the facilities with specific information on the MC&A elements. In Session 29 of this course, the preparation of the FNMC Plan will be discussed in more detail.

IV. SUMMARY

The MC&A elements in the current U.S. national regulations have been described. The purpose and role of the bulk-handling facility's FNMC Plan have been addressed.

For the national MC&A program, the U.S. licensed, bulk-handling facilities must follow the MC&A regulations in 10 CFR Part 70, the approved FNMC Plan, and any MC&A license conditions that the NRC may impose.

The U.S. SSAC for licensed, bulk-handling facilities consists of the national MC&A program, plus the international MC&A program (Session 6b) for those facilities selected by the IAEA.



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



April 27-May 12, 1981

SESSION 6b: NATIONAL SAFEGUARDS SYSTEM OPERATIONS AT A BULK-HANDLING FACILITY

DETAILS OF INTERNATIONAL MATERIAL CONTROL AND ACCOUNTING PROGRAM

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I. PURPOSE

The State Authority is expected to establish the appropriate national regulations for the nuclear material control and accounting (MC&A) program. (See Reference 1.) These regulations take into account, of course, the requirements of a State's International Safeguards Agreement with the IAEA and any applicable national laws. The purpose of this paper is to provide an example of how one State Authority has fulfilled this responsibility by developing the national regulations necessary for implementing its International Safeguards Agreement with the IAEA. Related State responsibilities regarding the national MC&A program are addressed in Session 6a.

In particular, this paper discusses the national regulations, for private sector nuclear facilities in the U.S., that enable implementation of the NPT-type U.S./IAEA Safeguards Agreement. Since the U.S./IAEA Safeguards Agreement corresponds, for the most part, exactly to INFCIRC/153 and most course participants are more familiar with INFCIRC/153, the regulations in Table 1 are referenced to INFCIRC/153, which is the general model for NPT-type Agreements. This table shows how each article of INFCIRC/153 has corresponding U.S. national regulations (Reference 2) which establish a system of nuclear material control and accounting for purposes of international safeguards and enable implementation of the international safeguards at nuclear facilities licensed by the U.S. Nuclear Regulatory Commission (NRC).

It should be noted that related to these national regulations regarding international safeguards there are more detailed national regulations for national safeguards (Reference 4) for licensing, inspection, accounting, and controlling of special nuclear material. These two sets of regulations complement each other and are inter-related. How the requirements for national safeguards are implemented by facility operators is addressed in Session 5.

II. BACKGROUND

Historically, the development of a comprehensive national MC&A program in the U.S. began about 10 years ago. National MC&A regulations were developed by the NRC for commercial facilities in the private sector. These regulations (Reference 3) apply to special nuclear material.

With regard to international safeguards, the U.S. as a party to the NPT, has actively joined with other nations in an effort to limit the spread of nuclear weapons. The U.S. President signed the instrument of ratification of the U.S./IAEA Safeguards Agreement on July 31, 1980. To encourage widespread adherence to the NPT by Non-Nuclear Weapon States (NNWS), the IAEA is being permitted to apply its safeguards to nuclear activities in the U.S. The instrument for applying IAEA safeguards in the U.S., i.e. the NPT-type U.S./IAEA Safeguards Agreement, entered into force on December 9, 1980. National regulations enabling the U.S. NRC to implement this Agreement at facilities in the private sector entered into force December 24, 1980. (The Department of Energy plays a role parallel to the NRC for DOE contractor facilities in the U.S.) The IAEA has received the list of U.S. facilities which are eligible for IAEA safeguards and has already selected three of them for the application of international safeguards. The first IAEA ad hoc physical inventory verification in the U.S. was conducted at the end of March, 1981, at a low enriched uranium bulk handling facility.

III. OBJECTIVES OF THE STATE SYSTEM FOR ACCOUNTING AND CONTROL (SSAC)

An SSAC may have two distinct, but interrelated, objectives (1). The SSAC national objective, for national safeguards, is addressed in Session 5. The SSAC international objective is to provide the essential basis for the application of IAEA safeguards, which in the case of the U.S., is pursuant to the U.S./IAEA Safeguards Agreement. For both objectives, the facility operators in the U.S. are required to maintain certain material control and accounting (MC&A) procedures. Many of these procedures contribute to the attainment of both objectives. Since the NRC has established a combined system to meet the two objectives, it is necessary to distinguish clearly those requirements which are necessary for the application of IAEA safeguards. Table 1 in this paper focuses attention to the national regulations and requirements that are appropriate to the SSAC's international objective.

IV. SSAC AUTHORITY AND RESPONSIBILITIES

In the U.S., the NRC historically has been designated as a U.S. authority that has responsibilities for nuclear material accounting and control, as well as health and safety, physical protection, etc. It has responsibilities for establishing provisions, or regulations, regarding the possession, transfer, or use of nuclear materials by the commercial operators in the U.S. private sector, taking into account the U.S. obligations under the U.S./IAEA Safeguards Agreement, and ensuring that the objectives related to MC&A are met. The NRC also has responsibilities for serving as a point of contact in implementing the U.S./IAEA Safeguards Agreement with the IAEA, and for developing, approving and implementing MC&A procedures necessary to enable the U.S. to discharge its obligations under the U.S./IAEA Safeguards Agreement. In the NRC, these responsibilities are undertaken by the four main Offices for licensing, inspection, research, and standards development. In particular, this includes authority for enforcement of the regulations. For example, the operator is required to promptly notify the NRC in the event that evaluation of accounting and control information suggests losses, unauthorized use or removal of nuclear material. Penalties for non-compliance with this and other regulations for the MC&A program have been specified by the NRC.

V. BASIC ELEMENTS OF THE INTERNATIONAL MC&A PROGRAM

The U.S./IAEA Safeguards Agreement, which conforms to INFCIRC/153 (Reference 4), provides that "...the State shall establish and maintain a system of accounting for and control of all nuclear material subject to safeguards under the Agreement...", and "the Agency, in its verification, shall take due account of the technical effectiveness of the State's system." The basic elements of this system are identified in paragraph 32 of INFCIRC/153. These eight elements, paraphrased below, are addressed by the NRC's national regulations (Reference 2) for implementing international safeguards:

1. A measurement system for determination of the quantities of nuclear material transferred and on inventory;
2. The evaluation and estimation of measurement uncertainty;
3. Procedures for evaluating shipper/receiver differences;
4. Procedures for taking a physical inventory;
5. Procedures for evaluating unmeasured inventory and losses;
6. A records and reports system showing the inventory and inventory changes for each material balance area;
7. Provisions to ensure that the accounting procedures are being operated correctly;
8. Procedures for submitting reports to the IAEA.

It is noted here that Safeguards Agreements conforming to INFCIRC/66/Rev. 2, on the other hand, do not explicitly call for States to establish and maintain a system of accounting for and control of nuclear material. (See Reference 5.) However, the fact that it calls for agreement between the IAEA and the State on a "system of records" and a "system of reports" is considered to imply the need for a State system. Thus, it is recognized that the establishment of an SSAC can serve a useful purpose in all IAEA Safeguards Agreements, whether or not such a system is explicitly required.

VI. NATIONAL REGULATIONS FOR IMPLEMENTING THE U.S./IAEA INTERNATIONAL SAFEGUARDS AGREEMENT

Taking into account the requirements of the U.S./IAEA Safeguards Agreement, the NRC has established national regulations enabling the IAEA to implement its international safeguards for establishing in a timely fashion whether there has been any diversion of significant quantities of nuclear material.

Table 1 lists each article from INFCIRC/153 which was used as a model for the U.S./IAEA Safeguards Agreement, which for the most part corresponds exactly to the model. Articles in the national regulations (i.e., 10 CFR Part 75) that correspond to the Safeguards Agreement articles and give force to the Agreement are listed in parallel by general heading and particular subject. The 10 CFR 75 regulations (Reference 2) recently were developed as national requirements for purposes of international safeguards; whereas, other regulations (Reference 3) were originally developed as national requirements for domestic safeguards. There is, however, a relationship between these two sets of national requirements. In particular, many, but not all, of the material control and accounting procedures that already have been implemented for national safeguards in the U.S. will also be made use of for purposes of international safeguards. This double use

becomes apparent upon detailed analysis of the implementation of the regulations for domestic safeguards. It is expected to become clearer as more experience is gained with implementation of the new regulations for international safeguards.

In particular, the national regulations in 10 CFR Part 75 include requirements for the operator's MC&A program in the following areas:

1. Starting point, termination, and exemption from MC&A requirements. The regulations apply to all operators licensed to possess source or special nuclear material (SNM) at an installation identified on the U.S. eligibility list. Excluded from this list are mining and ore processing activities and activities having direct national security significance. 10 CFR 75.3 identifies specific types of nuclear material that may be exempted from the requirements. This corresponds to the same types of nuclear material that may be exempted from IAEA safeguards in Nuclear Weapon States (NWS) with INFCIRC/153 type Agreements.

2. Categorization of nuclear material. 10 CFR 75.22 requires that the records show for each material balance area a separate listing for each type of nuclear material, i.e., plutonium, enriched uranium, natural uranium, depleted uranium, and thorium (including isotopic composition for SNM).

3. Material balance areas (MBAs). 10 CFR 75.11 requires operators to submit sufficient design information to enable the IAEA to determine MBAs and select strategic points for key measurement points (KMPs) (for flow and inventory) and for application of containment and surveillance measures.

4. Records system. A system of accounting and operating records is required by 10 CFR 75.21. Further, the accounting records are required by 10 CFR 75.22 for each MBA to include the inventory changes, measurement results, source, and batch data. Whereas, the operating records are required by 10 CFR 75.23 for each MBA to include measurement data, calibration data, physical inventory taking procedures, and other actions.

5. Reports system. The regulations in 10 CFR 75.33 through 10 CFR 75.36 identify requirements for the reporting forms and procedures for Inventory Change Reports (ICRs), Material Balance Reports (MBRs), Physical Inventory Listings (PILs), and Special Reports.

6. Measurement system. Operators are required by 10 CFR 75.21 to establish, maintain, and follow written MC&A procedures, including a measurement system for the determination of nuclear material transfer and inventory. Procedures for evaluation of precision and accuracy of measurements and estimation of measurement uncertainty are required also.

7. Nuclear material flow. The measurement system, measurement uncertainty evaluation, requirements of 10 CFR 75.21(b) apply to nuclear material flow as well as nuclear material inventory.

8. Physical inventory taking. 10 CFR 75.21(b)(4) requires the operators to establish, maintain, and follow written MC&A procedures which include the frequency and taking of a physical inventory.

9. Shipper/receiver differences. 10 CFR 75.21(b)(3) requires facility operators to establish, maintain, and follow written MC&A procedures for the identification, review, and evaluation of differences in shipper and receiver measurements.

10. Material balance closing. Using the required measurement system, the operating and accounting records are kept for each MBA (re 10 CFR 75.22-23). Accounting reports are also based on the MBA structure (re 10 CFR 75.33).

11. Measurement Control. 10 CFR 75.21(a)-(b) require operators to establish, maintain, and follow written MC&A procedures. This requirement includes, in particular, a measurement system for nuclear material inventory and transfers. It also includes the evaluation of measurement precision and accuracy, estimation of measurement uncertainty, and evaluation of unmeasured inventory and losses. In conjunction with this, operating records are required by 10 CFR 75.23 to include calibration data for the measurement system, measurement quality control procedures, and random and systematic error estimates.

12. Application of containment and surveillance. Each licensee is required by 10 CFR 75.11 to submit sufficient design information to enable the determination and selection of containment and surveillance methods and techniques at appropriate strategic points. In particular, these techniques might include, for example, use of seals on items, containers, doors, etc., and the use of cameras during physical inventory verifications by the IAEA. In the past, the IAEA has used these techniques to monitor nuclear material flows and to confirm the integrity of stores.

13. International transfers of nuclear material. 10 CFR 75.43 requires licensees to provide to the NRC advance notification for exports and imports as well as domestic transfers between facilities in the U.S. These advance notifications must include information regarding notification time, shipping arrangements, operator authorization, and reporting information such as material description and quantity.

VII. ENFORCEMENT OF THE NATIONAL REGULATIONS BY THE SSAC

Briefly, the NRC enforcement of 10 CFR 75 relies heavily on the functions identified earlier - information system, licensing, compliance, and technical support. First, an SSAC information system has been established (jointly by NRC and Dept. of Energy) and is being maintained to handle the extensive information, reports, and other communications required by 10 CFR 75. The information, etc., is provided by the operators per 10 CFR 75.6 and related sections. This information is collected, processed, recorded, and prepared for internal evaluation as well as for submission to other organizations; e.g., to the IAEA to satisfy international obligations.

In particular, the NRC maintains a list of nuclear facilities eligible under the US/IAEA Safeguards Agreement. Facilities having facility attachments (re 10 CFR 75.8) and being inspected by the IAEA (re 10 CFR 75.42) have provided detailed design information (re 10 CFR 75.11), including extensive MC&A procedures, and continue routinely to provide accounting reports on nuclear material inventory and transfers.

Second, the NRC maintains a comprehensive licensing, audit, and inspection program to assure the operator's compliance with the regulations and to assure continued effectiveness of the SSAC. Such a program helps assure that each operator's capability and performance for MC&A satisfies the requirements of the US/IAEA Safeguards Agreement. Additional assurance is derived from independent verification at facilities by NRC inspectors that the MC&A measures implemented by the operators are effective. These assurances contribute to the establishment by the IAEA, through its own independent verification activities, whether there has been any diversion of significant quantities of nuclear material.

Particular licensing and inspection activities re 10 CFR 75 include the following:

1. Examination of the operator's design information presented in the license application (re 10 CFR 75.8 and 10 CFR 75.11) in order to determine the capability of the applicant to perform the required MC&A functions. License amendments are issued vis à vis the facility attachments.

2. Periodic inspections at the facilities to determine whether the operator's MC&A program meets performance standards. These may be performed during construction, start-up, or full operation and may include independent verification activities by the NRC.

3. Evaluation of MC&A data routinely reported by the operators to the NRC.

To secure compliance with 10 CFR 75, the NRC licensees may be subject to license modification, suspension or revocation (re 10 CFR 75.51).

Finally, the NRC has provided technical support to help develop and establish national (and international) standards and procedures for adequate measurement systems, non-destructive assay techniques, data processing, and data analysis techniques. (It is also noted that the Dept. of Energy, in addition, has for many years undertaken extensive technical support and training in MC&A through its contractor laboratories.)

V. REFERENCES

1. IAEA Safeguards: Guidelines for States' Systems of Accounting for and Control of Nuclear Materials, December 1980, IAEA/SG/INF/2.
2. Title 10 of the U.S. Code of Federal Regulations, Part 75, Safeguards on Nuclear Material--Implementation of US/IAEA Agreement, Final Rule, Federal Register (45 FR 50705), July 31, 1980.
3. Title 10 of the U.S. Code of Federal Regulations, Part 70, Domestic Licensing of Special Nuclear Material, Final Rule, Federal Register.
4. The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons, IAEA/INFCIRC/153 (corrected), June 1972.
5. The Agency's Safeguards System (1965, as provisionally extended in 1966 and 1968), INFCIRC/66/Rev. 2.

TABLE 1: NPT AGREEMENT ARTICLES AND STATE AUTHORITY REGULATIONS

<u>INFCIRC/153 Article</u>	<u>INFCIRC/153 Heading (-Subject)</u>	<u>10 CFR 75 Article</u>	<u>10 CFR 75 Heading</u>
<u>Part I</u>			
1	Basic Undertaking	Part 75 in toto (especially 75.1)	(1) (Purpose)
2	Application of Safeguards	Part 75 in toto (especially 75.2 and 75.41)	(1) (Scope and Designation)
3	Co-operation Between the Agency and the State	75.1 75.2 75.42	Purpose Scope Inspections
4	Implementation of Safeguards - interference	-	(2)
5	Implementation of Safeguards - information protection	-	(2), (7)
6	Implementation of Safeguards - IAEA effectiveness	-	(2)
7	SSAC - establish and maintain	Part 75 in toto (especially 75.1)	(1) (Purpose)
8	Provision of Information to the Agency	75.6 75.12(a) 75.12(b) 75.14 75.37	Delivery of Information, Reports, and Other Communications (8) Communication of Information to IAEA Communication of Information to IAEA Supplemental Information Disclosure of Reports to IAEA (5)
9	Agency Inspectors - inspection - information protection	75.7 75.13 75.42 75.12(b)	IAEA Representatives Verification Inspections Communication of Information to IAEA (5), (7)
10	Privileges and Immunities	-	(9)
11	Termination of Safeguards - consumption or dilution	-	-
12	Termination of Safeguards - international transfers	75.43(b) (also 75.44) (also 75.45)	Circumstances Requiring Advance Notification (Timing of Advance Notification) (Content of Advance Notification)
13	Termination of Safeguards - non-nuclear use	75.3(b)(2)	Exemptions
14	Non-Application of Safeguards	-	(6)

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INFCIRC/153 Article	INFCIRC/153 Heading (-Subject)	10 CFR 75 Article	10 CFR 75 Heading
15	Finance	75.46	Expenses (21)
16	Third Party Liability for Nuclear Damage	-	(10)
17	International Responsibility	-	(11)
18	Verification of Non-Diversion - State action	-	(2)
19	Verification of Non-Diversion - inability	-	(2)
20	Interpretation and Application of Agreement - consult	75.5	Interpretations
21	Interpretation and Application of Agreement - requests	75.5	Interpretations
22	Interpretation and Application of Agreement - disputes	75.5	Interpretation
23	Final Clauses - amendments	-	(12)
24	Final Clauses - suspension	-	(13)
25	Final Clauses - entry into force	-	(14)
26	Final Clauses - duration	-	-
Part II			
27	Introduction - specify procedures	Part 75 in toto	(1)
28	Objective of Safeguards - timely detection	-	(2)
29	Objective of Safeguards - material accountancy; containment & surveillance	Part 75 in toto	(1), (2)
30	Objective of Safeguards - technical conclusions	-	(2)
31	SSAC - used by IAEA	-	(2)
32	SSAC - established measures	75.21(a)	Material Accounting and Control:
	(a) measurement system	75.21(b)(1)	General Requirements
	(b) measurement uncertainty	75.21(b)(2)	General Requirements
	(c) shipper/receiver differences	75.21(b)(3)	General Requirements
	(d) physical inventory	75.21(b)(4)	General Requirements
	(e) unmeasured inventory and losses	75.21(b)(5)	General Requirements
	(f) reports and records system	75.21(b)(6)	General Requirements
	(g) accounting procedures	75.22	Accounting Records
	(h) reporting to IAEA	75.31	Reports: General Requirements

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<u>INFCIRC/153 Article</u>	<u>INFCIRC/153 Heading (-Subject)</u>	<u>10 CFR 75 Article</u>	<u>10 CFR 75 Heading</u>
33	Starting Point of Safeguards - mining and ore processing	75.2(b)(2)	Scope
34	Starting Point of Safeguards - transfers	75.2(b)(1) & (2) 75.41	Scope Designation
35	Termination of Safeguards	75.41	Designation
36	Exemptions from Safeguards - use	75.3(b)(1)-(3)	Exemptions
37	Exemptions from Safeguards - quantity	75.3(a)	Exemptions
38	Exemptions from Safeguards - mixed	(?)	(24)
39	Subsidiary Arrangements - detailed	75.8(a)-(e)	Facility Attachments (22)
40	Subsidiary Arrangements - entry into force	-	(4)
41	Inventory - unified by IAEA	-	(2)
42	Design Information - provided	75.11(a)	Installation Information (5)
43	Design Information - specified	75.11(b)	Installation Information (5)
44	Design Information - other information	75.14	Supplemental Information (5)
45	Design Information - modifications	75.11(c)	Installation Information (5)
46	Design Information - purposes	75.11(d)	Installation Information (5)
46(b)(iv)	Design Information - special MBA	75.11(b)(4)	Installation Information (5)
47	Design Information - re-examination	-	(2)
48	Design Information - verification	75.13(a)-(c)	Verification (5)
49	Information Outside of Facilities	-	(6)
50	Information Outside of Facilities	-	(6)
51	Records System - MBA	75.22(a) 75.23	Accounting Records Operating Records
52	Records System - examination	75.42(d)(1)	Inspections

TABLE 1: NPT AGREEMENT ARTICLES AND STATE AUTHORITY REGULATIONS

<u>INFCIRC/153 Article</u>	<u>INFCIRC/153 Heading (-Subject)</u>	<u>10 CFR 75 Article</u>	<u>10 CFR 75 Heading</u>
53	Records System - retention	75.24	Retention of Records
54	Records System - accounting and operating	75.21(b)(6)	Material Accounting & Control: General Requirements
55	Records System - measurements basis	-	(23)
56	Accounting Records - each MBA (a) inventory changes (b) measurement results (c) adjustments & corrections	75.22(a) 75.22(a)(1) 75.22(a)(2) 75.22(a)(3)	Accounting Records Accounting Records Accounting Records Accounting Records
57	Accounting Records - - batch/source data - dates/MBAs	75.22(b) 75.22(c)(1)-(2)	Accounting Records Accounting Records
58	Operating Records - (a) changes (b) calibrations, etc. (c) PIT procedures (d) loss actions	75.23 75.23(a) 75.23(b) 75.23(c) 75.23(d)	Operating Records Operating Records Operating Records Operating Records Operating Records
59	Reports System - provided to IAEA	75.31 75.37	Reports: General Requirements Disclosure of Reports to IAEA
60	Reports System - in English	-	-
61	Reports System - based on records	75.31	Reports: General Requirements
62	Accounting Reports - initial	75.31 75.32(a)-(c)	Reports: General Requirements Initial Inventory Report
63	Accounting Reports - (a) inventory change reports (b) material balance reports	- 75.33(a)(1) and (b) 75.33(a)(2) and (b) 75.35(b)	(15) Accounting Reports Accounting Reports Material Status Reports
64	Accounting Reports - inventory change reports	75.34(a)-(b)	Inventory Change Reports (16)
65	Accounting Reports - inventory changes	75.34(a)-(b)	Inventory Change Reports (16)
66	Accounting Reports - semi annual	-	(2)
67	Accounting Reports - entries	75.35(a)	Material Status Reports
68	Accounting Reports - special reports	75.36	Special Reports

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<u>INFCIRC/153 Article</u>	<u>INFCIRC/153 Heading (-Subject)</u>	<u>10 CFR 75 Article</u>	<u>10 CFR 75 Heading</u>
69	Amplification and clarification of Reports	75.31	Reports: General Requirements
70	Inspections - general	75.42(a)-(b)	Inspections
71	Inspections - ad hoc (a) initial report (b) changes (c) transfers	75.42(c)(1) 75.42(c)(1) 75.42(c)(2)	Inspections Inspections Inspections
72	Inspections - routine	75.42(c)(3)	Inspections
73	Inspections - special	75.42(c)(4)	Inspections
74	Inspections - scope	75.42(d)(1),(3),(5) 75.42(e)(2)	Inspections (17)
75	Inspections - scope	75.42(d)(2) 75.42(d)(4)-(5) 75.42(e)(1)-(2)	Inspections (17) Inspections (17) Inspections (17)
76	Inspections - access (a) ad hoc (b) ad hoc (c) routine (d) unusual circumstances	75.42(c)(1) 75.42(c)(2) 75.42(c)(3) -	Inspections Inspections Inspections -
77	Inspections - access (special)	75.42(c)(4)	Inspections
78	Inspections - frequency and intensity	-	(2)
79	Inspections - frequency and intensity	-	(2)
80	Inspections - frequency and intensity	-	(2)
81	Inspections - frequency and intensity	-	(18)
82	Inspections - frequency and intensity	-	(18)
83	Notice of Inspections - Advanced	75.42(h)	Inspections
84	Notice of Inspections - Unannounced	75.42(h)	Inspections
85	Designation of Inspectors	-	(2), (3)
86	Designation of Inspectors	-	(3)

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<u>INFCIRC/153 Article</u>	<u>INFCIRC/153 Heading (-Subject)</u>	<u>10 CFR 75 Article</u>	<u>10 CFR 75 Heading</u>
87	Conduct & Visits of Inspectors - direct operation	-	(19)
88	Conduct & Visits of Inspectors - services	-	(3), (19)
89	Conduct & Visits of Inspectors - escort	75.42(g)	Inspections
90	Agency's Statements	-	(2)
91	International Transfers - exports and imports	-	(3), (20)
92	International Transfers - exports	75.43(a)-(b)	Circumstances Requiring Advance Notification (20)
93	International Transfers - exports	-	(2), (20)
94	International Transfers - exports	-	(3), (2v)
95	International Transfers - imports	75.43(a) and (c)	Circumstances Requiring Advance Notification (20)
96	International Transfers - imports	-	(2), (20)
97	International Transfers - losses	75.36(c)(1)	Special Reports
98-116	Definitions	75.4(a)-(r)	Definitions

Footnotes

- (1) Title: "Part 75 - Safeguards on Nuclear Material - Implementation of US/IAEA Agreement," Final Rule, 31 July 1980.
- (2) This is an obligation of the IAEA.
- (3) This is an obligation of the State Authorities.
- (4) See US/IAEA Agreement for specific schedule.
- (5) See also articles 40.31(g), 50.78, 70.21.
- (6) Due to the nature of the Voluntary Offer by the U.S. as a NWS, there is no corresponding article in US/IAEA Agreement.
- (7) See, for example, 10 CFR 95, "Security Facility Approval & Safeguarding of National Security Information & Restricted Data," Final Rule.
- (8) See referenced articles: 75.7, 8, 11, 12, 13, 14, 31, 32, 34, 35, 36, 42, 43, and 44.

TABLE 1: NPT AGREEMENT ARTICLES AND STATE AUTHORITY REGULATIONS

Footnotes (continued)

- (9) See INFCIRC/9/Rev. 2 and International Organization Immunities Act of the U.S.
- (10) See the Price-Anderson Act of the U.S.
- (11) There is recourse to international law.
- (12) Regulations (e.g. 10 CFR 75) may be correspondingly amended.
- (13) See, for example, USA/Japan/IAEA Safeguards Transfer Agreement (IAEA INFCIRC/119).
- (14) 10 CFR 75 enters into force the same date that the US/IAEA Agreement enters into force.
- (15) See also articles 40.64, 70.53, 70.54.
- (16) See also articles 40.64(e), 70.53(a), & 70.54.
- (17) In particular:

<u>INFCIRC/153</u>	<u>10 CFR 75.42</u>
74(a)	(d)(1)
74(b)	(d)(5)
74(c)	(d)(3)
74(d)	(d)(5), (3) (2)(i)-(ii)
74(e)	(e)(2)
75(a)	(d)(4)
75(b)	(d)(2)
75(c)(i)	(e)(2)(iii)
75(c)(ii)	(e)(2)(iv)
75(c)(iii)	(e)(2)(v)
75(c)(iv)	(e)(2)(vi)
75(d)	(d)(5), (e)(2)(i)
75(e)	(e)(2)(ii)
75(f)	(e)(1)

- (18) Details are negotiated between the IAEA and the State Authorities.
- (19) Note, however, article 75.42(f).
- (20) For the US/IAEA Agreement, in particular, see INFCIRC/207.
- (21) See also article 170.11(a)(10).
- (22) See also Subsidiary Arrangements for US/IAEA Safeguards Agreement.
- (23) See 10 CFR 70.57, "Measurement Control Program for Special Nuclear Materials Control and Accounting."
- (24) This situation does not exist under US/IAEA Agreement.



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



April 27-May 12, 1981

Session Objectives

SESSION 7: PANEL: IAEA - STATE SYSTEM INTERFACE

Panel members will be drawn from IAEA and Course Lecture Staff (DOE, NRC, Los Alamos, Battelle/Exxon), and will be structured to encourage maximum participation by Course Attendees. Emphasis will be placed on bulk facilities such as fuel-fabrication plants. Questions and problem areas that may have arisen during the preceding lectures 1-6 will be addressed. Typical topics:

Negotiation of Subsidiary Arrangements

Use of Design Information Questionnaires (DIQs)

Negotiation of Facility Attachments

IAEA Inspection and Verification (maximize parallels with SSAC requirements)

Complementary Roles of Materials Accounting and Containment and Surveillance

Format of Records and Reports for IAEA and State Inspections

Evaluation/Assessment of Inspection Results (e.g., Safeguards Implementation Reports)

Discussion of Institutional Arrangements (e.g., future IPS, Fuel-Cycle Centers, etc.)



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



April 27-May 12, 1981

SESSION 7: SUMMARY OF PANEL: IAEA-STATE SYSTEM INTERFACE
Compiled by C. R. Hatcher and G. R. Keepin
Los Alamos National Laboratory

PANELISTS

John Boright, Department of State - Moderator
Carlos Büchler, International Atomic Energy Agency
John Foley, Los Alamos National Laboratory
Roy Nilson, Exxon Nuclear Company, Inc.
Charles (Mike) Smith, Nuclear Regulatory Commission
Svein Thorstensen, International Atomic Energy Agency

Panel Objectives and Format

The objectives and format of the panel were outlined by Course Director Bob Keepin as follows:

To consider practical experience and problem areas in the Course topics covered in sessions 1-6; in particular to consider

1. IAEA experience in establishment and operation of SSACs
2. State system experience (including some States with extensive, and others with limited, experience) in implementing an SSAC, both as regards national system requirements and IAEA international requirements
3. Practical experience of operating facilities with regard to the application of both national and international safeguards
4. Experience, concerns, and problems of those countries that are just now starting, soon to start, or in the early stages of implementing State Systems of materials accounting and control
5. Summing up of panel deliberations and overall thrust, with a view toward establishing consensus conclusions, suggestions, or recommendations that may emerge from the panel.

Panel discussion was loosely structured intentionally in order to encourage free and open exchange of experience, problems, and ideas-for-solution among all participants. After individual panelists' response to initial questions from the Moderator and ensuing discussion, the session was opened to full discussion, questions, and input directly from the floor.

Panel Moderator, John Boright, introduced each panelist and presented the format for discussion of practical experience at the international (IAEA) and the national (SSAC) level. He proposed that initial discussions focus first on the "basics" of the interaction between the IAEA and the State -- i.e., the beginning stages of interaction through the period of getting the safeguards system into initial operation. Noting that the IAEA - State System interaction is an iterative process, he cited the feedback that occurs from the Agency to the state, the reports by IAEA to its Board of Governors, and the continuing series of communications between the Agency and the inspected state. Boright indicated that the appropriate follow-on to the initial discussion of "basics" is the so-called iterative or "feedback" stage of interaction, which is also closely coupled with the continuing process of inspection and verification of a State system

IAEA Experience

Carlos Buchler of IAEA first reviewed the sequence of IAEA interactions with States. The sequence begins with the negotiation of a safeguards agreement in accordance with the legal provisions governing both the IAEA (i.e., Agency statute and INFCIRC-153 or INFCIRC-66) and the inspected State (i.e., applicable State laws, regulations, etc.). This is followed in due course by negotiation of subsidiary arrangements, and later by the more detailed facility attachments and the preliminaries to implementation such as designation of inspections, inspectors, and other arrangements. With the ~25 year evolution of safeguards, beginning with the comparatively simple project agreements, evolving through safeguards transfer agreements into the current NPT type ("full-scope safeguards") agreements, general uniformity of agreements, or uniformity of implementation, is inherently not possible because the nature of the agreements has changed. The Agency has generally succeeded in maintaining uniformity among the newer, i.e., NPT type, agreements. Nevertheless, there are differences that inevitably arise out of detailed negotiations -- differences that reflect the inherently different views, approaches, and modus operandi of different States, and even of different facility operators within a State. Such differences in the implementation of safeguards (e.g., for similar facilities in different States) can be seen as discriminatory, and this is a matter of continuing concern for the Agency. These and many other factors must be taken into consideration in the negotiation process that constitutes the pre-implementation stages of IAEA-State System interaction. Despite the difficulties, Büchler noted that these negotiations leading to safeguards agreements have (with varying degrees of difficulty) been successfully concluded with some 50 IAEA member States.

The practical matter of getting into operation and actually applying safeguards was addressed briefly by Svein Thorstensen. Some typical difficulties encountered are: 1) problems in taking attribute samples, followed by licensing and other problems in "just getting the samples out of the country"; implementation of a satisfactory reporting system; uniformity of reporting; operator knowledge

(or lack thereof) of how his own national material balance system works; problems of minimizing safeguards interference with plant operations; timely designation of approved inspectors for a given country; role of State system in coordinating safeguards activities; incorporation of safeguards requirements into new plant design at an early stage, and in general, the fostering and promotion of more positive attitudes toward safeguards on the part of facility, State system and government officials.

In response to a request from the Panel Moderator, the IAEA representatives reviewed, from an operational standpoint, the organization of the IAEA Safeguards Department into: two Divisions of Operations, A and B (each of which is divided into three regional sections, for a total of six sections covering the Agency's worldwide safeguards operations); a safeguards evaluation section (which prepares the Agency's annual Safeguards Implementation Report (SIR); a section for Safeguards Standardization; a Division of Development and Technical Support; a Division of Safeguards Information Treatment; and a recently established Safeguards Training Unit.

Also discussed briefly was the very pragmatic matter of initiating inspection procedures via an ad hoc arrangement (Article 71-A of the Safeguards Agreement) that provides for interim inspection until detailed Facility Attachments can be negotiated. This ad hoc arrangement also provides for establishing contact between appropriate IAEA and State safeguards officials and marks the beginning of the very important process of building mutual trust and confidence between the two organizations.

US Experience at National and Facility Levels

John Boright outlined the necessity for each country, through its established government channels, to define the communication/authority relationship that provides the mechanism for the State's formal interaction with the Agency in all safeguards matters. Mike Smith of NRC then explained the modes through which the State system in the US (i.e., the NRC) interacts with other government offices. He cited as examples NRC review of DIQs, participation with State Department in negotiation of Facility Attachments, and NRC coordination of interactions between the IAEA and US facilities designated for IAEA inspection -- the first case in point being the recent ad hoc inspection at the Exxon fuel-fabrication facility in Richland, Washington.

An operator's perspective on the IAEA ad hoc inspection at the Exxon plant (conducted in March, 1981) was then provided by Roy Nilson of Exxon Nuclear who made the following general observations: 1) the operator must be an important part of the negotiation of Facility Attachments (he noted Exxon was involved in developing facility attachments for the Exxon plant in Lingen, FRG (Germany), and said this kind of industry involvement is necessary for industry support of IAEA safeguards), 2) measurements must be shown to be necessary, 3) good communication between the plant operator

and inspector is very important (he cited the language problem), and 4) the objectives of the inspection must be stated at the outset so that the operator understands the need for the sampling plan, verification measurements, etc. In general, Nilson concluded, if there is a mutual understanding of what the Agency wants and what the operator can do, there can develop a spirit of cooperation and degree of mutual trust that will make IAEA safeguards work, and help to achieve better understanding and acceptance of safeguards by facility operators and the nuclear industry.

John Boright then made the follow-on point that much of the expertise in the nuclear area resides in the industry, and that good safeguards must involve this expertise, to the ultimate benefit of both the plant operator and the overall effectiveness of safeguards. This is especially true in new safeguards situations, such as enrichment or reprocessing plants, where the process knowledge and expertise of plant people are indispensable, both in the design and the operation of safeguards systems for such complex bulk processing facilities. Boright and other panelists further pointed out the great value of having qualified people from the nuclear industry serve on the Agency staff for a period of time; the IAEA benefits from their practical knowledge of facility operations, and industry benefits in the long run by having operator personnel with a better understanding and appreciation of IAEA safeguards.

Problems of Implementing IAEA Safeguards

The IAEA representatives on the panel pointed out the Agency's need for more inspectors from developing countries and the two-fold problem of 1) too few applicants from developing countries, and 2) the need for training and improving the qualifications of those applicants who are accepted for IAEA safeguards inspector positions. This was cited as further underscoring the importance of a well-coordinated basic and advanced training program for safeguards inspectors.

In response to questions from Theodore Hürlimann (Switzerland) and Edwin McKay (Canada) concerning the cost of safeguards, the Panel pointed out that the major portion of costs are not in the materials accountancy and control area, but in physical security, surveillance, environmental protection, etc. Also the incorporation of advanced safeguards technology at an early stage of plant design was again stressed as far more efficient and economic than back-fitting at a later stage.

Answering another question from the floor, John Boright emphasized that Agency safeguards goals -- Significant Quantities and Detection Times -- are indeed goals that are to be recognized as such, and are not rigid numbers or absolute requirements. Responding to requests by Piero Vanni (Italy) and Gilbert Verstappen (Belgium) for comment on the necessity, and the cost, of shutdown and cleanout, Thorstensen of IAEA observed that cleanout is actually necessary, in any case, for the operator to determine what are his

in-plant material amounts and locations, and that this would be the case even without safeguards. He further commented 1) that the IAEA frequently tries to schedule inventory campaigns at times most convenient to the operator (occasionally even during Christmas and holiday shutdowns) and 2) the IAEA's task of verifying a given inventory-taking procedure is greatly aided and expedited when the plant operator already has in place an efficient and effective inventory procedure of his own -- again underscoring the importance of an effective in-plant safeguards system, for both national and international safeguards.

Need for Safeguards Training and Technology Transfer

Andrej Pietruszewski of Poland outlined the problems faced by many developing countries whose interest is typically focused just on reactors. Such countries may have a "fuel cycle" that begins with the receipt of fresh fuel from a supplier nation and terminates with the shipment of spent fuel (often sent directly back to the original supplier nation). Under these circumstances, the national SSAC safeguards system may consist of two or three people only, so that one individual must be able to perform nearly all safeguards tasks at two basic levels: 1) knowledge of regulations, records, and reports (i.e., all the basic information required to establish book value of material inventory) and 2) knowledge of measurement techniques for assay and accountability of nuclear material, for detecting physical inventory. Mr. Pietruszewski then asked if there is help available from, or through, the IAEA in technical training on NDA measurements and techniques for determining physical inventories.

In response to this and other inquiries concerning training in modern safeguards technology specifically, Bernardino Pontes of IAEA outlined the Agency's training program of basic and advanced courses -- both the series of courses for IAEA inspectors (the Agency's eight-weeks ICAS course plus advanced training courses at Los Alamos, Sandia, and elsewhere) and the present SSAC courses (basic and advanced) designed for Member State safeguards personnel.

Panelist John Foley also described the NDA technology courses regularly offered at Los Alamos including 1) Fundamentals of Non-destructive Assay of Fissionable Material Using Portable Instrumentation, 2) Advanced Gamma-Ray Spectroscopy for Nuclear Material Accountability, 3) Advanced Passive and Active Neutron-based NDA Techniques for Safeguards, and 4) Advanced Systems for Nuclear Materials Accounting. It was noted that while these courses are usually attended by IAEA, USNRC, and USDOE safeguards inspectors, some of the Los Alamos courses have in the past been attended by SSAC safeguards personnel from other countries. In addition, Foley noted, individual specialized training is provided on an extended time basis at Los Alamos for suitably qualified safeguards technologists from the IAEA and other countries (e.g., individual training has been provided to safeguards specialists from Japan, Korea, and Turkey.)

(Mid-Afternoon Break)

SSAC Staffing Requirements/The Need for Guidelines

After the mid-afternoon break, Viktor Dimic (Yugoslavia) raised the question of how small countries whose present nuclear facilities consist of only one or two reactors could organize their state system in the most simple and efficient way, particularly with regard to manpower.

John Boright and Mike Smith both said they were unaware of any written guidance or recommendations concerning what might be considered reasonable staffing or budget levels needed to establish and maintain an SSAC.

Several course participants then described the numbers and types of people supporting the SSAC in their own country:

- o Andrzej Pietruszewski said that Poland has two MTRs currently operating, each with one material balance area (MBA). In this situation two people are able to handle all records and reporting requirements. If Poland developed other nuclear facilities, the need might arise for safeguards training of industrial personnel, and the question was raised if such training might be provided by the IAEA.
- o Cheong Won Cho said that Korea has plans for a large nuclear program. Four to five people have received training in safeguards over a period of two to three years, and they have now designed and implemented their own reporting system. To meet commitments, it has been necessary to itemize priorities into categories such as regulations, technical measurements (NDA and DA), negotiations with the IAEA, etc.
- o Bernardino Pontes reviewed the situation in Brazil as of 1974. There were three small research reactors, one pilot fuel-fabrication plant and one power reactor under construction. The safeguards staff consisted of a total of four engineers, two engineers with backgrounds in chemistry and two with backgrounds in physics. Organizationally, one person was the supervisor and three were inspectors. Two individuals specialized in domestic safeguards and one in international safeguards.
- o Rudi Roenick said that Brazil is now ready to begin full scale operation of a fuel fabrication plant. He noted that they are starting on enrichment, are one year away from having a conversion facility, and may consider reprocessing in the future. Their approach to recruiting safeguards personnel has been to bring in people from industry with a background in quality assurance. Finding people and training them in the area of nuclear material measurement technology has been a problem, and for example, there is now only one person involved in safeguards at the fuel-fabrication plant. Mr. Roenick strongly emphasized the need for

cost and manpower guidelines. To help deal with problems of maintaining equipment, Roenick recommended standardizing safeguards instruments among all countries.⁽¹⁾

In closing out this subject, Panel Moderator John Boright said that concerns about SSAC infra-structure, manpower, and costs are important to every country, and that there may be a need for an IAEA advisory committee to consider such organization and manpower questions. In assessing manpower and costs associated with domestic safeguards, one should take care not to include the costs associated with perferial items such as quality assurance and physical protection.

The Need for Assistance to States in Implementing SSACs

From the subject of staffing requirements, the panel and course participants moved on to examine the types of assistance that States need in order to implement stronger SSAC's.

Bernardino Pontes recapitulated the difficulties that developing countries encounter due to the lack of trained personnel available for assignments in both domestic and IAEA safeguards. He said that since the necessary training involves both basic nuclear science and safeguards technology, the IAEA's Safeguards Training Unit could not possibly provide all of the training needed.

Roy Nilson indicated that it should be possible in some cases for a country to buy not only a nuclear reactor from a commercial supplier, but also the training, equipment, and technical assistance necessary to implement safeguards at such a facility.

(1) Rudi Roenick's point concerning the need for standardization of safeguards instruments was not responded to immediately, but shortly before the end of the session, John Foley returned to the subject. Foley said that Roenick had raised an important point, one that Los Alamos people appreciated because of their difficulties in helping to maintain equipment Los Alamos has supplied to the IAEA. Part of the difficulty arises because most instruments used in safeguards are not supplied on a large scale, and availability of instruments, repair parts, and service is frequently poor. Los Alamos is trying to cut down on the number of types of instruments used by standardizing on a few small modules. For example, the electronics module supplied with the high-level neutron coincidence counter (HLNCC) for measuring plutonium has also been used in other neutron instruments supplied to the IAEA for measuring cans of UO₂ powder, fuel drawers, and fresh fuel assemblies.

Carlos Buchler pointed out that some of the problems associated with the lack of adequate manpower and resources for training might arise because governments do not recognize the importance of safeguards. Safeguards are not easy to "sell" because there is no "product", if safeguards does its job and all goes well. Perhaps the IAEA and highly developed countries can best help by emphasizing the importance of safeguards, particularly at the national level.

Svein Thorstensen and Carlos Buchler both commented on the fact that the IAEA has, in a number of cases, provided teams for consultation and help to member states regarding their national systems, pointing out that the Agency advice had largely concerned technical aspects and not organization or personnel matters. Thorstensen said that since it was clearly in the self-interest of the IAEA to see state systems improved, he felt (in retrospect) that the Agency should take more initiative with the states in this regard. People involved in the implementation of state systems should be given the opportunity to get together to exchange ideas, so that each can take advantage of what can be learned from the experience of others. Perhaps this is an area in which the Agency's Safeguards Training Unit can take more responsibility.

Chung-Lu Lo (Taiwan) said that when the Agency (in one case) had sent a team of three people for four days to provide training and advise on SSAC problems, an understanding had been achieved, and it had been very, very helpful to his country.

Suror Mahmoud (Iraq) suggested that when inspectors visit countries, they might spend extra time there to give lectures on safeguards and discuss the latest techniques.

Mike Smith (NRC) mentioned the assistance that the US had provided to Korea regarding the development of their SSAC. John Boright said that the US has provided help in specific areas when requested (for example, tasks requested by the IAEA under the US Program of Technical Support), and that it might be useful to provide such support on a more generic basis.

In addition to the need for IAEA assistance in the form of safeguards training and technology transfer, a number of course participants indicated the need for help in explaining the importance of safeguards to plant operators and government authorities.

Andrzej Pietruszewski (Poland) said that an exchange of lecturers and technical experts would help, and also that Agency films have been useful.

Porfirio Palafox Garcia emphasized that nuclear safeguards is not always a popular subject. Facility people can view safeguards as an imposition, and governments may not be completely supportive. Svein Thorstensen said that part of the function of the national system is to make safeguards more acceptable, and industry is gradually coming to view safeguards as being in its own interest because

of public relations. Responding to Thorstensen, Garcia pointed out that it appeared that developing countries need help from the IAEA, while the IAEA needs help from the countries. In this situation, perhaps the answer must come from the "super-developed" countries.

Arrangements for Further Discussion of State Systems

Mike Smith agreed to meet with interested parties at the close of the panel discussion to provide further detail on the US state system. This informal meeting on the US system began at 6 p.m. and continued for approximately two hours.

Richard Olsson (Sweden) offered to present a brief summary of Sweden's state system on the following day. Because of the tight schedule during this part of the course, Olsson's presentation was rescheduled and presented during the bus ride to the Los Alamos safeguards laboratories on 30 April 1981.

Desire by Panel and Course Participants to Make Recommendations Known to the IAEA

As the session drew to a close, John Boright and Svein Thorstensen questioned how the views expressed during the session might be permanently recorded. They were told by the course director that the entire discussion would be available on video tape and that, in addition, a written synopsis would be included as part of the published course proceedings.

Viktor Dimic then restated two important recommendations that had been made earlier. One recommendation was that the Agency should take the initiative in getting State people together as soon as possible to discuss their experience in the practical implementation of SSACs. The second recommendation was that the IAEA should find ways to help convince governments of the importance of domestic safeguards.

Hafiz Higgy (Egypt) added another recommendation that had been touched on by several others. He said that industrial countries (who are nuclear suppliers) must take into consideration the developing countries' need for training. This will do much to help the Agency and the entire field of safeguards.

Panel Moderator John Boright noted, in summary, that a number of points had been made consistently by course participants during the session and should be reflected in the record. He added that any formal recommendations, if deemed appropriate, should be made through established channels where all parties are properly represented, such as, perhaps, the IAEA General Conference, the Board of Governors, or the annual Safeguards Implementation Report. The Panel adjourned at approximately 6:00 p.m.



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



April 27-May 12, 1981

Session Objectives

SESSION 8: SURVEY OF CHEMICAL AND DESTRUCTIVE ANALYSIS METHODS

Conventional methods of determining the concentration and isotopic composition of nuclear materials in the nuclear fuel cycle are reviewed. Problems of representative sampling and measurement uncertainties as they apply to conventional analytical problems are discussed.

After this session, participants will be able to:

1. describe current chemical and mass-spectrometric methods typically used to characterize nuclear materials,
2. describe basic techniques for obtaining samples representative of bulk liquid, powder, or solid materials,
3. identify principal sources of error for the above methods.



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



April 27-May 12, 1981

SESSION 8: SURVEY OF CHEMICAL AND DESTRUCTIVE ANALYSIS METHODS

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I. INTRODUCTION

Various chemical and nondestructive analytical techniques are required for either conventional or near-real-time accounting as well as for process control in nuclear facilities. Classical closure of a material balance requires high precision and accuracy for product input and output measurements. Near-real-time accounting places a premium on criteria associated with timeliness. Overall measurement system efficacy depends on such factors as standards, sampling, and the applicability of a measurement technique to a specific measurement point. This session surveys analytical chemistry methodology applicable to determining uranium and plutonium in nuclear materials with emphasis on fuel fabrication, conversion, and reprocessing.

II. SAMPLING PROBLEMS AND TECHNIQUES

The purpose of a sampling program is to obtain material for characterization that is representative of the bulk material in analysis; no analytical method can provide accuracy or precision that is better than that associated with obtaining an increment that is truly representative of the total population. In addition to the normal operations of selecting, splitting, and compositing the material, sampling also may encompass ancillary operations such as grinding, evaporating, drying, and screening. For on-line or in-line measurements, sampling may be as simple an operation as installing the measuring device directly in the process line or into a bypass line that samples a fraction of the process stream.

Samples may be in the form of solids, powders, or liquids (and occasionally gases). Samples derived from reprocessing operations may be associated with fission product activity of thousands of curies per kilogram. Each type of material presents its own unique sampling problems. This section reviews some of the basics of sampling; more detailed descriptions are found in Ref. 1, pp. 25-56 and Ref. 2.

A. Sampling of Liquids

Liquids in process materials normally are sampled using an air-lift sampling system. The air-lift sampling system should be designed to permit extensive recirculation of solutions through the sample lines and the sample bottle. Vessel sparging, mixing time, and sample-circulation time should be considered in establishing proper sampling procedures for replicate analyses. Any solids must be dissolved after sampling and be included in the total analysis.

For highly radioactive samples the possibility of bubble formation must be considered in volume measurements, and temperature corrections should be applied.

The main sources of sampling error for solutions are expected to be (1) concentration or dilution of the sample by the air-lift system, (2) incomplete mixing of the solution in the tank, (3) contamination of the sample in the sample lines, and (4) sample heterogeneity caused by suspended solids. Where analytical precision better than 0.5% is required, all sampling should be done on a weight basis rather than a volume basis. Remote volume samplers seldom can provide routine precision better than 0.5%, and even normal volumetric measurements are no better than 0.2% on a routine basis.

A sampling apparatus capable of providing pipetting accuracy of 0.1% under hot-cell conditions has been described.³ All steps, including pipet rinsing, are performed remotely, and the Teflon piston surface does not touch the solution being pipetted.

B. Sampling of Powders

Sampling of process powders to obtain a representative sample generally is more difficult than sampling liquids. Sample heterogeneity may be a function not only of such factors as mixing but also of particle size and proximity to the surface. Sampling plans must be properly designed to assure representative samples. Flowing streams generally are easier to sample than bulk containers. Powder samples are obtained using dippers, scoops, core samplers, powder thief probes, or rifflers.

Samples may be further subdivided using a splitting or riffling technique. Alternatively, the total sample may be dissolved and suitable aliquots removed for analysis.

C. Problems Associated with Sampling

Obtaining a homogeneous sample does not necessarily assure a representative sample. Care must be exercised that the sample form or composition is not altered after sampling. In the case of liquids, evaporation or radiolytic decomposition of the solution is a concern if subsamples are obtained subsequently. Dilution of plutonium nitrate solutions with water leads to formation of plutonium polymers that could precipitate or adsorb on container surfaces.⁴ Therefore, plutonium nitrate solution should be diluted with some concentration of nitric acid rather than with water.

Powders of UO_3 and PuO_2 are hygroscopic and gain weight rapidly, particularly in humid atmospheres. Powders of UO_2 may change mass through air oxidation as well as by moisture adsorption.

III. MEASUREMENT UNCERTAINTIES

The topic of measurement statistics will not be discussed here--that will be covered in subsequent sessions--but it is necessary to introduce the concept of measurements relative to true values.

For any analytical or physical measurement, one is never absolutely certain that the measured value represents the true value of the measured parameter. Two basic types of errors contribute to this uncertainty.

First, if we perform multiple analyses of the same material, we cannot exactly duplicate the sample either in quantity or quality (sampling error) or perform the measurement in exactly the same manner (measurement error). These errors are commonly referred to as random error of sampling and random error of measurement. The combination of these two errors, the random error of the analysis, is a measure of how precisely we can reproduce the same value for the measurement, or the precision of the analysis.

Secondly, after we have performed the analyses and obtained the best estimate of the quantity we are measuring, we cannot be sure that the measured value equals the true value. Contributing factors to this uncertainty could result from uncertainties (biases) in reference materials used in calibrating instruments or procedures or unknown biases in the instruments or procedures. These errors are referred to as systematic errors and are a measure of how accurately we can reproduce the true value, or the accuracy of the analysis.

IV. ELEMENTAL METHODS OF ANALYSIS

A. Gravimetric Methods

Gravimetric methods involve separating a compound of the element to be determined and igniting it to a constant-weight stoichiometric compound. The technique is applicable only to relatively pure materials; impurities must be determined by spectrographic or other procedures and the final weight corrected by difference. When clean separations from impurities can be obtained, precisions better than 0.1% often can be realized.

1. Uranium. Gravimetric methods can be used for the determination of uranium in pure product streams such as uranyl nitrate, U_3O_8 or UO_2 , and UF_6 . Nitrates are evaporated to dryness; UF_6 is hydrolyzed in H_2O and evaporated to dryness. Ignition is at 850-900°C to U_3O_8 and the final weighing provides a relative standard deviation (RSD) of 0.02 to 0.5% (Ref. 1, pp. 70-74). Ignition at temperatures >946°C leads to formation of UO_2 ; temperatures <800°C yield slow decomposition reactions.⁵ Presence of NO_3^- , F^- , Cl^- , or SO_4^{2-} does not interfere, but the presence of PO_4^{3-} leads to formation of uranyl pyrophosphate rather than U_3O_8 .⁶

2. Plutonium. Of the plutonium precipitates, only PuO_2 is reported to form a compound suitable for gravimetric analysis (Ref. 7, pp. 297-298). Even with PuO_2 the stoichiometry of the compound depends on initial composition and ignition temperatures, and even when the compound is heated to 1200°C the final composition is variable. In addition, PuO_2 is hygroscopic, with the amount and rate of H_2O adsorption dependent upon the ignition temperature. The suitability of gravimetry for determination of plutonium is questionable.

B. Spectrophotometric Methods

Spectrophotometric methods rely on the principle that a compound or complex in solution will absorb light of a specific wavelength in a quantity proportional to the concentration of the measured species.

Generally, the concentration-absorbance function is a simple proportional relationship expressed by Beer's law, but variations may result at high concentrations or when other competing reactions occur. The RSD attainable by direct spectrophotometric methods usually is 0.5% or more and is seldom better than 0.2%. However, it can be improved to 0.05% with differential techniques that compare the absorbance of the unknown to a reference that is known precisely.

Specificity in spectrophotometry is a complex function of factors such as sharpness of absorption bands, specificity of reagents, other elements or compounds present, and the quality of the monochromators. Specificity often can be improved by using preliminary separations, masking agents, and pH control. Because of the non-specificity of reagents for uranium and plutonium in the presence of each other and because of the nuclear reaction products (americium, neptunium, fission products), time-consuming separations often are involved. These additional separations may limit the precision in major element analysis. For these reasons, spectrophotometric methods are of limited use for measuring uranium and plutonium in fuel cycle materials and are usually restricted to process control applications and analysis of waste streams.

The sensitivity of many spectrophotometric reagents to high radiation levels necessitates several supplemental separations during analysis of dissolver or waste-stream solution, even in the absence of elemental interference.

1. Uranium. Spectrophotometric methods for determining uranium in reprocessing streams generally are limited to measurement of trace concentrations of uranium in waste streams and possibly in the final product plutonium. Reagents of interest are listed in Table I.

The method for determination of uranium with 2-(2-pyridylazo)-5-diethylaminophenol (PADAP) has been modified specifically for determining uranium in reprocessing-plant waste streams¹² and in plutonium nitrate and oxide products.¹³ The method for determination of uranium as the tetrapropylammonium complex has been automated for determining uranium and plutonium simultaneously in scrap materials.¹⁹

The uranyl-nitrate method^{8,9} used for in-line process control is sensitive to variations in nitric acid concentration and temperature and lacks the precision required for safeguards applications. Browning of the optics can be a serious problem in process streams containing fission products. However, by measuring absorbance at two wavelengths with an on-stream detector, the method has been adapted to measure uranium concentration in-line with a precision of 3%.²⁶

2. Plutonium. Most chromogenic reagents that react with plutonium also yield intensely colored species with uranium and many fission products; therefore, if plutonium is to be determined in reprocessing samples, a separation is required. For low plutonium concentrations, methods such as x-ray fluorescence, alpha, or gamma spectrometry may be preferred.

The tetrapropylammonium method²² is of interest because uranium and plutonium can be determined sequentially in the same sample. The method has been automated.¹⁹

TABLE I
SPECTROPHOTOMETRIC METHODS FOR DETERMINATION OF URANIUM AND PLUTONIUM

Element	Compound	Concentration Range or Amount/Sample	RSD (%)	Interferences; Comments ^a	Ref. No.
U	Uranyl nitrate	10-300 g/L	1-5	Temperature-sensitive	8,9
U	Dibenzoylmethane	30-750 μ g	1.7	Ce, Th, W, Fe(III), Cr(IV); Pu at Pu/U = 2	1, ^b 10
U	Peroxide	1-25 mg		Cr, Cu, Fe, Mn, Ni	1, ^c 11
U	PADAP	1-100 μ g	5	As ⁵⁺ , Cr ³⁺ , V ⁵⁺ , PO ₄ ³⁻ , SiO ₄ ²⁻ , Pu, Pd; Pu removed by extraction	12,13
U	PAR	1-100 μ g	1	R.E.'s, Th(IV), Pu(IV)?	14
U	5-Me-2-PAN	10-80 μ g	?	F ⁻ ; extraction removes most interfering cations	15
U	Bromo-PADAP	0.5-100 μ g	2	Cr ³⁺ , V ⁵⁺ , PO ₄ ³⁻	16
U	Tetrapropylammonia	0.12-14 mg	0.3-10	Ce, Th	1, ^d 17,18,19
U	Arsenazo-III	1-50 μ g	1-10	Th, Pu, R.E.'s, others	20,21
Pu	Tetrapropylammonia	1-30 mg	0.2-2	Cr ⁶⁺ , Th	19,22
Pu	Pu(III) nitrate	12-18 g/L	0.05	Differential spectrometry	23,24
Pu	Arsenazo-I	5-100 μ g	2-6	U, Zr, others	25

^aR.E. = rare earth; fp = fission product.

^bRef. 1, pp. 337-343.

^cRef. 1, pp. 222-225.

^dRef. 1, pp. 343-353.

The differential spectrophotometric method of determining plutonium²³ can be used for plutonium-nitrate product with precision and accuracy equivalent to that obtainable by the best electrometric methods for the analysis of scrap material.²⁴

A rapid off-line spectrophotometric method has been described for determining plutonium in dissolver and other reprocessing samples.²⁷ Plutonium is oxidized to the hexavalent state using AgO; neodymium is added as an internal standard; and plutonium and neodymium absorbances are measured in the near infrared region. Fission-product activity to 500 Ci/L and uranium concentration to 400 g/L do not interfere for determining 1-5 g/L of plutonium. Precision of better than 1.5% (1 σ) and an accuracy of 0.5% is claimed for an analysis time of 1 h.

C. Electrometric Titration Methods

Both uranium and plutonium can be determined with high precision and accuracy by the use of titrations involving oxidation-reduction reactions. Electrometric methods are classified by the technique used to detect the titration end point, such as potentiometric, amperometric, or coulometric. All of these methods can provide RSDs of better than 0.1%. To attain the highest precision, weight burets should be used in all critical volume measurements.

Potentiometric titrations are based on measurement of the change in potential of the system as a component is removed by oxidation or reduction. Because the change in potential is the critical measurement, the accuracy of potentiometric titrations is limited by the sharpness of the potential break at the equivalence point. An RSD of 0.02 to 0.5% is attainable; therefore, the method is used for measurement of final product such as U_3O_8 , UF_6 , PuO_2 , or $Pu(NO_3)_4$.

Amperometric titrations involve measurement of the change in current between two electrodes that are maintained at a constant potential as titrant is added. The precision of amperometric titrations is limited by the accuracy of the inflection point measurement in the current-titration curve; hence the potential is selected such that the limiting current for either reactant, titrant, or product can be measured, depending on which yields the sharpest end point.²⁸

Controlled-potential and constant-current coulometry are well-established methods for determining uranium and plutonium in solutions. Both methods are based on the principle that the weight of a substance oxidized or reduced at an electrode is proportional to the quantity of electric charge passed through the electrode.²⁸ In controlled-potential coulometry the potential of the electrode is maintained at a constant value relative to a reference electrode to minimize the number of reactions that can take place. Interference from the reactions occurring at lower potentials can be eliminated by performing a preliminary coulometric titration at a potential such that those reactions have occurred before measurements are started. Reactions requiring higher potentials cannot occur. Both uranium and plutonium can be titrated in the same sample without separation by performing successive titrations at different potentials. In constant-current coulometry an electrogenerated reagent reacts with the substance to be determined.

Coulometric methods can provide RSDs of 0.1% without the use of chemical standards. Generally, smaller samples are required than for potentiometric or amperometric measurements. Coulometric methods have gained increased popularity in recent years, but the determination of plutonium is subject to the following considerations (Ref. 29).

- The method is applicable to the determination of plutonium in nitrate product solutions and in dissolver solutions following an anion-exchange separation of fission products.
- The titration can be performed in $1N$ $HClO_4$, $1N$ HNO_3 , $1N$ H_2SO_4 , or $1N$ HCl electrolytes. However, any Pu^{6+} , if present, is only partially reduced to Pu^{3+} in HNO_3 , HCl , or $HClO_4$; therefore, $1.0N$ H_2SO_4 is preferred if the sample is believed to contain appreciable Pu^{6+} . Titration in $1.0N$ H_2SO_4 must be performed in an oxygen-free atmosphere.
- If iron is present, it is titrated quantitatively in H_2SO_4 and a correction must be applied. Iron does not interfere in $1N$ $HClO_4$ if the plutonium-iron ratio is >50 .
- If $1N$ HNO_3 is used as electrolyte, sulfamic acid must be added to reduce nitrites.
- Polymeric plutonium does not titrate in any case and must be destroyed. Fluorides, used to destroy polymeric plutonium, and organics interfere in all media and must be removed.

- Although electrical calibration can be used, for optimum accuracy the instrument should be calibrated using NBS-SRM-949 and a correction for isotopic composition of the sample should be applied.
- Replacement of the platinum electrodes with gold can result in a lower and more reproducible background and an approximately fivefold improvement in precision.³⁰
- Coulometers may be subject to serious interference from nearby RF generators, such as induction heaters.

1. Uranium. The electrometric methods for determining uranium rely on the reaction $U^{4+} - U^{6+}$ after quantitative reduction of the uranium to the tetravalent state (Ref. 1, pp. 74-83 and 86-88; Refs. 31-34). Differences between methods result from the reductants and oxidants used. Reducing agents used to obtain U^{4+} include zinc amalgam, the Jones reductor, Ti^{3+} , the lead reductor, Fe^{2+} in phosphoric acid, and electrical reduction. The Jones reductor can generate a mixture of U^{3+} and U^{4+} , and the trivalent uranium must be air-oxidized to the tetravalent state before titration. The reduction with an excess of ferrous ion in concentrated phosphoric acid followed by titration with dichromate can be performed in the presence of Pu^{4+} without interference. Some of the standard electrometric techniques for determination of uranium are summarized in Table II. Of these methods for determining uranium, the Davies-Gray method³¹⁻³² is the most versatile and has been automated for rapid analysis of process samples (Ref. 1, pp. 77-83 and 86-88; Refs. 32-35).

2. Plutonium. For the electrometric determination of plutonium, the plutonium may be oxidized quantitatively to Pu^{6+} , then titrated to Pu^{4+} . This couple is preferred if uranium or iron is present. Oxidants for the first step include AgO and $HClO_4$. If AgO is used, the excess is destroyed by gentle heating. The oxidizing power of $HClO_4$ is destroyed by diluting the sample after the plutonium has been oxidized. Errors can be introduced into the plutonium measurement if conditions for the dilution are not followed properly. The reduction to Pu^{4+} usually is carried out with Fe^{2+} , and can be performed directly or, by using a potentiometric

TABLE II
ELECTROMETRIC METHODS FOR DETERMINING URANIUM

Reductant	Oxidant	End Point	Interferences	RSD ^a (%)	Sample Size	Ref. No.
Zn amalgam	$K_2Cr_2O_7$	Colorimetric	None	0.62	200-300 mg	1, pp. 74-77
Fe^{2+} H_3PO_4	$K_2Cr_2O_7$	Potentiometric	Ag, Hg	0.07	200-300 mg	31,32
Electrolytic	Excess $K_2Cr_2O_7$ back-titrated with Fe^{2+}	Potentiometric	Cr, Fe, Mo, Ti, V	0.02	1-10 g	1, pp. 77-83
Electrolytic	Electrolytic	Coulometric	Fe, Hg, Ag, V	0.06-0.44	2-20 mg	1, pp. 86-88;33
Pb reductor	Ce^{4+}	Potentiometric	Mo	0.03	0.5-1 g	34

^aGenerally, the optimum obtainable for fuel process or product samples.

end point, can be sharpened by adding a measured excess of Fe^{2+} , the excess being titrated with Ce^{4+} . Methods involving the Pu^{4+} - Pu^{6+} couple are summarized in Table III.

Alternatively, plutonium can be determined by quantitative reduction to Pu^{3+} and subsequent titration to Pu^{4+} (Ref. 1, pp. 268-299 and 385-388; Refs. 38, 39, 43-47). Common reducing agents are liquid zinc amalgam, the Jones reductor, the lead reductor, Ti^{3+} , Cr^{2+} , and electrical methods. The liquid-zinc-amalgam method suffers in that an extra transfer is required to remove the amalgam before titration. Small amounts of titratable material can be leached from the Jones reductor. Fewer elements are reduced with TiCl_3 than with the Jones or lead reductors; therefore, there may be fewer potential interferences.⁴⁴ However, Ti^{3+} is readily destroyed by contact with air.

The oxidation titration to Pu^{4+} usually is performed electrolytically or with Ce^{4+} or $\text{K}_2\text{Cr}_2\text{O}_7$. Dichromate has the advantage of being available as a primary standard and is more stable than Ce^{4+} over extended storage periods. Uranium and iron interfere with methods involving the Pu^{3+} - Pu^{4+} couple. An exception is the controlled-potential coulometric technique in the presence of uranium, and with this method, the two elements can be measured successively in the same sample.³⁸ For the controlled-potential coulometric determination of plutonium in dissolver solutions, zirconium must be removed completely to prevent fouling of the electrode through adsorption of hydrous zirconia.²⁹ Methods involving the electrometric determination of plutonium using the Pu^{3+} - Pu^{4+} couple are summarized in Table IV.

D. Fluorimetry

The fluorimetric determination of low concentrations of uranium is based on the principle that uranium fluoresces when excited by ultraviolet light; the method is not applicable for determining plutonium. The fluorescent spectrum for uranium consists of four bands

TABLE III
ELECTROMETRIC METHODS FOR PLUTONIUM DETERMINATION USING THE Pu(VI) - Pu(IV) COUPLE

Reductant	Oxidant	End Point	Interferences	RSD ^a (%)	Sample Size	Ref. No.
Fe^{2+}	Ag_2O	Amperometric	Ce, Cr, V, Mn Ru, Au, Rh, Pt Pb, Am, Np	0.03	10-20 mg	36,37 ^b 38,39
Excess Fe^{2+} Ce^{4+}	Ag_2O	Potentiometric	Ce, Cr, V, Mn	0.1-0.19	4 mg	1, pp. 261-268
Excess Fe^{2+} $\text{K}_2\text{Cr}_2\text{O}_7$	Ag_2O	Potentiometric	Cr, Ce, Mn, V, Ru	0.17	20-80 mg	40
Excess Fe^{2+} Ce^{4+}	HClO_4	Potentiometric	Cr, Au, Mn, Pt,	0.03	200-250 mg	41 ^c
Electrically generated Fe^{2+}	KMnO_4	Coulometric	Ag, Hg, Ru, Pd, Os, Ce, Au, Sn, (U)	1	0.003-10 mg	42
Electrical	Electrical	Coulometric		0.1	1-10 mg	29

^aGenerally, the optimum RSD obtainable for fuel process or product sample.

^bSee also Ref. 1, pp. 254-261.

^cSee also Ref. 1, pp. 274-285.

in the visible region, with the most intense band at 554.6 nm. If 365-nm excitation from a high-intensity mercury lamp is used, few other elements will interfere by fluorescence.

Samples generally are evaporated and fused in a carbonate flux containing 10% NaF (Ref. 48) or a NaF flux, sometimes containing LiF (Ref. 49) or some carbonate. Carbonate fluxes are preferred for ease of handling the fusion mass and for providing better analytical precision. Fluoride fluxes provide better uranium sensitivity but are more sensitive to variations in flux temperature and cooling conditions.

Although few elements or compounds interfere with the method by overlapping fluorescent spectra, a number of elements interfere through quenching or enhancement. Quenching can result from absorption of the incident light, absorption of the fluorescent light, interference with the energy transfer paths at phosphor centers, or precipitation of uranium.⁵⁰

Most of the transition elements interfere by quenching to some degree. With a flux of 98% NaF-2% LiF, serious quenching is observed in the presence of small amounts of cadmium, chromium, cobalt, copper, iron, magnesium, manganese, nickel, lead, platinum, silicon, thorium, and zinc. Many of the interferences can be removed by a combination of precipitation and solvent extraction of the uranium into methyl isobutyl ketone containing tetrapropylammonium nitrate (Ref. 1, pp. 398-403) or into ethyl acetate (Ref. 1, pp. 232-237). Alternatively, quenching interference can be minimized by measuring the fluorescence from a fused button of the sample and a similar button containing a known added amount of uranium (spiking).

Fluorimetry has evolved as a standard method for determining small amounts (1-100 ng) of uranium. High-throughput, off-line

TABLE IV
ELECTROMETRIC METHODS FOR PLUTONIUM DETERMINATION USING THE Pu(III)-Pu(IV) COUPLE

Reductant	Oxidant	End Point	Interferences	RSD (%) ^a	Sample Size	Ref. No.
Zn amalgam	Ce ⁴⁺	Potentiometric	Fe, Mo, Ti, W	0.02-0.02	600 mg	1, pp. 274-285
Zn amalgam	K ₂ Cr ₂ O ₇	Potentiometric	Cr, Fe, Mo, Ti, U, V, W	0.03	250-400 mg	43 ^d
Pb or Jones reductor	Ce ⁴⁺	Spectrophotometric	Fe, Ga, Mo, Ti, U, W, V, Cr, NO ₃	0.07	500 mg	1, pp. 268-274
Ti ³⁺	Ce ⁴⁺	Potentiometric	Cu, Fe, U, W NO ₃	0.1	25 mg	44 ^e
Cr ²⁺	Ce ⁴⁺	Potentiometric	Fe, U, Cu, W	0.4	20-50 mg	39
Electrical	Electrical	Controlled potential coulometric	Dependent on electrolyte	0.04 ^b 0.63 ^c	1-10 mg	30, 45-47 ^f

^aGenerally, the optimum RSD obtainable for fuel process or product samples.

^bFor nitrates.

^cFor dissolver solutions.

^dSee also Ref. 1, pp. 285-292.

^eSee also Ref. 1, pp. 293-299.

^fSee also Ref. 1, pp. 385-388.

measurements of uranium in waste streams can be made by processing samples in the analytical laboratory. The RSD for measuring uranium in simulated reprocessing plant waste streams is reported to be 13%.⁵¹ In addition, an automated fluorimeter capable of processing sixteen samples per 1.5 h has been designed and tested at ORNL;⁵² sensitivity is 0.2 $\mu\text{g/L}$ and precision is 6% at the 10- $\mu\text{g/L}$ level.

Recently, a laser fluorometric method has been described that is simpler, more sensitive, and more rapid than the pellet fusion method.⁵³ The method is direct and requires no separations, extractions, or fusions. The commercially available laser fluorometer employs a pulsed nitrogen laser that emits at 337 nm. The uranium sample is added to a proprietary buffered pyrophosphate reagent, which causes the uranium to emit a green luminescence when exposed to the light from the laser. A green filter between the sample cell and the photomultiplier tube removes the blue fluorescence from organics. Longer wavelengths will still be transmitted, however. The instrument has electronic gating circuitry that waits for other fluorescence from organics to decay before the longer-lived uranium phosphorescence is measured. A standard addition technique is used to overcome sample matrix effects.

E. X-Ray Fluorescence

X-ray fluorescence techniques have been applied to the analysis of actinide solutions for over 25 yr. They are sensitive and accurate and are capable of measuring microgram quantities of material to relative accuracies of 1% or less. Typical analysis times are short (0.5 h or less). Currently, x-ray fluorescence is used primarily to measure solutions from the reprocessing of spent fuels. However, the technique has been applied to solutions at all stages of the fuel cycle.

The fundamentals of x-ray fluorescence analysis are reviewed in detail in the literature.⁵⁴⁻⁵⁷ The analyst has considerable latitude in selecting a technique, including choices of excitation source, x-ray line, and detector.

For uranium and plutonium measurements, lines in the K, L, or M series can be used; the more intense lines in these series are summarized in Table A-III of Ref. 58. The main considerations in the choice of a line to use in an x-ray fluorescence measurement are line intensity above background and interferences from adjacent lines. The most common choice is one or more of the L lines. They provide good intensities in an air path for solution or solid analyses, and can be used with any type of excitation or detection system.

The most commonly used excitation source is the x-ray generator. The use of radioisotopes is becoming more common because solid-state detectors required to measure the resulting lower intensity x rays are readily available. Both wavelength- and energy-dispersive detection systems have been used to measure uranium and plutonium in solution. Wavelength dispersion offers high resolution but at low efficiencies. Energy dispersion is generally more efficient but has poorer resolution at energies <20 keV. At energies >20-25 keV, a Si(Li) energy-dispersive spectrometer provides better resolution as well as efficiency. Energy dispersion using Ge(Li) or intrinsic germanium detectors is required for measuring actinide K-series x rays.

Although x-ray fluorescence measurements of nuclear material solutions have had wide exposure in the literature, current safeguards applications are limited because of competition from other less complex and less matrix-dependent methods. To reduce the matrix sensitivity, samples are often evaporated as thin films. That technique reduces the scattered background compared to the sample signal, thus increasing sensitivity and reducing counting times.⁵⁹ Measurements of thin films are linear with the concentration of nuclear material over a small range, above which saturation effects become important.

Several systems have been developed to assay highly radioactive spent-fuel solutions. One of these systems⁶⁰⁻⁶² uses the $L\alpha_1$ x rays measured with a wavelength-dispersive spectrometer to assay solutions having uranium-plutonium ratios of 50:1 to 300:1 with accuracies of $\sim 1\%$ (1 σ) in 2-5 min. Solutions having activities of <1 Ci/mL are handled routinely by evaporating small samples onto a filter paper. Samples having low beta-gamma activities can be analyzed directly in solution after addition of an internal standard. The fission products cause no serious line interference. An automatic sample-preparation system is being developed to allow on-line analysis.

Uranium and plutonium solutions that have beta-gamma activities to 1 Ci/L have been measured directly through a Plexiglas window.⁶³ An automatic sampler removes solutions from the sample line and yttrium is added to serve as an internal standard. Solution transfers are made by pneumatic tube. A minicomputer performs data reduction, and overall precision and accuracy of better than 1% are claimed for the technique.

In another system,⁶⁴ dissolver solutions containing uranium and plutonium at ratios up to 400:1 and uranium concentrations of ~ 50 g/L are measured with an x-ray tube in combination with a Si(Li) detector. Preliminary tests indicate that accuracies of 1-2% are possible with 10-min analysis times. However, accuracies of only 3% were obtained because of problems in sample preparation.

A proposed wavelength-dispersive system may be able to measure uranium and plutonium concentrations in irradiated samples to a precision of better than 1%.⁶⁵ The instrument should be adaptable to off-line analysis of dissolver-type samples (as slurries or solution) with an analysis time of 4-8 h. For samples of lower activity, analysis time is significantly shorter.

A system also has been developed for automatic sampling and sample preparation of dissolver solutions from the reprocessing of thorium-uranium fuels⁵⁹ and could be applied to uranium-plutonium fuels. For solutions emitting up to 2000 Ci/L, samples containing 1.0 mL of solution are automatically aliquoted and mixed with an internal standard. The aliquots are evaporated onto a filter paper, which is transferred to a shielded x-ray spectrograph. All operations are performed remotely under computer control.

The introduction of stable x-ray generators⁶⁶ that can operate to 200 KeV and the use of ^{57}Co gamma-ray sources^{67,68} have increased interest in K x-ray fluorescence analysis of uranium and plutonium. X-ray generators provide a significant improvement in peak-to-background intensity compared to radioactive sources such as ^{57}Co . The primary advantage in using the K x rays results from the ability to use normal process materials such as stainless steel

for cells; thus, in-line analysis is possible. The method is proposed for analysis of samples at any step of reprocessing from dissolver solutions to final product. Precision of better than 0.5% is anticipated where adequate peak to background intensity is obtainable.

The high sample throughput for analytical laboratories at large reprocessing plants may dictate automated analytical methods such as x-ray fluorescence to provide timely, accurate information for both process control and safeguards.

F. X-Ray Absorption Edge Densitometry

X-ray absorption edge densitometry is an element-specific analytical method that can be applied in-line, at-line, or off-line to many process measurement needs. In this technique the transmitted intensity through the sample is measured for two x rays or gamma rays selected above and below an absorption edge for the element determined. For determining uranium and plutonium both K and L_{III} absorption edges can be used. The L_{III} edge is useful for uranium and plutonium concentrations below ~100 g/L. The K edge allows greater versatility in selecting cell materials and cell thickness and, thus, is applicable over a wider concentration range in process-type cells. With proper selection of cell path length and absorption edge, the method is applicable to concentrations in the range 1-500 g/L.

Instruments using K and L_{III} edges have been developed at the Los Alamos National Laboratory for determining uranium and plutonium in a variety of process samples.⁶⁹ A radioactive ¹⁶⁹Yb source is used for routinely determining uranium in the 100-400 g/L range. The precision is better than 0.5%. For the determination of plutonium, a radioactive ⁷⁵Se-⁵⁷Co source is employed. Field tests at Tokai-mura, Japan, have demonstrated a precision of 0.3% over the concentration range of 150-300 g/L.^{70,71} A K-edge instrument designed by Lawrence Livermore National Laboratory and evaluated at Allied General Nuclear Services gave a precision of 0.5% for the design concentration range of 150-300 g/L.⁷²⁻⁷⁴ An on-line K-edge densitometer designed for lower concentration, typically 30 g/L, is being evaluated at the Savannah River Plant. Solution is circulated from process tanks through a 7 cm path length cell. Well characterized control samples having concentrations in the range 25-40 g/L were analyzed with a precision of 0.3%.⁷⁵

An L_{III} edge instrument using an x-ray generator as a source to permit simultaneous determinations of uranium and plutonium was designed at Los Alamos for the Savannah River Laboratory.⁷⁶ Precision of 0.25% was reported at the optimum concentration of 50 g/L.

A versatile densitometer that can be applied to K or L edge analysis using x-ray tube excitation has been designed and evaluated at Karlsruhe.⁷⁷ Proposed applications include determination of uranium in accountability tank solutions and both uranium and plutonium in intermediate process and final product solutions. The x-ray tube excitation approach to absorption edge densitometry also is being developed in the UK.⁷⁸

G. Alpha-Spectrometric Methods

Quantitative alpha-particle spectrometry is based on measurement of the alpha-radiation intensity of the sample. The alpha particles are ejected with discrete energies, and for the uranium, neptunium,

plutonium, and americium isotopes found in the nuclear fuel cycle these energies range from 4 to 5.5 MeV. Alpha-particle energies are rapidly degraded by interactions with bound electrons, and complete attenuation is effected by ~ 5 cm of air. Absorption by H_2O and self-absorption by the sample are even more rapid, and normal quantitative alpha spectrometry is limited to analysis of thin, dry films. The method has been applied to determination of plutonium in dissolver solutions following solvent-extraction separation of the plutonium (Ref. 79; Ref. 1, pp. 392-398). The RSD for dissolver samples is in the range 3-5% (1 σ). The method also is used for determining plutonium in process waste and uranium product streams.⁸⁰

Detectors used for alpha spectrometry include standard radiation instruments such as proportional counters, scintillation detectors, and solid-state devices. Special techniques have been developed for alpha-counting of Purex process streams, where the detector must be in direct contact with the alpha-radiation sources.⁸¹⁻⁸⁵ Performance requirements are severe. The detector must operate in a flowing-liquid environment that is often of high acidity; it must be corrosion- and abrasion-resistant; it should discriminate alpha signals in the presence of high beta-gamma fluxes from fission products; and it should be insoluble in organics. Originally, ZnS(Ag) scintillation detectors were used, but were too fragile and difficult to fabricate. Organic scintillators in general cannot withstand the liquid environments. A cerium-activated Vycor glass detector has been developed⁸² that will operate for months in a Purex process stream. The stopping distance for 5-MeV alpha particles in Vycor glass is estimated to be 25 μm , whereas beta particles of energies >0.5 MeV have penetration thicknesses in excess of 900 μm .⁸⁴ Thus, by reducing the cerium-activated layer to the alpha-particle penetration thickness, the alpha particles can be stopped in the active layer while most of the high-energy betas will pass through undetected. A further decrease in beta interference is attained by using thin sample cells⁸⁶ and electronic pulse-shaping circuitry.⁸⁷

The instruments can measure plutonium solutions in the concentration range between 10^{-4} and 1 g/L in the presence of beta-gamma fields up to 10^8 dis/min-mL.⁸⁸ Deviations from linearity at low plutonium concentrations ($<10^{-3}$ g/L) are caused by plating on the detector window and at high plutonium concentrations (>0.1 g/L) are caused by pulse pile up. Interference results from large variations in sample density that cause self-attenuation problems and from the presence of other alpha emitters such as neptunium, americium, or uranium. Calibration is performed empirically for each stream by chemical analysis. Modification of the electronics system was reported to provide a range of 0.1 to 30 g/L.⁸⁹

In-line alpha counters using a scintillation (ZnS) probe and a rotating drum to present the sample to the probe were developed in France for routine use in reprocessing plants.⁹⁰ The relative standard deviation is 3.2% for the aqueous phase and 4.6% for the solvent phase in the first cycle extraction and partition banks.

Diamond detectors were investigated in the Soviet Union as in-line alpha monitors, but data for process operation in the presence of high beta-gamma fluxes are not available.⁹¹

H. Mass-Spectrometric Methods

In most nuclear fuel cycle facilities thermal-ionization mass spectrometry is used to determine the amount of each isotope of

uranium and plutonium and, subsequently, to determine the effective atomic weights used in calculating the total uranium and plutonium from the chemical analysis of accountability-tank samples. Isotope-dilution mass spectrometry can be used for high precision-high accuracy measurement of the plutonium and uranium concentrations in tanks.

The instrumentation for mass spectrometry is complex and expensive, consisting basically of a source, which is either a single or triple filament; a mass spectrometer; a detector, which is either a Faraday cup or an electron multiplier; and associated control and readout electronics.^{92,93} Much of the instrumentation can be computer controlled.⁹⁴ Single-filament ion sources require precarburization to provide high metal ion yields, and triple filaments are preferred. The mass spectrometer should have an abundance sensitivity of 100 000 or better and a resolution, expressed as $M/\Delta M$, of 400 or greater, where ΔM is the peak width at 5% of the height above background. The Faraday cup detector provides better measurement accuracy but the electron multiplier yields better sensitivity.

The methods require elaborate sample preparation (Ref. 1, pp. 353-368; Refs. 95-97). A typical mass-spectrometric procedure involves (1) dissolving and diluting the sample with HNO_3 , (2) for isotope-dilution mass spectrometry, spiking part of the diluted sample with accurately known amounts of ^{233}U and ^{242}Pu or ^{244}Pu , (3) oxidizing plutonium to the hexavalent state, (4) sequentially separating the fission products, plutonium, and uranium by an anion-exchange procedure or by solvent extraction; and (5) transferring aliquots of the separated uranium and plutonium fractions to separate mass spectrometer filaments.

Because small amounts of uranium and plutonium (<100 μg , and generally <1 μg for plutonium) are to be analyzed, extreme care must be taken in sample preparation and filament loading to avoid contamination by environmental uranium. Determination of ^{238}Pu is particularly sensitive to the presence of ^{238}U , and for ^{238}Pu concentrations <0.7%, alpha spectrometry is preferred. For the measurement of ^{241}Pu , ^{241}Am must be completely separated. For the isotope-dilution mass-spectrometric determination of plutonium, both spiked and unspiked samples must be analyzed to correct for ^{242}Pu in the sample, if ^{242}Pu is added as the spike.

Chemical errors may arise also from the presence of high concentrations of alkali elements. Potassium, in particular, interferes with the measurement of ^{234}U and ^{236}U because of overlap of K_6 polymers. Filaments must be checked to ensure that they are free of organics. If organics are detected at ion currents greater than background, the analyses are suspect.

In thermal ionization sources, the light isotopes are evaporated and ionized preferentially relative to the heavier isotopes of an element.⁹³ This effect is temperature dependent and is a function of the mass, sample size, and time. It is referred to as the filament bias and must be measured for the instrument every 6 months, and must be controlled as accurately as possible between samples and standards in a series. Temperature can be controlled by direct pyrometer measurement or by adjusting to a constant signal intensity of a filament ion.

The abundances of major isotopes can be determined with RSDs of 0.01 to 0.02%.⁹⁸ The precisions obtained for well-characterized

material (a solution of a standard reference material) are significantly better than for process and product solutions, particularly at isotopic concentrations $>1\%$. Studies show that improvements in precision and accuracy may be obtained if proper care is taken to minimize instrumental and operating errors. In an interlaboratory exchange program an overall RSD of 0.1% was obtained in measuring total plutonium in four samples having different isotopic compositions.⁹⁹ In terms of these data an RSD of 0.1 to 0.2% should be attainable for measuring total plutonium in fuel cycle samples if careful attention is paid to details of separation chemistry and instrument operation.

High gamma-radiation levels limit the mass-spectrometric analysis of dissolver solutions to extremely small samples or to samples that have been purified previously in shielded facilities. Microsamples of uranium and plutonium can be adsorbed on ion-exchange resin beads for subsequent analysis.¹⁰⁰ The analytical precision is better than 1% (RSD). Alternatively, the mass spectrometer can be modified for analysis of radioactive samples by enclosing the sparking chamber and the initial stage of the flight tube with 10 cm (4 in.) of lead shielding.¹⁰¹ Samples emitting up to 100 R/h of gamma activity can be analyzed in this fashion.

Mass spectrometry currently provides the most accurate isotopic analysis, even in the presence of fission products. The isotope dilution method provides overall accuracy of 0.3 - 1% for the measurement of total uranium and plutonium concentrations in dissolver solutions. However, it is believed that improvements in sampling and analysis techniques could improve accuracy to better than 0.3% . The control of sample preparation is crucial to the accuracy, particularly where analyses are performed on nanogram amounts of uranium or plutonium.

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



April 27-May 12, 1981

Session Objectives

SESSION 9: SURVEY OF BULK MEASUREMENT TECHNOLOGY AND MEASUREMENT STANDARDS

This session will define "bulk measurement" as it refers to nuclear material control and accounting and will describe methods of performing bulk measurements and methods of calibration and certification of the various measurements.

After completion of this session, participants will be able to:

1. define bulk measurement and the components that make up this concept,
2. define methods for measurement of volume, density, mass, and pressure necessary to perform bulk measurements,
3. describe standards and control programs for analytical methods used in bulk measurement,
4. define a system of national standards,
5. define techniques for using national standards to calibrate and certify plant measurement systems.



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April 27-May 12, 1981

SESSION 9: SURVEY OF BULK MEASUREMENT TECHNOLOGY AND MEASUREMENT STANDARDS

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I. INTRODUCTION

In previous sessions of this course, concepts of national and international safeguards were presented. Historical development of these safeguards concepts, establishment and evolution of international safeguards through various treaties and agreements, and the characteristics and interactions of state and international safeguards systems were also presented.

The basis for safeguards, whether it be the international or state system, is the careful control, measurement, and accounting of all nuclear materials possessed by a country. Control of nuclear material is conducted administratively on international, state, and facility levels; however, measurement and accounting is generally conducted at the facility and subfacility levels.

As described earlier, a facility can contain one or more Material Balance Areas (MBAs), each with one or more Key Measurement Points (KMPs). Nuclear material passing through a facility is measured into or out of the facility MBAs at the KMPs using a variety of techniques and appropriate accounting documentation is generated.

There are two types of facilities that handle nuclear materials. These are a "bulk-handling facility" and an "item-handling facility." A bulk-handling facility is one that handles or processes nuclear material in nondiscrete quantities either by batch or continuous processes. Examples of bulk-handling facilities include enrichment plants, reprocessing plants, and fuel-fabrication plants. Item-handling facilities include reactors and nuclear material storage facilities that handle discrete, identifiable pieces or packages in sealed containers.

Accounting in a bulk-handling facility involves "bulk measurement" to determine the mass or volume of these nondiscrete quantities of material and sampling and analysis to determine the nuclear material content. Session 8 presented a survey of analytical methods for measurement of nuclear material content. In this session, methods of bulk measurement will be presented, along with considerations of sampling, quality control, and verification of measurements against accepted standards.

Bulk measurement, in general, involves three steps. First, a measurement of the mass or volume and density of the quantity of material must be determined. Second, a sample or samples representative of the material must be obtained and analyzed; and, finally, the total quantity of nuclear material must be computed from the volume or mass and the analytical data.

Bulk measurement seems very simple until one starts asking questions, like "how do you measure the volume or mass?", "How does one obtain a representative sample?", "What are the accuracy and precision of these measurements?", "How can the values be verified?", and so on. This session will provide some of the answers to these types of questions.

For the purposes of this session, it will be assumed that the material is homogeneous, i.e., uniformly mixed. (Nonhomogeneous materials present problems that are beyond the scope of this session.)

Before proceeding, two more definitions ought to be made, those of precision and accuracy. Precision will be used to describe the variation of a set of repeated measurements of a given mass, volume, or concentration. In other words, precision describes the repeatability of a measurement. It says nothing about how close the measurement is to the true value. Accuracy, on the other hand, describes how representative a measurement is to the true value. Figures 9-1 and 9-2 graphically illustrate these concepts.

II. VOLUME, DENSITY, AND MASS MEASUREMENTS

Nuclear materials may be in the form of gases, solids, or liquids in a bulk-handling facility. In the case of gases and solids, mass measurement or weighing is generally used. A variety of methods are used for liquid measurements including mass and volume determinations and in some cases flow measurements (integrated over time to determine volume). The density of the material may also need to be measured to compute the quantity of nuclear material.

A. Mass Measurement

A wide variety of weighing devices are available for making mass measurements. These devices vary in operating principle, capacity, reliability, stability, and precision. (As a general rule, the accuracy of these devices can be controlled with an appropriate calibration program.) Some typical devices are listed below.

1. Pan Balance (see Figure 9-3). The material to be weighed is placed in one pan and the weight is determined by placing "known" weights in the opposite pan until the system balances. These devices are generally of low capacity.

2. Beam Balance (see Figure 9-4). The material to be weighed is placed on the weighing platform which is in turn mechanically linked to a beam with a movable poise weight. The position of the poise weight determines the weight of the material. Beam balances are available in a wide range of capacities and configurations.

3. Hydraulic Load Cells (see Figure 9-5). A typical hydraulic load cell consists of a platform connected to one or more piston assemblies that impart pressure to a fluid. The pressure is directly proportional to the weight of the material. These devices are also available in a wide variety of configurations and are generally used for measurement of large masses.

4. Mechanical Load Cells (see Figure 9-6). These devices work on the principle of determining the deflection of a support member and relating this to the weight of the material being measured. The support member may be a spring, a suspension rod, a tank support, or a cantilevered beam. The amount of deflection may be measured mechanically, electronically (strain gage), or optically. These devices are generally limited to high-capacity systems.

Selection of a weighing device depends on the application. Load cells have application where high capacity is required, where weights of highly radioactive materials must be determined, or where the environmental conditions are harsh. Pan and beam balances are generally selected where small quantities are to be measured and where environmental conditions can be controlled (i.e., in a non-corrosive atmosphere).

Consideration should also be given to making corrections for buoyancy and acceleration of gravity. In some cases the system accuracy may warrant making these corrections.

All of these devices require calibration using known weights of material. The type and frequency of calibration usually establishes the accuracy of the device.

B. Volumetric Measurement

One of the standard bulk measurement problems is to determine the volume of liquid containing nuclear material. This is generally done at a key measurement point and involves a batch transfer of material into or out of a material balance area. A quantity of liquid is transferred into a tank designated as a key measurement point. After mixing, a sample is drawn from the tank and analyzed. The volume of the liquid is determined and the liquid is transferred to the next point in the process. The volume of any liquid remaining in the tank is measured and deducted from the original volume. The quantity of material is then computed using the analytical result and the net volume transferred.

One standard technique of measuring volume in a tank is by dip-tube manometry. This technique involves measurement of the back-pressure on an air-purged tube submerged in the liquid in the tank (see Figure 9-7). The air purge displaces the liquid from the tube and develops a back-pressure equal to the hydrostatic head pressure of the displaced liquid. (The air purge rate is at a very low rate so that frictional pressure drop due to flow is negligible.) This back-pressure can be reliably measured 50 to 100 feet from the tank which makes this an attractive method for level measurement in a radioactive process.

Simply measuring the back-pressure, however, is not sufficient. The vapor-space pressure in the tank also contributes to the back-pressure. To compensate for the vapor-space pressure, a second air-purged tube is routed to the top of the tank and is connected to the low-pressure side of the manometer (see Figure 9-8).

The hydrostatic head pressure for a given liquid level is also proportional to the density of the liquid. A third tube, also submerged in the liquid, is installed a known distance above the level tube or probe (see Figure 9-9). The differential pressure, ΔP , between the two submerged dip-tubes divided by the known separation, H_1 , is equal to the density of the solution (if ΔP is measured in cm of H_2O and the separation is measured in cm).

The true liquid level in turn is equal to the overall differential pressure, ΔP_2 , divided by the fluid density P . Measurement of the differential pressures can be done with U-tube manometers, well-type manometers, pressure gages, or pressure transducers.

Typical differential pressure measurement devices are shown in Figures 9-10 through 9-12. These are a well-type fluid manometer, a Taylor differential pressure transmitter, and a Ruska electromanometer. The fluid manometer is read visually from the centimeter scale and is accurate to about 0.03 centimeter of fluid height. The column height of this manometer is about 150 centimeters in length. By selecting the appropriate fluid density, this instrument can be ranged from about 100 centimeters of H_2O , (using 0.66 density fluid) up to approximately 2000 centimeters of H_2O (using mercury as the fluid). The Taylor transmitter converts differential pressure to a 4 to 20 mA analog output. This instrument can be calibrated to a selected span (up to approximately 1200 centimeters of H_2O) and is normally accurate to 2 to 5 centimeters of H_2O . The Ruska electromanometer has a range of 0 to 750 centimeters of H_2O and has a digital voltmeter readout. This instrument is accurate to about 0.02 centimeter of H_2O .

The relationship of level to volume is normally established by "calibrating" the tank. Known increments of liquid (usually water) are added to the tank and the corresponding levels recorded. These increments can be weighed or can be measured volumetrically prior to addition. A polynomial equation is then established by least squares fit of the data. This equation can then be used for subsequent volume determinations or a table of volume versus liquid level can be generated. Table 9-1 is an example of a typical tank calibration table.

The relationship of level to volume can also be established by carefully measuring the dimensions of the tank and calculating the volume per increment of level. This method is not generally used for nuclear materials measurements because it has a low accuracy and precision.

Another method of volume measurement is the use of a "constant volume" tank (see Figure 9-13). The measuring tank is equipped with a fixed overflow back to a sending vessel. It is filled above the overflow and allowed to drain down to the level of the overflow. The retained volume is then moved ahead to the next point in the process. This can be a very accurate method if the tank is properly designed; however, it is more temperature dependent than the dip-tube approach.

A flowmeter can also be used as a volume measurement system as previously indicated. Flowmeters used in remote, radioactive environments in the past have included differential pressure devices (orifice and weir meters), positive displacement flowmeters, magnetic flowmeters, and electronic rotameters. A number of other types of flowmeters including thermal, ultrasonic, and gyroscopic deflection (Coriolis effect) devices also offer possibilities.

A flowmeter which is to be used for bulk measurement in nuclear materials accounting must be calibrated. Theoretical equations are simply too inaccurate to be used dependably. These calibrations must be designed to cover at least the normal operating range of the instrument and should result in the establishment of a relationship between instrument output and actual flow, either in terms of mass or volume. The calibration should also be designed to establish the accuracy and precision of the measurement.

One major drawback to the use of a flowmeter is that it may be subject to changes in output which will seriously bias the result. These changes can occur as a result of changes in fluid properties (i.e., temperature, viscosity, density, etc.), fouling of the measurement elements by solids or other deposits, or by changes in the electronic components. These changes may be very difficult to detect since there is no effective method of checking the output except by recalibration.

Temperature is an important measurement in bulk measurement. The specific volume of a given quantity of fluid varies with temperature, causing corresponding proportional changes in solution density and nuclear material concentration. Analytical measurements are generally made at a standard temperature (normally 25°C), while the process solutions are invariably at some other temperature. One approach is to perform lab measurements at the process temperature; however, this is not very practical and opens another route for significant errors. A more reasonable approach is to make analytical determinations on a weight basis (i.e., milligram uranium per gram of sample) and to convert the batch volume to grams or kilograms of solution.

To convert a measured volume (from a KMP batch transfer) to weight, one must use the best possible solution density as the conversion factor. It has been determined at AGNS that the analytically determined density (measured from the sample using a Parr-Mettler vibrating U-tube densimeter), corrected to tank temperature using an empirically determined equation, is the most accurate value.

Another temperature consideration involves the thermal expansion and contraction of the tank walls and the measurement dip-tubes. Changes in tank wall dimensions will change the cross-sectional area and height of the tank. Corrections can be made mathematically using the thermal expansion coefficient for the material of tank construction. This correction is normally very small and therefore, even if inaccurate, it will have little impact on the measurement uncertainty. Dip-tube expansion and contraction is a more serious problem, particularly in a vessel with a nonuniform cross-section. In this case (nonuniform cross-section), correction to the tube length must be made. In the case of uniform cross-section vessels (i.e., vertical cylindrical tanks), this correction need not be made if a measurable liquid heel is left in the tank. The transfer volume in this case is a difference between two measurements with the same error and the errors cancel out.

III. SAMPLING AND ANALYTICAL MEASUREMENTS

In Session 8, the major analytical methods for determining concentrations of nuclear materials were presented. These methods provide the nuclear material control and accounting personnel with the second part of the bulk measurement information, i.e., grams of nuclear material per unit of volume or mass.

The first step is to obtain a representative sample or samples of the material to be analyzed. Sampling generally involves removing a small quantity of material from a container or vessel after the contents are mixed.

Sampling of radioactive liquids is the primary consideration of this session. (Solids sampling will be covered in later sessions.) Three basic sampling techniques have been used in the past, including gravity draindown, recirculation (Figure 9-14), and dip sampling. Normally, practice requires that several samples be taken as part of the quality control routine. Before an accountability sample is accepted for analysis, it must be subjected to a test for homogeneity. The homogeneity of the sample is tested by determining the density on two different sample bottles of the same solution. The density of the solution in the two bottles must agree to within the uncertainty of the density measurement method. If the densities on the two bottles do not agree within the specified limits, the samples are rejected. These densities must also agree with the density measurement from the tank, after correction for any difference between the tank temperature and the temperature at which the analyses are performed.

A major concern in analysis of accountability samples is the quality of the results, i.e., the accuracy and precision of each measurement. A number of programs can be devised that will provide continued assurance of the measurement quality and, at the same time,

provide an estimate of the accuracy and precision of the data. These programs include a QC standards program, duplicate analyses, replicate analyses, analytical instrument calibrations, and interlaboratory round-robin programs.

A QC standards program is normally based on routine performance of assays on "blind" samples, either in parallel with actual analyses or on some scheduled basis. Comparison of actual results to the known value of the "blind" sample will provide an estimate of the accuracy of a given method.

Duplicate and replicate programs involve repetitive analysis of samples. In a duplicate program, the same analysis is performed on the same batch of material. Variations can be designed in to include analysis of separate samples, analysis by two or more different technicians, or analyses by two or more different methods. This program provides an estimate of analytical precision. A replicate program is similar except that the repeat analyses are done on a "blind" sample, such that the technician does not know the batch or sample identity.

Analytical instrument calibration programs involve routine electronic calibration and measurement calibration with "known" standards and blanks. These programs must be performed frequently enough to maintain a high degree of precision and accuracy. Results of the QC standards program can be used to determine frequency of the calibration program.

Finally, interlaboratory programs involving the repetitive analysis of standards and actual process samples will provide further definition of accuracy. Problems with a particular laboratory's basic standards preparation methods will be quickly detected with this program.

IV. DATA COLLECTION AND COMPUTATION

A major problem in bulk measurement is assuring that all of the data for every batch at every KMP is properly recorded and checked. One method of accomplishing this is through the use of step-by-step written procedures with check sheets (see Figure 9-15) and data sheets (see Figure 9-16). These forms provide assurance of data collection and quality control checks for each measurement.

Computation of contained quantities involves conversion of instrument readings to engineering units, application of bias corrections (i.e., air buoyancy corrections or temperature corrections for differences between laboratory and process temperatures), conversion to contained volume or mass based on prior calibrations, and calculation of the desired quantity using the analytically determined concentrations. These steps will vary depending on the measurement system and desired level of precision and accuracy. Generally, these calculations should be done by nuclear material control personnel and should be done in a prescribed manner using documented and approved methods to assure consistency.

V. CALIBRATIONS AND MEASUREMENT STANDARDS

The objective of a bulk measurement program is to make measurements as close as possible to the true value, i.e., accurate and precise. To do this, each measurement system must be "calibrated" or tested with "known" values of weight, volume, pressure, or length such that the relative accuracy and precision can be determined and controlled.

These principles will be illustrated for a volumetric measurement system for liquids and for the supporting analytical measurements performed on samples of the liquid.

Earlier in this session, a volume measurement system involving purged dip-tube pressure measurements was described. A calibration method involving incremental additions of calibrating liquid was also discussed. The basic measurements involved in this system are mass, pressure, temperature, length, and density. How then does a facility operator obtain the "known" values of these measures?

One approach is to establish and use a national system of standards for weights and measures. A national organization, such as the United States National Bureau of Standards, would establish and maintain reference standards for the various increments of mass, temperature, and length. Measurement standards used by a facility would then be compared to these national standards and would be assigned estimates of precision and accuracy. The facility would in turn use their standards to calibrate field standards. These field standards would in turn be used to calibrate the measurement systems. One purpose of this rather involved process is to minimize the routine use of each level of standard in order to preserve the precision and accuracy of each level. Another reason is that the national reference obviously cannot be used at all facilities, therefore a means of relating the facility standards to the national reference must be established. The documentation of the relationship of facility measurements to facility standards to national standards is referred to as traceability.

Figure 9-17 is a tolerance chart for the United States mass system. This chart shows the various increments available and the tolerances or accuracies of each class. A typical facility standard would be rated at Class S-1 and their field standard would be rated at Class C.

Pressure standards are generally traced in two ways, one being a mercury U-tube manometer using high-purity mercury. This system requires a traceable scale for measurement of column height and a traceable thermometer for measurement of temperature. Accepted values of mercury density versus temperature can then be used to compute pressure.

A second pressure standard is a dead weight pressure tester. This device uses certified mass standards, acting on a piston of known cross-sectional area, to develop a pressure. These devices are available in a range of capacities and accuracies.

Density standards include high-purity mercury, triple distilled water, and some other substances with extremely well defined physical properties. Standard methods of measurement and error estimation are described in handbooks prepared by the NBS.

Another area of standards is that of material standards. In the United States, the traceability of chemical assay measurements is obtained through the use of various reference standards made available through the NBS. Chemical assay measurements require certified mass standards for the traceability of mass measurements, and the use of various Standard Reference Materials (SRM) for chemical components. The SRM's are used to characterize a secondary or working standard to provide the traceability required for the assay of a particular chemical entity such as uranium or plutonium concentration.

To provide the most accurate analysis requires that all analytical equipment and methods are working properly. This is obtained through analytical instrument calibrations and the analysis of standards. The standards are used in the surveillance of analytical methods, calibration of equipment and methods, and training and testing laboratory personnel. Standards also provide the means of determining the uncertainty of an analytical method.

Reference standards can be of three types: Primary Certified Reference Material (PCRM), Secondary Certified Reference Material (SCRM), and Working Reference Material (WRM). The Primary Certified Reference Material is a material of high purity possessing chemical stability or reproducible stoichiometry and generally used for the development and evaluation of reference methods and for the calibration of reference materials. Primary Certified Reference Materials are certified using the most accurate and reliable measurement methodologies available consistent with end-use requirements for the reference material. Examples of PCRM's are Standard Reference Materials of the National Bureau of Standards and materials provided by the International Atomic Energy Agency (IAEA) bearing the IAEA "S" classification. Secondary Certified Reference Materials are reference materials characterized relative to a primary certified reference material. They are generally used for development/evaluation of field measurement methods, for day-to-day interlaboratory quality assurance, or for interlaboratory comparison programs. The SCRM's may be less pure or less stable than PCRM's, depending on their end-use. Accuracy required of the certified measurements also depends on the intended use. Examples of SCRM's are some reference materials from New Brunswick Laboratory and IAEA reference materials classified as "R".

The lowest member of the reference material hierarchy is the Working Reference Material. The WRM is a reference material characterized relative to a PCRM or a SCRM usually for use within a single laboratory or organization. Working Reference Materials are generally used to assess the level of performance of measurements on a frequent basis and are usually prepared from material typical of a given process. Ideally, the WRM should:

- (1) Be stable over extended storage periods,
- (2) Closely match the material routinely analyzed,
- (3) Have an uncertainty consistent with its intended use,
- (4) Be convenient to use, and
- (5) Be economical.

VI. AN EXAMPLE OF BULK MEASUREMENT CAPABILITY

The Barnwell Nuclear Fuel Plant uses bulk measurements extensively in nuclear materials accounting. As a result, the BNFP has about 160 individual tanks and associated measurement systems calibrated for bulk measurement.

Two key measurement points, the input accountability tank and the uranium product tank, were used for a measurement experiment in 1979 designed to assess the accuracy and precision of routine measurements. These tanks have a capacity of about 8000 liters each and have been calibrated to an accuracy of ± 2 liters. Batch measurements of uranyl nitrate solution (at about 300 grams uranium per liter) were made in the product tank. This material was then transferred to the input tank where a repeat measurement was made. These transfers were then compared to assess the variations in measurements. For approximately 130 transfers of about 2000 kilograms uranium each, the average difference in measurement was ± 1.0 kilograms per batch or 0.05%. This is a good approximation of accuracy.

The standard deviation of the differences was about 6.0 kilograms per batch or 0.3%. This is a good approximation of the single batch precision. (Precision of these measurements is largely random error which tends to cancel when batches are added. The two standard deviation limit-of-error for this experiment was only 0.19%.

These values represent a composite evaluation of all of the components of bulk measurement including tank calibration, instrument calibration, and analysis and are fully traceable to NBS reference standards.

Later in this course you will see a videotaped presentation of the Allied-General Nuclear Services tank calibration procedure. In this tape, you will see actual application of many of the methods and standards discussed in this session. The tape presentation should help you better understand some of the concepts in bulk measurement.

TABLE 9-1

PLUTONIUM NITRATE STORAGE TANK 36-D-311A
 MEASUREMENT POINT 3-19 SAMPLER N-108
 DATE CALIBRATED OCTOBER 19 1977

VESSEL VOLUME IN LITERS VS LL IN CM.

CM *	0	1	2	3	4	5	6	7	8	9
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
180*	552.4	552.7	553.0	553.3	553.6	553.9	554.2	554.6	554.9	555.2
181*	555.5	555.8	556.1	556.4	556.8	557.1	557.4	557.7	558.0	558.3
182*	558.7	559.0	559.3	559.6	559.9	560.2	560.5	560.9	561.2	561.5
183*	561.8	562.1	562.4	562.7	563.1	563.4	563.7	564.0	564.3	564.6
184*	564.9	565.3	565.6	565.9	566.2	566.5	566.8	567.1	567.5	567.8
185*	568.1	568.4	568.7	569.0	569.3	569.7	570.0	570.3	570.6	570.9
186*	571.2	571.6	571.9	572.2	572.5	572.8	573.1	573.4	573.8	574.1
187*	574.4	574.7	575.0	575.3	575.6	576.0	576.3	576.6	576.9	577.2
188*	577.5	577.8	578.2	578.5	578.8	579.1	579.4	579.7	580.0	580.4
189*	580.7	581.0	581.3	581.6	581.9	582.2	582.6	582.9	583.2	583.5
190*	583.8	584.1	584.4	584.8	585.1	585.4	585.7	586.0	586.3	586.6
191*	587.0	587.3	587.6	587.9	588.2	588.5	588.9	589.2	589.5	589.8
192*	590.1	590.4	590.7	591.1	591.4	591.7	592.0	592.3	592.6	592.9
193*	593.3	593.6	593.9	594.2	594.5	594.8	595.1	595.5	595.8	596.1
194*	596.4	596.7	597.0	597.3	597.7	598.0	598.3	598.6	598.9	599.2
195*	599.5	599.9	600.2	600.5	600.8	601.1	601.4	601.7	602.1	602.4
196*	602.7	603.0	603.3	603.6	603.9	604.3	604.6	604.9	605.2	605.5
197*	605.8	606.1	606.5	606.8	607.1	607.4	607.7	608.0	608.4	608.7
198*	609.0	609.3	609.6	609.9	610.2	610.6	610.9	611.2	611.5	611.8
199*	612.1	612.4	612.8	613.1	613.4	613.7	614.0	614.3	614.6	615.0
200*	615.3	615.6	615.9	616.2	616.5	616.8	617.2	617.5	617.8	618.1
201*	618.4	618.7	619.0	619.4	619.7	620.0	620.3	620.6	620.9	621.2
202*	621.6	621.9	622.2	622.5	622.8	623.1	623.4	623.8	624.1	624.4
203*	624.7	625.0	625.3	625.6	626.0	626.3	626.6	626.9	627.2	627.5
204*	627.8	628.2	628.5	628.8	629.1	629.4	629.7	630.0	630.4	630.7
205*	631.0	631.3	631.6	631.9	632.2	632.6	632.9	633.2	633.5	633.8
206*	634.1	634.4	634.8	635.1	635.4	635.7	636.0	636.3	636.6	637.0
207*	637.3	637.6	637.9	638.2	638.5	638.8	639.2	639.5	639.8	640.1
208*	640.4	640.7	641.0	641.4	641.7	642.0	642.3	642.6	642.9	643.2
209*	643.6	643.9	644.2	644.5	644.8	645.1	645.4	645.8	646.1	646.4
210*	646.7	647.0	647.3	647.6	648.0	648.3	648.6	648.9	649.2	649.5
211*	649.8	650.2	650.5	650.8	651.1	651.4	651.7	652.0	652.4	652.7
212*	653.0	653.3	653.6	653.9	654.2	654.6	654.9	655.2	655.5	655.8
213*	656.1	656.4	656.8	657.1	657.4	657.7	658.0	658.3	658.6	659.0
214*	659.3	659.6	659.9	660.2	660.5	660.8	661.2	661.5	661.8	662.1
215*	662.4	662.7	663.0	663.4	663.7	664.0	664.3	664.6	664.9	665.2
216*	665.6	665.9	666.2	666.5	666.8	667.1	667.4	667.8	668.1	668.4
217*	668.7	669.0	669.3	669.6	670.0	670.3	670.6	670.9	671.2	671.5
218*	671.8	672.2	672.5	672.8	673.1	673.4	673.7	674.0	674.4	674.7
219*	675.0	675.3	675.6	675.9	676.2	676.6	676.9	677.2	677.5	677.8
220*	678.1	678.4	678.7	679.1	679.4	679.7	680.0	680.3	680.6	680.9
221*	681.3	681.6	681.9	682.2	682.5	682.8	683.1	683.5	683.8	684.1
222*	684.4	684.7	685.0	685.3	685.7	686.0	686.3	686.6	686.9	687.2
223*	687.5	687.9	688.2	688.5	688.8	689.1	689.4	689.7	690.1	690.4
224*	690.7	691.0	691.3	691.6	691.9	692.3	692.6	692.9	693.2	693.5

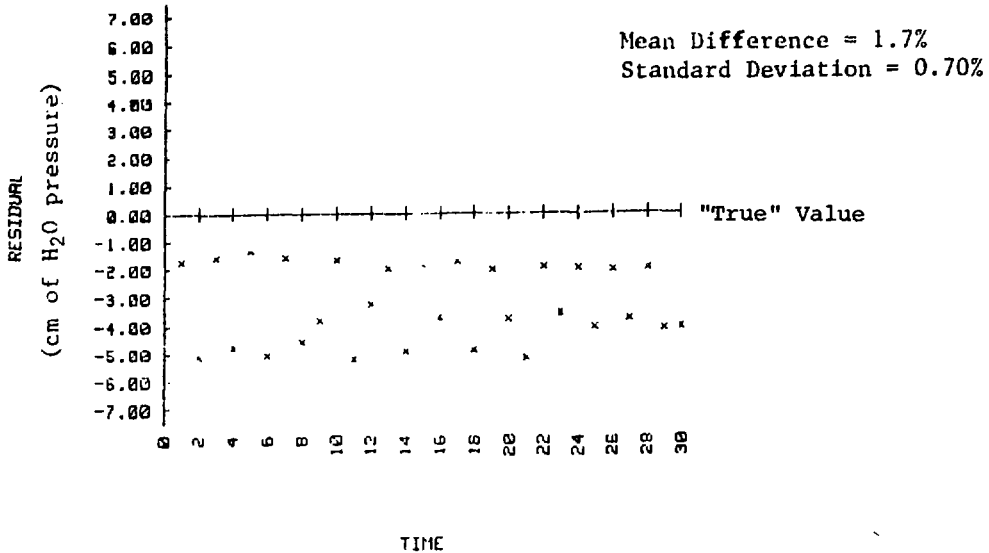


FIGURE 9-1

EXAMPLE OF INACCURATE (BIASED) AND
INPRECISE (SCATTERED) MEASUREMENTS

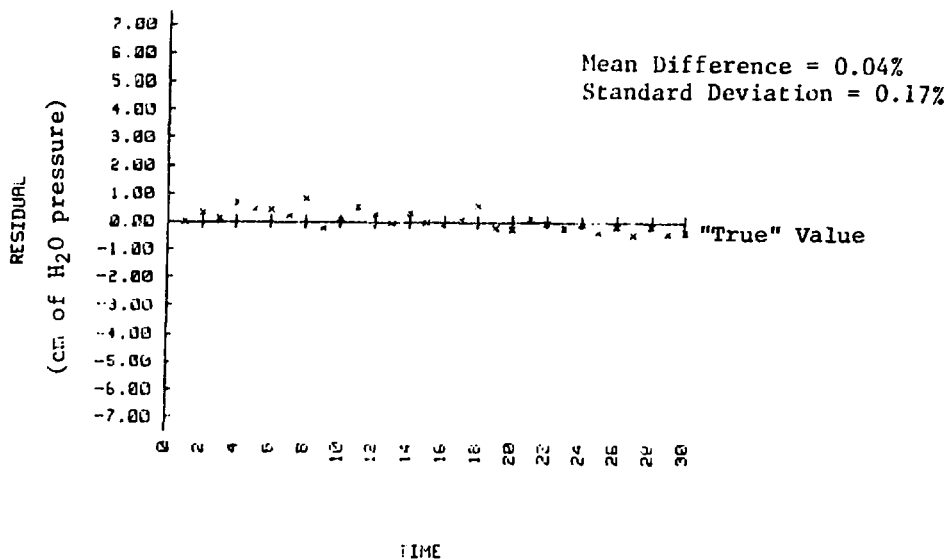
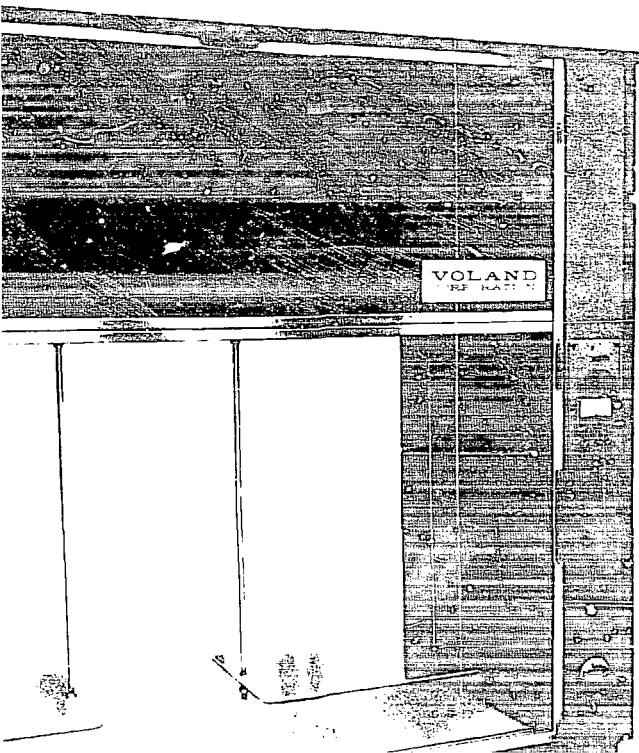


FIGURE 9-2

EXAMPLE OF ACCURATE (UNBIASED) AND
PRECISE (REPEATABLE) MEASUREMENTS

VOLAND
 high capacity
 ultra precision
 balances
 with capacity
 to sensitivity
 ratios of
 one part in
 10 million*



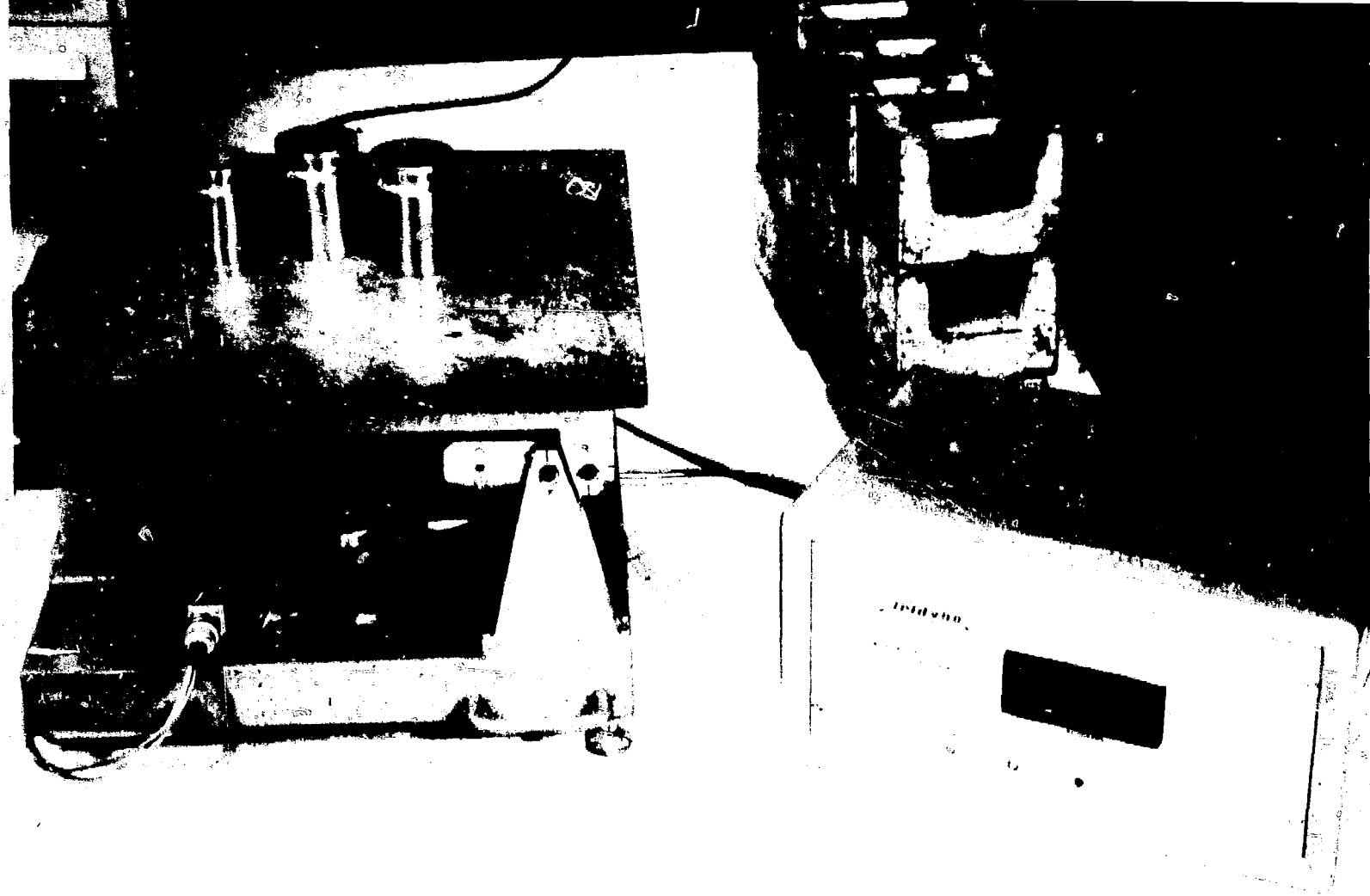
Equal arm balances above the range usually identified with laboratory balances are used for a wide variety of high precision measurements of mass. They are extremely simple in design and rugged enough for continuous operation over many years. Because of their inherent simplicity, they can be used with virtually no service and by the application of proper weighing techniques can be used to make measurements with a precision of 1 part in ten million of capacity. They are useful not only for the measurement of the mass of samples of material, but are particularly well adapted for the calibration of standard weights, calibration of weights used in dead weight testers and are widely used for the manufacture of gas mixtures by gravimetric means.

Because of the unitized construction of all of the balances described in this brochure, it is possible to make modifications to suit specific applications. Pan size can be varied over a wide range and the elimination of the center column permits much larger pans than are usually possible with equal arm balances. The A-500 Null Indicator permits higher sensitivities as well as the convenience of external zero and sensitivity adjustments. Magnetic dampers permit the rapid determination of rest points eliminating the need for measuring a series of oscillations of the pointer. The chain weight eliminates the handling of small weights.

Balances are available in two basic models with some variation in capacity and sensitivity available within the models. Capacity to sensitivity ratios of one part in ten million are standard. All controls are grouped together for ease of operation. Electrical output is available to provide recording of weight changes as a function of time or to provide high resolution within a limited range for the measurement of weight changes by differential weighing. All of the balances described here feature intermediate knife edges in the suspensions for high reproducibility. They are the finest high capacity equal arm balances available in the world.

**Higher sensitivities available on special order.*

FIGURE 9-3



9-14

FIGURE 9-4

The Tridyne Triple Beam Scale (above) provides weight of calibration liquid increments to 0.02%. The scale is field calibrated with calibration weights traceable to class S-1 NBS standards.

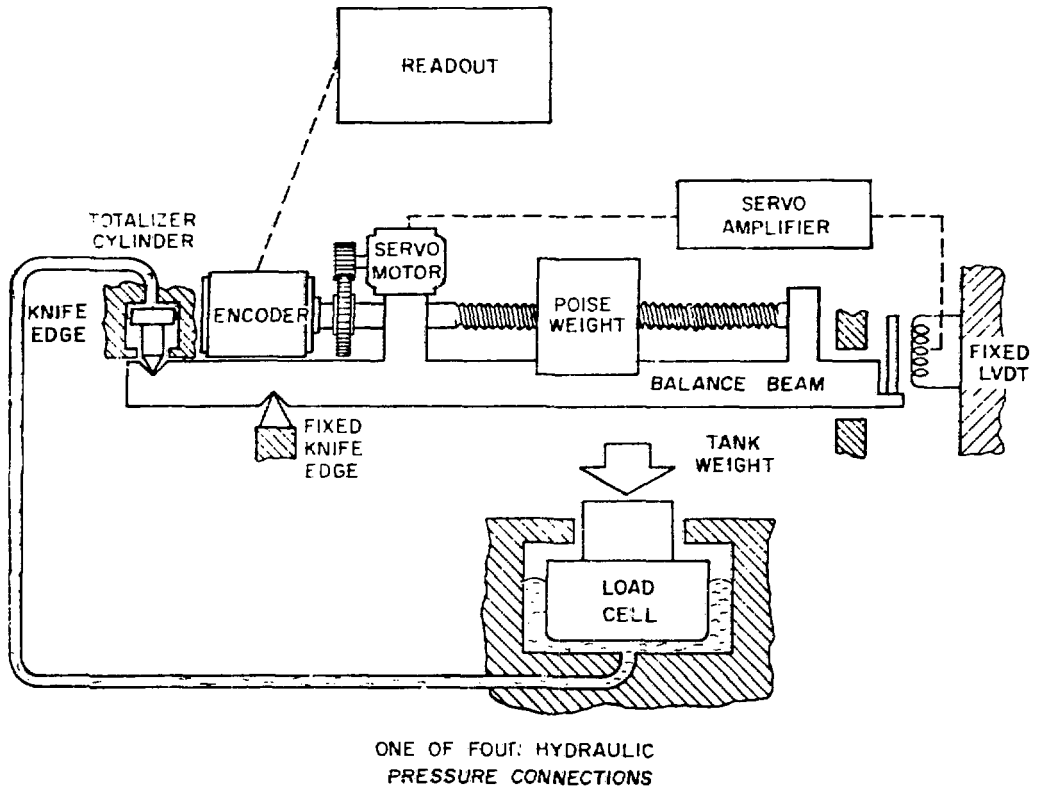
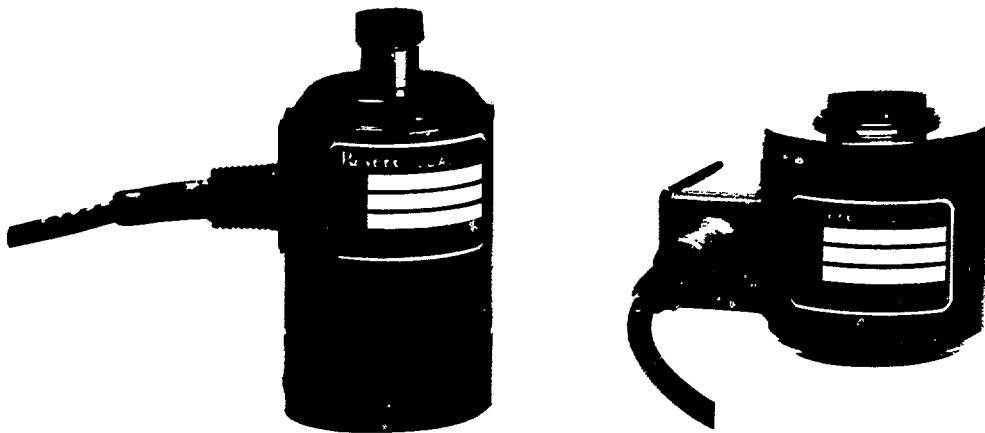


FIGURE 9-5

**HYDRAULIC LOAD CELL COMBINED WITH
A BEAM BALANCE SYSTEM**

LOAD CELL MOUNTING ASSEMBLIES



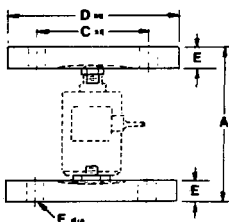
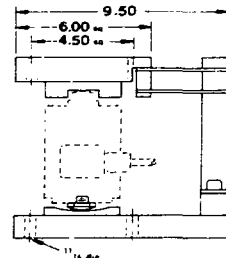
Hardy Scales uses Revere load cells as a standard for our process weighing systems. Revere's USP, CP and CSP load cells are precision strain gage devices that are hermetically sealed to protect them from the environment.

The mounting hardware assemblies that follow are specifically designed for application of the Revere USP, CP and CSP load cells. When properly applied these mounting assemblies will provide high accuracy and reliability.

Type I—This configuration is recommended for inside applications free from vibration and shock. Designed for load cells ranging in capacity from 500 to 100,000 lbs., this parallel plate configuration eliminates the need for external check rods, maintains load cell alignment and assures that side loads do not reach the cell.

PART NO.	USE WITH LOAD CELL		HEIGHT, INCHES
	TYPE	CAPACITY, lbs.	
C-48520-7	USP	500/1,000	7.90-8.08
C-48520-6		2,500	6.61-6.73
C-48520-1		5,000/10,000	9.09-9.28
C-48520-2	CP, CSP	10,000/25,000	6.22-6.38
		50,000	
C-48520-5	CP, CSP	100,000	9.69-9.84

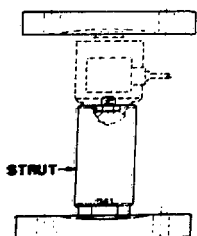
TYPE I



TYPE IIA

Type IIA—This all-purpose arrangement, available for all load cells with capacities from 10 to 500,000 lbs., is used in compression loading and is the simplest of the assemblies. It is recommended for heavy duty weighing systems such as large platform scales, large silos and tank applications. External check rods are required.

Type IIB—In the Type IIB configuration, a strut is added to the load cell, increasing the distance between the upper and lower plates and reducing inaccuracies due to lateral movement by reducing the incurred angle. The height of the strut is dependent on the distance between the supporting load cells. See table, page 12. Type IIB is designed for load cells ranging in capacity from 10 to 500,000 lbs. External check rods are required.



TYPE IIB

PART NO.	USE WITH LOAD CELL			DIMENSION, INCHES			
	TYPE	CAPACITY, lbs.	A	C	D	E	F
C-52400-10	USP	10/25	4½	4	5	½	13/32
C-52400-9		50/100	4½				
C-52400-8		250	5 13/16				
C-52400-1		500/1,000	7 1/16			1	
C-52400-2		2,500	5%				
C-52400-3	CP CSP	5,000/10,000	8 7/16	5	7 ½	1	1 1/16
C-52400-4		10,000/25,000/50,000	5%				
C-52400-5		100,000	7%				
C-52400-6		200,000/300,000	11%			2	
C-52400-7		500,000	15%				

FIGURE 9-6

MECHANICAL LOAD CELL MOUNTING ASSEMBLIES

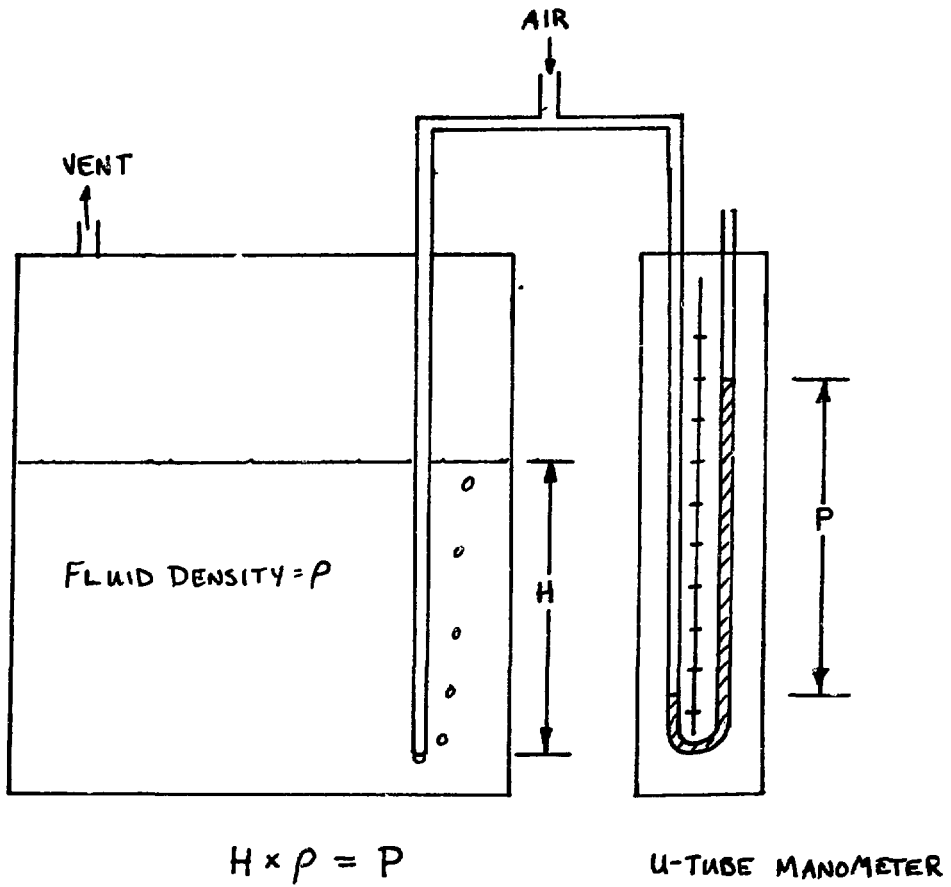
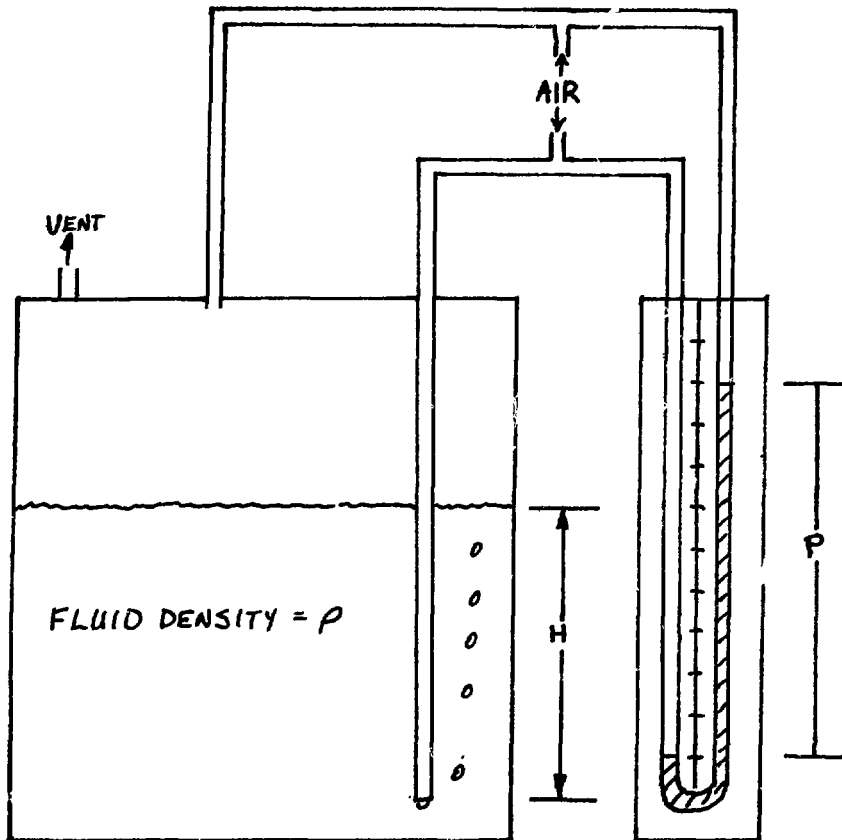


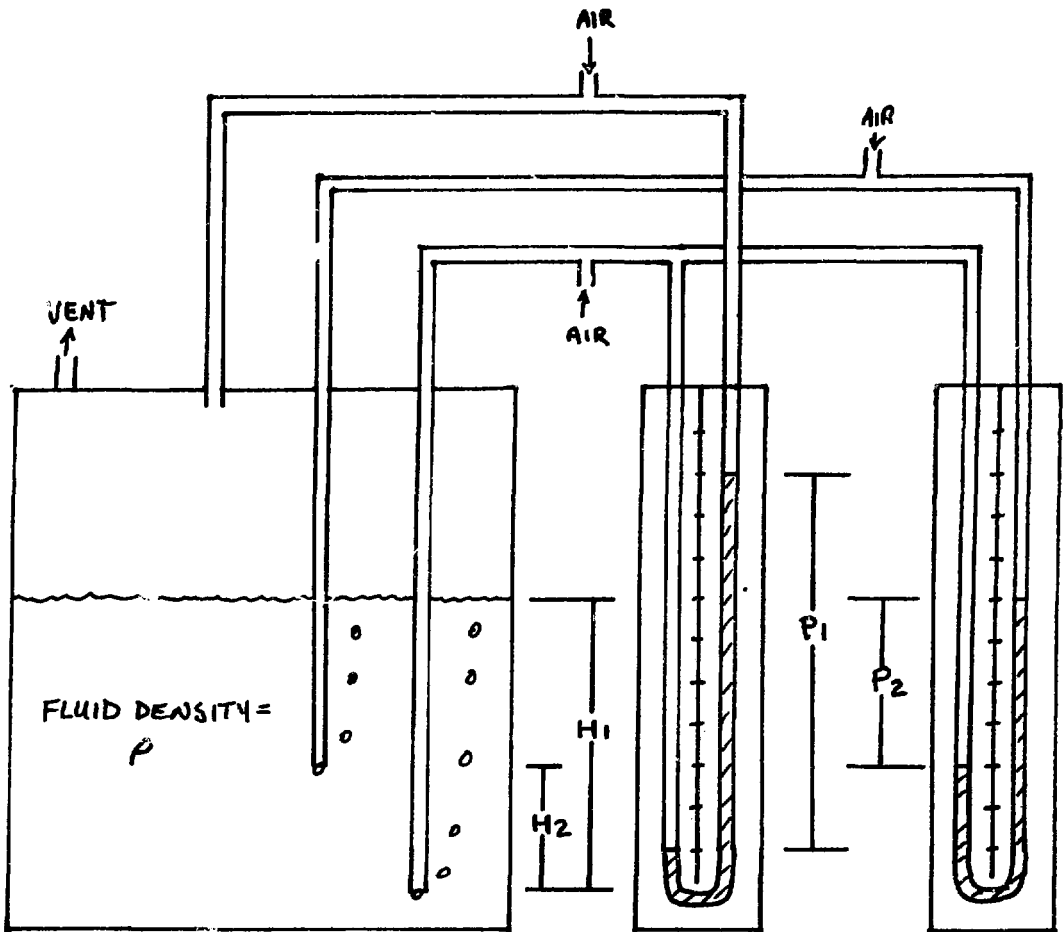
FIGURE 9-7
DIP-TUBE MANOMETER MEASUREMENT OF LIQUID LEVEL



$$H \times \rho = P$$

FIGURE 9-8

IMPROVED DIP-TUBE MANOMETRY SYSTEM



$$\rho = \frac{P_2}{H_2}$$

$$H_1 = \frac{P_1}{\rho} = \frac{P_1 H_2}{P_2}$$

FIGURE 9-9

**DENSITY AND LEVEL MEASUREMENT WITH
DIP-TUBE MANOMETRY**

PRECISION CALIBRATING STANDARD

TYPE FA-187

FOR VACUUM, ABSOLUTE, GAUGE, AND DIFFERENTIAL PRESSURE

This mercurial manometer is widely used as a primary pressure standard. As well as high accuracy, it features dependability and convenience in use—especially easy-to-take readings. It is a universal primary-pressure standard which can be quickly and easily connected to measure either gauge, absolute, or differential pressure, or vacuum.

The W&T Precision Calibrating Standard has a range of 31.5 in. Hg. Operation is direct and dependable. Compensation for temperature and gravity is accomplished without the use of mathematical tables. A unique magnetic vernier makes possible readings to 0.005 in. Hg. Accuracy of the instrument is 0.02% of full scale; sensitivity is 0.004% of full scale.

The FA-187 Manometer is ideal for calibrating secondary or working pressure standards. It is also used for calibrating or checking such instruments as aircraft and surveying altimeters, pressure transducers, meteorological and laboratory barometers, and absolute pressure elements having controlling or telemetering functions.

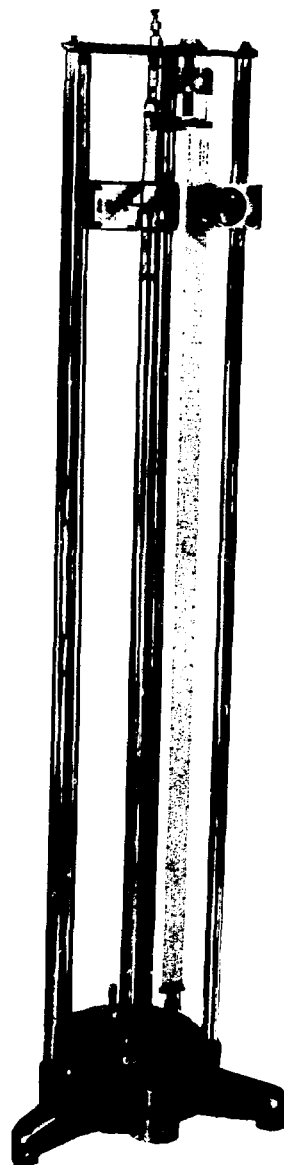


FIGURE 9-10

WELL-TYPE MANOMETER

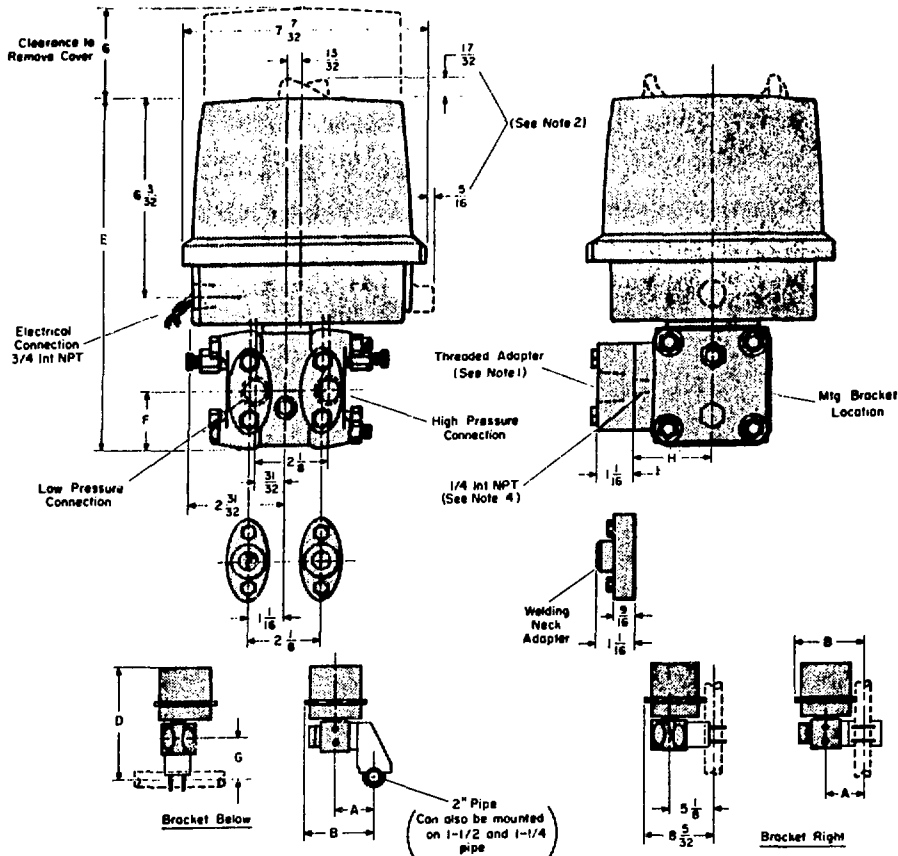
FENNWALT
WALLACE & TIERNAN
MEASUREMENT & CONTROL

FIGURE 9-11

Differential Pressure Transmitter

1302T, 1303T, 1304T, 1306T, 1308T

Installation

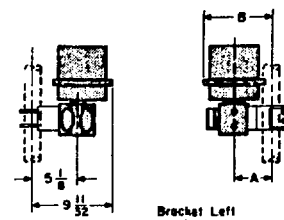


HORIZONTAL PIPE MTG

All dimensions in inches.

For reference only; not for construction.

- Notes: 1. Threaded adapters are eccentric and can be positioned to obtain center-to-center pressure connection of 1-15/16, 2-1/8 and 2-5/16.
2. These dimensions apply to 130_T_4 Instruments.
3. Electrical connections are two 28-inch leads.
4. Threaded adapters not supplied on 130_TD ____ 0.
1/4 Int NPT holes in flanges, 2-9/32 apart



VERTICAL PIPE MTG

C-1209-774

CATALOG NO.	A	B	D	E	F	G	H
1302TD ____ 0,1,2,3	6	10-1/2	14-27/32	12-11/32	2-19/32	5-1/8	3-1/8
1303TD ____ 0,1,2,3	5-1/8	8-3/4	13-31/32	10-19/32	1-23/32	5-1/8	2-1/4
1304TD ____ 0,1,2,3	5-1/8	9	13-31/32	9-5/8	1-1/4	5-5/8	2-1/2
1306TD ____ 0,1,2,3	5-1/8	8-3/4	13-31/32	10-19/32	1-23/32	5-1/8	2-1/4
1308TD ____ 0,1,2,3	5-1/8	9	13-13/32	9-5/8	1-1/4	5-5/8	2-1/2

Mounting Dimensions for Transmitters with Pipe Adapter Process Connections, 130_TD ____ 0,1,2,3



FIGURE 9-12
RUSKA ELECTRONMANOMETER
WITH DEAD WEIGHT
PRESSURE TESTER

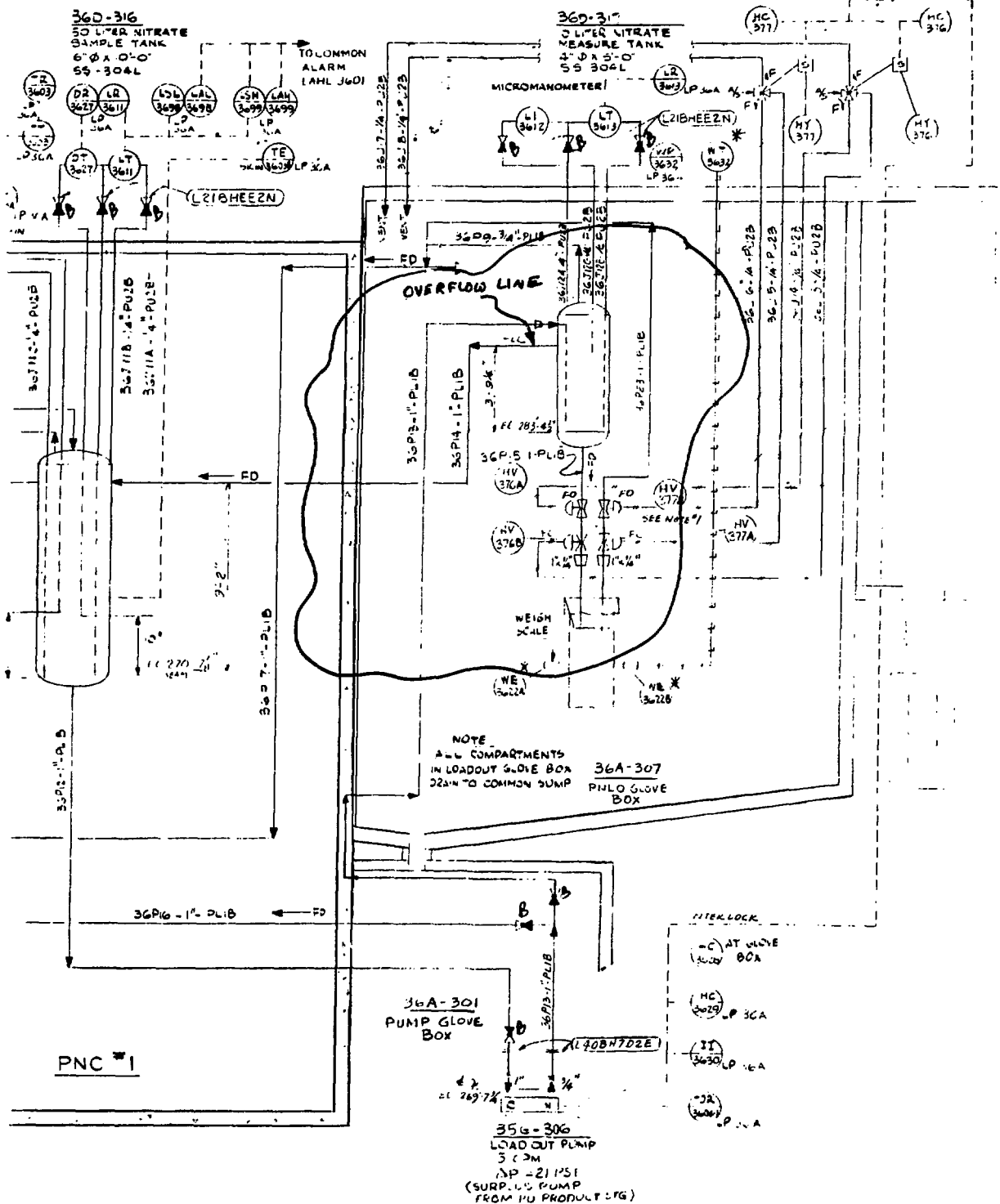


FIGURE 9-13

EXAMPLE OF A CONSTANT VOLUME TANK

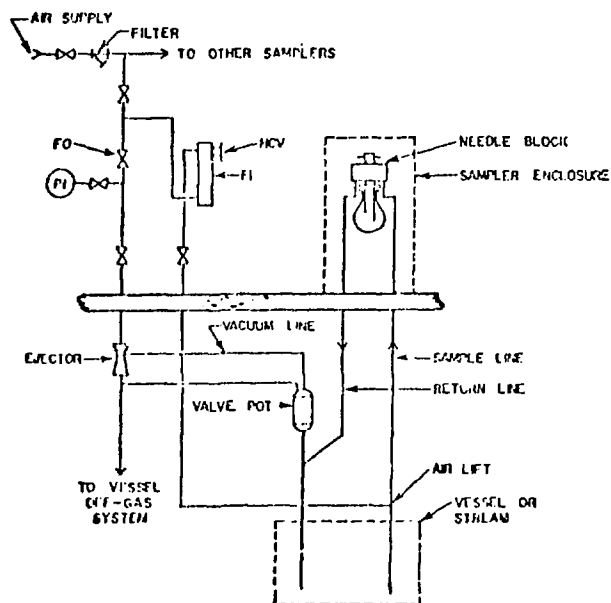


FIGURE 9-14

RECIRCULATING TYPE SAMPLER

9-25
FIGURE 9-15

INPUT ACCOUNTABILITY MEASUREMENT CHECKSHEET

Batch No.: _____ Date: _____

	TIME	OPER. INIT.
1. Record "Before Receipt" measurement data		
a. Sparge off, purges set		
b. Record data		
c. Take CNMCAS data		
2. Receive transfer		
a. Set transfer valving		
b. Transfer started		
c. Transfer integrity check complete		
d. Transfer complete		
e. After transfer valving complete		
3. Record "Before Sampling" measurement data		
a. Sparge a minimum of 15 minutes before readings		
b. Sparge off, purge set		
c. Record data		
d. Take CNMCAS data		
e. Receipt volume comparison		
4. Sample the Accountability Tank.		
a. Sparge off		
b. Request sample		
c. Sampling complete		
5. Record "After Sampling" measurement data		
a. Sparge off, purges set		
b. Record data		
c. Take CNMCAS data		
6. Compare "Before" and "After" sampling measurements		
a. Compare measurement data		
7. Transfer tank contents; if not transferred, enter "NA".		
a. Set transfer valving		
b. Transfer started		
c. Transfer integrity check		
d. Transfer complete		
8. Record "After Transfer" measurement data		
a. Sparge off, purges set		
b. Record data		
c. Take CNMCAS data		
9. Complete Accountability Logbook entries		

Input Accountability

Transfer To:

#2 FAT

Diss. Fl'sh Accm.

Sump Coll. Tank

Date/Time/Op. Init.

Inst. Air Purge Rate
LEVEL

LR-125

Ruska "Zero"

LR-125-R

DENSITY

DR-166

Ruska "Zero"

DR-166-R

TEMPERATURE

TRJ-108-10

SAMPLE RESULTS

Log No.

Density

U Conc

VOLUME

**Volume
Received**

**Volume
Transferred**

**Kg U
Transferred**

Transfer Complete

Shift Supervisor

Date _____

* Use log number and density from previous batch sample.

FIGURE 9-17

TOLERANCE CHARTS

AVOIRDUPOIS DENOMINATIONS								
CLASS:	S-1	P	Q	T	A&B	C	METRIC	AVOIR.
100 lb.	450 mg	910 mg	2.3 g	7.0 g	--	15 GN	4.5 g	0.010 lb
50	230	450	1.1	4.1	2 GN	10	2.3	.005
25	110	230	570 mg	2.4	1.2	6	--	--
20	91	180	450	2.0	1.2	6	.91	.002
10	45	91	230	1.3	0.8	4	.45	.001
5	23	45	110	810 mg	0.6	3	227 mg	500 µlb
4	18	36	91	700	0.4	2	--	--
2	9.1	18	46	440	0.3	1.5	91	200
1	4.5	9.1	27	270	0.2	1.0	70	154
.5	2.3	4.5	16	170	0.1	0.5	45	100
.2	.91	1.8	8.3	94	0.06	0.3	18	40
.1	.58	1.1	5.3	59	0.04	0.2	9.1	20
.05	.38	.75	3.4	37	0.04	0.2	4.5	10
.02	.24	.48	1.9	20	0.02	0.1	1.8	4
.01	.17	.34	1.2	12	0.01	0.05	1.45	3.20
.005	.13	.27	.81	7.7	0.01	0.05	1.17	2.58
.002	.096	.19	.49	4.2	0.01	0.05	0.87	1.92
.001	.076	.15	.36	2.9	0.004	0.02	0.70	1.54
10 oz	2.8	5.6	19	170	0.1	0.5	--	--
8	2.3	4.5	16	170	0.1	0.5	45	100
4	1.1	2.3	9.6	110	0.1	0.5	23	50
2	0.65	1.3	6.1	70	0.06	0.3	11	25
1	.43	.86	3.9	42	0.04	0.2	5.4	12
1/2	.30	.59	2.5	27	0.04	0.2	2.8	6.2
1/4	.21	.43	1.6	17	0.02	0.1	1.68	3.70
1/8	.16	.31	1.1	10	0.01	0.05	1.34	2.96
1/16	.12	.24	.70	6.5	0.01	0.05	1.08	2.38
1/32	.095	.19	.48	4.2	0.01	0.05	--	--
1/64	.078	.15	.36	2.8	0.004	0.02	--	--

1 µlb = 0.000001 lb (avoirdupois) = .454 mg = .007 GN

METRIC									
CLASS:	M	S	S-1	P	Q	T	A&B	C	F
25 Kg	125 mg	62 mg	250 mg	500 mg	1.2 g	4.5 g	--	--	2500 mg
20	100	50	200	100	1.0	3.8	120 mg	600 mg	2000
10	50	25	100	200	500 mg	2.2	80	400	1000
5	25	12	50	100	250	1.4	50	250	500
3	15	7.5	30	60	150	1.0	--	--	300
2	10	5.0	20	40	100	750 mg	30	150	200
1	5.0	2.5	10	20	50	470	20	100	100
500 g	2.5	1.2	5.0	10	30	300	14	70	70
300	1.5	0.75	3.0	6.0	20	210	--	--	60
200	1.0	.50	2.0	4.0	15	160	8	40	40
100	0.50	.25	1.0	2.0	9.0	100	6	30	20
50	.25	.12	0.60	1.2	5.6	62	4	20	10
30	.15	.074	.45	0.90	4.0	44	--	--	8
20	.10	.074	.35	.70	3.0	33	2	10	4
10	.050	.074	.25	.50	2.0	21	1.5	7	2
5	.034	.054	.18	.36	1.3	13	1.0	5	1.5
3	.034	.054	.15	.30	0.95	9.4	--	--	1.28
2	.034	.054	.13	.26	.75	7.0	0.6	3	1.12
1	.034	.054	.10	.20	.50	4.5	0.4	2	.90
500 mg	.0054	.025	.080	.16	.38	3.0	0.3	1.5	.72
300	.0054	.025	.070	.14	.30	2.2	--	--	.61
200	.0054	.025	.060	.12	.26	1.8	0.14	0.7	.54
100	.0054	.025	.050	.10	.20	1.2	0.10	0.5	.43
50	.0054	.014	.043	.085	.16	.88	0.07	0.35	.35
30	.0054	.014	.038	.075	.14	.68	--	--	.29
20	.0054	.014	.035	.070	.12	.56	0.04	0.20	.26
10	.0054	.014	.030	.060	.10	.40	0.03	0.15	.21
5	.0054	.014	.028	.055	.080	--	0.02	0.10	.17
3	.0054	.014	.026	.052	.070	--	--	--	.14
2	.0054	.014	.025	.050	.060	--	0.01	0.05	.12
1	.0054	.014	.025	.050	.050	--	0.01	0.04	.10



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



April 27-May 12, 1981

Session Objectives

SESSION 10: 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.



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



April 27-May 12, 1981

SESSION 10: 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.

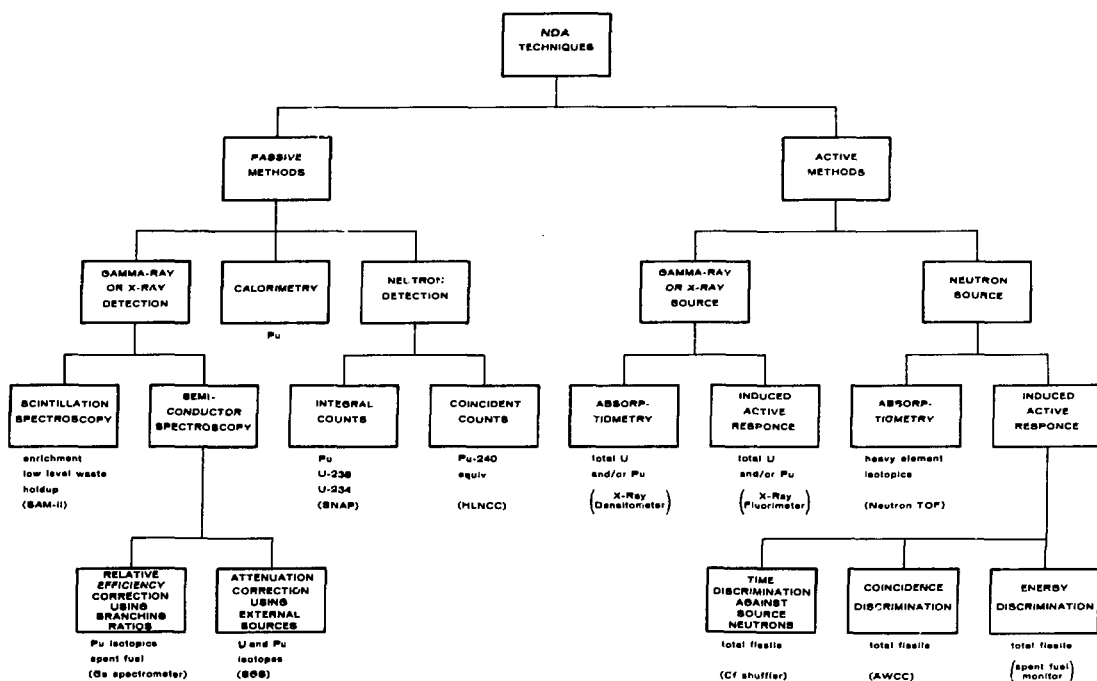


Fig. 1

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.

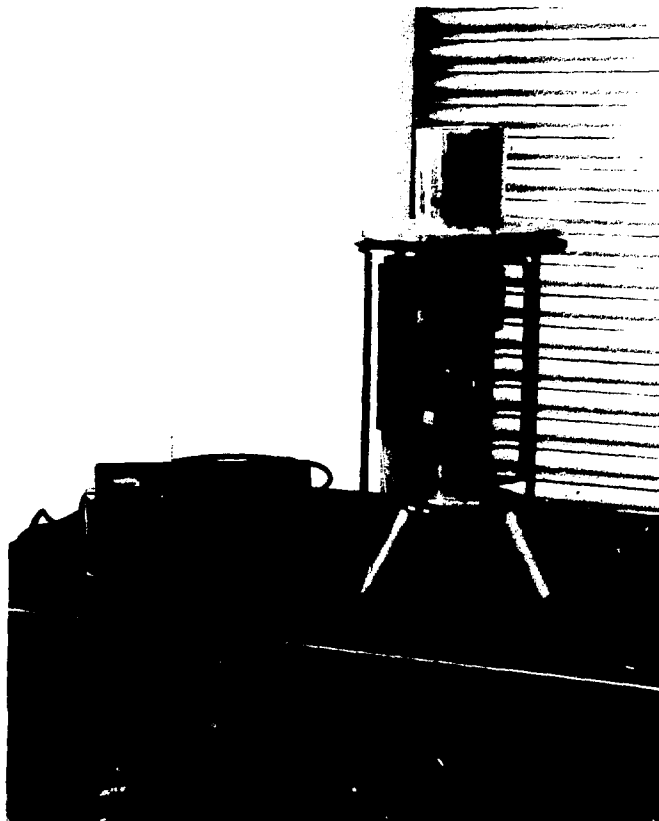


Fig. 3
Characteristic
pulse height
spectrum obtained
with a NaI
detector viewing a
 ^{235}U sample.
The curve was
obtained with a
SAM-II by varying
one of the single
channel analyzers.

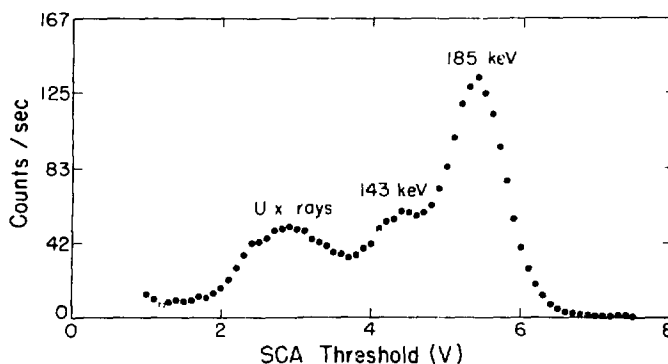


TABLE I
URANIUM, PLUTONIUM, AND AMERICIUM
GAMMA-RAY EMISSION RATES

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⁾

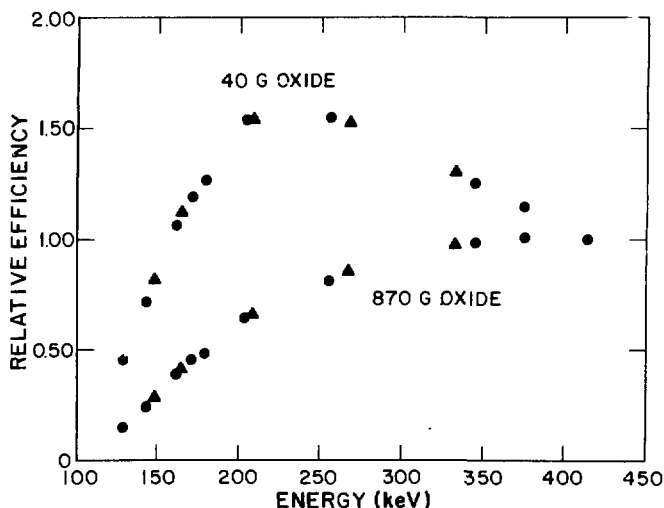
2. Other Applications. Although the enrichment meter is perhaps the most well known, gamma-ray instruments using sodium iodide and other scintillation detectors have been used for many other applications in safeguards, such as assaying low level waste, monitoring effluents, and estimating the holdup 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.



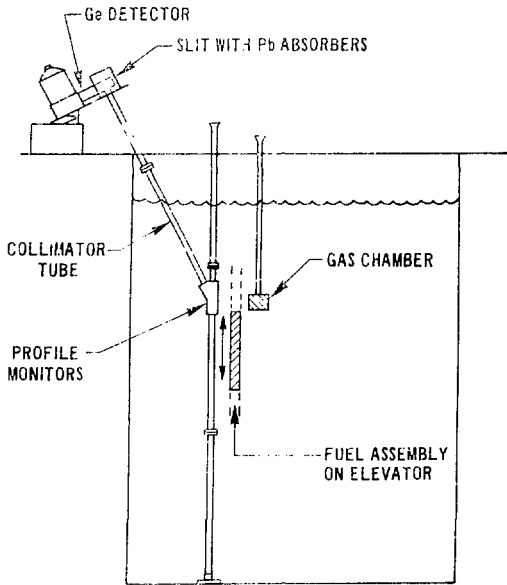


Fig. 9

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.

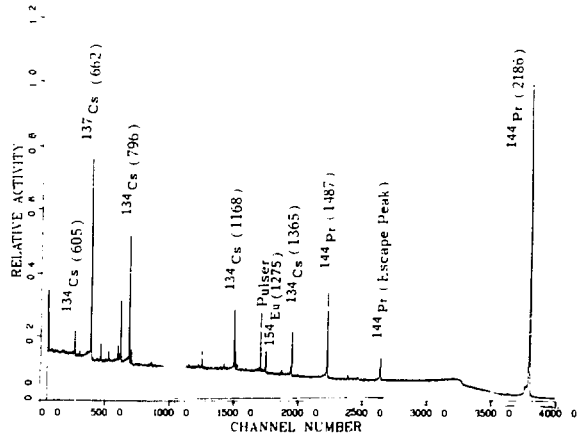


Fig. 10

Characteristic gamma-ray spectrum observed with spent fuel. From fission product isotopic ratios, it is possible to verify cooling time and burnup.

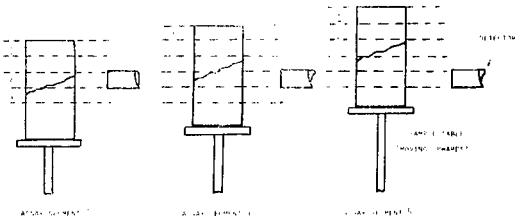


Fig. 11

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.

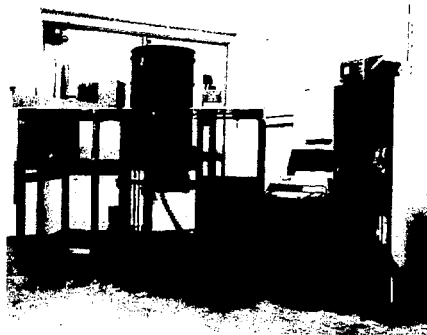


Fig. 12

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

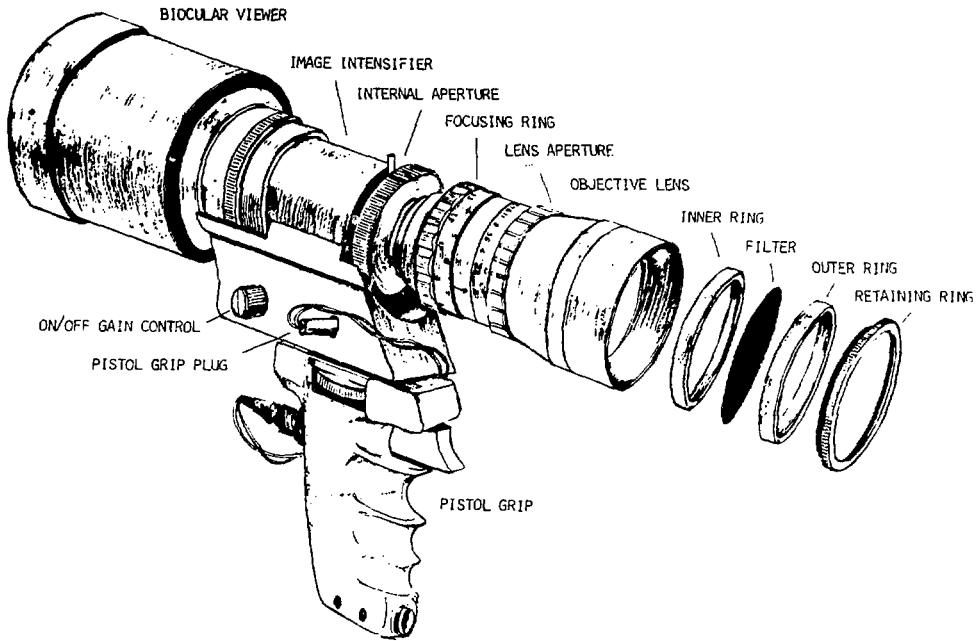


Fig. 13

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.

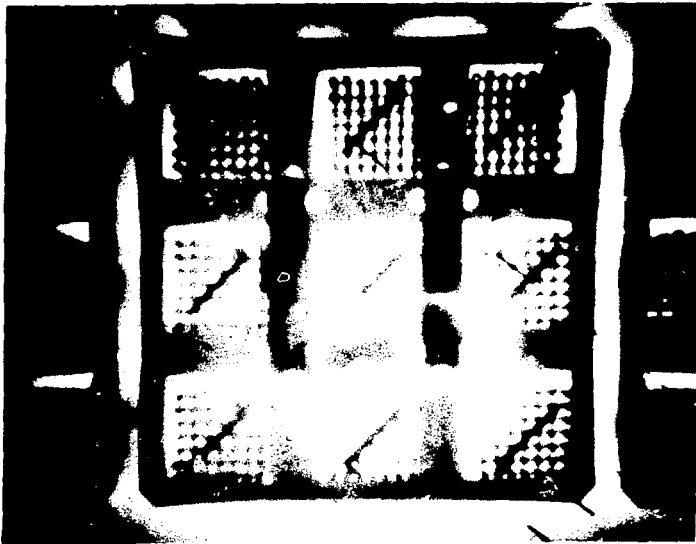


Fig. 14

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.

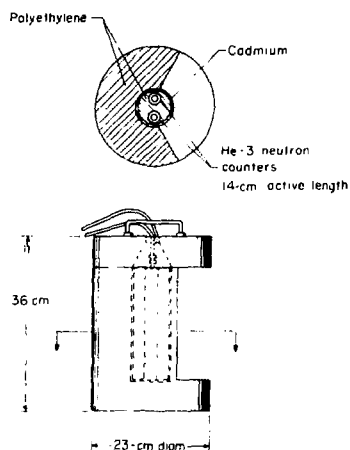


Fig. 15
Assembly drawing of
the Shielded Neutron
Assay Probe (SNAP),
showing two ^3He
proportional tubes
inside a cadmium
shield.

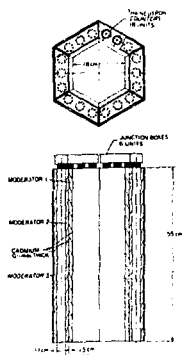


Fig. 17
The High-Level Neutron
Coincidence Counter
(HLNCC) contains 18 ^3He
proportional tubes in a
hexagonal polyethylene
moderator. Coincidence
counting allows one to
detect fission neutrons
from ^{240}Pu and other
even isotopes, while dis-
criminating against (α, n)
neutrons in the sample.

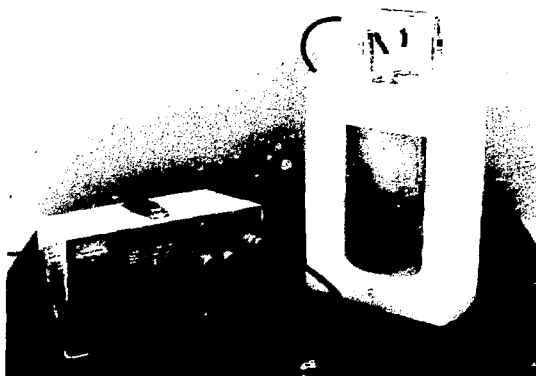


Fig. 16
Shielded Neutron Assay Probe
(SNAP) connected to the Eberline
SAM-II electronics unit. The SNAP
can be used to assay plutonium
samples by counting both (α, n) and
fission neutrons.

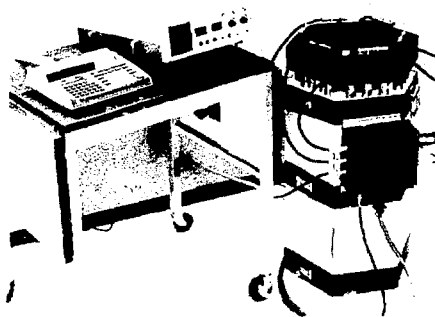


Fig. 18
Portable assay station consist-
ing of a High-Level Neutron Co-
incidence Counter (HLNCC), shift
register electronics, and HP-97
calculator. Designed for use by
the IAEA, this arrangement al-
lows inspectors to make rapid
assays of plutonium samples
under field conditions.

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).

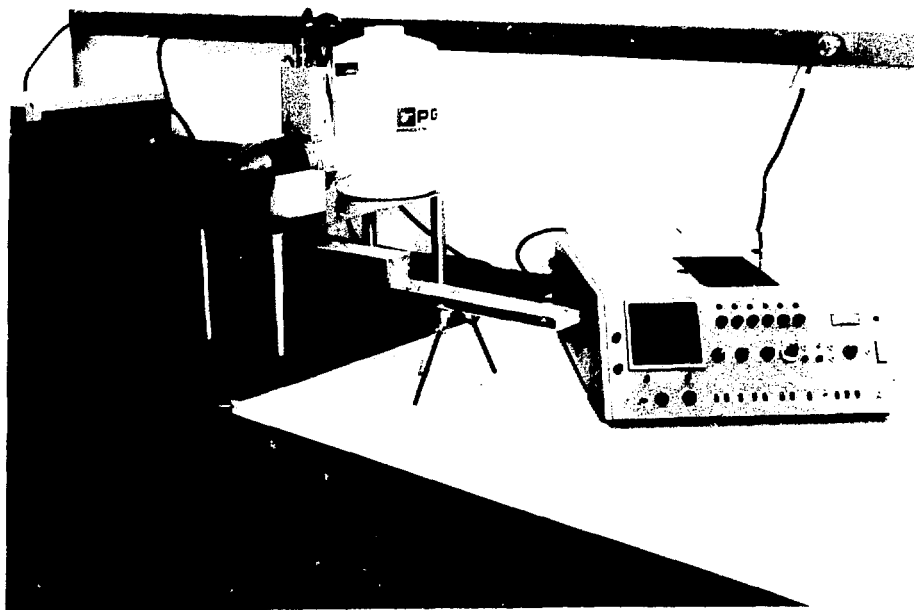


Fig. 19

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

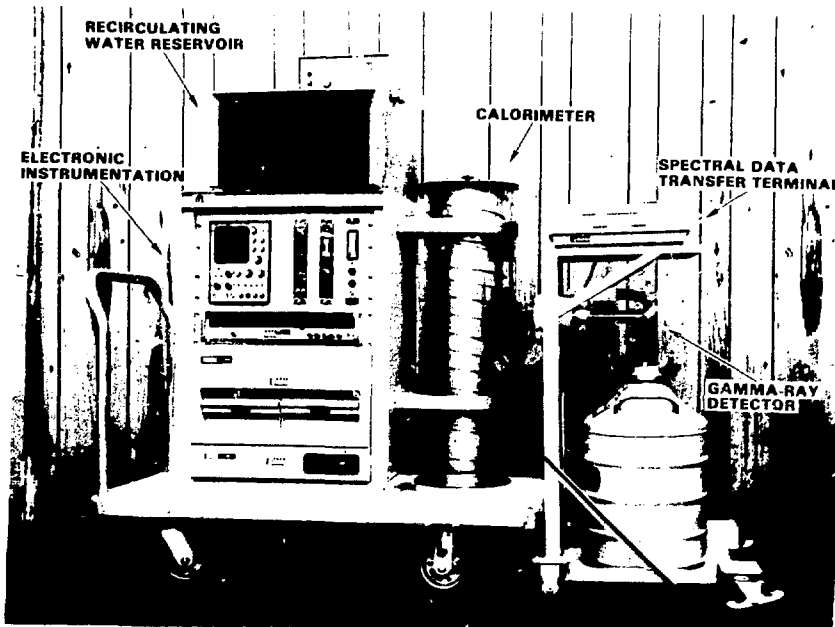


Fig. 20

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.

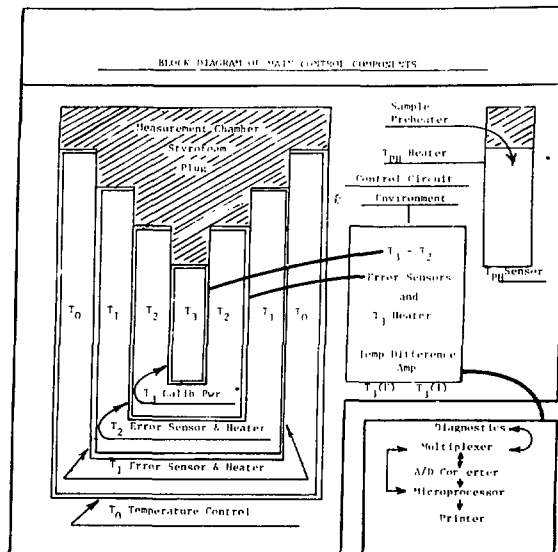


Fig. 21

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

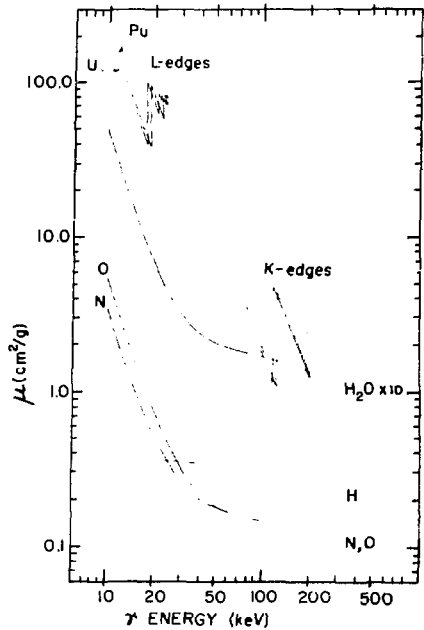
A. Absorption Spectrometry (Including X-Ray Densitometry)

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

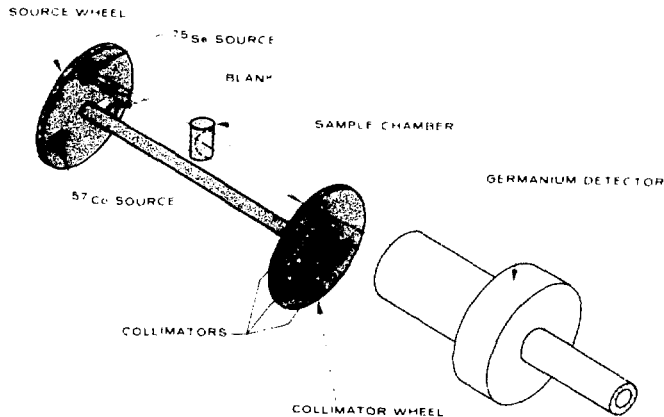


Fig. 23
In the K-edge densitometer installed at Tokai, isotopic sources and collimators are automatically rotated into position to measure x-ray attenuation of the sample just above and below the plutonium K-edge. Here a ⁷⁵Se source is positioned to measure the transmission at 121.1 keV.

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

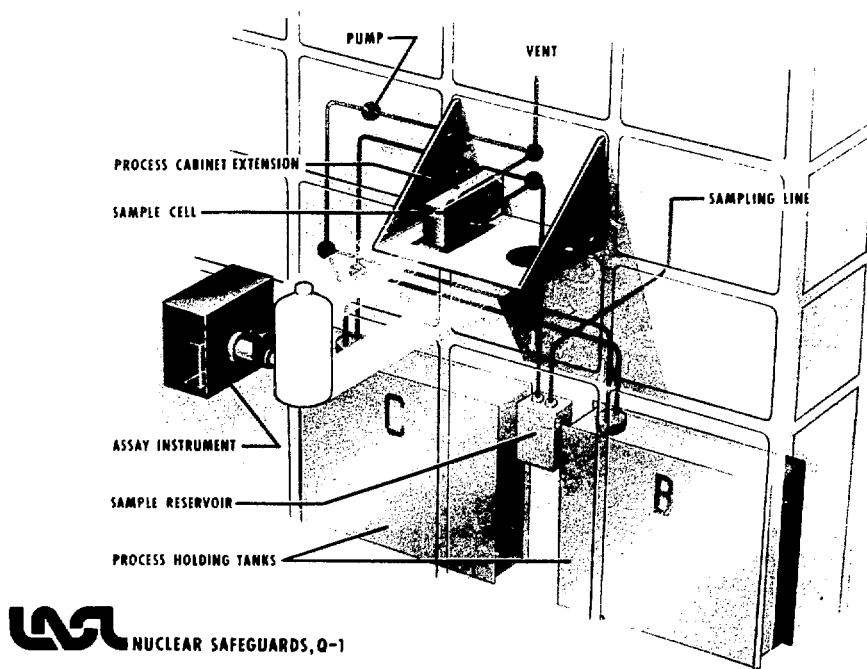


Fig. 24

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

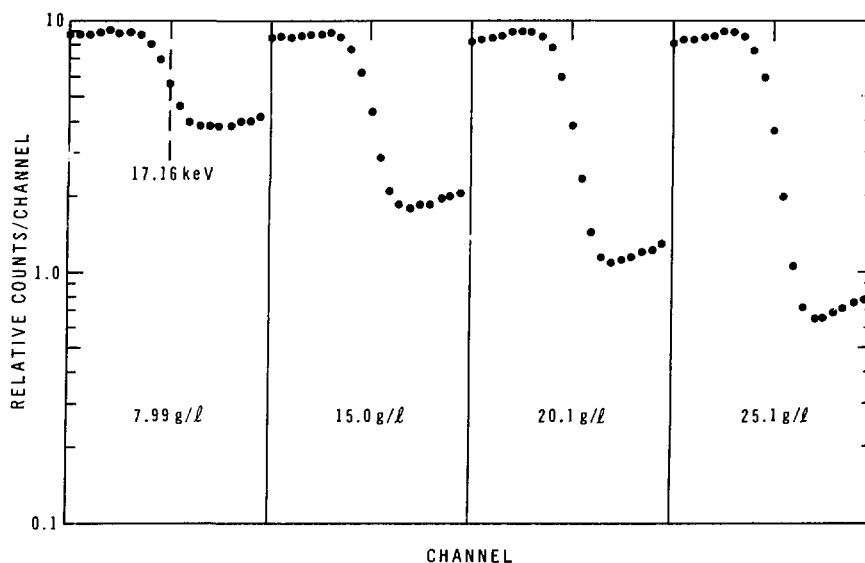


Fig. 25

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.

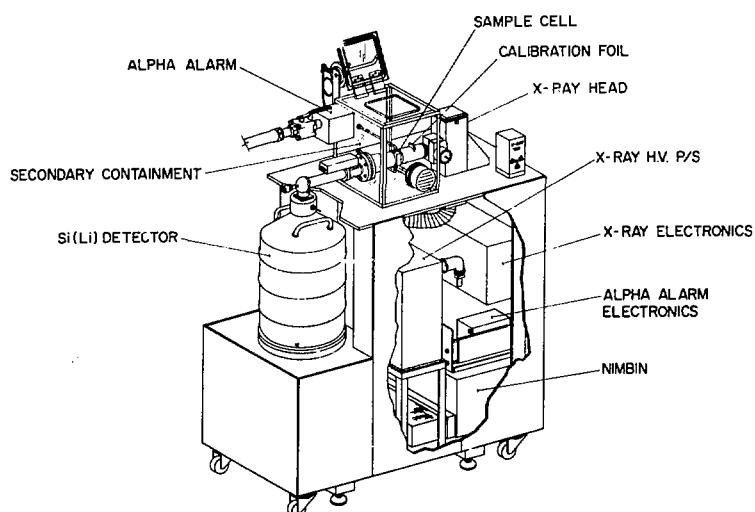


Fig. 26

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.

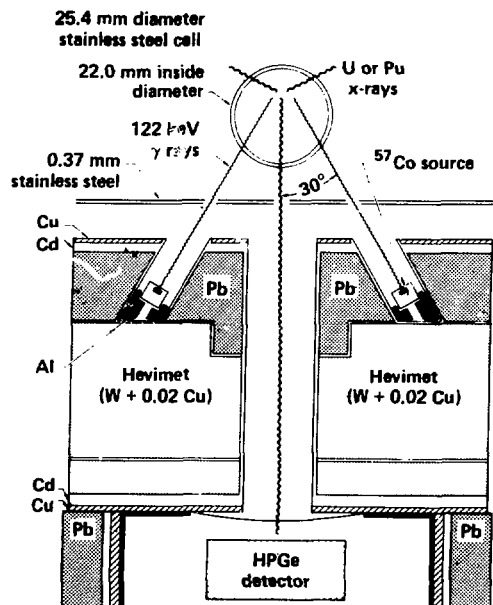
of energy across the absorption edge (Fig. 25). The use of a continuous x-ray spectrum provides a complete assay in one measurement, and the same x-ray machine can be used for assaying plutonium, uranium, and mixed U-Pu solutions (Fig. 26). Unlike K-edge assays, L-edge assays are sensitive to low Z matrix 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

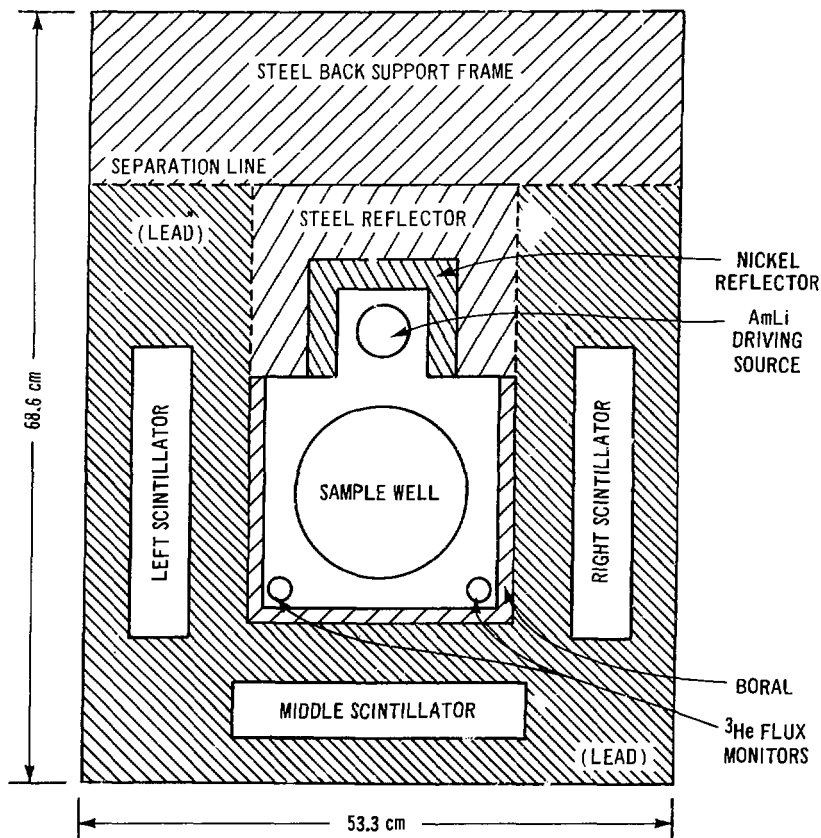


Fig. 28

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.

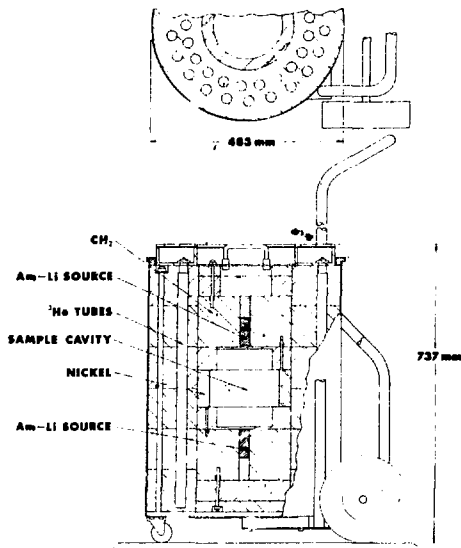


Fig. 29

Cross-section of Active Well Coincidence Counter, showing location of neutron sources in end plugs above and below the sample well.

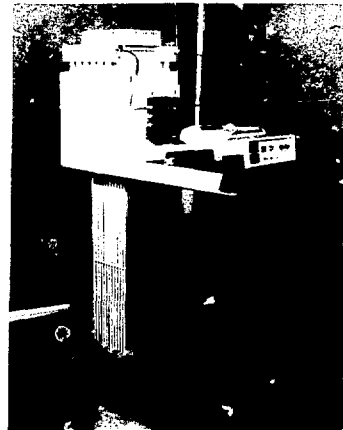


Fig. 30

The Active Well Coincidence Counter was designed as a transportable instrument for IAEA use in assaying uranium samples.

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.



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.

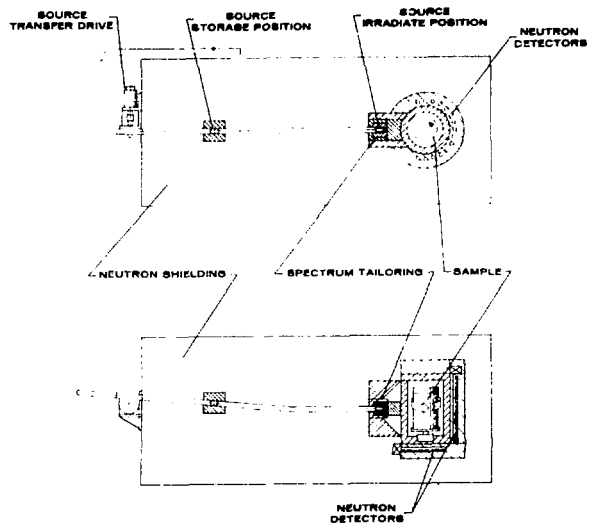


Fig. 33
Complete Savannah River Cf shuffler showing terminals, electronics rack, and hoist for lowering samples into the measurement well.

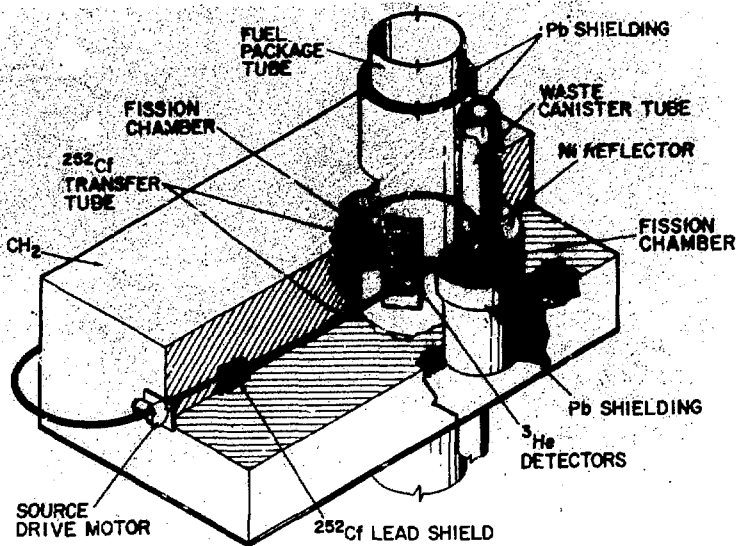


Fig. 34

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 moves around the fuel package tube during the irradiation cycle. This instrument is to be installed in the Florinel and Storage (FAST) Facility at the Idaho Chemical Processing Plant.

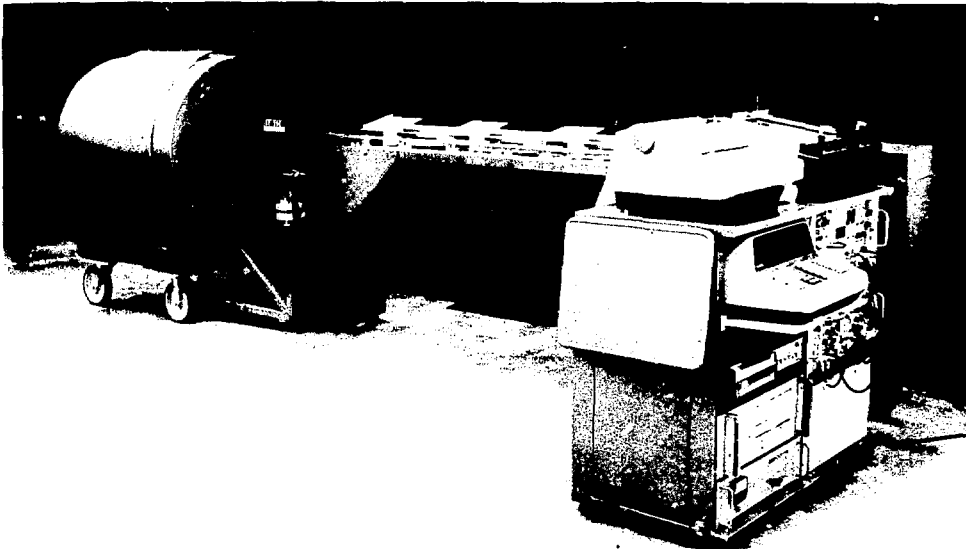


Fig. 35

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.

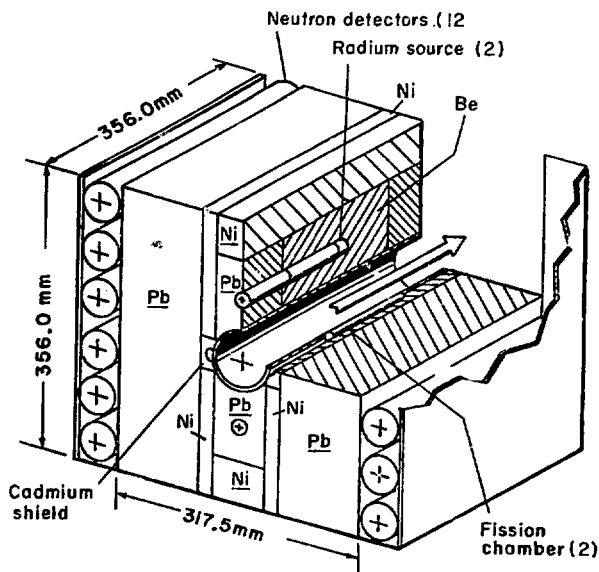


Fig. 36

^{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 spatial properties, but poorly defined isotopic properties, then a gamma-ray or x-ray assay technique is likely to provide the best assay. Consider, as examples, enrichment measurements, solution assay systems, x-ray densitometry, and plutonium isotopic ratio measurements, all of which require knowledge of key spatial characteristics of the sample, in order to account for gamma-ray scattering and absorption.

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.

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



April 27-May 12, 1981

Session Objectives

SESSION 11: ELEMENTS OF IN-PLANT INSTRUMENTATION DESIGN AND IMPLEMENTATION

This session will provide an overview of the important elements of in-plant NDA instrumentation design and a review of some implementation experience with general NDA techniques.

Following this session, participants will be able to:

1. identify key design elements of at-line and in-line instrumentation,
2. describe some limiting factors on instrument performance,
3. discuss the in-plant application experience of several NDA techniques.



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



April 27-May 12, 1981

SESSION 11: ELEMENTS OF IN-PLANT NONDESTRUCTIVE ASSAY INSTRUMENTATION DESIGN AND IMPLEMENTATION

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I. INTRODUCTION

A variety of active and passive nondestructive assay (NDA) techniques have been developed in physics and chemistry research laboratories where their application to measurements of special nuclear material (SNM) have been studied in detail.^{1,2} These studies have determined the practical limitations of the individual techniques when used to assay or verify SNM content in solids, liquids, and gases of varying chemical composition and physical geometry.³

Many of these techniques have been incorporated into assay instrumentation that is routinely used by safeguards inspectorates, analytical chemistry laboratories, and SNM processing facilities. The in-plant instrumentation supplies information that is important to timely materials accounting, process control, plant safety, and safeguards response capabilities. However, the acceptance of this instrumentation by the responsible process personnel is predicated upon its ability to meet stringent criteria in the areas of instrument-user interface, routine measurement precision and accuracy, and instrument reliability and maintenance.

These criteria differ from those imposed upon the design of similar instrumentation that is to be used in an analytical laboratory. The laboratory technician's responsibilities require the knowledgeable use and maintenance of the instrumentation. The plant operator's principal responsibilities lie with the process, and as a result, the level of instrument care and user-measurement sophistication is often lower. The in-plant instrument must exhibit long-term stability and sample variation insensitivity, as the ease with which calibration, sample preparation, and restandardization procedures may be conducted is severely limited. Poor precision and/or accuracy that result from in-plant instrument instabilities, poor reliability, and difficult maintenance features may result in the production of unsatisfactory material, inadequate SNM accounting, the exceeding of some safety-imposed process limits, or possibly the stopping of a process. Furthermore, important instrument environment features, such as the temperature and humidity, the presence of corrosive substances, and the possibility of radioactive contamination, are generally well controlled in the laboratory when compared to those available in-plant.

This paper describes the fundamental elements of in-plant NDA instrumentation design and summarizes the implementation experience obtained for several individual instruments. Specific features that address the important criteria listed above are discussed in the

context of operating instrument experience. Some speculations as to the future direction of in-plant NDA instrumentation development are offered in the concluding section.

II. INSTRUMENT DESIGN ELEMENTS

Five principal design elements may be defined. They are:

- sample-sensor measurement configuration,
- information processing,
- measurement integrity,
- instrument-user interface, and
- safeguards and process control systems interfaces.

Often the instrument developer places his emphasis upon the first three elements, whereas the user's primary interest lies in the latter three.

In this section, we will discuss these elements and draw upon five developed in-plant instruments as examples. The instruments are the Tokai-mura (T-M) absorption-edge densitometer,⁴ the Savannah River Plant (SRP) ²⁵²Cf Shuffler,⁵ the plutonium solution assay system (PUSAS),⁶ the neutron coincidence counter,⁷ and an enrichment monitor.⁸

A. Sample-Sensor Measurement Configuration

A number of factors determine an instrument's measurement port design. Key among these is the basic NDA technique that is being applied. This choice determines the sample and sensor characteristics and relative geometries and the physical arrangement of any active driving or assay correcting sources. The myriad of possible combinations, however, masks certain unifying parameters that depend primarily upon the in-plant location of the instrumentation. For the purposes of this discussion, three principal site locations are defined: off-line, at-line, and in-line.

Off-line instrumentation is usually placed in a measurement area or laboratory that may include both NDA and analytical chemistry capabilities. Discrete samples or items are assayed before admission to, or upon removal from, the process area by trained measurement personnel. It is this classification that has received the major attention of the instrument developers over the last 10 years.⁹ Examples include the uranium solution assay system,¹⁰ the T-M densitometer, the SRP Shuffler, the fuel-rod scanner,¹¹ the segmented gamma-ray scanner,¹² the random driver,¹³ and various packaged waste assay devices.²

At-line instrumentation is placed in the process area. Discrete samples or entire batches may be assayed without removing samples from the processing lines or glovebox environment. Discrete samples may be obtained manually or piped directly to the measurement port. Assays are made by process personnel. Recent efforts have led to the adaptation of off-line technology to the at-line environment. Examples include the PUSAS, the DYMAC neutron coincidence counter, the Savannah River Laboratory LIII-edge densitometer,¹⁴ and the SRP densitometer.¹⁵

In-line instrumentation is built directly in or onto process elements, such as transfer pipes or holding tanks. Measurements are made continuously or on a batch basis. The devices are often equipped with alarming systems that inform the operator when process

control limits have been exceeded. Examples of this classification of instruments, which include in-line uranium enrichment monitors and discharge effluent monitors, are less numerous than those in the previous two classifications.

In general, the complexity of the chosen NDA technique and the associated measurement configuration decreases as the instrument approaches an in-line state. This simplification is allowed as the dynamic measurement range is lessened, and required as the hardware environment criteria are made more stringent. Counter-examples may be found to this generalization, and some will be pointed out in the course of this discussion.

An in-plant, off-line instrument, which in a sense enjoys the best of all possible worlds, is the T-M densitometer. This gamma-ray spectroscopy NDA system is placed in a dedicated glovebox, in a climate-controlled analytical chemistry laboratory and is operated by trained chemists and technicians. Furthermore, it is designed to assay the total plutonium concentration and isotopic distribution of clean, freshly separated to moderately aged, product plutonium-bearing solutions, whose components vary over a relatively narrow range.

It is the complex NDA techniques used that require a sophisticated measurement station. The total plutonium concentration is determined by a K-absorption-edge densitometry technique. Transmission measurements are made at two discrete gamma ray energies that closely bracket the plutonium K-absorption edge. The ratio of these transmissions gives a matrix-independent signal proportional to the sample plutonium concentration.^{16,17} Two gamma-ray transmission sources are used. The isotopic distribution is determined by a transmission corrected, passive assay of the sample.¹⁸

The measurement station, shown in Fig. 1, is mounted beneath a modified glovebox. Solution samples, in plastic disposable vials, with well-defined dimensions, are placed in the sample well, c in the figure, between the high-resolution Ge(Li) detector, a, and the transmission source, b. The two-step (transmission and passive) assay is performed by rotating the transmission sources in and out of the measurement position. The two motor-driven wheels containing sources, i, and collimators, j, are positioned synchronously by a Geneva mechanism, f, such that the detector observes primarily the tightly collimated radiation from one of the two transmission sources or that from the sample with collimation open. The assay procedure is fully automated.

This design may be contrasted with an at-line gamma-ray instrument that also assays the plutonium content of solutions, the PUSAS. In this case, the instrument is placed in a SNM processing glovebox line, through which a variety of plutonium materials are moved and chemically processed. It is designed to allow process technicians to assay the plutonium concentrations of impure oxide metal dissolutions, ion-exchange column eluates and effluents, and precipitation filtrates. Plutonium concentrations vary widely, 1 mg - 500 g/L, as do the ²⁴¹Am and ²³⁷U contaminants. The degree of precipitation in the samples may vary.

A schematic of the measurement station is shown in Fig. 2. The design adapts the transmission corrected, passive gamma-ray assay technique used in the T-M densitometer to determine only the ²³⁹Pu concentration. The sample is placed between the Ge(Li) detector and

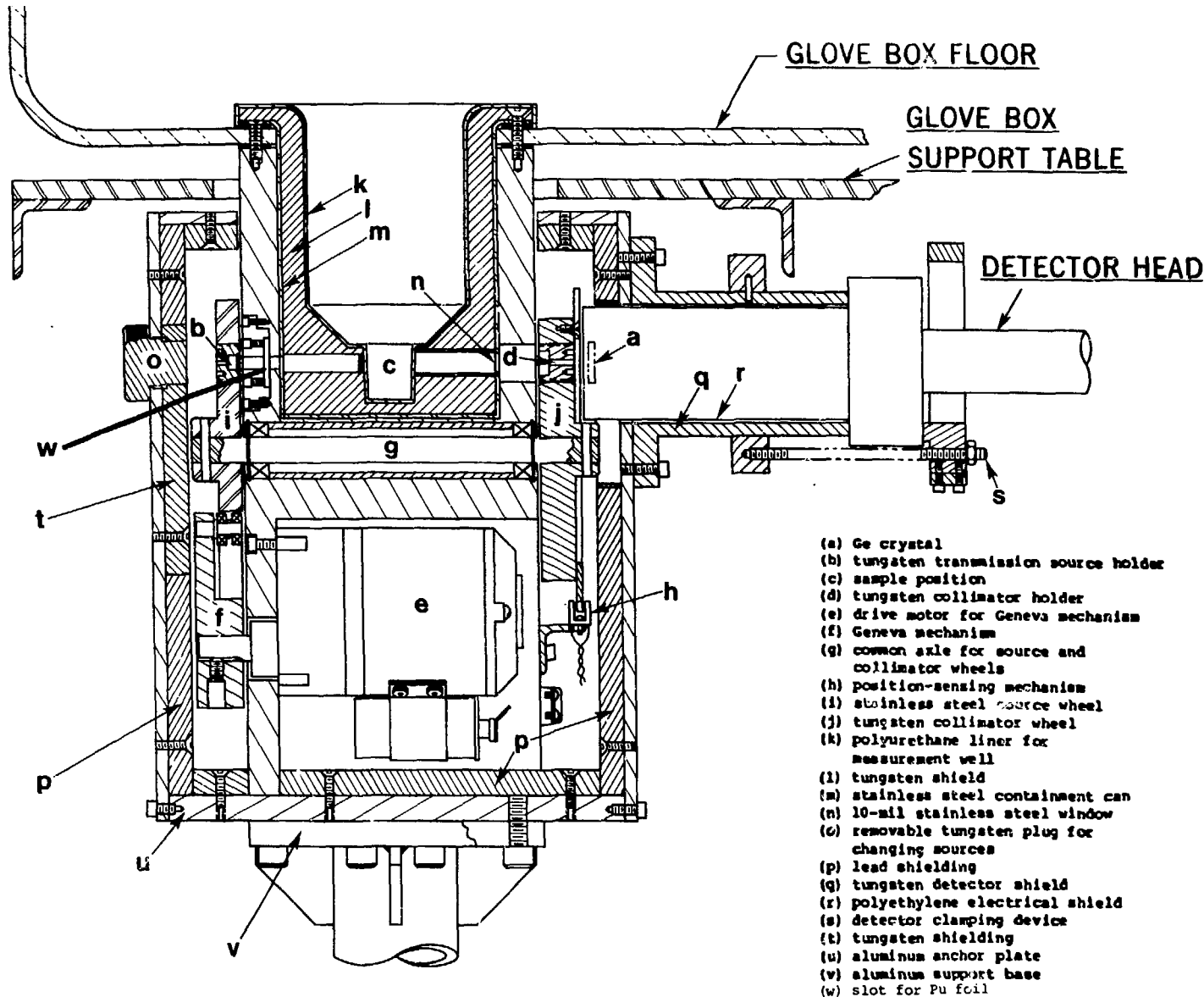
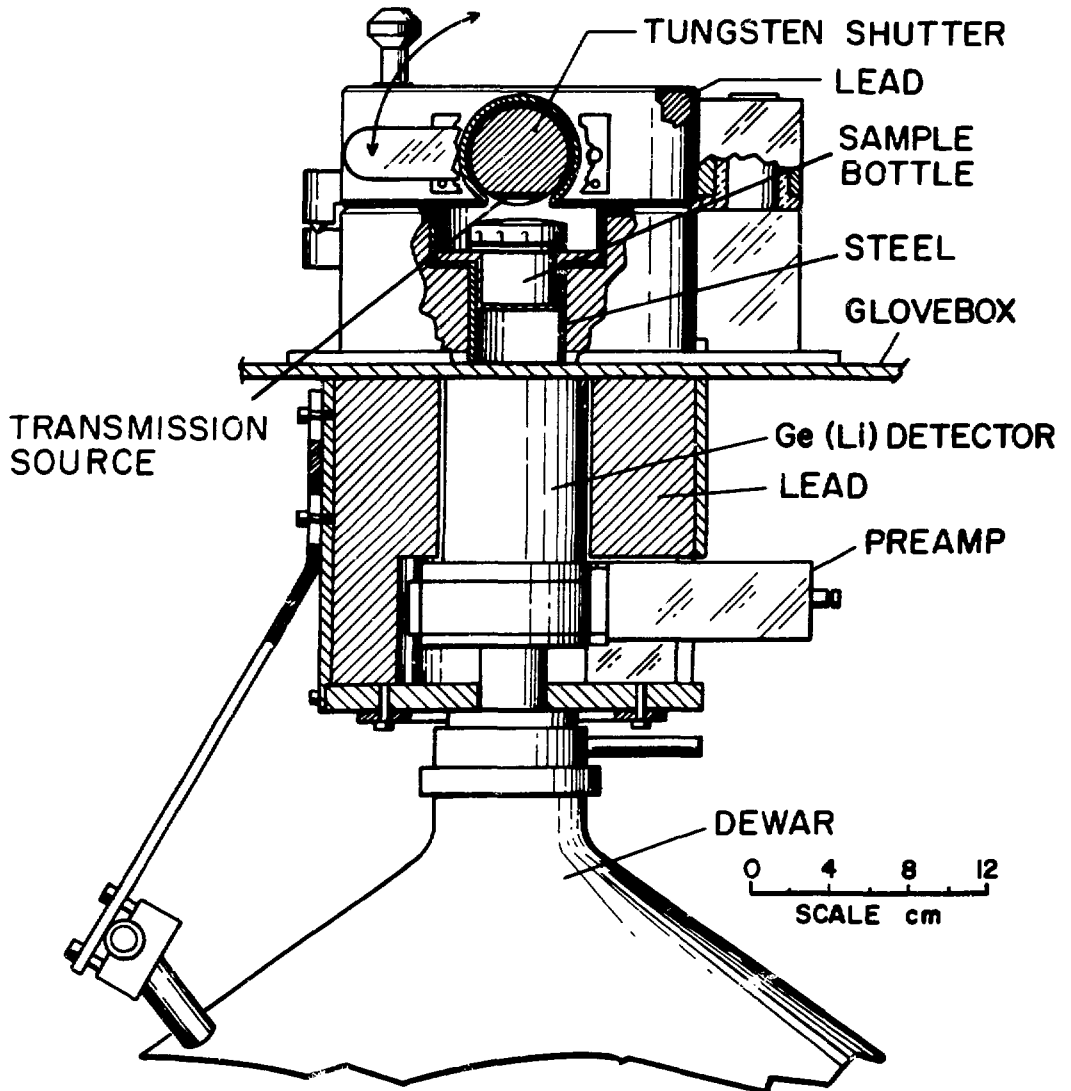


Fig. 1. A cross-sectional view of the Tokai-mura densitometer measurement well.



PLUTONIUM SOLUTION ASSAY INSTRUMENT

Fig. 2. A cross-sectional view of the plutonium solution assay instrument measurement port.

a transmission source that is mounted upon a two-position, pneumatically operated, computer controlled shutter. The detector-sample assembly is heavily shielded from plutonium in the glovebox and is protected from the corrosive glovebox atmosphere by a stainless-steel shell. Views of the sample chamber and the overall measurement station are shown in Figs. 3 and 4, respectively.

Fig. 5 shows a schematic diagram of an in-line instrument that measures the ^{235}U and ^{234}U enrichment in the low-enriched UF_6 product of a gaseous-diffusion plant. The measurements are made on liquid UF_6 prior to withdrawal into product cylinders. The instruments see daily temperature variations of 10°C and even greater seasonal variations. The ^{235}U enrichment is measured by counting the ^{235}U 186-keV gamma rays with a NaI detector. For a sample of constant volume, the intensity of this gamma ray is directly proportional to the ^{235}U enrichment.¹⁹ The ^{234}U enrichment is determined by measuring the singles neutron rate, arising from the $^{19}\text{F}(\alpha, n)$ reaction, in a fixed mass of UF_6 .²⁰ The gamma-ray enrichment meter measurement configuration, shown in Fig. 6, is comparatively simple, consisting of a flow-thru sample cell, a detector, and shielding. The same components are present in the neutron counter where the detector is an array of ^3He counters and their associated polyethylene moderator.

The basic design of the at-line DYMAC thermal-neutron coincidence counters (TNCs) includes many of the ^{234}U enrichment counter components shown in Fig. 5, adapted to fit a plutonium processing glovebox line. These counters are designed to assay or verify the plutonium content of heterogeneous, low-content, residual materials and dense product materials such as PuO_2 powder, in a variety of container configurations.²¹ The neutron signal from these samples arises from (α, n) reactions and the spontaneous fission neutrons emitted from the even plutonium isotopes. If the isotopic composition is known, the measured spontaneous fission coincident neutron rate may be used to determine the total plutonium mass.

As shown in Fig. 7, the TNCs are an integral part of the glovebox line. Sample cans are placed in the counting well, which is lined with cadmium to reduce the probability of induced fission caused by thermalized neutrons back-scattered from the moderator. The moderator's outer radius is also lined with cadmium. This liner and the polyethylene shield reduces the background rate and enhances the instrument's sensitivity.

The complexity associated with active neutron NDA techniques has resulted in their incorporation primarily into off-line instruments. An example is the SRP ^{252}Cf Shuffler that is designed to measure the ^{235}U content of scrap and waste items generated at a reactor fuel fabrication facility. These items include high-purity uranium-aluminum alloy ingots, pieces of castings, saw and lathe chips from machining operations, low-purity items such as oxides of uranium or uranium intermixed with flux materials found in recovery operations, and floor sweepings or residues from the uranium scrap recovery operation.

The Shuffler, shown schematically in Fig. 8, uses an NDA technique based upon the delayed-neutron emission rate from ^{235}U following irradiation by a strong ^{252}Cf neutron source.²² The active interrogation cycle consists of a two-step sequence. First, the source is transferred to the assay chamber for neutron interrogation of the item being assayed. After interrogation, the source is



Fig. 3. A sample being placed in the PUSAS sample chamber.

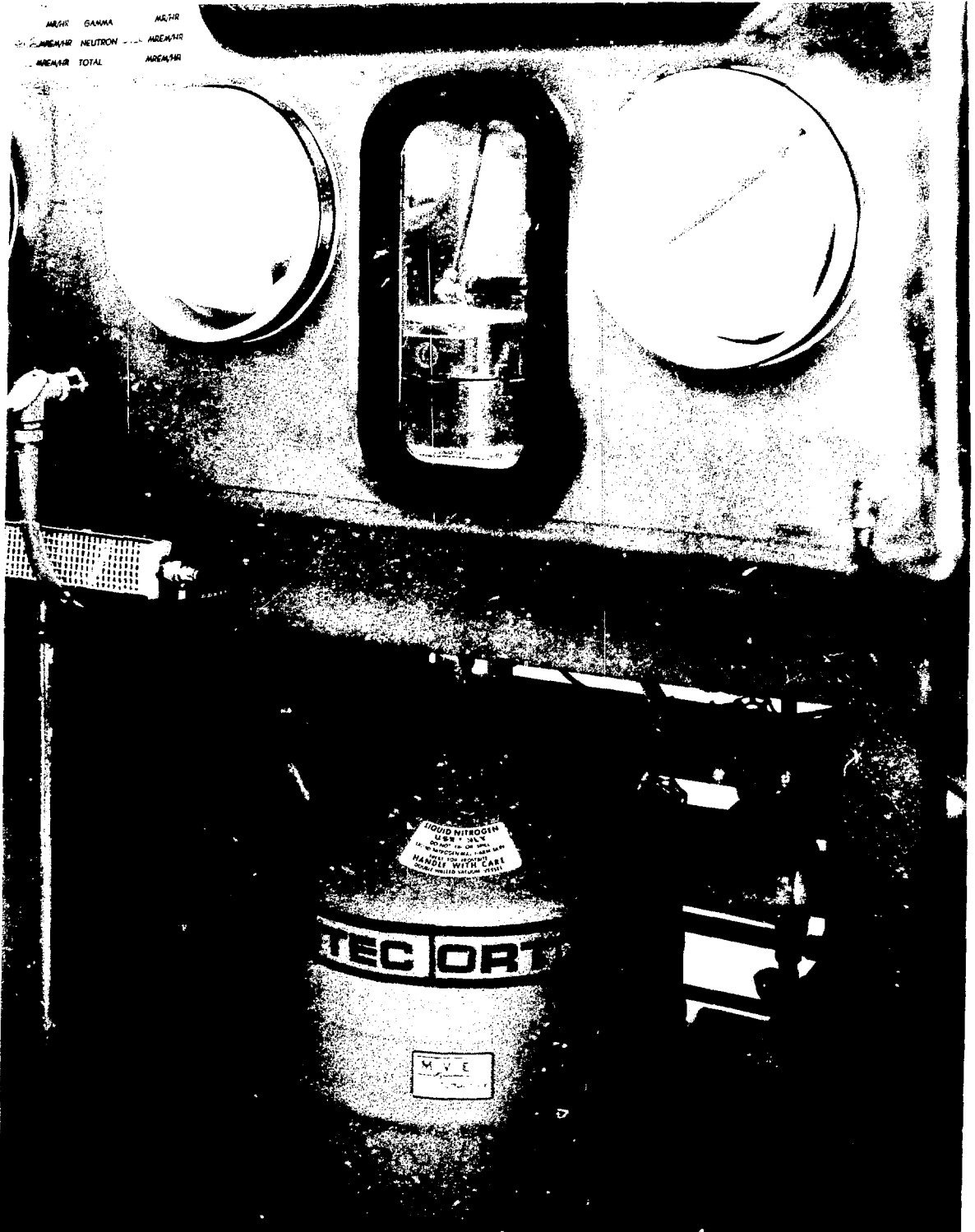


Fig. 4. An overall view of the PUSAS measurement port environment.

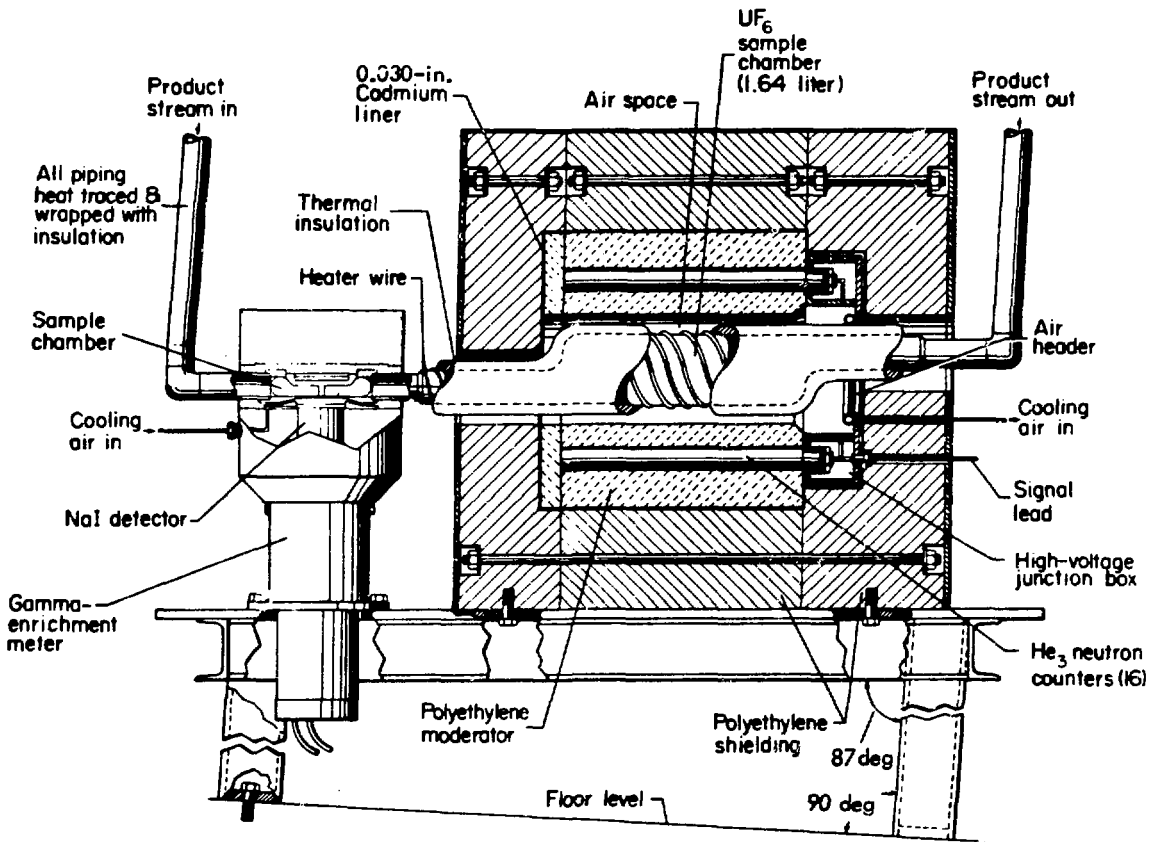


Fig. 5. UF_6 enrichment monitor - schematic diagram of gamma-ray spectrometer and neutron detector with shield assemblies.

transferred back to the storage location, and delayed neutrons are counted in the assay chamber. A full assay sequence also includes a background measurement, with the source in the storage position, and a weight measurement.

Neutrons from the ^{252}Cf source have a fission energy spectrum with a mean energy of 2.3 MeV. To minimize the response from the even uranium isotopes, the mean energy must be reduced below that for which the even isotope fission cross-sections are appreciable. However, if the energy distribution is moderated such that a significant fraction is below the energy where the ^{235}U fission cross section begins to increase rapidly, sample self-shielding will make the assay sensitive to the size, shape, and uranium density of the items being assayed. Extensive neutron transport calculations were used to design an assay chamber, Fig. 9, that would yield a penetrating neutron spectrum without excessive response from the even uranium isotopes. Nickel and steel are used to provide some moderation, while boron and cadmium are used to absorb low-energy neutrons.

Two general observations conclude this section. First, as demonstrated by the examples in this section, off-line instruments have fewer plant constraints imposed upon their measurement station

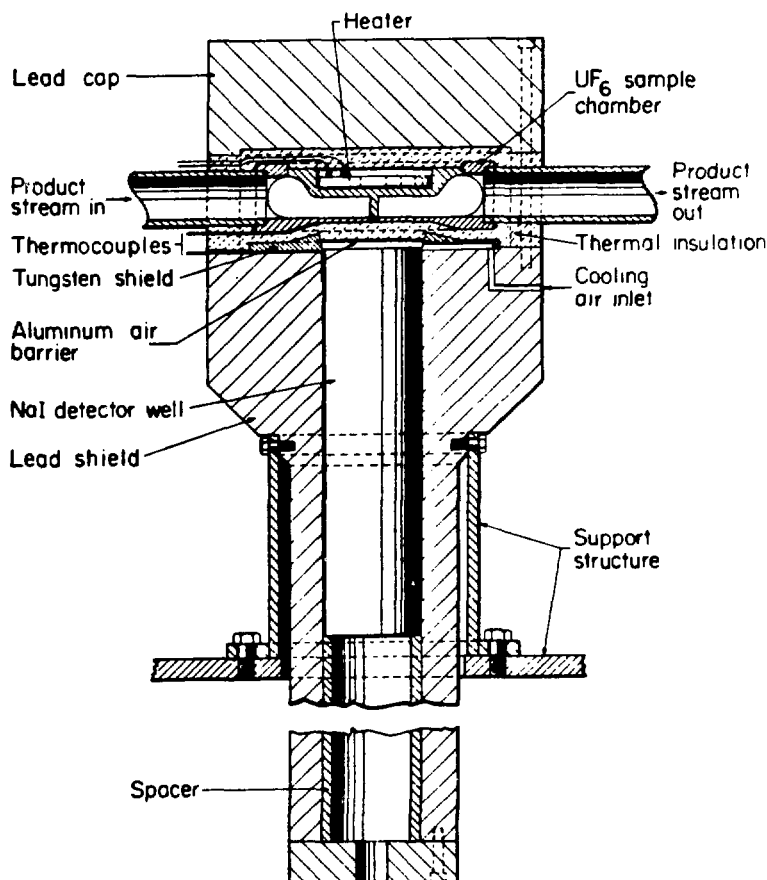


Fig. 6. Gamma ray enrichment meter - schematic diagram of detector, sample chamber, and shield assembly.

design. It should be noted, however, that activities are presently underway that are attempting to bring the sophistication of a T-M densitometer or an active neutron interrogating system like the Shuffler, to on-line application.^{15,23,24} Secondly, off-line instrument measurement configurations may be standardized and find a reasonable number of applications at a number of facilities. At-line and in-line configurations, on the other hand, are generally custom designed.

B. Information Processing

The information processing element of in-plant NDA instrumentation design deals with data that arise from external signals, such as those generated by a sample being assayed, and internal signals that deal with overall instrument status or assay sequence monitoring. The most common form of external signal is an analog pulse resulting from an ionization event occurring in the instrument detection system.

These signals are processed by a series of components whose function is to shape the pulses, sort those out that satisfy some

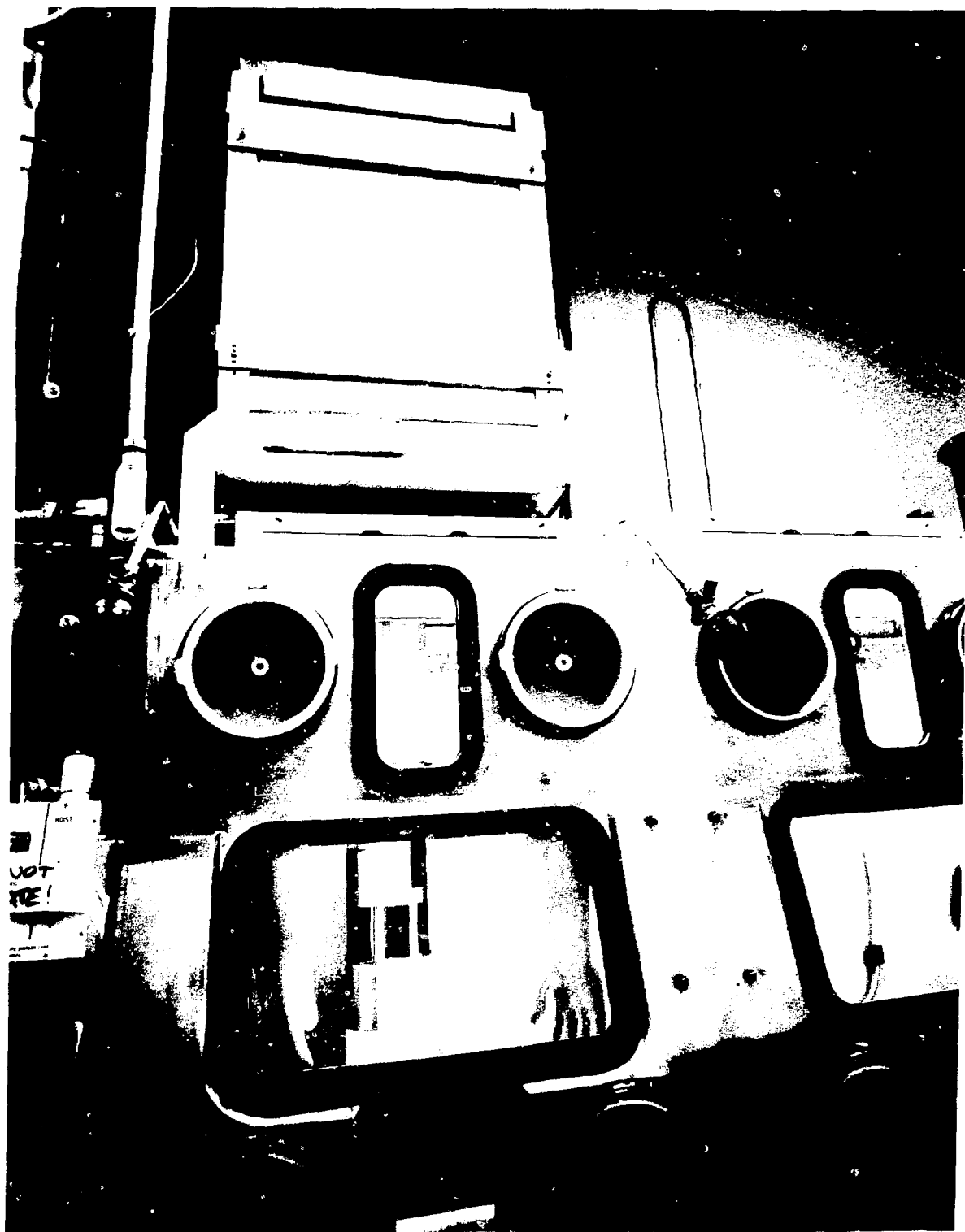
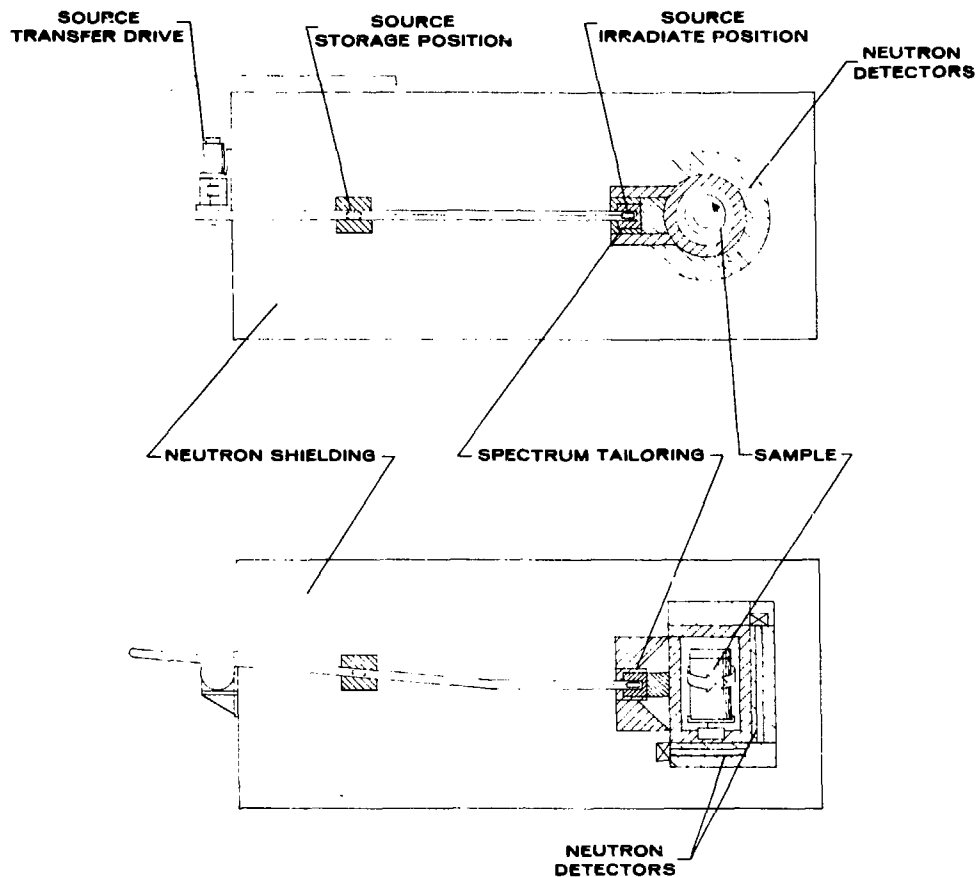


Fig. 7. An at-line thermal neutron coincidence counter with an elevator assembly for raising samples into the counter visible through the glovebox window.



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Fig. 8. A schematic of the ^{252}Cf Shuffler

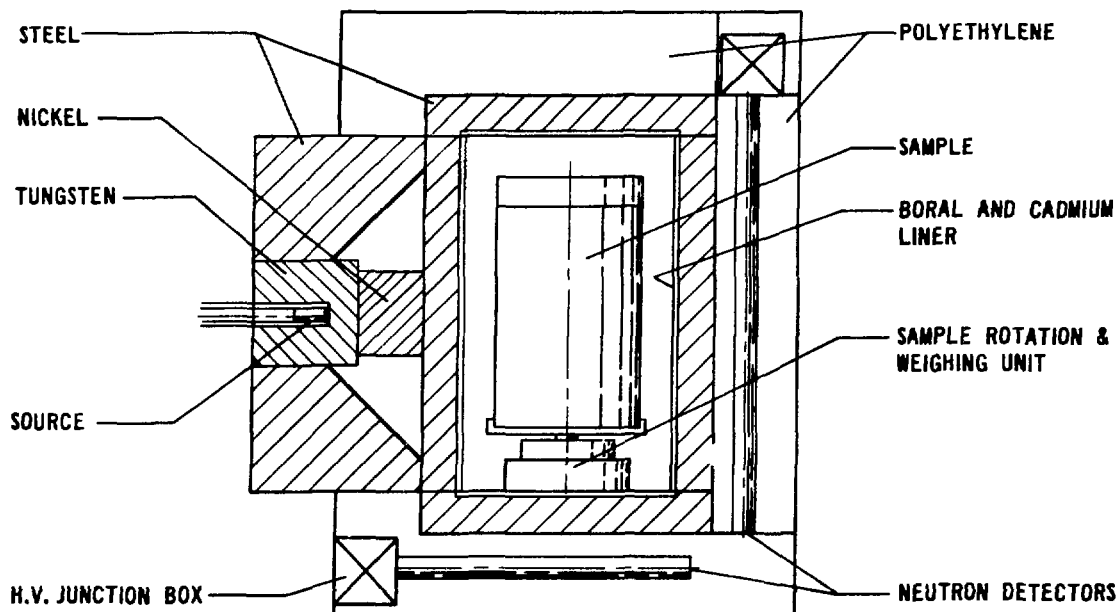


Fig. 9. A cross-sectional view of the Shuffler sample assay chamber.

energy and/or time criteria, count those that satisfy the sorting criteria, infer from this count the assay result, and finally, present to the user an assay value. The pulse-shaping components include detector high-voltage power supplies, pre-amplifiers, and shaping amplifiers, the detailed electronic design of which depends upon the system's energy- and/or time-resolution requirements. The crudest form of energy sorting is a simple pulse-height discriminator that accepts all pulses larger than a preset amplitude. The single-channel analyzer accepts those pulses that are larger than a lower-level discriminator and smaller than an upper-level discriminator, and the multichannel analyzer sorts full spectral information in a similar manner when the analog pulse amplitude has been digitized. Time sorting components may be used to maintain the energy spectral quality by removing pulses that occur too close in time (pile-up rejection) or to identify a fission event by detecting two time-correlated neutrons. The later is done using fast pulse (ns) electronics or slower (μ s) shift-register electronics²⁵ depending upon the neutron detector used. Most of these pulse shaping and sorting components are available as single NIM electronics modules that are powered by a NIM bin when incorporated into an instrument. Pulse-counting components include rate meters, scalars, multichannel analyzers, or computer memory. These devices integrate the number of pulses that have satisfied the sorting criteria for a preselected integration time. At the end of this period, the total values are read by a computing component that is electronically designed or programmed to calculate the assay correction factors, the total SNM mass or concentration values, and the associated uncertainties. These may be presented to the user through a simple dial reading, printed on a teletype or printer, or displayed on a CRT screen.

These output devices are often used in an interactive mode that allows direct input from the instrument user. This feature is discussed in Section D below.

Internally generated signals may be active, such as pulse-height gain stabilizers that correct drifts as they are detected, or passive in the sense that they control or monitor the assay process and only alert the user when an unacceptable condition, which must be corrected, exists. Examples include simple, mechanical position indicators, clocks that time the entire (or parts) of an assay, or predetermined parameter control limits that are not to be exceeded. The latter are discussed in Section C below.

In general, off-line instrumentation is designed with extensive and flexible information processing capabilities. Figure 10 is a photograph showing the T-M densitometer measurement well (extreme right), control hardcopy terminal, and the rack-mounted electronics. The electronics are (bottom to top) the NIM electronics, including a high-voltage power supply, a shaping amplifier, a pile-up rejector, and an analog-to-digital converter; an LSI-11 microcomputer used to sort, store, and analyze the converted data and to control the acquisition system; the computer display terminal, which is a key component for system installation and maintenance diagnosis; the control electronics for the Geneva mechanism; an oscilloscope for maintenance or repair use; and a dual floppy disk for software and data storage.

Equivalent or identical components are shown in Fig. 11, a photograph of the complete Shuffler system. The electronics rack, an enclosed, air-conditioned unit, houses a NIM bin with high-voltage bias supplies and single-channel analyzers for the neutron detectors, an LSI-11 microcomputer, a load-cell transducer, a temperature transducer, the ^{252}Cf source stepping-motor controller, and a dual-drive floppy disk unit. The two communications terminals used with the Shuffler are also shown. One terminal has a keyboard and printer, the other a detachable keyboard and a large format CRT screen. The operator can interact with the instrument through either keyboard, and all output appears at both terminals.

Because of basic environmental and user constraints, many at-line instruments are not designed with these extensive information processing capabilities. Figure 12 is a photograph of the PUSAS electronics that are designed to fit under a glovebox. Many of the same components seen in the T-M densitometer, NIM modules, minicomputer, small interactive terminal, and a control panel, are present, but it is not a complete unit. Because of severe space constraints, this unit contains only the components required for routine measurement procedures. The system is initialized and serviced with the additional information capabilities of a mobile maintenance and graphics cart. The cart has a paper-tape reader for loading the operating or diagnostic software into the computer, a graphics display for a multichannel analyzer capability and pulse-shape observation, and an interactive control panel.

The Neutron Coincidence Counter system, shown schematically in Fig. 13, is even more compact. The power, pulse shaping, and energy sorting functions are performed by a single NIM module, a quad-amplifier, discriminator, high-voltage module. The time-correlation sort and event count is performed by a shift-register coincidence module, and the data are processed by a microprocessor. The results are

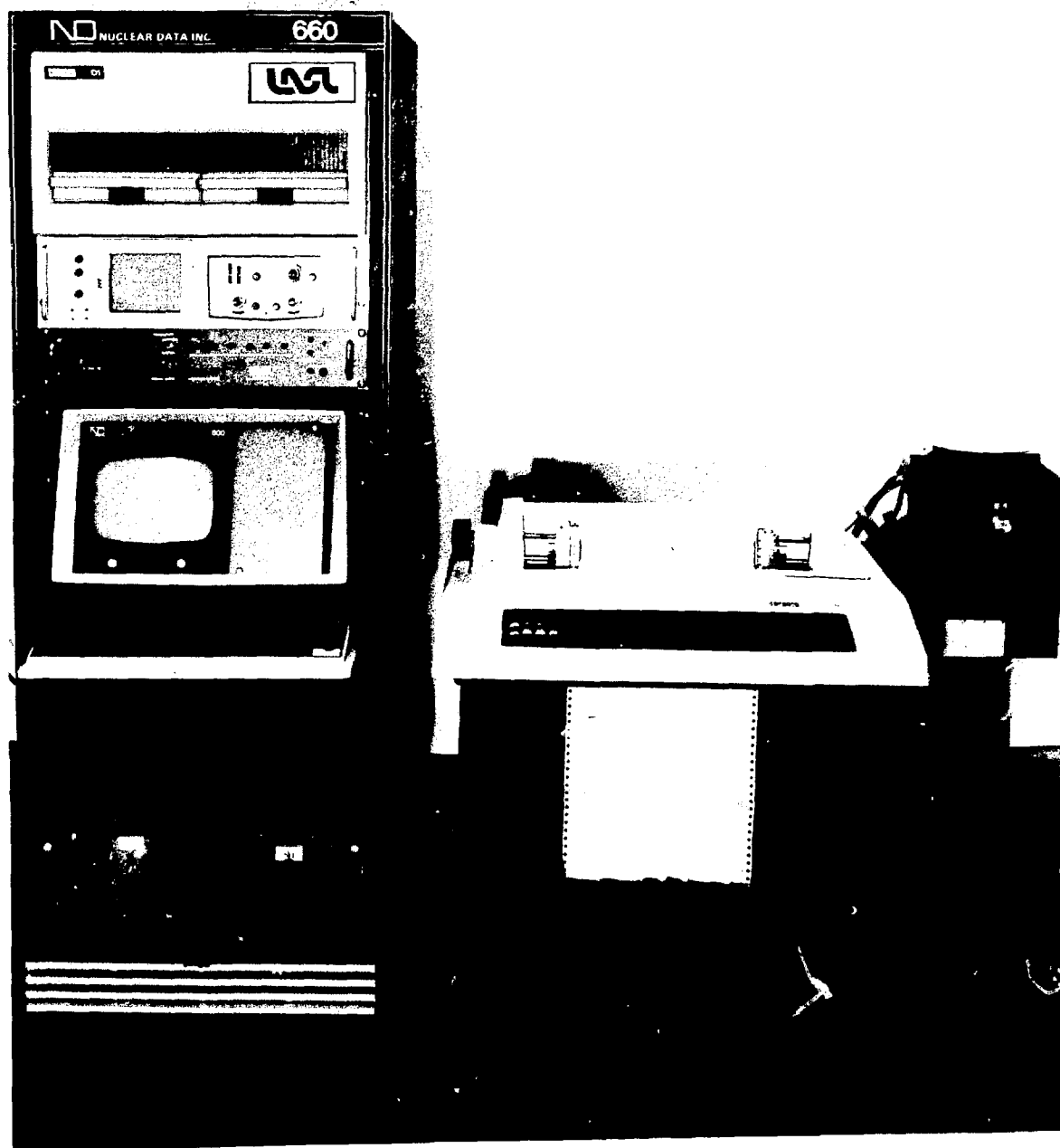


Fig. 10. Complete T-M densitometer including electronics cabinet, terminal, and measurement well.



Fig. 11. Complete ^{252}Cf Shuffler including electronics cabinet, terminals, and complete measurement station.

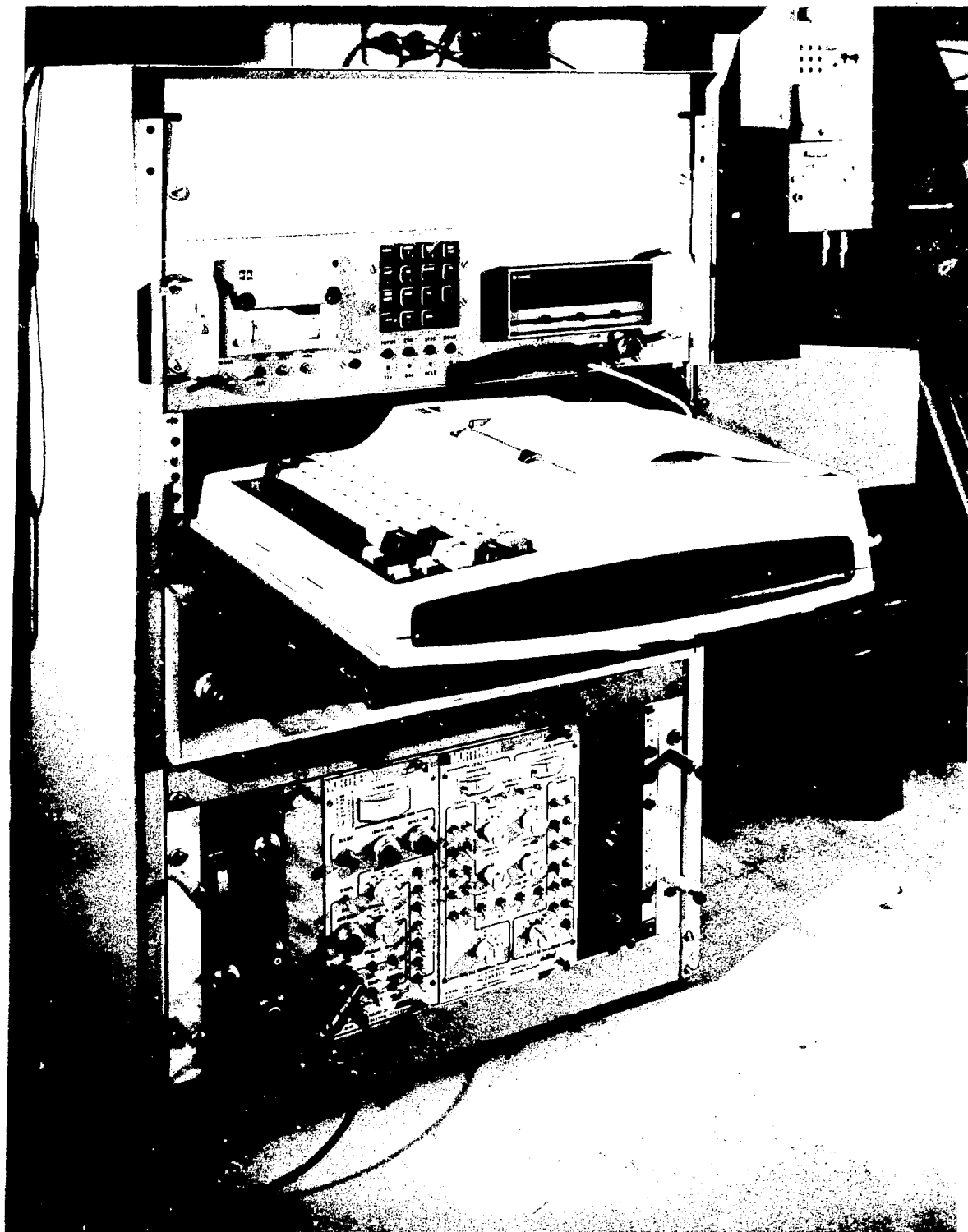


Fig. 12. The PUSAS electronics cabinet.

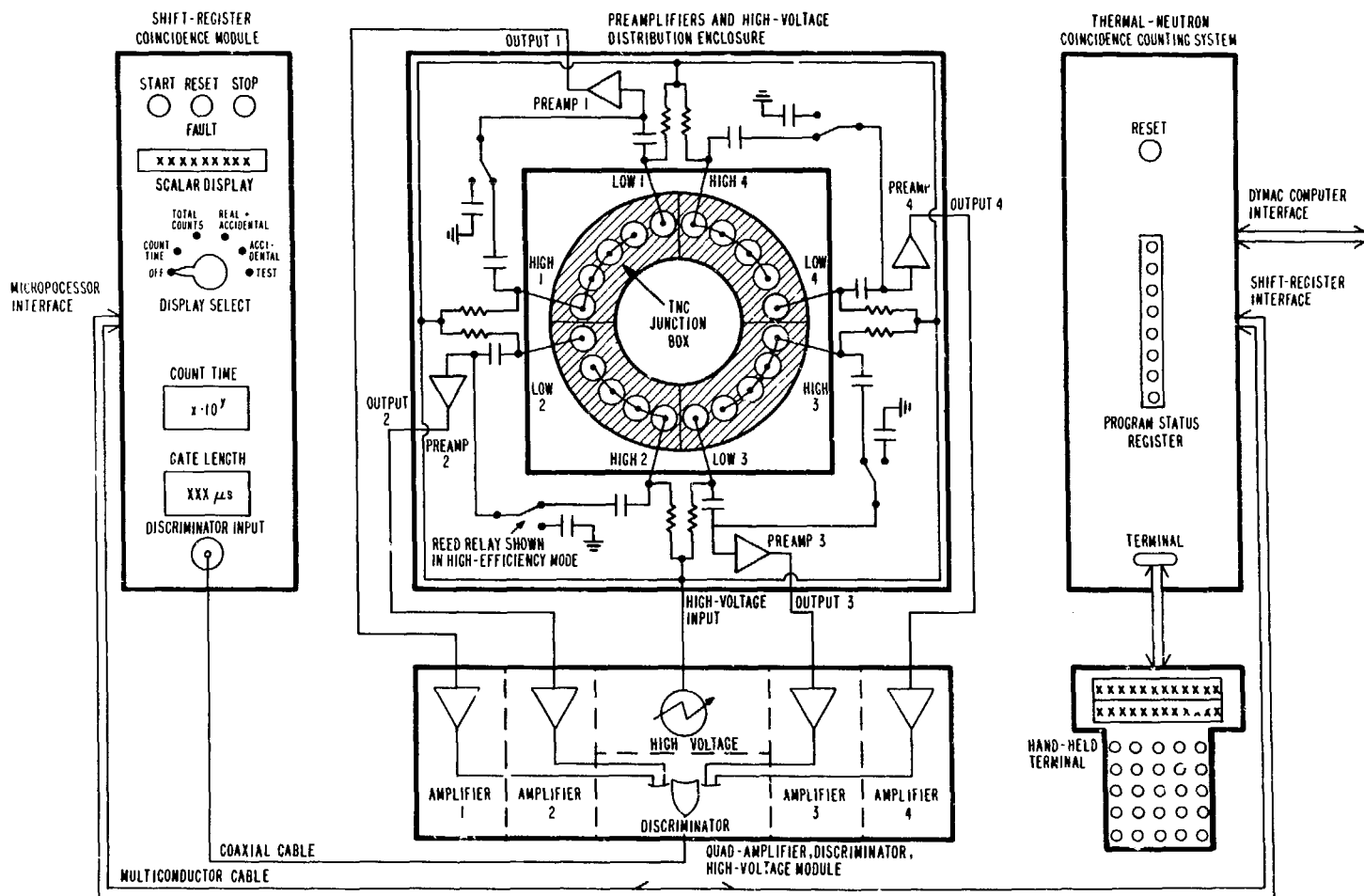


Fig. 13. A block diagram of the thermal neutron coincidence counter electronics.

presented to the user on a small hand-held terminal. The entire unit is housed in one standard NIM bin, as shown in Fig. 14, and is easily mounted in the constrained plant working environment.

The in-line enrichment monitor's information processing system is equally compact, but somewhat simpler. Only single neutrons are counted, so no coincidence sort is required. The gamma-ray spectrum is not complex so a low-resolution detector is used, and no pulse digitization is required. System calibration constants are set by front-panel thumbwheel switches, and the computed enrichment is displayed on front panel LEDs and printed on a teletype.

Many operating facilities employ mechanical engineers who are capable of diagnosing and repairing the mechanical problems encountered with NDA instrumentation. However, trouble-shooting the sophisticated electronics involved in the information-processing element may require maintenance and repair capabilities that exceed those available in a plant. This necessitates a highly reliable design, and the definition and identification of repair resources.

C. Measurement Integrity

This instrument design element includes those components, procedures, and activities that determine the measurement accuracy and precision obtained with routine plant samples and demonstrate that these parameters are obtainable upon a day-to-day basis. The latter are often referred to as measurement control procedures.

The procedures by which the accuracy and precision are determined differ for off-line and at-line instruments only in the degree of difficulty to perform. Two steps are generally involved. In the first, the instrument is calibrated over the entire range of its application with standards that, ideally, replicate the plant materials. Practically, a close replication is often not achievable. This is followed by a comparison of assay values, for routine process samples, between the NDA instrument and an independent analysis, often a destructive analytical chemistry measurement. The results of a T-M Densitometer calibration, over the range 150 to 300 g Pu/L, is shown in Fig. 15, where the percent difference between the calibration constant determined with a given standard on a given run and the calculated average calibration factor is plotted versus run number. The error bars reflect the measurement statistical precision, which is consistent with the scatter in the data. Figure 16 shows similar calibration data obtained with the PUSAS over a much broader plutonium concentration range. Accurate, well-characterized solution standards are usually obtainable, and differences between these standards and plant solutions must be dramatic to influence the instrument accuracy significantly.

Neutron assay instruments, on the other hand, are sensitive to material types and sample geometries because of self-shielding, multiplication, and matrix moderation effects, which are difficult to correct. For the Shuffler, self-shielding occurs if outer layers of the material absorb a large fraction of the interrogating neutrons. Multiplication is a problem when the sample fission neutrons make an appreciable contribution to the total interrogating neutron flux, and moderation increases the response because of the increasing ^{235}U fission cross section at lower energies. The wide variety of material types that the Shuffler assays excluded the possibility of generating standards that would be representative. Instead, a limited number of well-characterized standards, which could be used

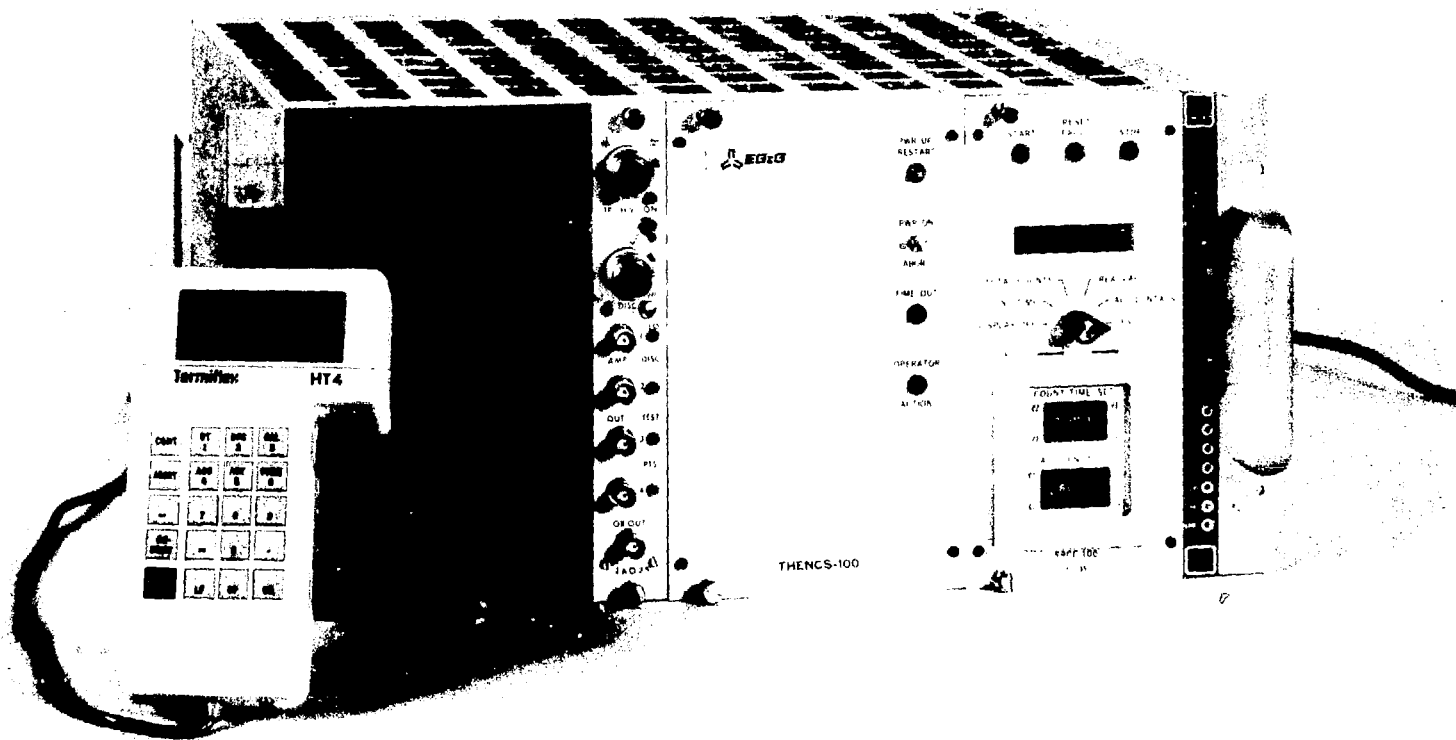


Fig. 14. The TNC electronics: A high-voltage power supply, Quad-Amplifier/Discriminator module, a shift register module, a microprocessor control module, and a hand-held terminal.

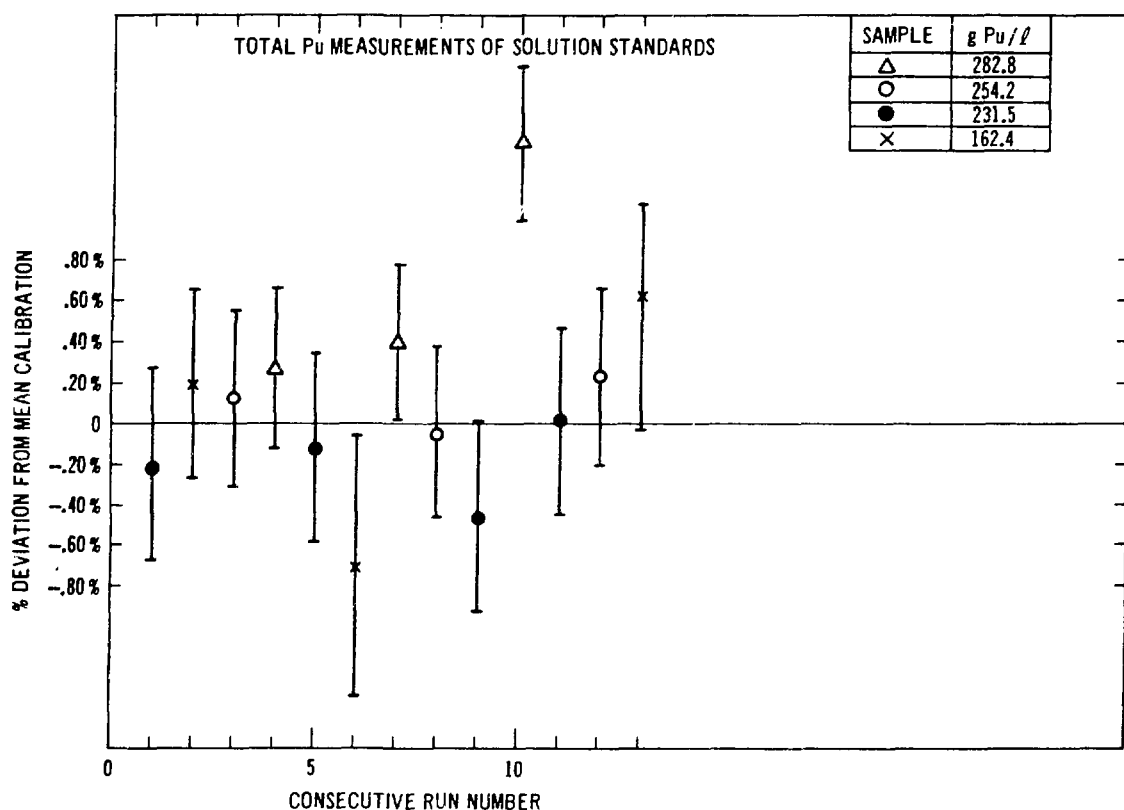


Fig. 15. T-M densitometer calibration results for four solution standards.

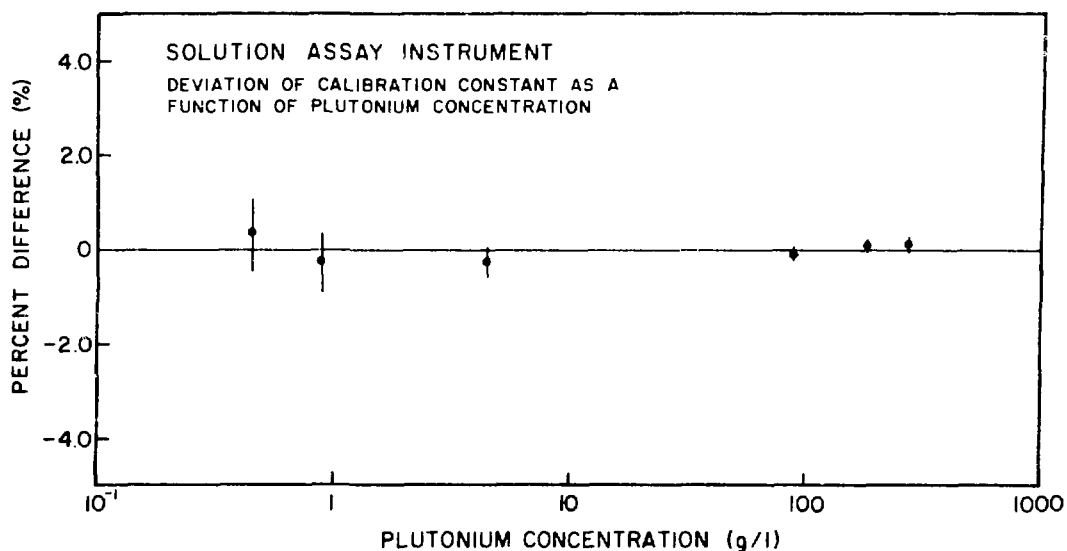


Fig. 16. PUSAS calibration results plotted as a function of plutonium concentration.

singly or in multiple combination, were produced that covered the desired ^{235}U mass range and allowed the definition of measured correction factors, based on mass and fill height. The entire calibration procedure is lengthy, requiring 30-40 independent measurements.

In-line instrumentation presents a special problem in that it is often not possible to calibrate the system with laboratory-prepared standards. The enrichment meter was calibrated against routine mass-spectrometry results obtained for samples taken from the gas stream ahead of the in-line monitor. If the sample enrichment changes at the withdrawal station, there is a time delay, 30-40 minutes, before this change is seen in the instrument loop. Therefore, calibration data are obtained when the withdrawal assay is running relatively constant. A large number of data points (67) was obtained over a three-week period and least-squares fit to the calibration equation. The results for a 6-day period are shown in Fig. 17, where the measured enrichment monitor and laboratory values are compared versus date. Excellent agreement, within $\sim 0.25\%$, is found between the two methods.

The checking or comparison of an NDA in-plant instrument against a laboratory analysis is usually more difficult than anticipated. Often the agreement is poor and the identification of the reason for this is difficult, especially because the process personnel have greater confidence in, and experience with, the laboratory analysis and thus assume, first, an inaccurate NDA instrument. One of the

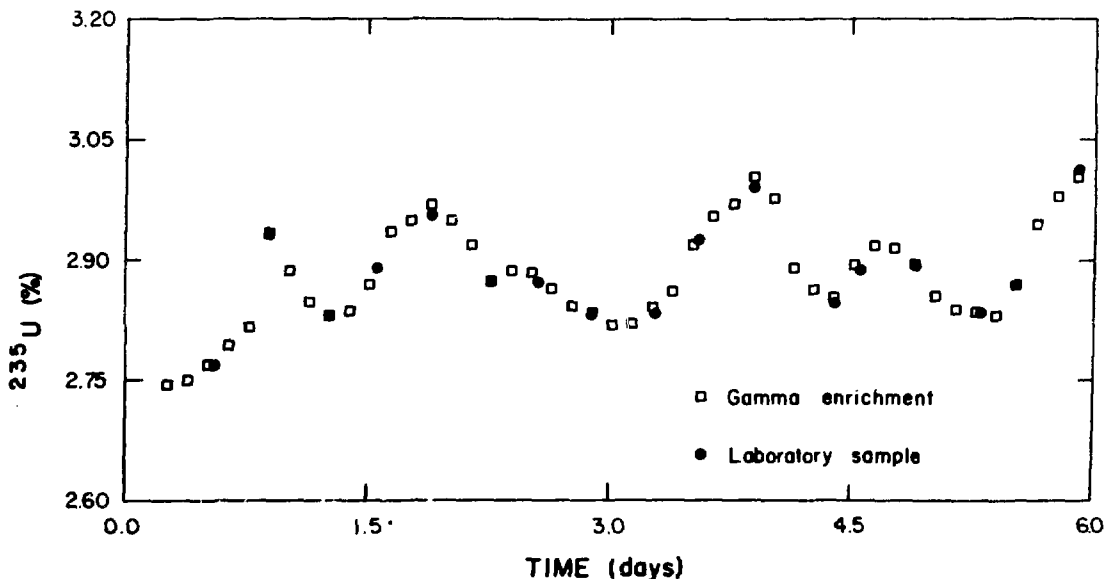


Fig. 17. A comparison of gamma-ray enrichment measurements with percent ^{235}U as determined from laboratory analysis. The black squares indicate where the two measurements overlap.

principal reasons lies in the difficulty of obtaining a representative sample for laboratory analysis. Rarely is a completely homogeneous liquid or gaseous sample available from a process, and if so, it may not be representative of a given chemical batch or stream average.

An extreme example was observed with the PUSAS when assaying one category of low-concentration solutions and comparing the results with a radioanalytic technique (alpha-particle counting).²⁶ On the basis of this comparison the PUSAS appeared to exhibit a bias of >100%. The results are plotted in Fig. 18 where the relative difference between the PUSAS (SAI) and radioanalysis assays is plotted versus plutonium concentration. The comparison is made for those samples in which a residue, caused by post-precipitation or process tank slurry, was observed [Fig. 18(A)] and for those that appeared reasonably clear [Fig. 18(B)]. Following the PUSAS assay, 1 to 2 ml were drawn from the top of each 25-ml sample and sent to the laboratory for analysis. If the observed residue contained plutonium, the

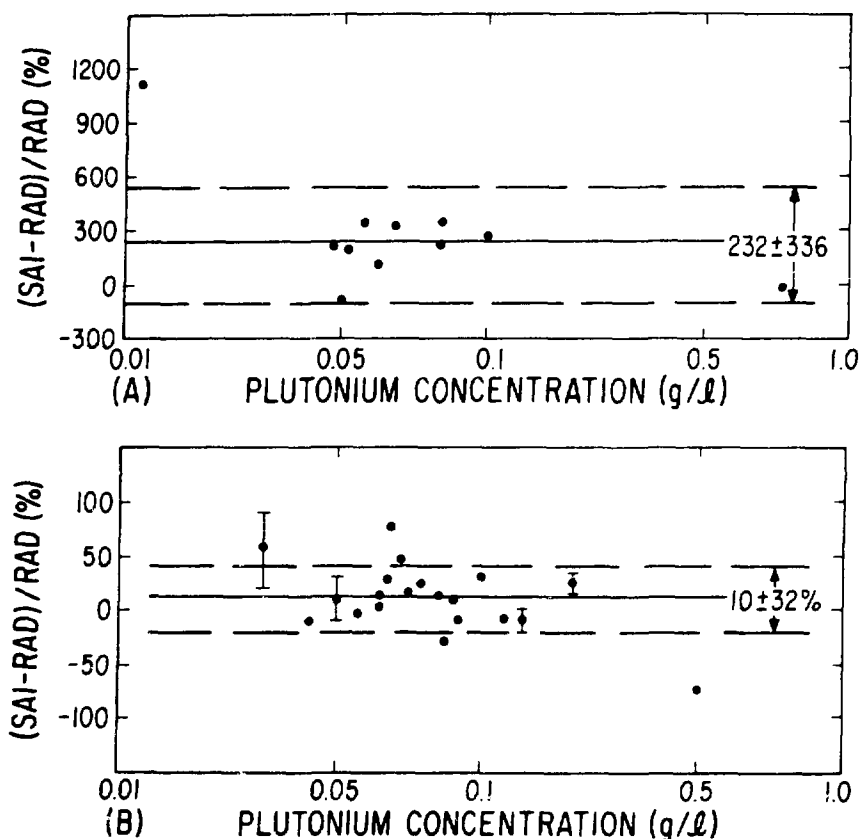


Fig. 18. A comparison of PUSAS (SAI) and chemical radioanalysis results for low-level plutonium solutions with (A) visible precipitates and with (B) no visible precipitates, plotted vs plutonium concentration.

radioanalysts' assay would only include the soluble portion of the plutonium and would be proportionately lower. To determine whether this was a correct explanation, a large container of the solution was decanted, and the plutonium concentration of samples from the top was measured as a function of time. The results are shown in Fig. 19 where the measured relative concentration is plotted versus time. A variation of greater than 50% is observed within 5 minutes, and the equilibrium value is approximately one-fourth of the initial value. Thus, the discrepancy in Fig. 18 is identified as a sampling error.

Laboratory analysis errors may also arise from other sources, including contamination during the transport or processing of the sample, sample variation caused by evaporation or other chemical processes while awaiting analysis, and inadequate laboratory measurement control. For example, Fig. 20 shows the results obtained with the T-M densitometer for a set of precisely prepared (0.5%) reference materials. The error bars reflect only the densitometer statistical uncertainty. Because three out of four of the outlying data points agreed with independent measurements from another NDA

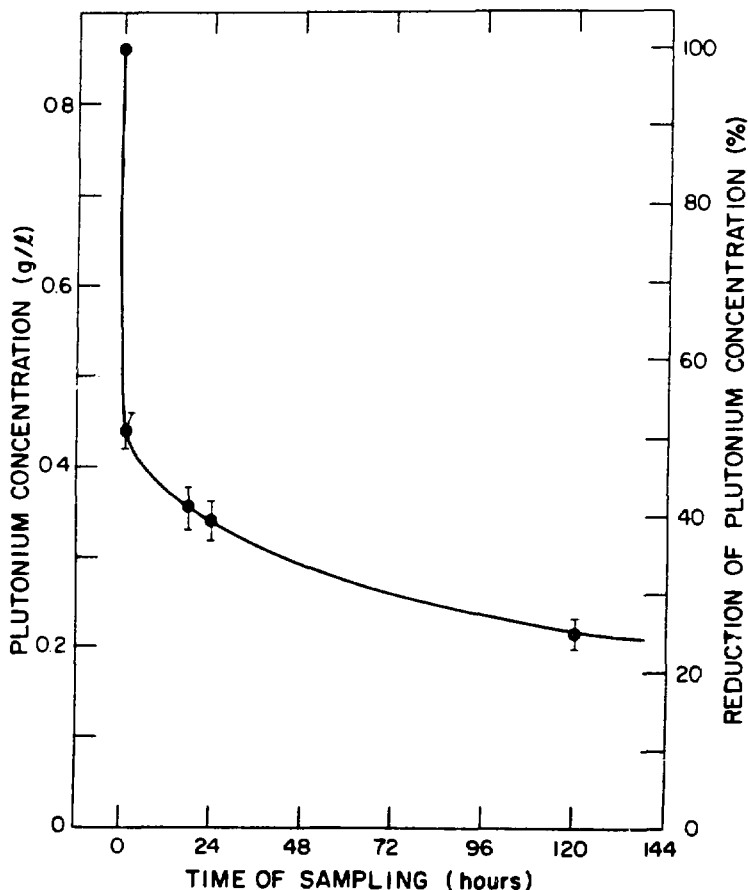


Fig. 19. Measured plutonium concentration in decanted solution vs sampling time.

TOTAL Pu RESULTS OBTAINED AT TOKAI-MURA

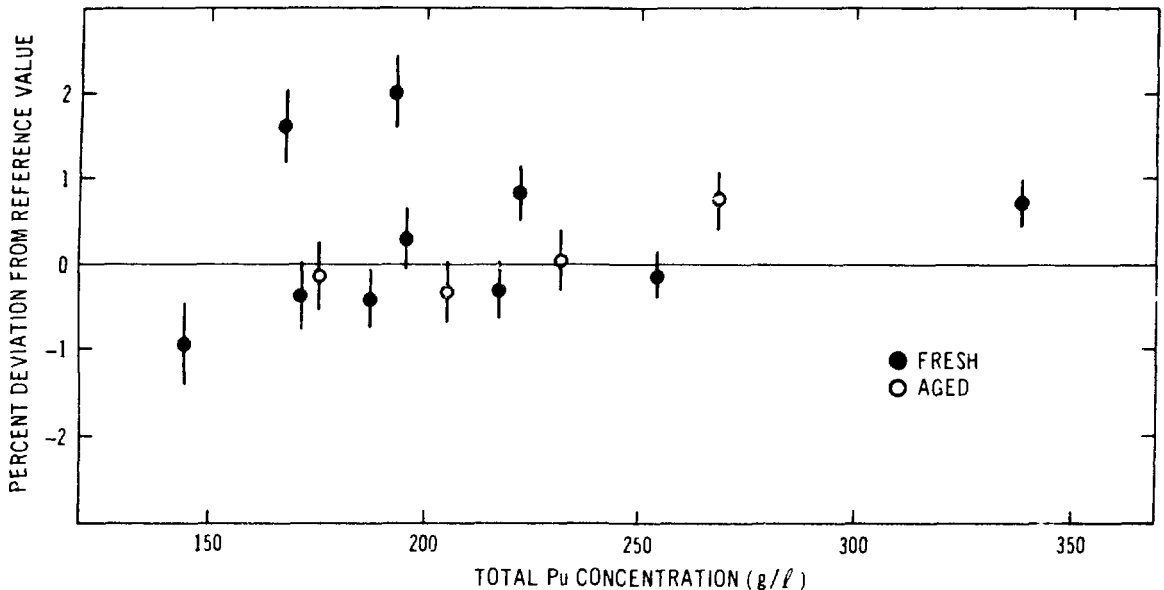


Fig. 20. A comparison of T-M densitometer and analytical laboratory determination of total plutonium solution concentration vs plutonium concentration. Fresh and aged correspond to 2 weeks and 1 year after Am separation.

instrument, these reference samples were reanalyzed in the analytical laboratory and found to be in agreement with the densitometer result.

Measurement control data are obtained during routine assays and during special control sequences. The former is often done with high-resolution gamma-ray spectroscopy systems, where a comparison of the system's energy resolution and gain may be made with previously defined limits. Other checks of this kind may include the statistical uncertainty upon a transmission-correcting peak intensity, which when too large indicates the need to replace the transmission source, and checks upon the detector's relative efficiency.

A routine measurement control sequence duplicates an actual assay, using a well-defined standard in an accurately replicative geometry. These two requirements have resulted in the use of secondary foil standards for solution assay systems, rather than primary solution standards whose concentrations change with time because of evaporation and radiolytic decomposition. The assay values are compared with a range of predetermined values to check the system's accuracy and with other recently measured values to check the system's precision and identify the onset of a measurement bias. Often a control sequence is required during a defined time period before the instrument may be used for an assay. Similar internal controls may close the instrument to any assay use if control parameters are found to have been exceeded. Figure 21 shows some T-M densitometer measurement control data obtained during a four-week period using a

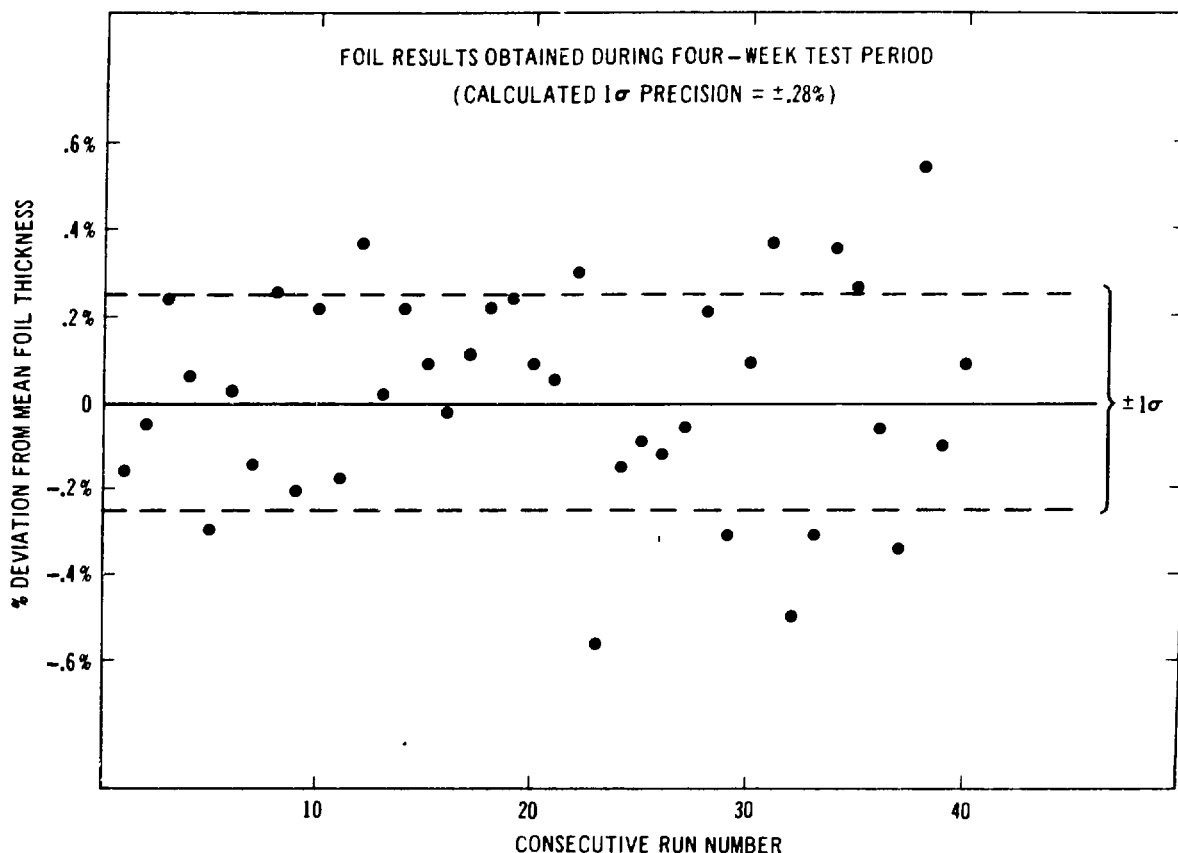


Fig. 21. Four weeks of foil measurement control data from the T-M densitometer.

secondary foil with an equivalent plutonium thickness of ~ 235 g Pu/L. The experimentally determined precision indicated by the dashed lines is equal to the statistical uncertainty assigned to each point.

Similar data have been obtained with the Shuffler where a standard assay is required at the beginning of each assay session. Here the long-term data, summarized in Table I, show a small drift, 0.1% per month. The detection of an effect of this magnitude requires a rigorous measurement control procedure that provides adequate data to (a) verify the effect statistically, (b) suggest its cause and solution, and (c) correct past data that may indicate an SNM loss.

A well-designed, effective measurement control program is an extremely important component of any in-plant instrument. It is this system that determines the validity of results that are used by the plant operator to make nontrivial decisions concerning the status of the process and its safeguarding. After all, this is the reason for installing the instrumentation.

D. Instrument - User Interface

The ideal NDA instrument, one which calibrates automatically, exhibits no electronic or mechanical instabilities, requires no

TABLE I
SUMMARY OF LONG-TERM ASSAY REPEATABILITY

<u>Month and Year</u>	<u>Number of Assays</u>	<u>Average Response</u>
June 1979	8	28 408.2
July	13	28 431.6
August 1979	5	28 379.9
September 1979	6	28 401.4
October 1979	13	28 464.2
November 1979	13	28 444.1
December 1979	8	28 425.4
January 1980	1	28 558.6
February 1980	2	28 696.2
March 1980	3	28 608.5
April 1980	12	28 622.4
May 1980	11	28 689.4
June 1980	11	28 709.2

Average Response 28 522.1

Standard Deviation 122.1 (0.4%)

Drift Coefficient 0.2% per month

maintenance or repairs, and presents an instant assay with the push of a single button, meets the basic requirements of the plant operator if the assay accuracy is adequate. The in-line UF₆ enrichment monitor attempts to address these requirements with a simple design, which reduces instabilities and repairs, with a short (2, 5, or 10 minutes as selected by the operator) assay time and with a single button push to initiate repeated process stream assays. No complex measurement control or operator interactions are required. Correspondingly, there are no data available to assure the operator as to the accuracy of his measurements and no instrument flexibility that would allow him to diagnose, in a timely manner, unusual assay values.

Recent in-plant NDA instrument development has attempted to meet the user's requirements with the adaptation of laboratory approaches and techniques, such as the measurement control features described above, and carefully designed instrument flexibility. To bring laboratory flexibility into the process environment requires an instrument-user interface that is directed to a broad spectrum of potential operators. The incorporation of minicomputers and microprocessors and interactive terminals into instrument design allows this requirement to be met.

A number of interactive software packages have been written.^{10,27} In general, the user is presented a menu of measurement procedures from which to choose and is stepped through a given procedure by being presented queries that require a direct response. An example of options that may be presented an operator is shown in Fig. 22, the flow chart of an interactive driving program.²⁸ The

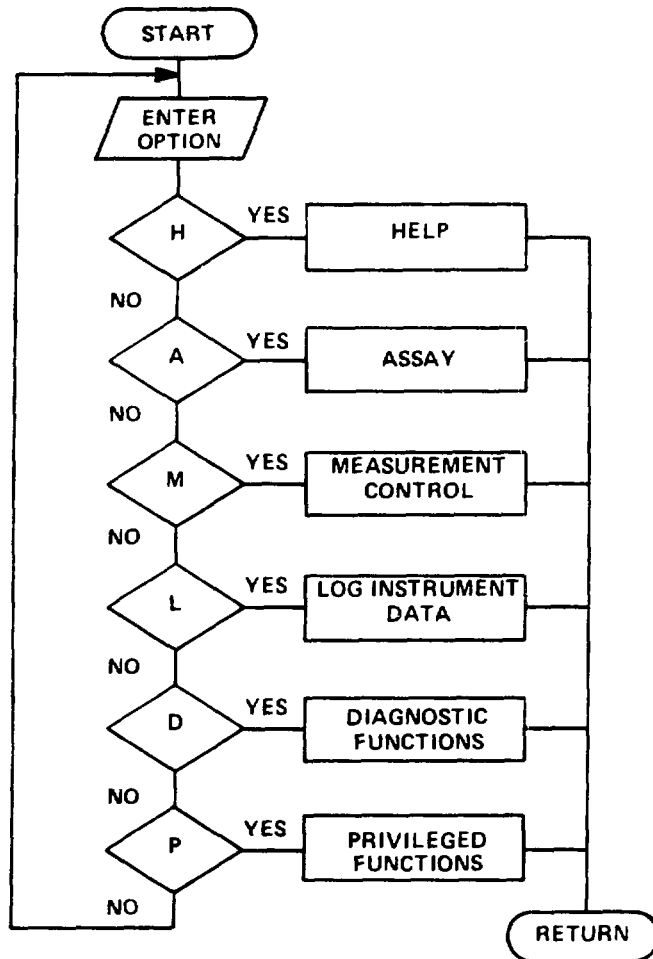


Fig. 22. Interactive driving program flow chart.

may call the HELP subprogram at any time to obtain a list of available options. The return key is used to abort a sequence and return to the driver program. The single letter command call for each subprogram is shown in the figure.

Some of the functions and options of the subprograms are:

- ASSAY executes a single or multiple assays of a single sample, as chosen by the operator,
- MEASUREMENT CONTROL executes precision and/or accuracy checks as chosen by the operator,
- LOG INSTRUMENT DATA stores and communicates, to a central accounting computer, performance test data from ASSAY and MEASUREMENT CONTROL,
- DIAGNOSTICS executes tests of the hardware, and

- PRIVILEGED FUNCTIONS executes functions that are limited by a password system to the supervisor and system manager. These functions include entry of a constant for data analysis, override of an operator error, expansion of the operator ID table, override of a measurement control flag, change of password, override of count time, and execution of graphics.

Figure 23 shows the flow diagram for a portion of the assay program. This program requires the operator to enter a valid identification number. This procedure limits the use of the instrument to those who have been authorized and tags each measurement with an operator. It also requires that the measurement control sequences have been satisfactorily completed before an assay is made.

A program written for the TNC microprocessor enables the instrument to perform as a stand-alone system. The microprocessor automatically turns on the counting electronics, collects the data, stops the counting, transfers the data into the memory core, and performs the appropriate calculations to determine the result. Six measurements are possible: deadtime, background, calibration, assay, accuracy, and precision. The program includes a step-by-step prompting routine that guides the operator through the required steps of each measurement by messages displayed on the hand-held terminal. Table II presents the operating procedures and terminal display for an assay measurement.

An important interface, which is often given inadequate attention, is that supplied by documentation and training. Operating, maintenance, and repair manuals must be complete, clear, and concise to complement the initial training provided and to allow future operators to become familiar with the instrument without benefit of formal training.

E. Safeguards and Process Control Systems Interfaces

In-plant instrumentation is approached by the developer as a "single point - single component" problem. Safeguards or process management personnel have a broad set of concerns, for which a given NDA instrument may provide only limited input. This is demonstrated to a small degree by the flow diagram shown in Fig. 24.²⁹ The diagram shows the materials flow between the receipt areas of a fast flux test facility (FFTF) process line, and the type of measurement made at each transfer point. A "snap shot" picture of the process requires a number of carefully developed data points. To maintain a motion picture (real-time accounting) requires a timely, accurate data base that may be summarized in a clear and effective manner.

This element of NDA instrument design has received relatively little consideration. However, the DYMACE program, a near-real-time SNM accounting system installed at the Los Alamos National Laboratory plutonium facility, incorporates instrumentation that includes components of this element.^{30,31} The facility has been divided into 17 distinct accountability areas, called materials balance areas. Material is permitted to cross such boundaries only on a measured basis; therefore, the resulting inventory differences can be localized. The materials balance is closed at three levels: the station, or entire facility balance, is monitored by the Nuclear Materials Officer. The account, or MBA balance, is monitored by the account supervisor, but all the process data are input by process personnel, and the balance is closed at the unit process area, as

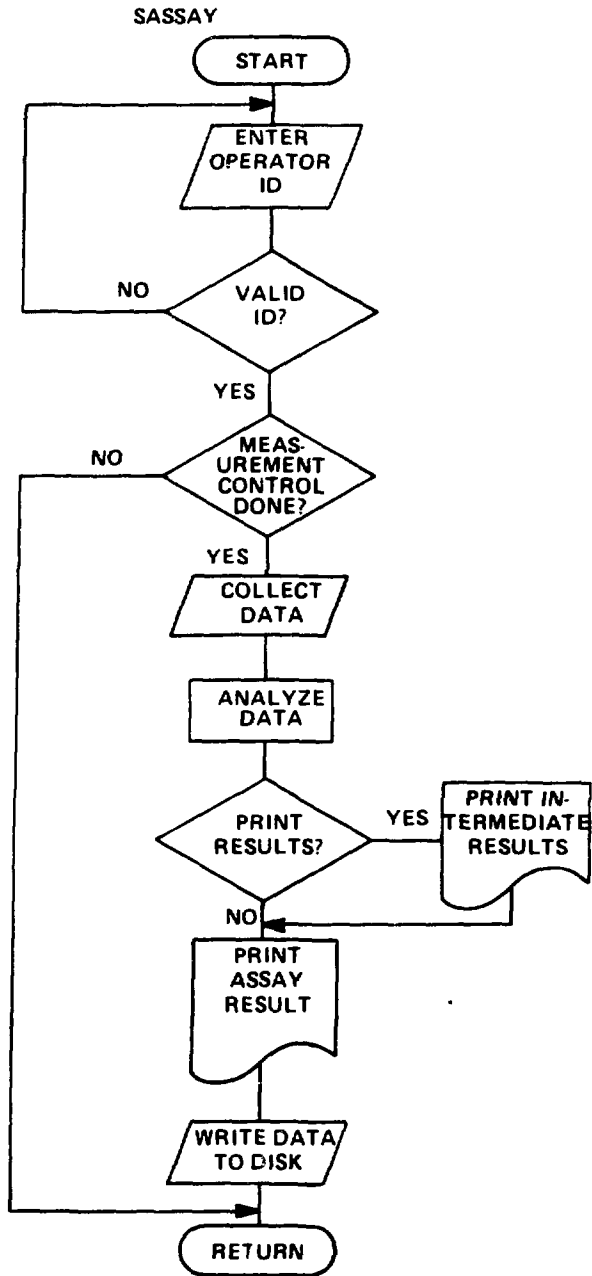


Fig. 23. Assay program flow chart.

TABLE II
INSTRUCTIONS FOR ASSAY MEASUREMENT

<u>Operator Action</u>	<u>Terminal Display</u>
	NOT BUSY ENTER OPTION
1. Press CONTINUE	ENTER OPTION?
2. Press 5 ASY, CONTINUE	ASY DISPL Y = 1
3. Press 1 if results of previous assay desired. IF NOT	
4. Press CONTINUE	ASSAY MEASUREMENT
5. Press CONTINUE	SENSITIVITY LO = 0 or HI = 1
6. Press CONTINUE	LO = 0 or HI = 1?
7. Press 1, CONTINUE	?1 SENS = HI
8. Press CONTINUE	MAT CATEGORY?
9. Press 2, CONTINUE	?2 2
10. Press CONTINUE	INSERT SAMPLE TO BE ASYD
11. If not already done, insert sample in counter now	
12. Press CONTINUE	ENTER ID?
13. Press Any 1 or 2 digit ID, CONTINUE	?ID ID
14. Press CONTINUE	ASSAY MEAS IN PROCESS
When assay is completed, operator-action light will flash.	
	ID = ID CATEGORY = 2
15. Press CONTINUE	C/S <u>+</u>
16. Press CONTINUE	MASS = gPu240 UNMS = gPu240
17. Press CONTINUE	WRITE ASSAY TRANSACTION
18. Press CONTINUE or Press ABORT	DATA TRANSMITTED DATA NOT TRANSMITTED
19. Press CONTINUE	NOT BUSY ENTER OPTION

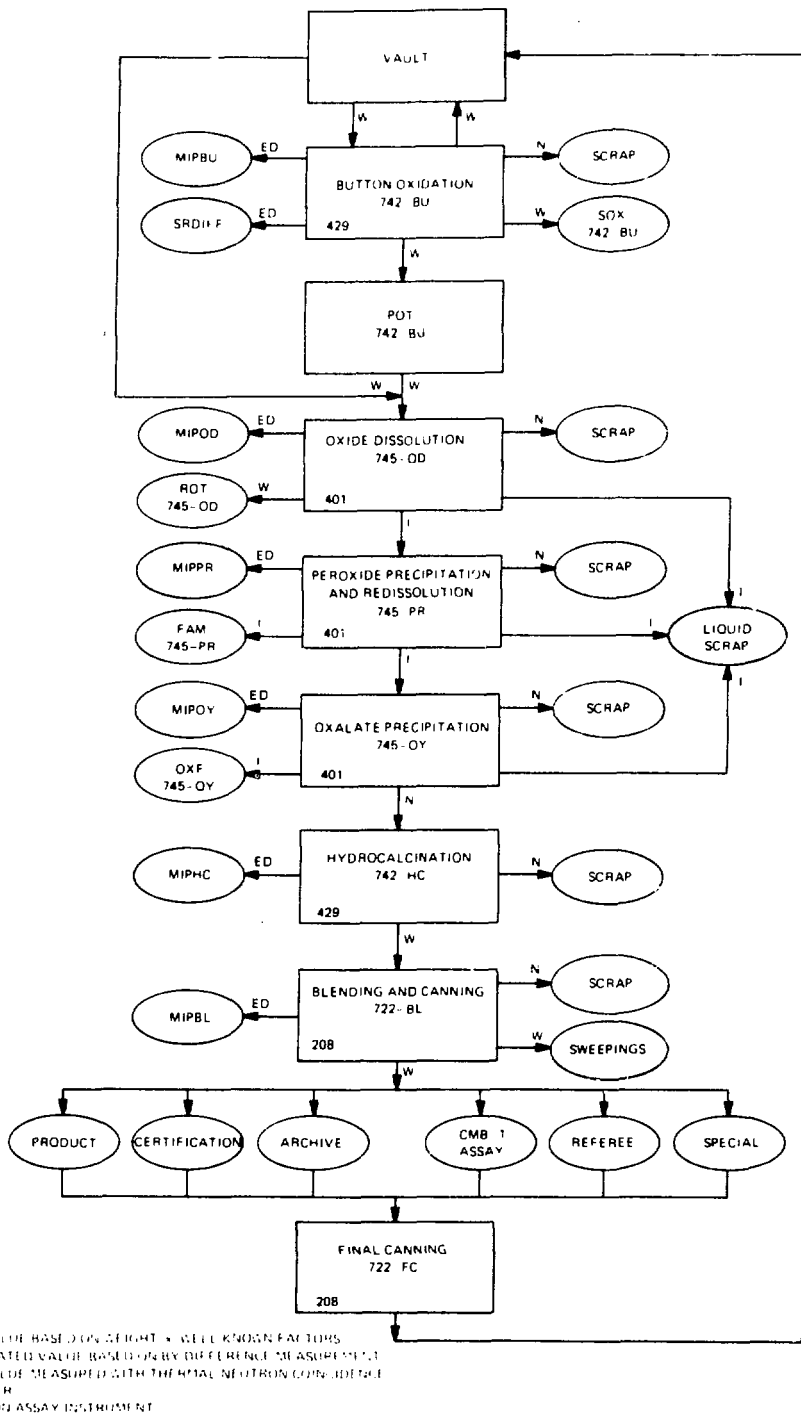


Fig. 24. Flow diagram for production of FFTF-grade plutonium oxide, showing location and types of material measurements.

well. A materials balance is maintained around each account by measuring the material entering and leaving it. If, however, the material is in a sealed can, the recorded value is accepted.

The heart of the DYMAC system is a dedicated computer, which receives information on activities and transactions within the Plutonium Processing Facility and can provide at any time the location, quantity, and composition of all SNM. NDA instruments are located strategically throughout the plant. Measurements made with this instrumentation are sent to the computer, either directly or by operator intervention, at 40 computer terminals, as shown in Fig. 25, located throughout the plant.

The DYMAC measurement control program uses two kinds of checks to assure proper instrument performance. An accuracy check is made four times per week to verify that no changes have occurred in instrument response to working standards. Precision checks are made weekly for changes in reproducibility, and to detect nonrandom fluctuations in counting instruments that may indicate electronics problems. The data generated by these checks are transmitted to the computer for checks against control limits. The control limits used are a 95% confidence level warning limit and a 99% confidence level as an action limit.

The data are stored in instrument history files for use when an unusual occurrence requires historical data for clarification and for limit-of-error calculations. Figure 26 shows a summary plot of a TNC accuracy parameter, measured for a 50-day period. If an instrument check exceeds the action limit, or exceeds the warning limit in two consecutive measurements, the computer does not allow the instrument to be used for accountability measurements until the instrument's performance has been demonstrated to be within the defined limits.

III. DISCUSSION

Materials accounting for safeguards purposes has occasionally been viewed by the process operators as a regulatory nuisance, which is to be satisfied with little or no impact upon production costs or capabilities. As a result, NDA instrumentation has found operator acceptance primarily in those problem areas where no reasonable alternatives are available, for example, scrap and waste assay, or in specific areas defined by quality assurance and safeguards regulations. Continued exposure to the process control impact that such instrumentation has is influencing the operators' generally neutral-to-negative view of the subject. Indeed, future instrument developments that directly address the operators' concerns will allow the strengthening of the safeguards system while improving plant efficiency.

Future instrument development activity may be anticipated in the following four areas:

- systems,
- summarization,
- standardization, and
- simplification.

The systems approach to measurement technology development considers the composite performance of individual measurement components rather than the "single point-single component" traditional approach.³² These considerations are made within the context of



Fig. 25. In-process DYMAC terminal.

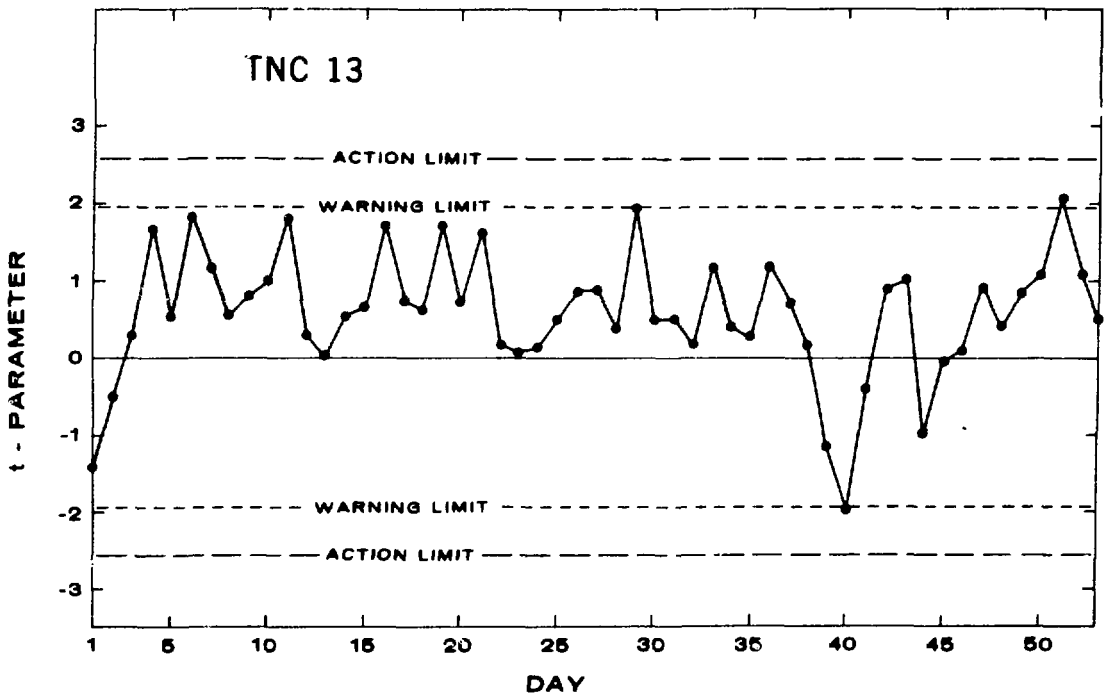


Fig. 26. Accuracy measurement control parameter summary for TNC 13.

the process control and safeguards systems, and thus reveal tradeoffs that are acceptable or desirable to both systems. This approach allows a broader parametrization of instrument requirements and an optimization procedure that considers those parameters.

In-plant instrumentation has the ominous capability of inundating process and safeguards managers with what appear to be irrelevant data. To be used effectively for routine operating conditions and to be massaged flexibly in unusual conditions, these data must be sorted, summarized, and displayed in an effective manner. This capability requires the development of software packages that offer the plant managers and external inspectors flexibility in the interpretation of results in a meaningful time period. The instrument should not only present an assay result but should allow some interpretation of the assay within the context of its environment.

As described above, many of the individual element components and their corresponding functions are very similar, if not identical, for a number of instruments. Standardizing these components, both hardware and software, will greatly facilitate the transfer of the NDA technology into the processing facilities. This off-the-shelf feature is important to management when considering the training necessary for plant personnel, the identification of maintenance and repair resources, and the future expansion of existing measurement capability to meet anticipated regulatory changes.

In a number of situations, the systems analysts may indicate that the high precision and accuracy available with the more complex instruments is not required and that a simpler, more timely measurement technique is applicable. Simpler systems are attractive to process managers because of the generally lower cost, higher reliability, and ease of use. It may also be possible to increase the appearance of simplicity in the instrument-user interface by adapting new high-technology techniques and human-factors research results.

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



April 27-May 12, 1981

Session Objectives

SESSIONS 12-13: DEMONSTRATION OF NDA INSTRUMENTS AND METHODS AT LOS ALAMOS

The group will visit the Los Alamos National Laboratory and tour the facilities of the nuclear safeguards nondestructive assay program. During the day many of the instruments and techniques described in Sessions 10 and 11 will be on display. The morning will be spent touring the NDA development laboratories at Los Alamos. Instruments presently under development plus exhibits of systems in use in other nuclear facilities will be available for examination and discussion. Exhibited instrumentation includes x-ray absorption edge densitometers for various uranium and plutonium solution measurements, neutron coincidence counters for bulk plutonium measurement, gamma-ray spectroscopy systems for product isotopic and bulk scrap measurements, various active neutron interrogation systems, and portable/transportable equipment for use by safeguards inspectors. The afternoon will include a visit to an MTR research reactor facility. Here instrumentation will be demonstrated for the examination and assay of irradiated reactor fuel. This includes high resolution gamma-ray scanning equipment, gamma ray and neutron profile measurements systems, and optical equipment to measure Cerenkov radiation. Exhibits will describe similar instrumentation used to examine spent fuel from large power reactors. The Los Alamos tour will also include the meson physics facility and science museum.



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



April 27-May 12, 1981

SESSIONS 12-13: DEMONSTRATION OF NDA INSTRUMENTS AND METHODS AT LOS ALAMOS

Douglas Reilly and Charles Hatcher
Coordinators

I. INTRODUCTION

The participants visited the Los Alamos National Laboratory and toured the nuclear safeguards nondestructive assay facilities. Many of the instruments and techniques described in sessions 10 and 11 were demonstrated in the course of this tour. The morning was spent at the NDA development laboratories at Ten-site. Additional non-destructive assay techniques for the measurement of irradiated fuel materials were demonstrated at the Omega West Reactor during the afternoon. The afternoon also included visits to the Los Alamos Meson Physics Facility (LAMPF) and the Bradbury Science Museum to give participants an overview of the major research and development programs at the laboratory.

II. NONDESTRUCTIVE ASSAY DEVELOPMENT LABORATORY (TEN-SITE)

The participants were divided into five small groups to tour five demonstration areas.

A. NDA Training Program

In this room, various displays described the nondestructive assay training program conducted at Los Alamos. This program includes courses for domestic and international nuclear materials managers and special courses for IAEA safeguards inspectors. The exhibits included instrumentation, manuals, and photographs from past training sessions.

Also on display was a new portable multichannel analyzer developed for use by IAEA inspectors and several night vision devices used to measure the Cerenkov radiation produced by irradiated fuel materials stored under water.

B. Gamma-Ray Assay of Scrap and Waste

Several general purpose instruments were on display in the gamma-ray spectroscopy laboratory to measure the isotopic composition of plutonium materials. A demonstration was given of a system for transmission-corrected, segmented gamma scanning which is a useful procedure to measure uranium and plutonium scrap and waste materials.

C. Absorption-Edge Densitometry

In this laboratory, several absorption-edge densitometry systems were demonstrated. This technique is used to measure the concentration of uranium and plutonium in small liquid samples. The demonstration used the prototype of an instrument that has been installed and tested at the Tokai Fuel Reprocessing Plant in Japan and the Savannah River Plant in the United States. A new L_{III}-edge densitometer was just beginning preliminary tests before evaluation in a nuclear production facility. A third instrument on display here was a plutonium isotopic composition assay system which will shortly be delivered to the Savannah River Laboratory for evaluation.

D. Van de Graaff and FAST Assay System

The Safeguards Assay Group operates a 3.75-MeV Van de Graaff to produce monoenergetic neutrons for the assay of small uranium samples and general technique development. This facility was shown and described. At the same time, a description and tour was given for the Fluorinel and Storage Facility (FAST) assay system which is being designed and fabricated at Los Alamos to measure irradiated fuel materials and waste at the Idaho Chemical Processing Plant. This instrument is a large "Shuffler" which uses a movable ²⁵²Cf neutron source for delayed neutron activation analysis.

E. Irradiated and Fresh LWR Fuel Assay Techniques

At one of the group's hot cell facilities, a demonstration was given of a technique to measure the fissile content of irradiated and unirradiated LWR fuel assemblies. A small transportable instrument called the "Neutron Coincidence Collar" was also displayed. This instrument has been developed for use by IAEA inspectors to verify unirradiated fuel assemblies at reactors and fuel fabrication plants. A demonstration was also given of the High-Level Neutron Coincidence Counter (HLNCC); another transportable instrument developed here for the use of IAEA inspectors. This instrument is used largely to measure plutonium fuel materials using the spontaneous fission neutron signature of plutonium.

III. IRRADIATED FUEL MEASUREMENT DEMONSTRATION AT REACTOR

In the afternoon, the group visited the Omega West Reactor facility, an MTR-type research reactor. Again, the group was divided into three smaller tour groups.

A. General Reactor Operation

A general description of the reactor and its operation was given in the control room; the various uses and experiments were explained out in the experimental area. The latter includes isotope production, neutron activation analysis, neutron radiography, and the National Uranium Resources Evaluation (NURE) program. The NURE program is a very extensive hydrogeological sampling program designed

to evaluate potential areas for future uranium (and other strategic mineral) exploration.

B. Irradiated Fuel Verification: Cerenkov Radiation

At the top of the reactor vessel, several night vision devices were set up to look through viewing ports at the reactor core and spent-fuel storage racks. These devices are hand-held or tripod mounted; they allow the observation of irradiated elements in storage positions outside the core (reactor was shut down for this demonstration) by viewing the Cerenkov radiation produced from interaction of fission product gamma rays with the cooling water. A photo display gave information on experiments performed with these devices at LWR power reactor stations. Several of these units have been provided to the IAEA to aid their physical inventory verification procedures at power and research reactors.

C. Irradiated Fuel Verification: Gamma-Ray and Neutron Counting

An irradiated fuel element had been moved to the cooling/transfer basin north of the reactor to demonstrate fission product measurements using a variety of gamma-ray and neutron detectors. A high resolution spectroscopy system was collecting fission product gamma-ray spectra. The gross gamma-ray and neutron activity profiles were measured using ion chambers and fission chambers connected to a small portable microprocessor-based instrument developed at Los Alamos for the IAEA. A photo display showed results obtained at LWR power reactors.

IV. LOS ALAMOS LABORATORY PROGRAMS

A. Bradbury Science Museum

A tour of the museum showed much of the history of the laboratory and gave an overview of the major research and development programs.

B. Los Alamos Meson Physics Facility (LAMPF)

LAMPF is the highest intensity meson production facility in the world. It is one of the laboratory's major fundamental and applied research facilities and attracts experimenters from around the world. The group toured the major accelerator sections and visited the Biomedical Research and Treatment area where a negative pion beam is being evaluated for cancer therapy.

V. CONCLUSION

The participants had a very busy day offering an overview of the NDA development efforts at Los Alamos in support of domestic and international safeguards agencies. They were also given a brief overview of the history and major research programs of the Los Alamos National Laboratory.



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



April 27-May 12, 1981

Session Objectives

SESSION 14: 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,
4. identify special safeguards design considerations and applications to selected fuel-cycle facilities.



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



April 27-May 12, 1981

SESSION 14: PRINCIPLES OF NEAR-REAL-TIME MATERIALS ACCOUNTING AND CONTROL SYSTEMS

James P. Shipley
Los Alamos National Laboratory

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:

1. Excluding all unauthorized persons from the facility and selectively excluding others from sensitive areas within the plant;

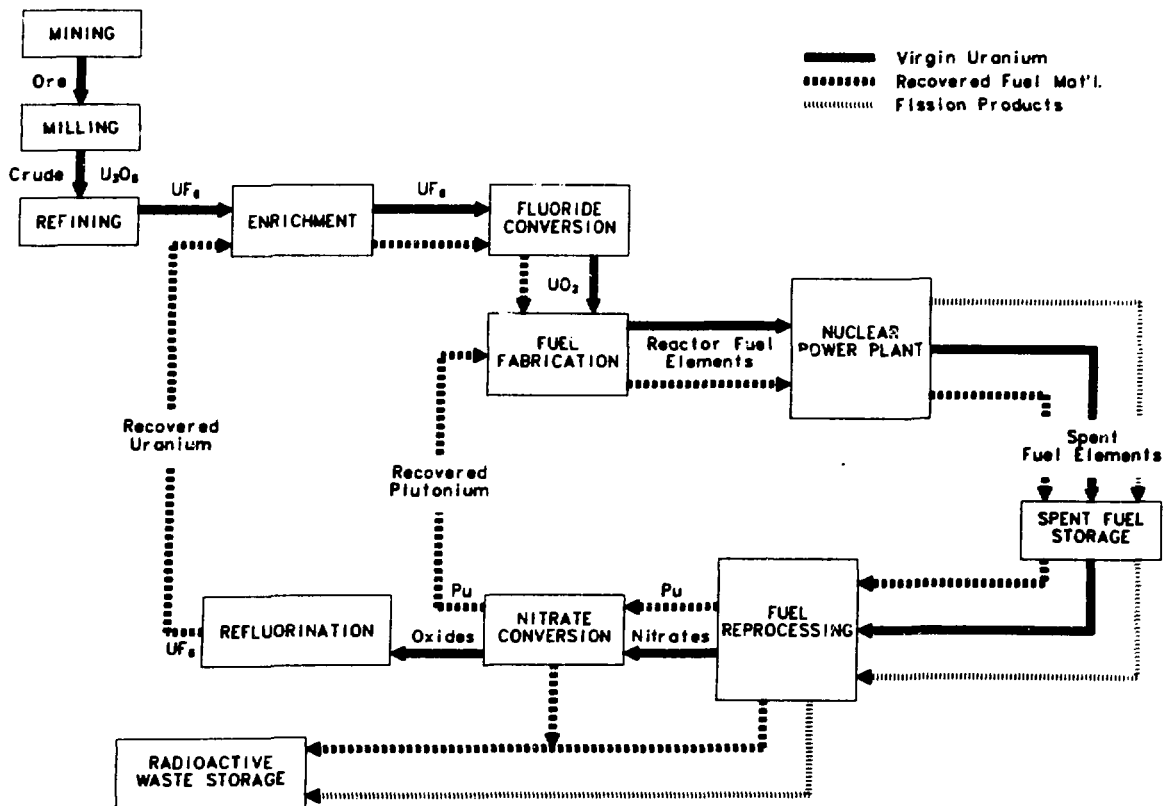


Fig. 1.
The power reactor nuclear-fuel cycle.

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 ensure effective safeguards

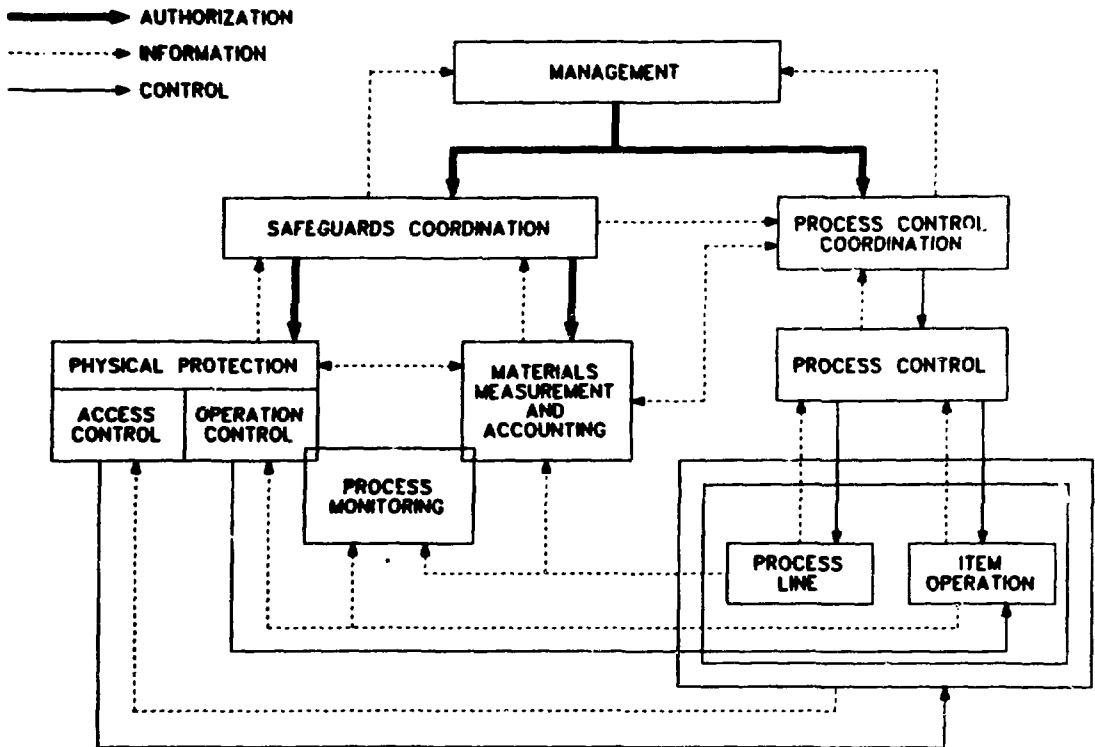


Fig. 2.
Structure of the safeguards system.

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 and 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 the containment. The result of the Agency's verification activities is "a statement, in respect of each

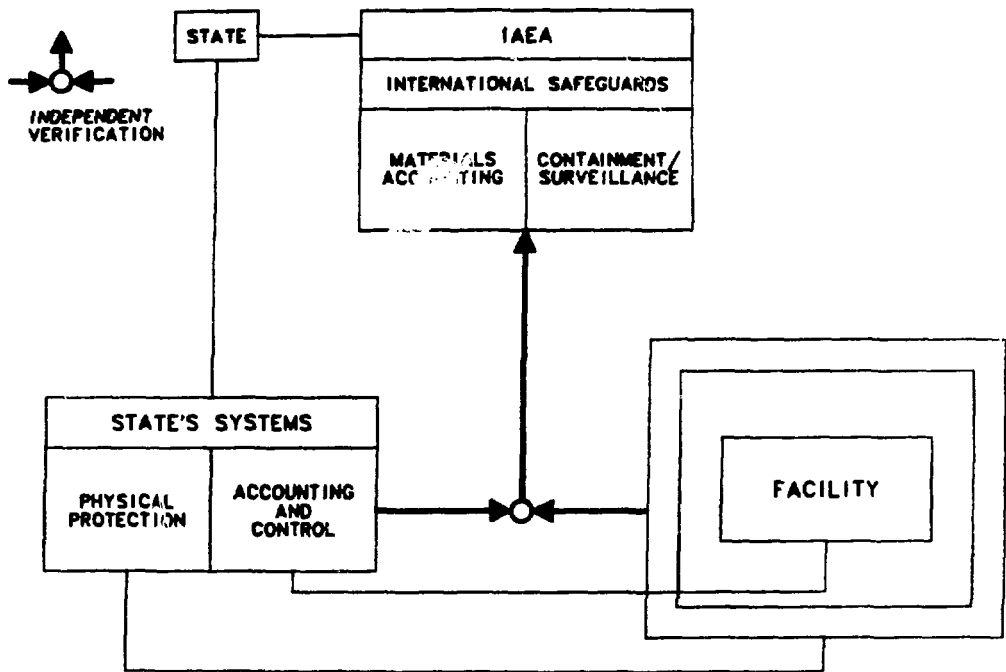


Fig. 3.

Relationship between the State and IAEA safeguards systems.

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)

At present, materials accounting primarily relies on forming materials balances following process shutdown, cleanout, and physical inventory. The materials balance area (MBA) often contains the entire plant or a major portion of the process. The classical materials balance is formed by adding all measured receipts to the initial measured inventory and subtracting all measured removals and the final measured inventory. During routine production, materials control is vested largely in administrative and process controls augmented by secure storage of discrete items.

Although current accounting practices are essential to safeguards control of nuclear materials, they have inherent limitations in sensitivity and timeliness. The sensitivity limit results from measurement uncertainties that may conceal losses of significant quantities of nuclear material in large plants. The timeliness of materials accounting is limited by the frequency of physical inventories. There are practical limits on how often a facility can be shut down for inventory and still remain productive.

Improvements in materials measurement and accounting can be obtained through implementation of dynamic (or near-real-time) materials accounting concepts. This approach combines conventional chemical analysis, weighing, and volume measurements with the on-line measurement capability of NDA instrumentation to provide rapid and accurate assessment of the locations and amounts of nuclear materials in a facility.

To implement dynamic materials accounting, the facility may be partitioned into discrete accounting envelopes, called unit-process accounting areas (UPAAs). A UPAa can be one or more chemical or physical processes and is chosen on the basis of process logic and the ability to draw a materials balance, rather than on geography, custodianship, or regulatory requirements. By dividing a facility into unit processes and measuring all significant materials flows and in-process inventories, quantities of material much smaller than the total plant inventory can be controlled on a timely basis. Also, any discrepancies are localized to that portion of the process contained in the UPAa.

Materials balances drawn around UPAAs during plant operation are referred to as dynamic materials balances to distinguish them from materials balances drawn around MBAs after cleanout and physical inventory. Ideally, dynamic materials balances would be zero unless losses of nuclear material have occurred. In practice, they never are zero for two reasons. First, measured values are never exact because of the errors inherent in any measuring procedure. Second, constraints on cost or effects on processing operations may dictate that not all components of a dynamic materials balance be measured equally often; therefore, even if the measurements were exact, the dynamic materials balances would not be exactly zero until all side-streams and holdup residuals are measured. In the interim, historical data can be used to estimate unmeasured material, and then the estimates can be updated when additional measurements become available.

The mechanism within the facility safeguards system that ensures the quality of the measurement data is an organized measurement-control program designed to measure and monitor the accuracy and precision of each instrument in the system and to verify application of

NDA techniques in compliance with accepted practices. This measurement-control program is an integral part of the safeguards system in that the computer system records and monitors both measurement and calibration data. A performance history thus is maintained for each instrument.

Dynamic materials accounting must be applied flexibly to be useful. Proper application must take account of specific process design and operating features and should be graded according to the strategic value and vulnerability of process materials.

Computer-generated control charts derived from measurements and process operating characteristics can be used to indicate thefts, losses, or excessive holdup. This detailed control forces a potential divertor to remove material in sufficiently small quantities that his individual removals will be masked by measurement uncertainties. Thus, to obtain a usable quantity of material, the divertor must commit many diversions with the concomitant high risk of detection by the accounting system, surveillance instruments, and the physical protection system.

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 key measurement points 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 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

$$m = M(1 + \epsilon + \eta) \quad , \quad (1)$$

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 4 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. 4a), whereas storage areas for feed and product are in separate MBAs and are not shown.

Figures 4b and 4c show two possible divisions of the process MBA into UPAA's for dynamic accounting purposes. In Fig. 4b the MBA is divided into a series of five UPAA's. To accomplish this division, transfers of nuclear material between adjacent UPAA's and the in-process inventory in each UPAA must be measured. In Fig. 4c, the MBA is divided into five parallel UPAA's. 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 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}^2 (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 n error), the variance, $\sigma_{\Delta I}^2$, of the net inventory change, ΔI , is given by

$$\sigma_{\Delta I}^2 = (I_0^2 + I_N^2)\sigma_{\epsilon I}^2 + (I_0 - I_N)^2\sigma_{n I}^2 \quad , \quad (6)$$

where $\sigma_{\epsilon I}^2$ and $\sigma_{n I}^2$ are the ϵ - and n -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

$$\sigma_{\Delta I}^2 = 2I_0^2\sigma_{\epsilon I}^2 \quad . \quad (7)$$

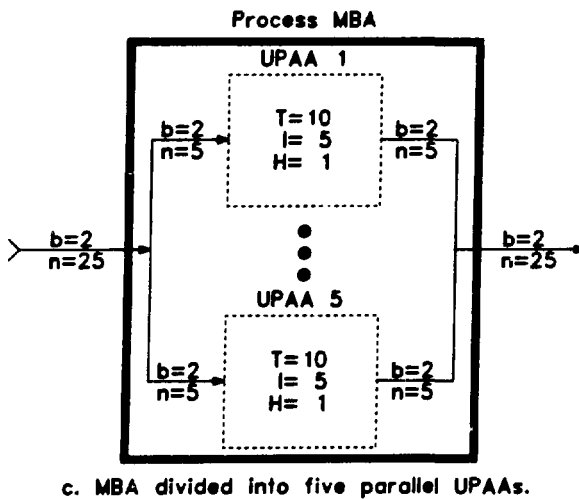
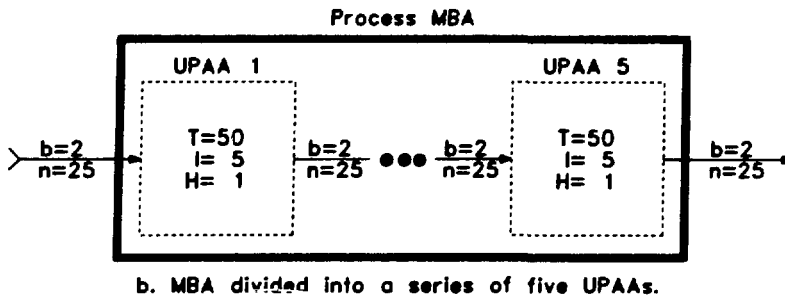
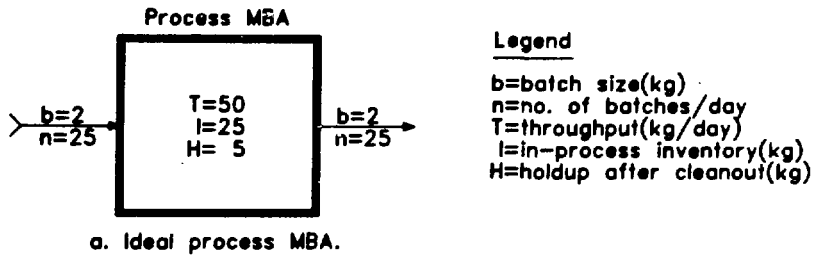


Fig. 4.
Ideal process block diagram.

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 σ_{nI} is weak [Eq. (6)]; hence, a well-known value for σ_{nI} 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 ($\sigma_{eI} = 10\%$ in this example) limits the dynamic accounting sensitivity over short accounting periods.

2. Net-Transfer Variance. The variance σ^2 of the net material transfer T is given by

$$\sigma_T^2 = 2Nb^2(\sigma_{\epsilon b}^2 + \sigma_{nb}^2) + 2N(N-1)b^2\sigma_{nb}^2, \quad (8)$$

where b is the input and output batch size, and $\sigma_{\epsilon b}^2$ and σ_{nb}^2 are the ϵ - and n -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^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

$$N_0 = \frac{\sigma_{\epsilon b}^2 + 2\sigma_{nb}^2}{\sigma_{nb}^2}. \quad (9)$$

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^2 is given by

$$\sigma_T^2 = 2Nb^2(\sigma_{\epsilon b}^2 + \sigma_{nb}^2) + 2b^2\sigma_{nb}^2 \sum_{k=1}^K n_k(n_k - 1), \quad (10)$$

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. 5. 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 σ_{eb} and σ_{nb} have been taken to be 2% and 0.5%, respectively; these values correspond to $N_0 = 18$ [Eq. (9)]. The net-transfer RSD varies as $[(\sigma_{eb}^2 + \sigma_{nb}^2)/N]^{1/2}$ for small N and as $(\sigma_{nb}^2/K)^{1/2}$ 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 σ_{nb} and K are especially important. The value of σ_{nb} 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 I 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

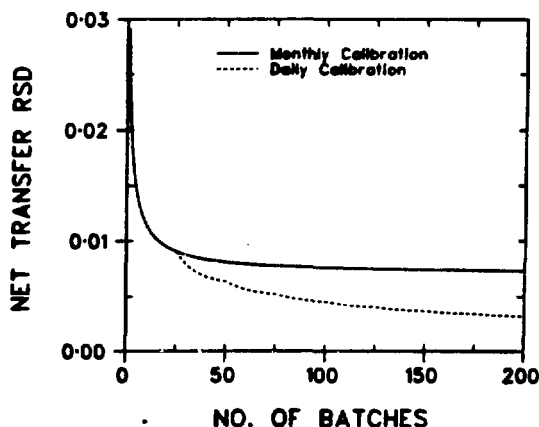


Fig. 5.
Effect of calibration on transfer measurement errors.

TABLE I

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

for one UPAA in a series arrangement, one UPAA in a parallel arrangement, and for the entire process MBA (see Fig. 4). 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 I 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 (σ_{EI}). For longer accounting periods, σ_{MB} is 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 6. 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 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. 6 labeled FAP for false-alarm probability,

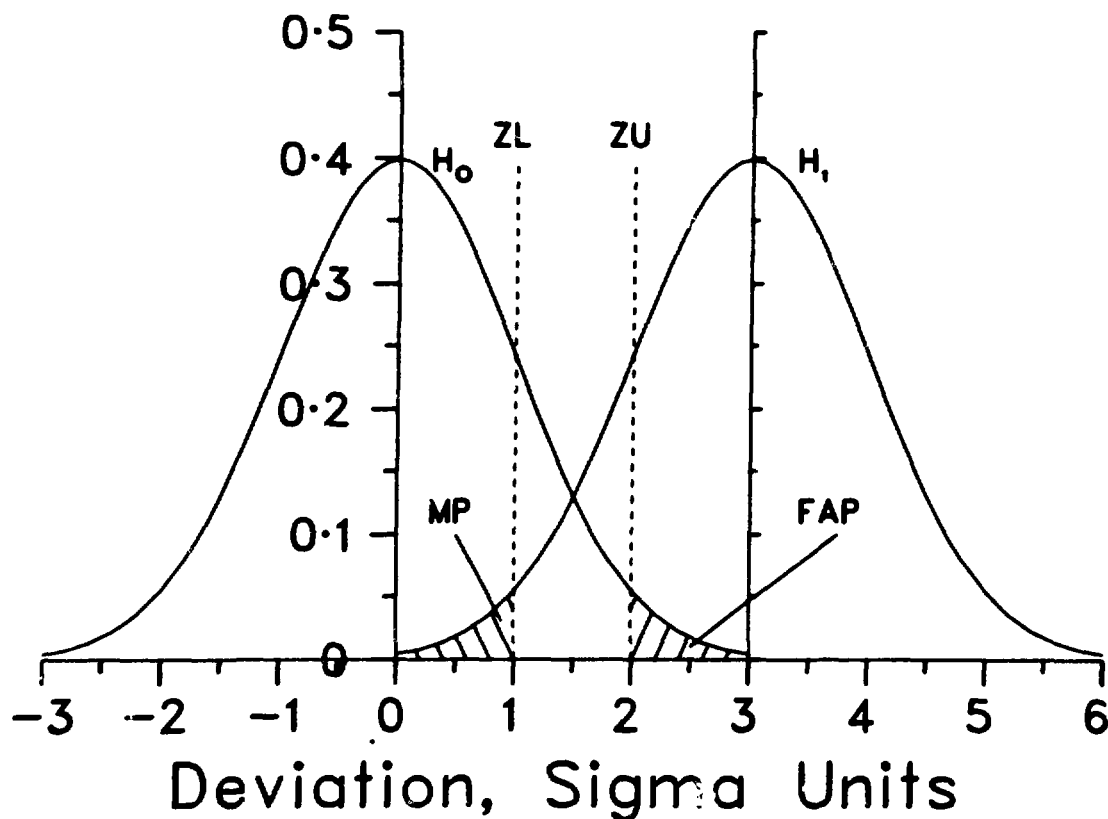


Fig. 6.
Probability density functions representing no missing
nuclear material and missing nuclear material.

or one can conclude that there is no missing nuclear material when in fact there is, denoted by the shaded area in Fig. 6 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 1 σ 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 II. 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 II

ALARM CLASSIFICATION FOR THE ALARM-SEQUENCE CHART

<u>Classification</u> <u>(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. 7-9. 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

$$P[L, N, \alpha] \quad ,$$

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 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

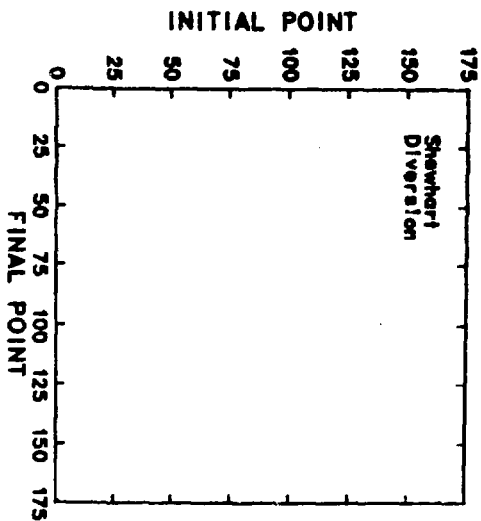
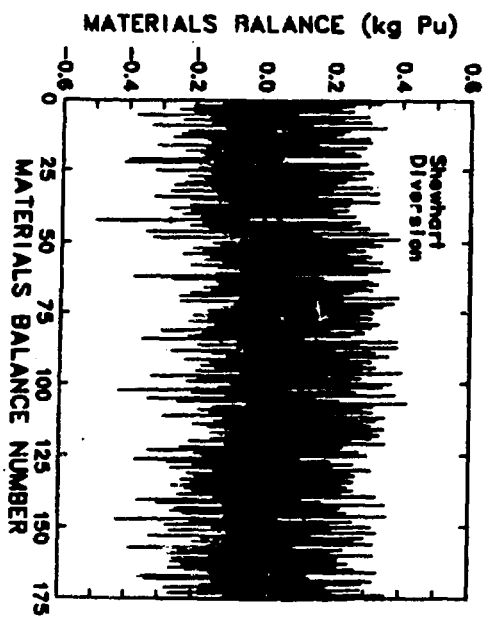
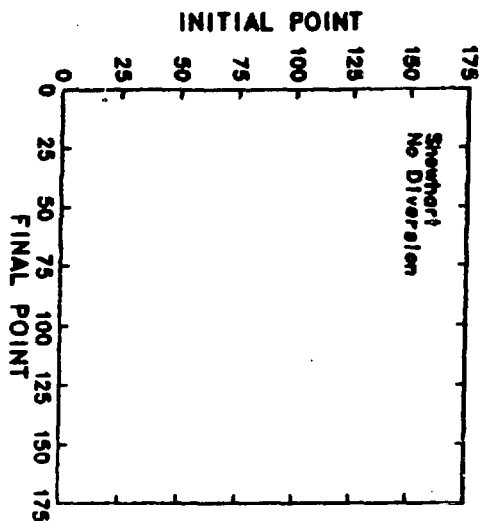
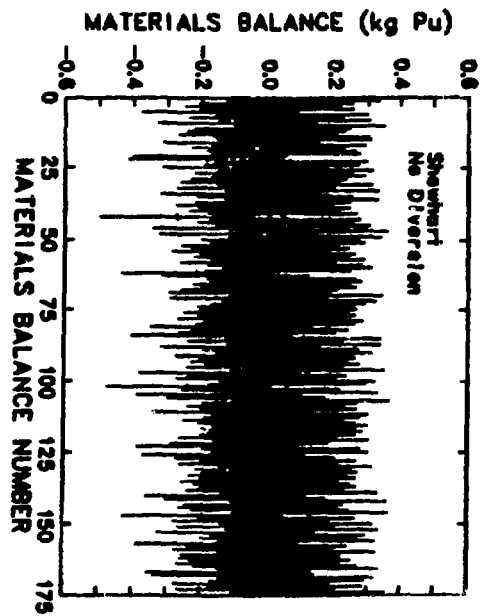


Fig. 7.
Shehart and alarm charts.

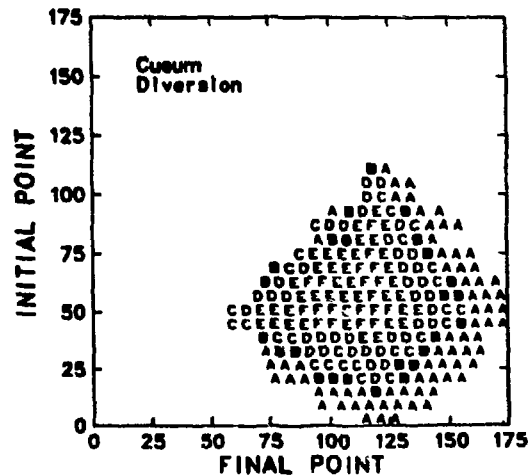
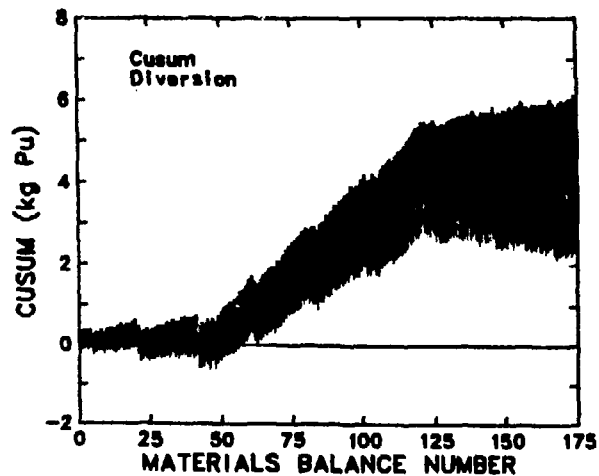
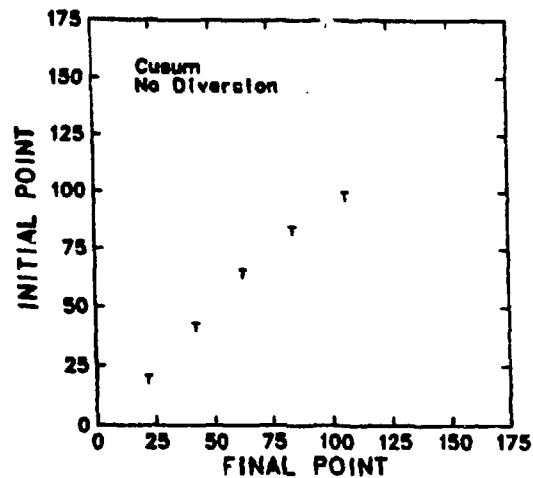
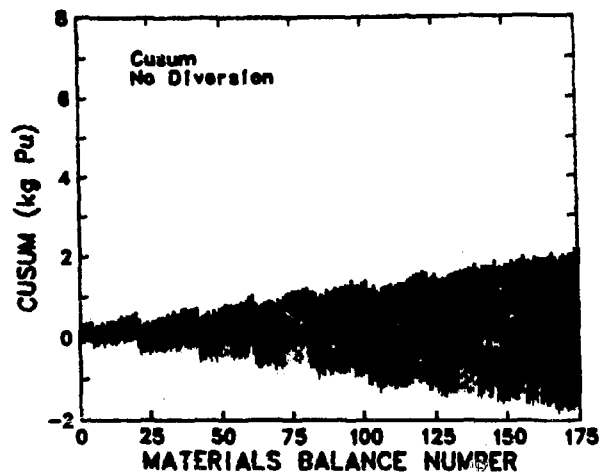


Fig. 8.
Cusum and alarm charts.

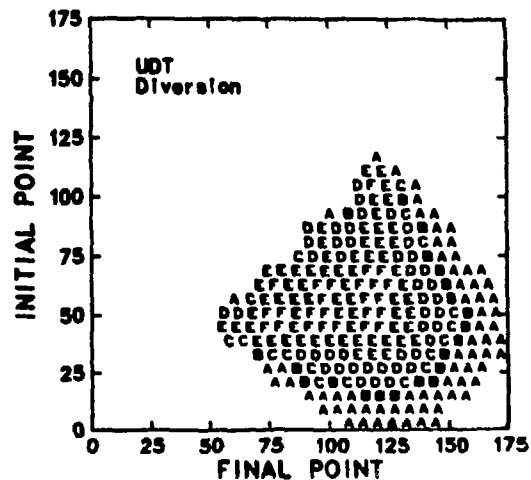
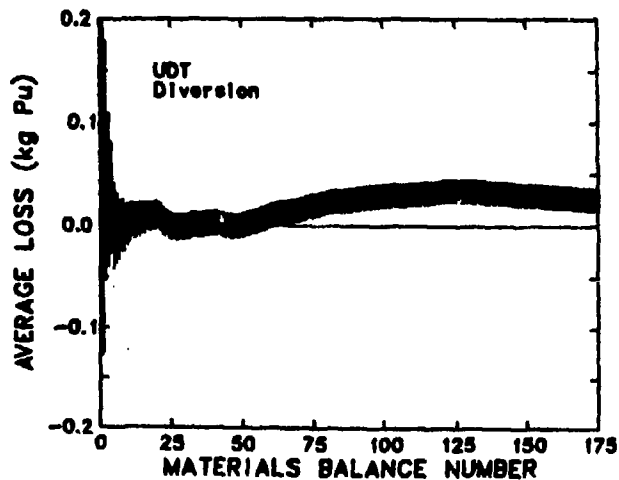
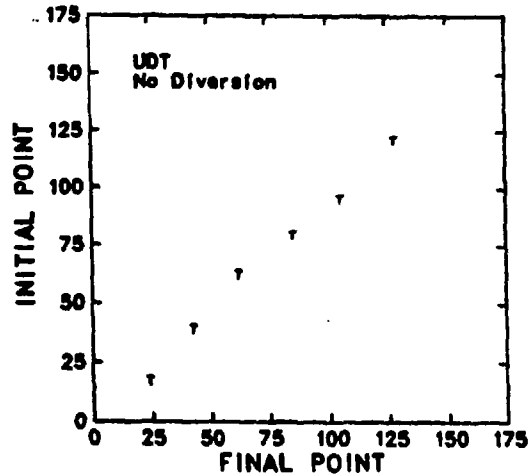
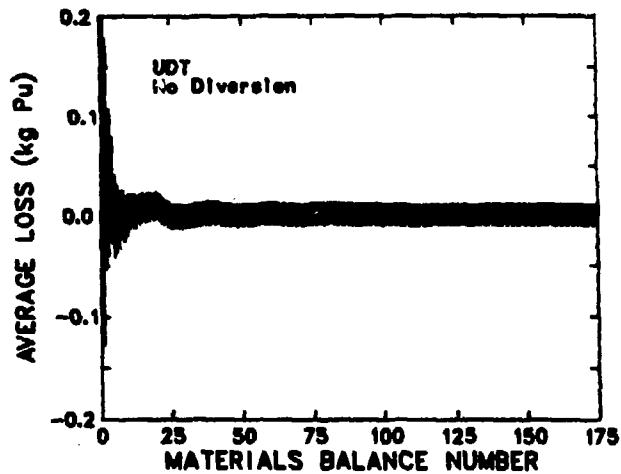


Fig. 9.
UDT and alarm charts.

performance surfaces. They are plotted in the three-dimensional space (N, L, P) illustrated in Fig. 10. 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.

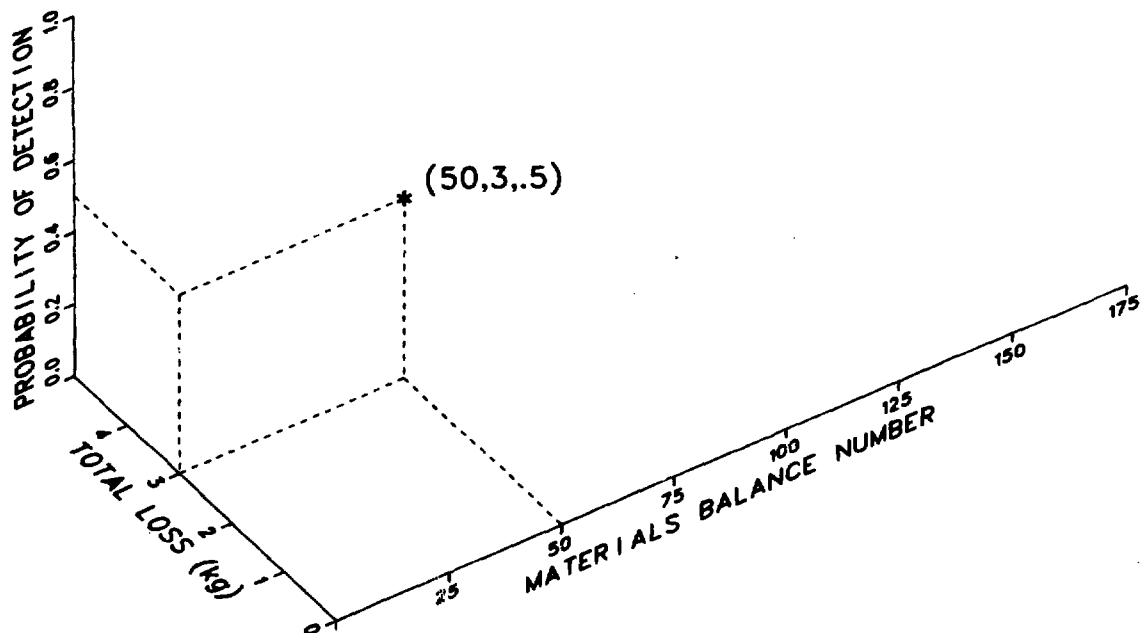


Fig. 10.
Three-dimensional space of performance surfaces.

3. Examples. Figure 11 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 11 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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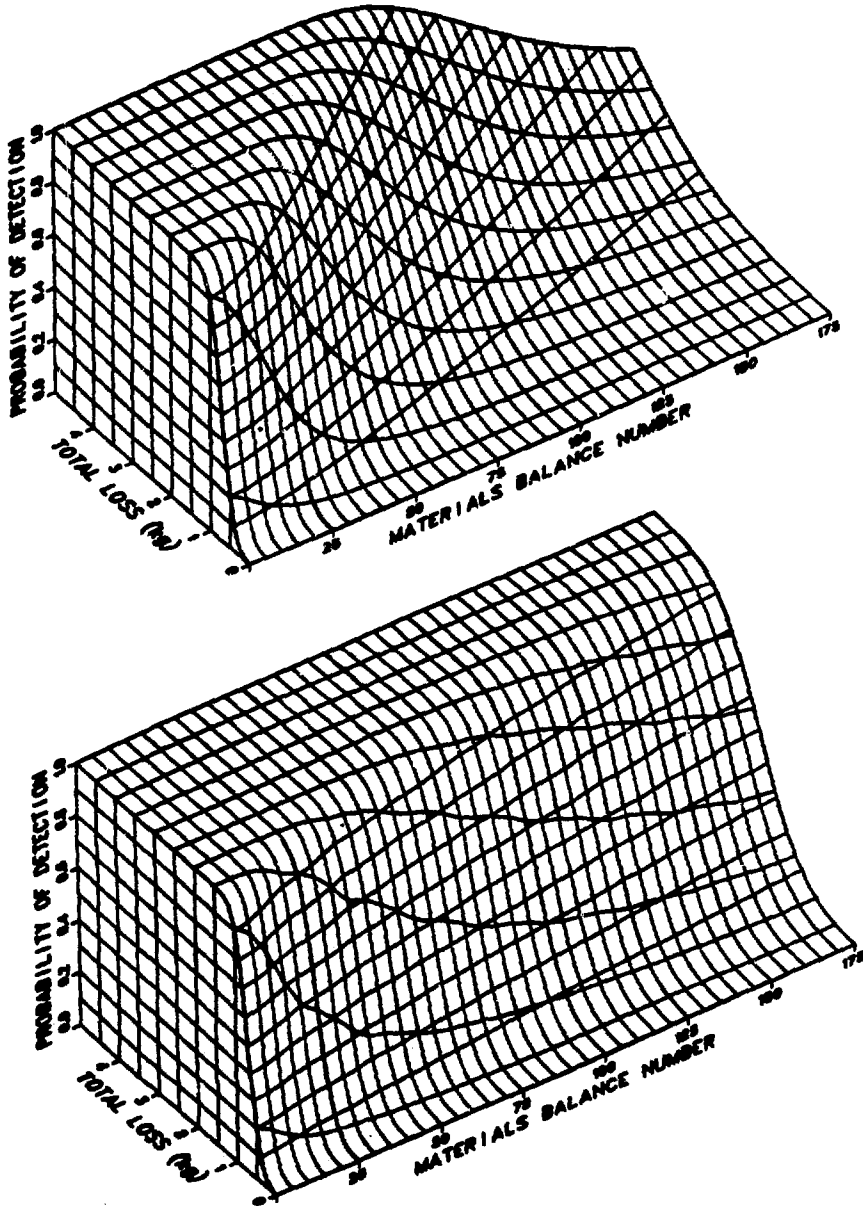


Fig. 11.
Cusum performance surfaces for two accounting cases;
worst (upper), best (lower).

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



April 27-May 12, 1981

Session Objectives

SESSION 15: EXAMPLE OF AN IN-PLANT NEAR-REAL-TIME ACCOUNTANCY/ PROCESS CONTROL SYSTEM

This session will describe an existing computerized in-plant near-real-time accounting and process monitoring system at the Allied-General Nuclear Services (AGNS) Barnwell Nuclear Fuel Plant (BNFP). Details of the system performance, objectives, hardware, plant instrumentation, and system functions will be presented. Examples of actual programs for accounting and monitoring will be described and system benefits will be discussed.

After the session, participants will be able to:

1. identify the major computer hardware components of functional near-real-time accounting systems,
2. identify the types of process instrumentation necessary to perform near-real-time accounting,
3. describe the major nuclear material control and accounting functions of the AGNS computer system,
4. assess the benefits to safeguards and plant operations of a computerized near-real-time accounting system.



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



April 27-May 12, 1981

SESSION 15: EXAMPLE OF AN IN-PLANT NEAR-REAL-TIME ACCOUNTANCY/PROCESS CONTROL SYSTEM

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I. INTRODUCTION

The final proof of the effectiveness, reliability and, indeed, the capability to implement a new technology depends on placing the technology to use in a full-scale operation and evaluating its performance. Such is the case with near-real-time accounting.* Allied-General Nuclear Services has developed, installed, and is testing a Computerized Nuclear Materials Control and Accounting System (CNMCAS) in the solvent extraction portion of the Barnwell Nuclear Fuel Plant (BNFP). This system is capable, among other things, of performing near-real-time accounting for the separations process.

Work on CNMCAS has been on-going since 1977, primarily under US-DOE research and development contracts.

II. GENERAL DESCRIPTION

CNMCAS is a collection of Digital Equipment Company (DEC) PDP-11 mini-computers and support hardware designed to perform nuclear material control and accounting functions such as measurement, reporting, surveillance, and quality control. Figure 15-1 shows the major components which make up the CNMCAS system. AGNS identified four major objectives in developing the CNMCAS system. These objectives were to:

- (1) Develop a computerized nuclear materials control and accounting system that meets NRC, DOE, and IAEA requirements and goals for accuracy, sensitivity, and timeliness.
- (2) Demonstrate a system that is operable and maintainable using plant personnel.
- (3) Demonstrate a system that will aid operation of the facility rather than hinder it.
- (4) Develop a system that can be adapted readily to other facilities.

*Near-real-time or dynamic accounting is not really a "new" concept. The method has been used in the past; however, it was not until advances in solid-state electronics made low-cost, small computers generally available that the data acquisition and analysis could be effectively handled at a reasonable cost.

This session will describe the components of the CNMCAS system including computer hardware, plant instruments, analytical instruments, and the major functional programs that are used for nuclear materials control and accounting. In addition, some of the operational aids developed for process control will be presented. Finally, a videotape tour of the Barnwell Nuclear Fuel Plant will be shown.

Five mini-computers make up the system. These are the RDAS Computer (Remote Data Acquisition System), the MACS Computer (Materials Accounting and Control System), the LDS Computer (Laboratory Data System), the PDS Computer (Program Development System), and the MIU Computer (Management Information Unit).

The RDAS Computer performs the functions of reading the plant instruments, converting the instrument outputs to engineering units (i.e., cm of H₂O, °C, etc.) and providing specific readings to the other computers on demand. RDAS, which is located in the Control Room Area, controls the sequence in which instruments are read and in some cases computes an average of a series of readings on an instrument to reduce the random "noise" error.

Instruments are assigned to one of three "scan modes" to accommodate the different requirements. These scan modes include:

Scan Mode 1: General instruments - one reading per cycle, no averaging.

Scan Mode 2: Special readings - locks on and reads all Scan Mode 2 instruments for 20 seconds, saving all readings. Computes average and stores. Memory retains last five averages.

Scan Mode 3: Same as Scan Mode 2, except three averages retained.

RDAS also has upper and lower alarm limits for each instrument reading and can print out alarm messages or display alarms on a video terminal. Table 15-1 shows typical channel or instrument definitions for RDAS.

MACS is the main processing computer and is located in the Control Room Area of the plant. It performs all the calculations, etc., required for the various accounting and control programs. It sends the data commands to RDAS, as needed, receives the data, executes the programs, stores results, and transmits to the various terminals. Storage capabilities include magnetic tape, one RL01 5.5 megabyte disk system, and an 88 megabyte RP04 multihead disk system. Up to 16 terminals can be supported including LA-120 printer/terminals, VT-100 video terminals, LA-180 printer, Centronics line printer, Intecolor Video Console, and a VT-30H video graphics system. MACS also emulates a terminal for the LDS system and receives, sorts, and stores all analytical data reported by LDS. Terminal links to other areas such as the AGNS Administration Building are generally over spare telephone lines.

The LDS Computer is located in the AGNS Laboratory Area. It performs the various lab functions, including sample logging,

sample number assignment, computation of results from input variables, and control of the Standards/QC Program. Many analytical instruments are directly interfaced to the computer through converters or micro-processors. LDS has disk and tape data storage and multiple terminals. LDS uses phone lines and installed cables for data links.

PDS is also located in the Control Room Area. It is used for development and initial testing of new programs and as an on-line backup to MACS. It has a number of printers and video terminals, one 5.5 megabyte RL01 disk system, one 88 megabyte RP04 disk system, and a magnetic tape system.

The MTU Computer is located in the AGNS Safeguards Coordination Center (SCC). This computer will be used as an archiving and report generation unit in the future. It has been used in the past to collect and store complete sets of instrument readings from RDAS after each four-minute cycle and has been used for off-line data analysis.

The RDAS/MACS/PDS systems are powered through the Separations Facility uninterruptible power system. This system assures reliable, regulated electrical power to the computers. The LDS Computer is on a separate uninterruptible power system in the laboratory. The MIU system runs on direct commercial power.

III. PROCESS MEASUREMENT INSTRUMENTS

Process measurement instruments read by CNMCAS include such things as liquid level, liquid density, temperature, and flowrate instruments. Some of the on-line analytical instruments installed in the BNFP, such as alpha, gamma, and neutron monitors, can also be read directly by RDAS. The majority of these instruments transmit an analog voltage or current signal to the Control Room Area where the output is recorded on strip charts or indicated on dials or gauges. The RDAS Computer picks up these signals from the Control Room Area.

Figures 15-2, 15-3, and 15-4 show the various methods of interfacing these instrument signals to the computer system. Two types of interface units are used for this application. One device is an analog to digital converter and controller called a wide-range controller. This device, which is itself controlled by the RDAS Computer, is used to multiplex up to 512 analog signals into RDAS. The other device, called a Universal Controller, is used to pick up digital signals and to transmit control signals from RDAS. This output function will be described later.

Liquid levels, liquid densities, and flowrates are generally measured with differential pressure instruments which have electrical analog (current) outputs. The differential pressure represents the pressure drop across an orifice (in the case of the flowmeters) or the back pressures across a pair of purged dip-tubes (in the case of liquid levels or liquid densities). (The principles of dip-tube measurement were presented in Session 9.) Figure 15-2 shows a typical transmitter interface with the RDAS system. Over 300 of these transmitters are currently connected to RDAS.

A special, high-precision differential pressure device, called a Ruska Electromanometer, is used at AGNS for primary accountability liquid-level and liquid density measurements. This device, which consists of a quartz bourdon tube, an electronic sensing system, and a digital voltmeter (DVM) readout, provides accuracy approaching the limiting capability of the dip-tube measurement system. (The pressure change resulting from formation and displacement of the air bubblers on the tip of the dip-tube can be measured with this instrument.) Ruskas at AGNS have a range of 0-700 cm with an uncertainty of about ± 0.04 cm or 0.006% of full scale. The Ruska device is, however, susceptible to shifts in the "zero" value. This is due to the inherent instability of the "zero" value on the DVM. To overcome this problem, an automated, computer-controlled zero-check routine was set up for each Ruska. On command from the computer, two solenoid valves are closed, blocking off the dip-tube sensing lines and a third solenoid is opened, equalizing the pressure on both sides of the Ruska pressure cell. The computer then reads the "zero" value and deducts it from the actual reading (taken previous to the zero check). The solenoid valves are then switched back to the normal configuration. Figure 15-3 shows a typical Ruska interface arrangement. AGNS currently has nine Ruska units in service.

The output potential voltage of each thermocouple is read directly through the wide-range controller (see Figure 15-4). To compensate for reference temperature, the terminal junctions of each thermocouple are made on a special insulated plate (called a Unithermal Reference Plate) inside the computer. The plate temperature is sensed using a resistance thermal device. The voltage reading and reference junction temperature are then used to compute the sensor temperature with an RDAS program. Over 130 thermocouples are currently read by RDAS.

IV. ON-LINE ANALYTICAL INSTRUMENTATION - APPLICATION AND CALIBRATION

A. Introduction

During the design stage of the reprocessing plant it was recognized that sampling and on-line monitors are an important part of such a facility. Essentially all process operations are conducted remotely in heavily shielded concrete cells, and it is necessary to rely on remote instrumentation, remote samplers, and on-line monitoring systems for adequate process control.

B. Remote Sampler System

The remote needle samplers installed at Barnwell are dry-jet, air lift type samplers which provide a continuously circulating air-liquid mixture, from the tank or line being sampled, through the sample bottle and back to the originating tank or line. A graphic description of the operation of this type of sampler is given in Figure 15-5.

Figure 15-6 shows a modified sample loop which has an on-line monitoring device. A separator pot is installed to separate the air from the sample before it flows through the monitor detector.

C. Non-Radiation On-Line Monitors

There are four types of non-radiation on-line monitors installed in the plant (Table 15-2).

1. Nitrite Monitors. Two nitrite monitors have been installed (Table 15-3). The nitrite concentration is measured by determining the NO_2 concentration in air which is purged through a nitric-nitrous acid mixture. A DuPont Model 400 photometric process analyzer is used to monitor the NO_2 in the gas phase of the sample loop. The range is 0-2000 ppm NO_2 with a sensitivity of 30 ppm NO_2 .

2. Uranium Concentration Monitor. A uranium concentration monitor is installed on the sampler loop to a uranium waste stream (Table 15-4). A DuPont Model 400 photometric process analyzer is also used in this application. The monitor has a range of 1-16 grams uranium per liter, a sensitivity of 0.5 gram uranium per liter, and an accuracy of about $\pm 5\%$. Calibration is performed on-line using standards and is checked by comparison with stream samples analyzed in the laboratory. Variations in nitric acid concentration cause some bias even with the best selection of wavelengths.

3. Conductivity Monitors. Conductivity monitors are calibrated for, and used as, nitric acid concentration monitors (Table 15-5). They cover the range of 0.1-4.0 M nitric acid, have a sensitivity of about 1% of full scale, and have an accuracy of 5%. Bench calibration is done with solution standards and is checked by comparison with stream samples analyzed in the laboratory. Variations in uranium concentrations have a small effect on the results.

4. Density Monitors. Two types of density monitors are installed in the process (Table 15-6). Both types are based on measuring the period of oscillation of a cell through which the liquid stream flows. Several Dynatrol Model CL-10HY monitors are installed in-line on the recovered nitric acid system. They have a range of about 1.00-1.13 grams per milliliter, a sensitivity of 0.0005 gram per milliliter, and an accuracy of about 0.001 gram per milliliter. One Dynatrol is installed experimentally on a uranium-nitric acid process stream. It has a range of 1.0-1.2 gram(s) per milliliter.

One Mettler Model DPR412YWS on-line density monitor is installed experimentally on a uranium-nitric acid process stream. It has a range of 0.0011-2.0 gram(s) per milliliter, a sensitivity of 0.0001 gram per milliliter, and an accuracy of 0.0005 gram per milliliter. Bench calibration on both types is done with air, water, and liquid standards. Good temperature control as well as a stream free of gas bubbles is required for good results.

D. On-Line Radiation Monitors

1. Total Alpha - On-Line Alpha Monitor (OLAM) (Figure 15-7). The on-line alpha monitors (OLAM) are designed to detect alpha in corrosive aqueous or organic solutions that might be found in process streams of a nuclear fuel reprocessing plant. The monitor consists of three principal parts: a optimized cerium-activated Vycor scintillator, the liquid sampling cell, and the processing electronics.

Each OLAM is laboratory calibrated for the particular process stream on which it is installed. The calibration is performed by using simulated process solutions with known concentrations of uranium and plutonium. After installation, recalibration can be performed by comparison with analyses of samples withdrawn from the process stream.

Within a range of 1×10^{-4} to 2 grams plutonium per liter, the sensitivity of the OLAM is 52.3 ± 1.9 cps/ μ Ci/ml, which is independent of beta and gamma activity. High concentrations of uranium reduce this sensitivity somewhat.

2. Gamma - On-Line Gamma Monitor and On-Tank Monitor (OLGM and OTGM) (Figure 15-8). The fission product concentrations for process streams and tanks are monitored by scintillation detectors and associated electronics. The monitors are 2.5 cm by 2.5 cm NaI(Tl) crystals coupled to photomultiplier tubes. Monitors on process streams (OLGM) are mounted on sample loops and monitors on tanks (OTGM) are mounted directly on the tank. All of the gamma monitors are mounted in lead shields for low background operation.

The OLGM's provide the capability for gross gamma counting of energies above 0.4 MeV to determine the fission product levels. The monitors may be interfaced with recorders to provide continuous level readings or they may be interfaced to multichannel analyzers. The multichannel analyzers permit the acquisition of quantitative data for the four to six fission product nuclides present in significant quantities in light water reactor (LWR) fuel reprocessing solutions.

The precision of the analysis provided by the OLGM's is on the order of 2% for fission products of comparable activity.

3. Gamma Isotopic - On-Line Isotopic Concentration Monitor (OLICM) (Figure 15-9). The on-line isotopic concentration monitors (OLICM) use the techniques of gamma spectroscopy to quantitatively assay plutonium concentrations in process solutions. The OLICM uses a small sample cell with appropriate internal absorbers and windows and a high purity germanium detector (HPGe). The detector acquires a gamma spectrum from the naturally emitted radiation of the plutonium. These data are analyzed by computer to provide information on the total plutonium concentration as well as on the isotopic distribution.

The OLICM is carefully optimized for the particular process stream on which it is installed. This process consists of the selection of windows and internal absorbers of the correct thickness and material and the calibration of the monitor with simulated process solutions. On-line isotopic concentration monitors have been calibrated for streams which have plutonium concentrations which range from 0.5 to 150 grams per liter. Accuracies of 0.5% are obtainable using highly purified plutonium solutions, while accuracies of 2-5% are obtainable for coprocessing solutions containing large concentrations of uranium relative to the plutonium concentrations.

4. X-ray Fluorescence Analysis (XRFA) (Figure 15-10). The technique of x-ray fluorescence is currently being adapted to measure the concentration of uranium in process streams. The measurement is based on the determination of the intensity of the fluorescent K-x-rays emitted following excitation of the solution. At this time, these monitors are being considered for the determination of uranium concentrations only.

The XRFA monitor uses a Co-57 source (122 keV) as the source of excitation radiation. The resulting x-rays are detected by a high purity germanium detector (HPGe), and the data are processed by a computer to provide concentration values. Operation of the monitors is completely automated.

Current tests indicate that the monitors as they are currently constructed (stainless steel sample tube with 65 mil wall) are capable of measuring uranium concentrations on the order of one gram per liter in near-real-time. To date, all measurements are based on laboratory experiments which are simulated processing solutions and attempt to duplicate the conditions of a flowing process stream. Further tests to determine the sensitivity and precision of these monitors are in progress.

V. ANALYTICAL LABORATORY COMPUTER SYSTEM

The primary functions of the Analytical Services Laboratory at the BNFP are to provide:

- (1) Nuclear materials accountability analyses,
- (2) Specification analyses for product uranium and plutonium, and
- (3) Process control analyses.

At capacity operation, approximately 200 samples requiring about 800 determinations will be analyzed daily. Keeping track of this quantity of samples, assuring that quality control samples have been analyzed, comparing laboratory results with expected process control limits, and compiling results and preparing reports are tasks that are best handled by computers.

To perform these functions, a laboratory computer system was designed. This system consists of a PDP 11/35 CPU with 128K of memory, multiple disk drives, dual magnetic tape transports, and various input/output terminals (DECwriters and CRT terminals) (Figure 15-11). These terminals are located at strategic points in the laboratories, the process control rooms, and the administration building. Initially only two laboratory instruments were interfaced directly to the system, a mass spectrometer and a multi-channel analyzer. These instruments have their own dedicated mini-computers for control, data acquisition, and data reduction -- the interface merely serves as a data link to the laboratory system for long-term storage of data and results.

We are currently interfacing other laboratory instruments to the system. A laboratory instrument interface unit (LIU) was designed to simplify the normally complex process of interfacing analytical instruments to computers (Figure 15-12). This unit also

serves as an input/output terminal to enter analyst and sample identification, to prompt analyst entry, and to print data and results. This was accomplished by using a serial data link between the LIIU and the laboratory computer, and by using a standardized set of cards to link the LIIU to the analytical instrument. The set of cards includes:

- (1) Analog-to-digital converters,
- (2) Transistor-Transistor Logic (TTL) one-shot modules,
- (3) TTL Binary Coded Decimal (BCD) modules,
- (4) TTL pulse-counter modules, and
- (5) Universal Asynchronous Receiver-Transmitter (UART) controller modules.

To interface an instrument, the appropriate cards are inserted into the LIIU and the leads are connected. When the analyst presses the "START" key on the LIIU, the system prompts the analyst and generates single word commands. These commands reset and start the instrument as required. The software reduces the data and prints the result for the analyst to approve.

The system is built around the Resource Sharing-Time Sharing (RSTS/E) operating system, Version 7, and utilizes a BASIC-PLUS language processor. All applications programs are written in a modular format using this powerful version of BASIC.

We strive to make the system as easy as possible for the analysts to use. To accomplish this, we make all programs self-prompting, with a minimum number of short commands and responses. Also, the analyst has a chance to review and reject his data entry, prior to acceptance by the system, if he detects an error.

Let us follow a sample through the entire process now. An analyst draws a sample from one of the needle samplers, for instance N001. This could be either a routine sample specified on the formal run plan or a special sample requested by one of the Control Room operators via one of the system terminals. The analyst steps to the terminal and types LOG. Refer to Figures 15-13, 15-14, and 15-15 for examples of the three log-in options available. In all examples, the analyst entries are underlined. The routine log-in sequence is the simplest and requires fewer analyst responses. When the sequence is complete, the system reprints the information that was entered and also the requested analyses. At this point, the analyst can accept or reject the log-in.

When the log-in is complete, a work sheet containing the sample heading is printed at the log-in terminal for each requested analysis.

After the log-in is completed, the samples along with the pre-printed work sheets are distributed to the various labs for analysis. When an analyst completes an analysis, he steps to a nearby terminal and types DATA. Figure 15-16 is an example of the data entry for a typical analytical method. Notice the simple responses to the questions -- usually only a single character or numerical data.

Every sample point has programmed in the system upper and lower limits for each requested analysis. The calculated result is compared

with these limits and the appropriate message is printed, e.g., CONC IN LIMITS. At this point, the analyst has a chance to review his data and result. If the analyst approves the result, the system accepts the data, stores it on disk, and prints the results in the appropriate Control Room on a dedicated output terminal. If he does not approve it, the data are discarded.

Any time after a sample has been logged in, one can determine the status by typing STATUS on any terminal on the system. Several options are available. If the sample log number is known, the log number option is used (Figure 15-17). The analyst can direct the STATUS reports to print on any terminal or line printer on the system. If a particular analysis has not been completed, INCOMPLETE is printed on the report. The STATUS report can also be requested for a particular sample point or sample identification for a specific date or time frame. Figure 15-18 demonstrates a very useful summary STATUS report. This option lists all samples that have been logged in on a specific date or time frame. It also indicates if the sample is Complete or Incomplete. If the sample is incomplete, the incomplete analyses for each sample are listed.

After all analyses for a sample have been completed, the shift supervisor reviews the data and results for the sample and approves it using the APPROVAL program (Figure 15-19). This is a "privileged" function and requires a nonprinting password to access the program. At this time, a final report is printed on multi-copy paper by the line printer for distribution as required (Figure 15-20). Considerable information is contained in the final reports, e.g., the requesting department, the sampling date and time, and the log-in date and time. Also, any COMMENT that was entered during the log-in is printed. The result for each constituent, the appropriate units, and the standard deviation for the determination are printed. Also the method used for the determination, the crew and analyst, and the date and time the data were entered are printed on the final report. After approval, all data (including calibration information and the calculated result) are retained on disk for 24 hours. At that time, they are automatically transferred to magnetic tape. The tape is duplicated and the original is sent to Records Management for long-term retention. The copy is maintained in the computer facility for six months and then transferred to Records Management for retention.

Data for the laboratory methods quality control program are also handled by the system. For each analytical method, a series of quality control standards is prepared, and aliquots are flame-sealed in glass ampuls. Each ampul is assigned a unique number. The reference values, along with the appropriate upper and lower limits, are logged into the system via the terminal located in the quality control chemist's office.

We require that a quality control sample be analyzed for each method at least once each shift that method is used. If satisfactory results are not obtained, the system locks out that method and will not accept sample data until satisfactory results are obtained for a quality control standard. Referring to Figure 15-21, notice that the method is locked out for calculation until a quality control sample is analyzed that shift. Also notice that the analyst has a chance to review his result before the computer compares it to the reference value.

Naturally, these quality control data are not available to anybody with a terminal. Only the quality control chemist has access to these files (Figure 15-22). These data are evaluated each month, and factors to estimate the precision and systematic bias corrections are determined and automatically applied to subsequent analyses. The quality control data are retained on disk for 24 hours and then transferred to magnetic tape for long-term retention. However, a compressed version of these data is retained on disk for the monthly data evaluation.

A communications link connects the laboratory computer system to the Computerized Nuclear Material Control and Accounting System (CNMCAS). This link operates over two separate unidirectional data transmission lines. Requests for analysis are received by the laboratory system and results are transmitted to the CNMCAS as the analyses are completed.

VI CNMCAS FUNCTIONS

Thus far in the session, we have addressed system hardware, data acquisition, instrumentation, and analytical systems. How this is put together as a nuclear materials control and accounting system is the subject of the next part of this session.

The AGNS CNMCAS performs seven major functions related to material control and accounting. These are:

- (1) Measurement
- (2) Measurement control
- (3) Item and seal control
- (4) Physical inventory
- (5) Accounting
- (6) In-process or near-real-time inventory
- (7) Process monitoring and surveillance.

These functions, which are performed primarily in MACS, represent a collection of over 250 program modules and over 50 data files. (see Table 15-7 for an example listing of program modules.) With the exception of the LDS Computer, a real-time operating system (DEC's RSX-11M) is used and programs are written in Basic-Plus-2 or Assembly. LDS uses a time sharing system (DEC's RSTS-E) and Basic-Plus language.

A. Measurement

The measurement programs coordinate input, output, and waste batch measurement activities. These programs acquire measurement data from RDAS and LDS, examine data for gross errors, calculate solution and uranium quantities for process control use, and transfer information to the data base upon completion of a batch measurement. A summary of activities is listed below:

- Batch initiation
- Before receipt measurements
- Before sample measurements
- Sample request

- After sample measurements
- Analytical data handling
- Transfer
- After transfer measurement
- Batch summary information.

Figure 15-23 is an example of the measurement program dialogue conducted between the operator and the computer during a measurement routine. Figure 16-24 is a typical measurement batch summary report.

B. Measurement Control

The measurement control program provides for various automated checks and comparisons of measurement data to:

- (1) Identify and control measurement anomalies prior to transfer of a batch and prior to acceptance of data into the accounting files,
- (2) Provide trend and error analysis from stored data,
- (3) Propagate limits of error for measurements, and
- (4) Provide bias corrections for measurements.

The "measurement control data" table at the bottom of Figure 15-24 is a summary of comparisons provided to the operator for each batch measurement. More extensive control data is also provided on a CRT screen, including trend analyses for appropriate measurement instruments.

Limit-of-error propagation incorporates a wide variety of information including the measurement control data, vessel and instrument calibration data, and analytical method evaluation data (from QC and replicate measurement programs). Figures 15-25 and 15-26 are typical summary reports of error data from CNMCAS.

Another measurement control function provides for the automated calibration of process differential pressure transmitters (other than Ruska's). Figure 15-27 shows a typical arrangement using computer-controlled solenoids to switch the transmitters onto a test manifold. Selected pressures are applied to the transmitters and the outputs are collected by the computer and compared to a reference standard pressure gauge (a Ruska). Figure 15-28 presents a set of corrected and uncorrected transmitter readings. A significant reduction in reading bias and random error can be achieved with this function.

C. Item and Seal Control

The item and seal control function involves control and accounting of identifiable items such as fuel assemblies, product containers, and waste containers. To date, the only program work that has been done is for waste package control. Figure 15-29 is an example of the operator dialogue for data entry. Program logic, file structure,

file size, and record information has been identified for the other functions, but no programming has been done.

D. Physical Inventory

The physical inventory programs coordinate performance of the plant physical inventory, acquire instrument and analytical data for each vessel, calculate quantities, generate status reports, and monitor inventoried vessels for unauthorized changes. Figures 15-30 and 15-31 are examples of an inventory status report and an inventory summary report.

E. Accounting

The accounting programs define accounting control units and produce accounting summary and material balance reports. (Accounting control units consist of individual measurement batches, lots consisting of several batches, and an inventory period consisting of several lots.) Figures 15-32, 15-33, and 15-34 are typical accounting program reports. Lot number, batch number, and measurement point number are controlled by the accounting programs.

F. In-Process Inventory

The in-process inventory or near-real-time accounting programs in CNMCAS are designed to provide a measurement of the current quantity of uranium (and eventually plutonium) in each material balance area. With the capability to measure the current in-process inventory, material balances can be closed on a high frequency (in theory as often as every four minutes; however, more probably, once every hour). A typical near-real-time material balance equation would be as follows:

$$\begin{aligned} & (\text{In-Process Inventory})_{t-1} + (\Sigma \text{ Inputs} - \text{Outputs})_{t-1 \rightarrow t} \\ & = (\text{In-Process Inventory})_t + (\text{Inventory Difference}) \end{aligned}$$

Where: t = current time and

$t-1$ = time of last in-process inventory determination.

The advantage of this approach is that small quantities of material are involved (compared to total plant throughput), and therefore, the accounting program will be sensitive to smaller changes. For example, the annual throughput of the BNFP is about 15,000 kilograms of plutonium. Conventional accounting (input/output and annual physical inventory) will at best have a total uncertainty of $\pm 0.5\%$ or 75 kilograms. A once-per-hour IPI balance will have uncertainties as shown below:

Uncertainty of In-Process Inventory @ $t-1$	≈ 4.8 kilograms
Uncertainty of In-Process Inventory @ t	≈ 4.8 kilograms
Uncertainty of Input/Output Measurements $t-1 \rightarrow t$	≈ 0.1 kilogram
TOTAL	± 9.7 kilograms

Application of sequential material balance analyses, such as described by Dr. Shipley in Session 14, will further reduce the uncertainty of these measurements.

Performance of the in-process inventory measurement requires that liquid-level, density, and temperature readings be taken for each tank that contains SNM and that an estimate of uranium/plutonium concentration be established for each tank. The concentration is obtained from analytical results where available, on-line monitor readings, or be derivation from parameters such as density. Hold-ups in columns are being estimated in a number of ways including modeling, measurement of column weight changes, and through performance of running material balances. Waste streams will generally have on-line analytical monitors associated with them. Combining measured flowrate with the output of the on-line monitor will permit estimation of material loss via each of these streams. Process line volumes have been determined by applying appropriately estimated concentrations, the line hold-ups can also be estimated. Figure 15-35 is a summary of IPI data collected during one of AGNS' tests with natural uranium. In this example, line hold-ups and waste stream losses were not estimated and, therefore, contributed to the unmeasured inventory or inventory difference. Figure 15-36 is a plot of sequential material balance differences with time for a similar test. Figure 15-37 is a plot of column material balance data.

G. Process Monitoring and Surveillance

The possibilities for computerized process monitoring and surveillance applications of the CNMCAS system are virtually endless, limited only by the ingenuity of the safeguards personnel and the resources available to develop and install software and hardware needed for the functions. A wide variety of approaches have been identified at the Barnwell Facility and have been set up on a demonstration basis. Examples of typical programs include:

- (1) Quantity Transferred Versus Quantity Received Program -- This program monitors transfers into and out of key measurement points and compares shipper/receiver volume and uranium content.
- (2) Summary of Tank Transfers (see Figure 15-38) -- This program is similar to (1), above, except that transfers within the material balance area are monitored on a near-real-time basis. Volume differences of less than 500 milliliters have been detected.
- (3) Measurement Program Status (see Figure 15-39) -- This program keeps track of the current status of multiple, simultaneous measurement programs and provides a coded display of the status for the accountability personnel.
- (4) Penetration Surveillance -- This program monitors detection instruments on penetrations through the process containment and provides an alarm message if unauthorized activity is detected.

- (5) Storage Function -- This is a program to monitor level, density, and temperature of Plutonium Nitrate Storage Tanks. This program can be written to discriminate between "normal" changes in tank parameters due to evaporation and radiolysis and "abnormal" changes.
- (6) Data Base Edit Log (see Figure 15-40) -- This program monitors and records changes made to the data base. The example printout is a summary of changes to the accounting files.

VII. BENEFITS OF COMPUTERIZED ACCOUNTING

When one considers the cost of installing an advanced computerized accounting system is estimated to be over \$6 million for the entire AGNS facility, there must be some significant benefits realized from the system to justify its installation.

Purely from the safeguards standpoint, benefits include:

- (1) Improved Accuracy -- The computer reads the instrument output directly eliminating errors from chart calibration, estimation of fractional chart percentages, and human errors in reading and transcription.
- (2) Improved Timeliness -- Current accounting data is available on a near-real-time basis.
- (3) Calculations and Monitoring -- Use of the computerized system permits such things as near-real-time accounting and process surveillance that simply could not be done by hand with a reasonable number of operating and accounting personnel.

The cost benefit of this system is, however, best realized on the operating side. If the computerized accounting system can contribute to only about 15 additional operating days during its lifetime, it will have paid for itself. These additional available operating days can be expected to be gained by shortening the down time required for physical inventories.

Another operating benefit is in the area of process control. Since CNMCAS has access to process instrument readings and analytical data, it can be a powerful tool for the process operators. CNMCAS has been programmed to provide this type of information via a number of demonstration functions. These include such things as a process status report (Figure 15-41) which is updated every 15 minutes, a set of color-graphic video displays of process systems (see Figures 15-42 and 15-43) which are updated every four minutes, and an operator assistance program which calculates quantities and readings for a feed blending procedure (see Figure 15-44). In addition to this, a number of programs are available which give current instrument readings; calculate current tank volume and free-board; and provide plant location coordinates for plant instruments, valves, pumps, etc. These programs are available to the operators on demand at a number of different terminal locations.

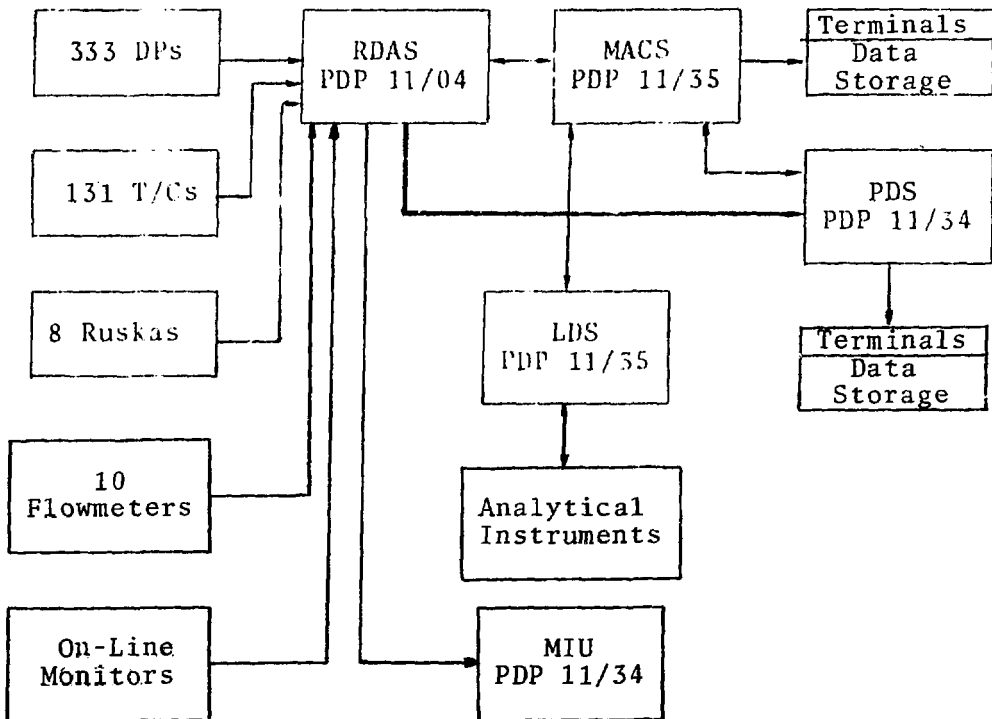


FIGURE 15-1
COMPUTER HARDWARE LAYOUT

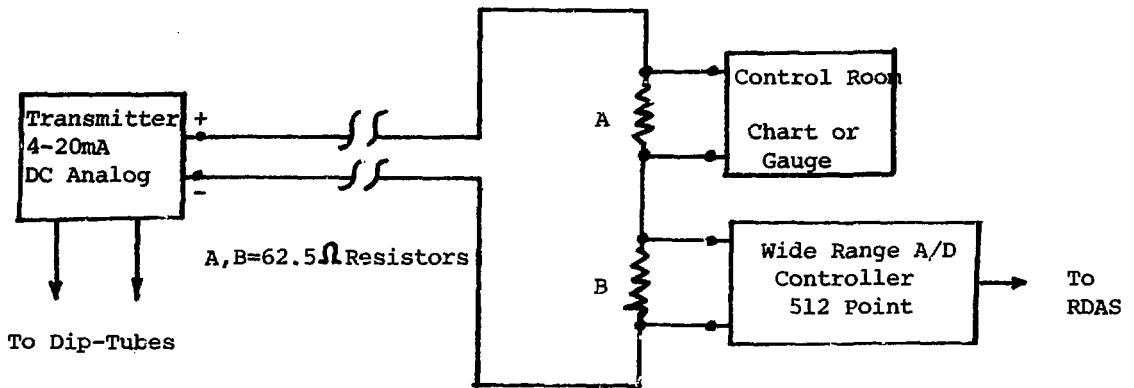


FIGURE 15-2 -- ANALOG TRANSMITTER INTERFACE

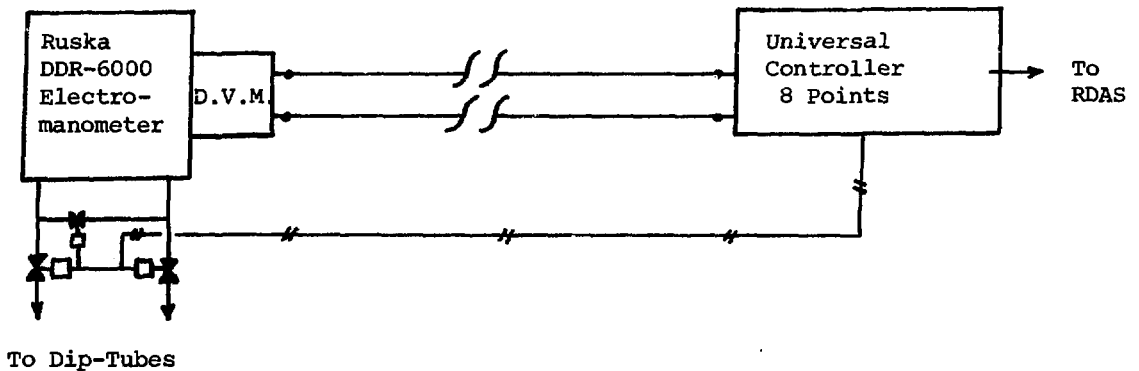
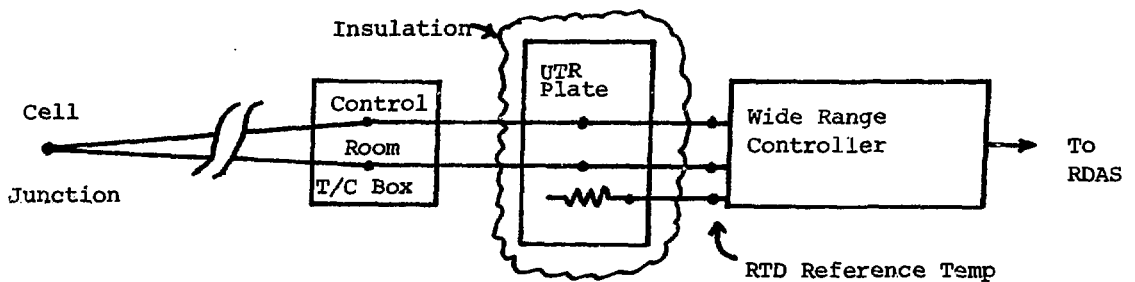


FIGURE 15-3 -- DIGITAL TRANSMITTER INTERFACE



UTR = Unithermal Reference

RTD = Resistance Temperature Device

FIGURE 15-4 -- THERMOCOUPLE INTERFACE

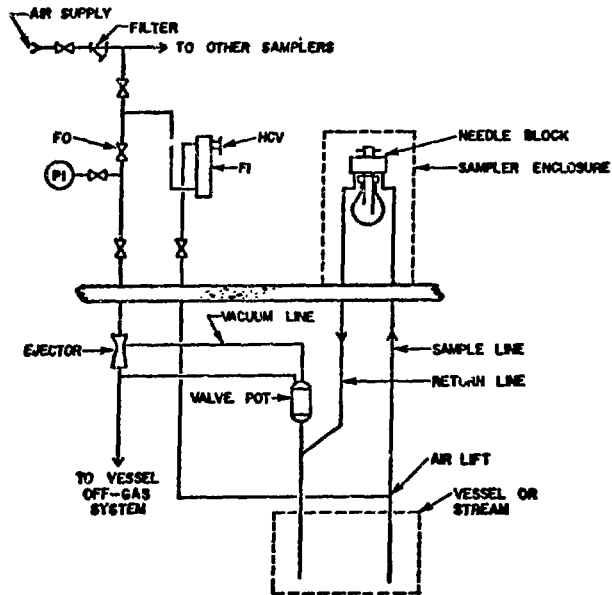


FIGURE 15-5

TYPICAL REMOTE NEEDLE BLOCK SAMPLER
WITHOUT ON-LINE MONITOR

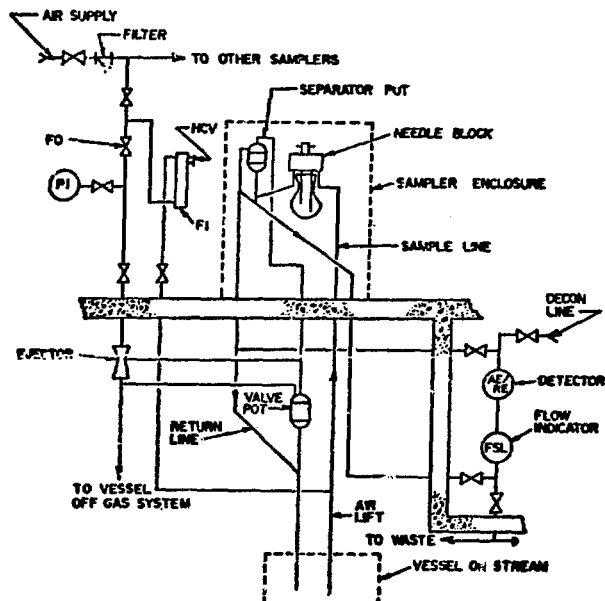


FIGURE 15-6

TYPICAL REMOTE NEEDLE BLOCK SAMPLER
WITH ON-LINE MONITOR

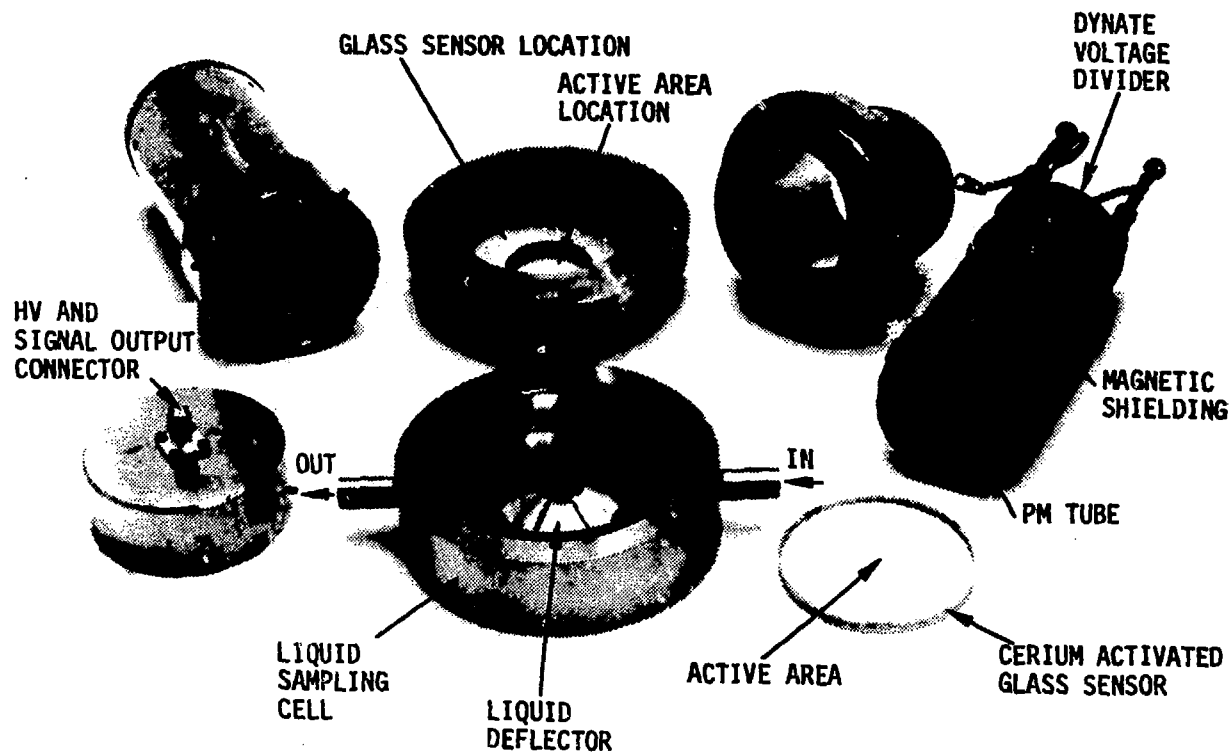


FIGURE 7 -- ON-LINE ALPHA MONITOR

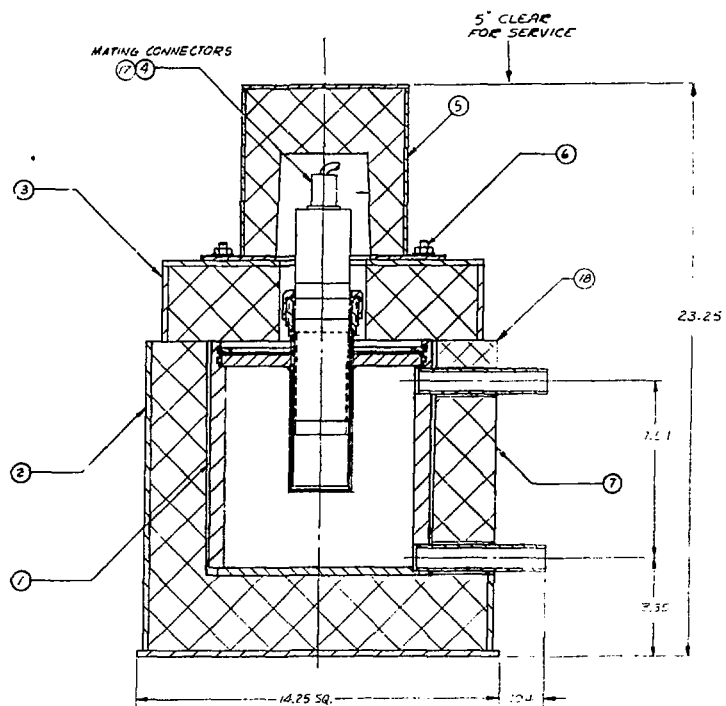
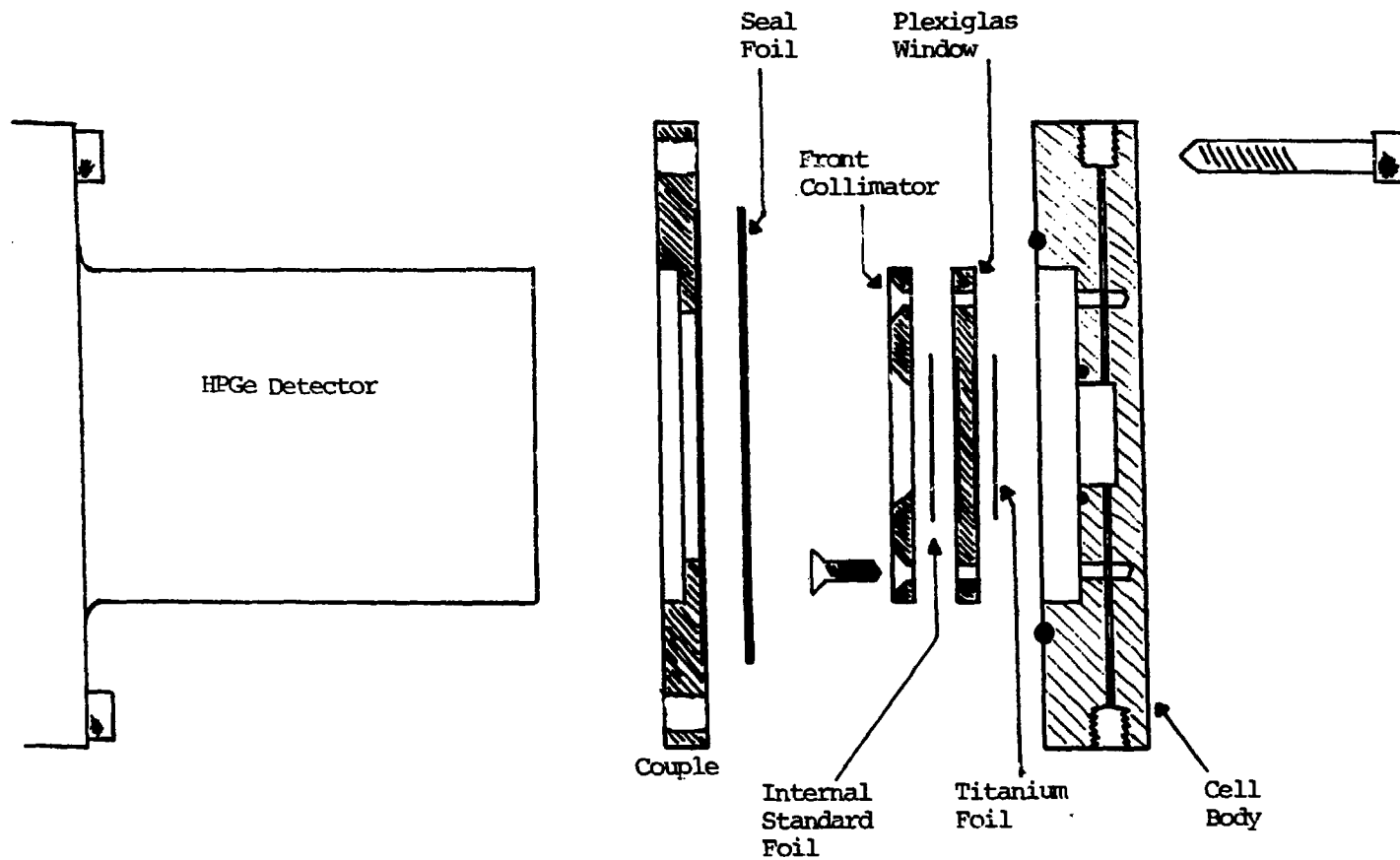


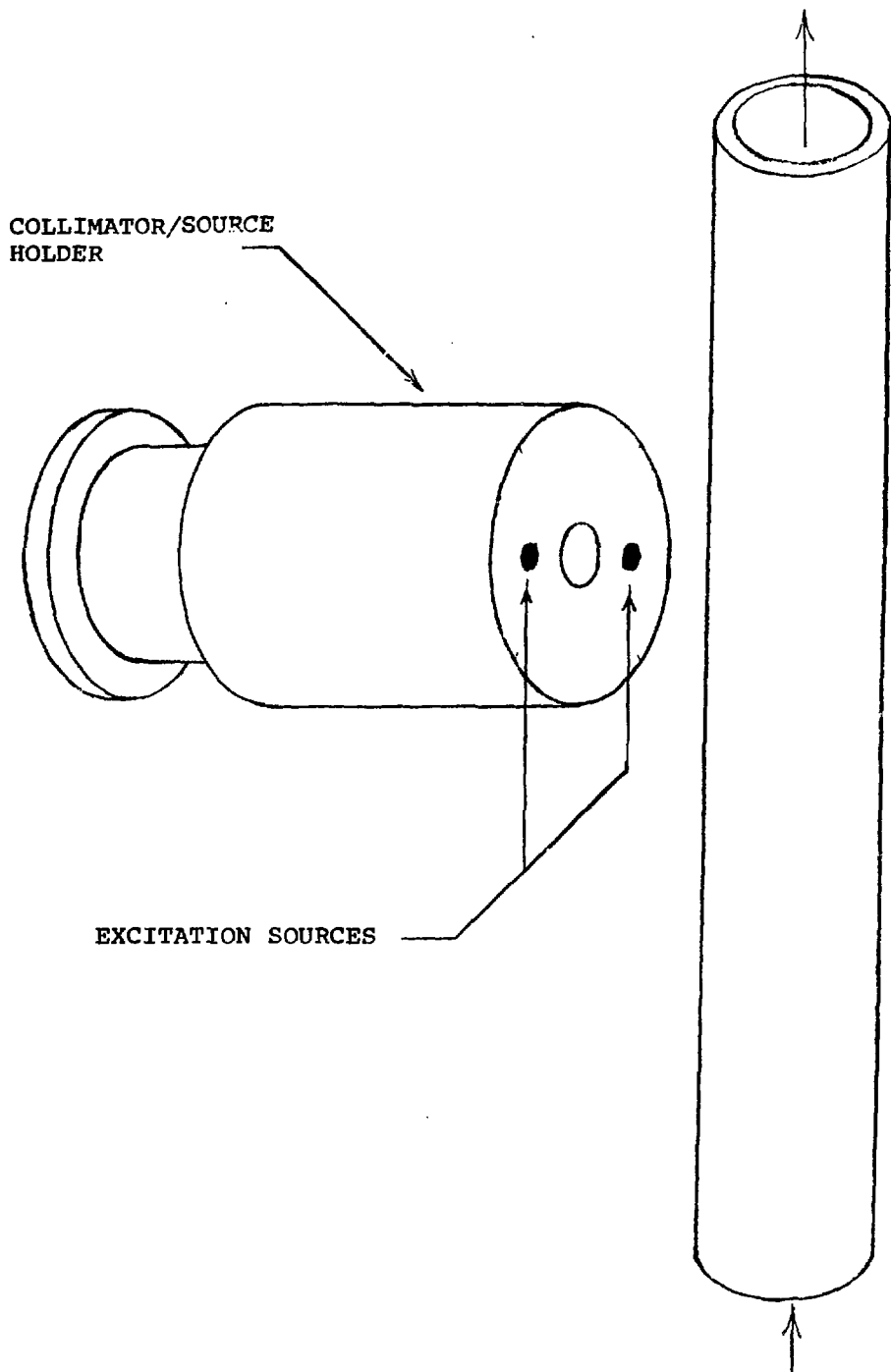
FIGURE 15-8

ON-LINE GAMMA MONITOR



SCHEMATIC OF PLUTONIUM ANALYSIS CELL

FIGURE 15-9



X-RAY FLUORESCENCE SOURCE AND CELL

FIGURE 15-10

FIGURE 15-11

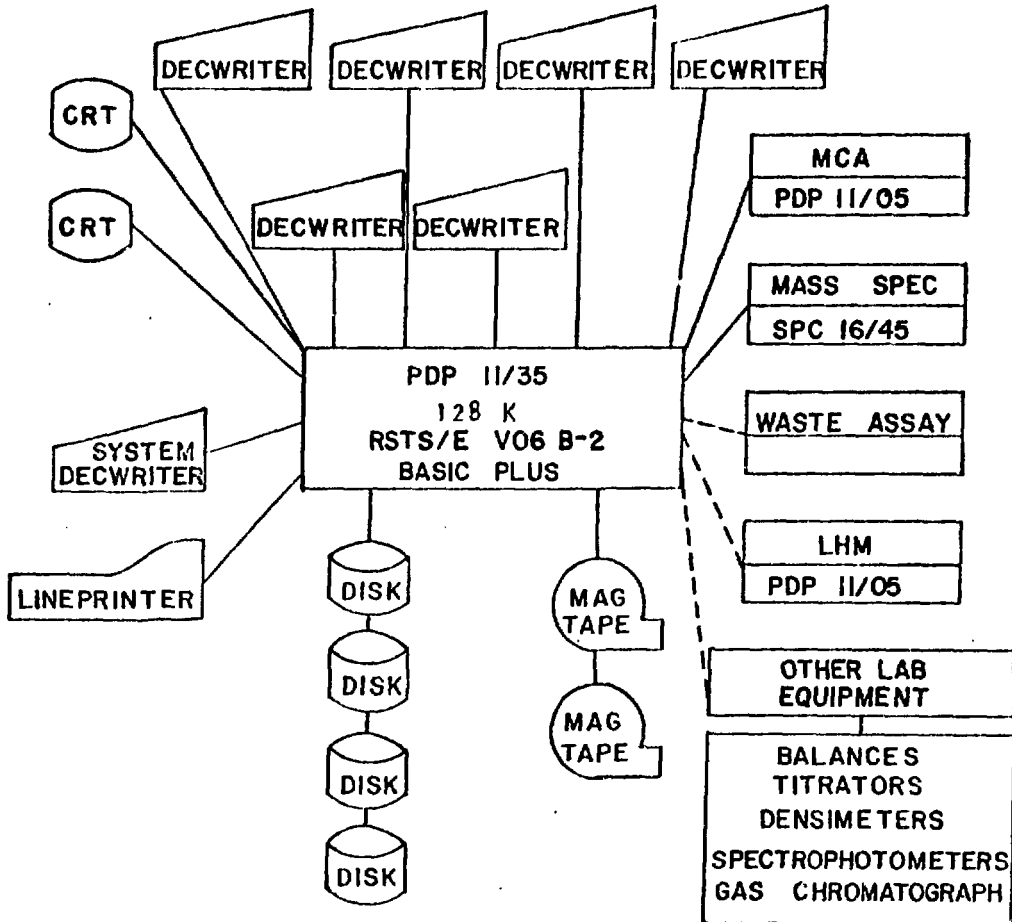
LABORATORY COMPUTER SYSTEM

FIGURE 15-12

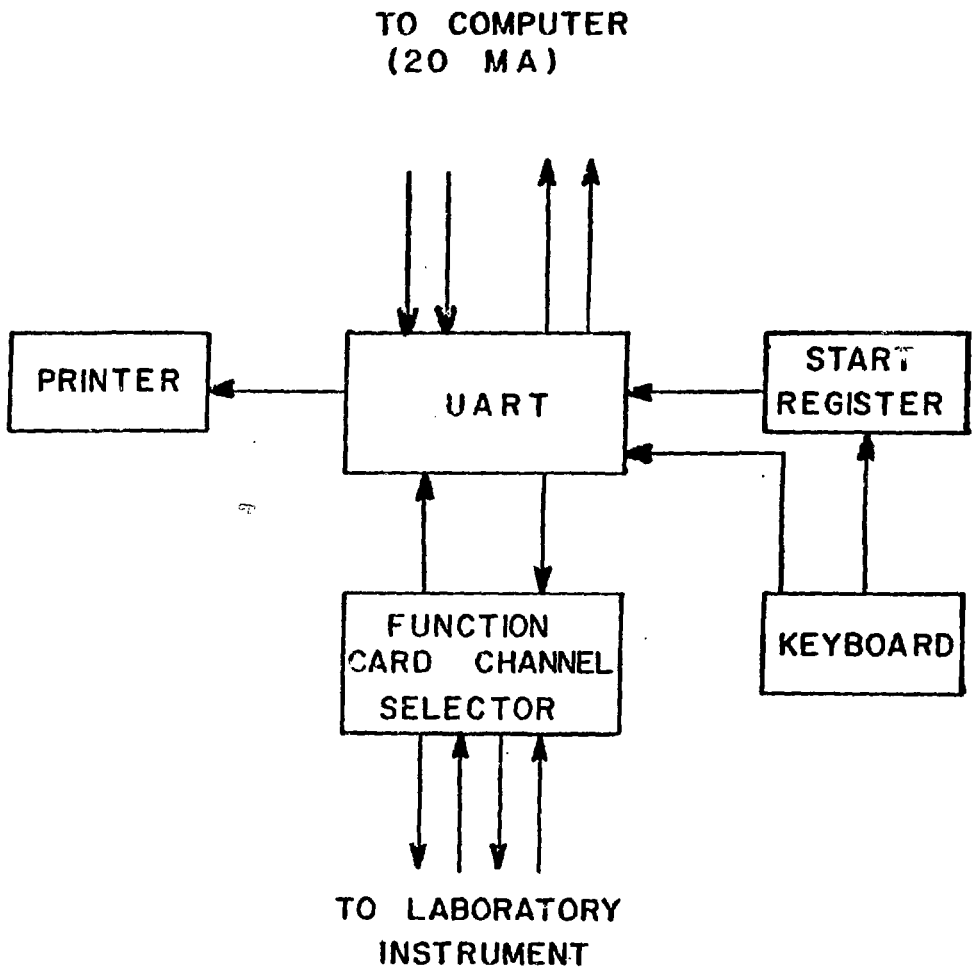
LABORATORY INSTRUMENT INTERFACE UNIT

FIGURE 15-13ROUTINE LOGINLOGLOG NUMBER ? 32760SAMPLE POINT = N1REQUESTED BY = 37/GDWPC OR A? PCSAMPLING DATE ? 14-OCT-77SAMPLING TIME ? 10:00

COMMENT ?

ROUTINE (Y OR N)? Y

LOG IN COMPLETE

LOG NUMBER = 32760

SAMPLE POINT NUMBER = N001

SAMPLE ID = ACCT TK, 18D-101

NUMBER OF SAMPLE BOTTLES = 6

DATE 14-OCT-77 TIME 12:47

SAMPLING TIME = 10:00

ANALYSES REQUIRED

U

H+

DN

UI50

OK (Y OR N)? Y

VERIFIED

FIGURE 15-14NON-ROUTINE LOGINLOGLOG NUMBER? 32761SAMPLE POINT=N1REQUESTED BY=37/GDWPC OR A? PCSAMPLING DATE? 14-OCT-77SAMPLING TIME? 10:50

COMMENT?

ROUTINE (Y OR N)? NNUMBER OF SAMPLE BOTTLES? 3

ANALYSES REQUIRED

1=? U2=? DN3=? H+

4=?

LOG IN COMPLETE

LOG NUMBER=32761

SAMPLE POINT NUMBER=N001

SAMPLE ID=ACCT TK,18D-101

NUMBER OF SAMPLE BOTTLES=3

DATE 14-OCT-77

SAMPLING TIME=10:50

ANALYSES REQUIRED

U

DN

H+

OK(Y OR N)?Y

VERIFIED

FIGURE 15-15MISCELLANEOUS LOGINLOGLOG NUMBER ? 32762

SAMPLE POINT=

REQUESTED BY = 37/GDWP C OR A ? P C

SAMPLING DATE ?

SAMPLING TIME ? 12:05

COMMENT ?

SAMPLE ID = BEACON PONDNUMBER OF SAMPLE BOTTLES ? 1

ANALYSES REQUIRED

1 = ? PH2 = ? COND3 = ? GSCAN

4 = ?

LOG IN COMPLETE

LOG NUMBER = 32762

SAMPLE POINT NUMBER =

SAMPLE ID = BEACON POND

NUMBER OF SAMPLE BOTTLES = 1

DATE 14-OCT-77

TIME 12:52

SAMPLING TIME = 12:05

ANALYSES REQUIRED

PH

COND

GSCAN

OK (Y OR N) ? Y

VERIFIED

FIGURE 15-16DATA ENTRY

DATA
 14-OCT-77, 15:17
 CREW/ANALYST = E/GDW
 METHOD = U-VP-1-B
 UF₆ OR HCL_A (U OR H) ? H
 LIST DICRO VALUES (Y OR N) ? N
 CALIBRATE (Y OR N) ? N
 BATCH = 7/27/77
 DICRO (AV) = 5.96191 MG U/G
 ON 24-AUG-77
 QC OR SPL ? SPL
 LOG NUMBER ? 32760
 INCORRECT ENTRY
 LOG NUMBER ? 32760-A
 SPL POINT = N001
 SPL ID = ACCT TK, 18D-101
 ENTER SAMPLE DATA:
 14-OCT-77, 15:17
 SPL WT(G) ? 0.9500
 DICRO WT(G) ? 40.2234
 CONC = 252.43 MG U/G
 NO BIAS CORRECTION ON FILE
 CONC WITHIN LIMITS
 RESULTS OK (Y OR N) ? Y

QC OR SPL ?

FIGURE 15-17STATUS

STATUS
 13-OCT-77, 11:20
 ? LOGNUMBER = 32767
 STOPS? N
 OUTPUT STATUS TO?
 LOG NUMBER = 32767
 SAMPLE POINT =
 SAMPLE ID = DEMO
 LOG DATE 13-OCT-77 SAMPLING TIME 11:12
 SAMPLING DATE = 13-OCT-77
 U 13.1 PPM
 DN INCOMPLETE
 H+ 0.21 M

DONE

FIGURE 15-18STATUSSTATUS

07-NOV-77, 13:08

? DATE = 27-OCT-77, 29-OCT-77

OUTPUT STATUS TO?

SPL PT	SPL ID	LOG NUM	DATE	TIME	I/C	I/F
	HOWNET 2	13827	27-OCT-77	12:05	I	I
ESIMP						
NO14	LAB SPL TK, 79D-736	13820	27-OCT-77	13:06	I	I
	PU GG					
NO14	LAB SPL TK, 79D-736	13846	27-OCT-77	14:27	I	I
	PU GG					
M001	ANAL VENT CHAR TRAP	13850	28-OCT-77	14:36	I	I
	G-SCAN 1-131					
	36D310F	13851	28-OCT-77	14:43	C	F
	36D311F	13852	28-OCT-77	14:44	C	I
	D-619	13848	28-OCT-77	14:55	I	I
H+	DN					
D-605		13847	28-OCT-77	14:57	I	I
H+	DN					
			ESIMP			

DONE

FIGURE 15-19APPROVALAPPROVINITIAL = GDR

CODE =

LOG NUMBER = 14305 - 14311, 14314/1

LOG NUMBER =

BYE

FINAL REPORT
SAMPLE 11157

N-34 QC 32

REQUESTED BY
AS/JPC

APPROVED BY
JDS

LOG IN
15-SEP-77, 15:33
SAMPLING DATE
9-15-77

LOG OUT
15-SEP-77, 23:10
SAMPLING TIME
15:33

15-29

COMMENT

U-VI REQUESTED AND RUN

SMALL AMOUNT OF SAMPLE DID NOT TITRATE ENOUGH

ANALYSIS	RESULT	UNITS	SD(1SIGMA)	METHOD	ANALYST	DATE	TIME
U	0.5	G U/L	.03	U-VI-I-A	C/LAK	15-SEP-77	18:10
H+	3.623	N	.07	ACID-VP-I-B	C/LAK	15-SEP-77	20:06
DN	1.1222	G/ML	.0006				
		AT 25 DEG C		DN-DM-I-A	C/LAK	15-SEP-77	20:20

FIGURE 15-21

QC DATA ENTRY BY ANALYST

DATA

03-FEB-78, 10:45

CREW/ANALYST = E/JALMETHOD = U-F-I-B

WHICH INSTRUMENT

ENTER 1 FOR JA, 2 FOR ORNL (HCLA), 3 FOR ORNL (UF6)? 2CALIBRATE (Y OR N)? N

LAST EQUATION COEFFICIENTS

ON 22-JUL-77 BY E/JMR

A = .644664

B = .859144

C = .179854 E-3

CORR COEF = .999998

QC OR SPL? SPL

NO SPL ANALYSIS UNTIL A QC STANDARD IS RUN THIS SHIFT

QC OR SPL? QCQC NUMBER? 2U00503

ENTER QC DATA:

03-FEB-78, 10:45

AQUEOUS SAMPLE (Y OR N)? YDILUTION (Y OR N)? NSPL ALIQUOT (ML)? .5MIBK VOLUME (ML)? 2ORG ALIQ VOLUME (ML)? .1INSTRUMENT READING? 421.5CONC = 15.79 PPMRESULTS OK (Y OR N)? Y

RESULTS BETWEEN 2 AND 3 SD

FIGURE 15-22

STATUS OF ANALYZED QCS

QC STATUS

? ACRONYM = 2U02
 ~ (DENOTES INSTRUMENT)
2U02

<u>STD #</u>	<u>REF</u>	<u>EXP</u>	<u>BIAS</u>	<u>SD</u>	<u>IN/OUT</u>	<u>DEVIATION</u>	<u>C/A</u>	<u>DATE</u>
501	1.00	1.15	.15	.1	IN	1.5	E/JAL	27-JAN-78
502	1.1	1.05	-.05	.1	IN	-.5	A/CJA	31-JAN-78
503	1.3	15.8	2.8	1.3	IN	2.15	E/JAL	03-FEB-78
504	11.7	15.2	3.5	1.3	IN	2.69	B/LAK	06-FEB-78
505	56	62	6.0	2.5	IN	2.4	E/JAL	07-FEB-78
506	58.5	66.5	8.0	2.5	OUT	3.2	E/JAL	07-FEB-78
90005	30.0	36.0	6.0	1.5	OUT	4.0	E/JAL	07-FEB-78
90006	30.0	29.0	1.0	1.5	IN	-.33	E/JAL	07-FEB-78

FIGURE 15-23

MEASUREMENT PROGRAM DIALOGUE

五

```
TANK 02003      BATCH 308      10-Jul-79      04:33 AM
02003      >      I'M READY TO MEASURE BEFORE-SAMPLE DATA
02003      >      THE SPARGER SHOULD BE OFF
02003      >      INSTRUMENT PURGES SHOULD BE SET AT 0.5 SCFH
02003      >      SHALL I PROCEED (YES OR NO)
YES
```

```
TANK 02003      BATCH 308      10-Jul-79      04:33 AM

02003      > RTP COMMUNICATION IS STARTING
02003      > WILL CALL WHEN MEASUREMENT IS COMPLETE
```

```
TANK 02003      BATCH 308      10-Jul-79      04:38 AM
02003      >      RTP COMMUNICATION IS COMPLETE

02003      >      LR-125      = 139.234
02003      >      LR-125R     = 348.763
02003      >      DR-166      = 15.0683
02003      >      DR-166R     = 310.382
02003      >      DT-166S1    = 35.2845
02003      >      TJR-108-10   = 33.466
02003      >      TI-109       = 29.3318
02003      >      POSSIBLE OPTIONS ARE:  1 = PROCEED
02003      >                                     2 = REMEASURE
02003      >      ENTER OPTION ( 1 OR 2 )
02003      >      ? 1
```

TANK 02003	BATCH 308	10-Jul-79	04:39 AM
02003	>	TANK CONTAINS	8330.26 KG SOLUTION
02003	>	TANK CONTAINS	5480.2 LITERS SOLUTION
02003	>	TANK CONTAINS	2042.07 KG URANIUM

```
TANK 02003      BATCH 308      10-Jul-79      04:39 AM

02003      >  THE BEFORE-SAMPLE COMPARISON FOR:
0 003      >  PRIMARY TO TAYLOR LEVEL IS SATISFACTORY
02003      >  LR-125R = 348.763 AND LR-125 = 353.653
```

```

ANK 02003      BATCH 308      10-JUL-79      04:39 AM

02003          > THE BEFORE-SAMPLE COMPARISON FOR:
02003          > TJK 10 TI TEMPERATURE IS SATISFACTORY
02003          > TJR-108-10 = 33.466 AND TI-107 = 29.3318

```

```
TANK 02003      BATCH 308      10-Jul-79      04:40 AM

02003      >  THE BEFORE-SAMPLE COMPARISON FOR:
02003      >  PRIMARY-TO-TANK DENSITY IS SATISFACTORY
02003      >  DR-166R = 1.52007 AND DR-166 = 1.51577
```

FIGURE 15-24

BATCH SUMMARY FOR					
02003 - 308 ACCT TK		10-Jul-79 07:24 AM			
REC FROM SENT TO	02007 02005	BEFORE RECEIPT	BEFORE SAMPLE	AFTER SAMPLE	AFTER TRANSFER
LR-125	(IN H2O)	17.26	139.23	139.25	18.97
LR-125R	(CM H2O)	42.076	348.763	348.78	46.352
DR-166		14.907	15.068	15.07	15.073
DR-166R	(CM H2O)	4.124	310.382	310.372	7.982
DT-166S1		34.956	35.285	35.162	35.37
TJR-108-10	(DEG C)	33.5	33.5	33.4	33.4
TI-109	(DEG C)	27.7	29.3	29.2	28.6
LR-125	(CM H2O)	43.84	353.65	353.7	48.19
LR-125R	(CM H2O)	42.076	348.763	348.78	46.352
DR-166	(G/ML)	1.5	1.516	1.516	1.516
DR-166R	(G/ML)	1.503	1.52	1.521	1.52
DT-166S1	(G/ML)	3.517	3.55	3.537	3.558
TJR-108-10	(DEG C)	33.5	33.5	33.4	33.4
TI-109	(DEG C)	27.7	29.3	29.2	28.6
SAMPLE RESULTS					
LOG NO.		30743	NA	30771	NA
DENSITY @ 25 (G/ML)		1.5112	NA	1.5306	NA
U (MG/G)		245.138	NA	249.899	NA
H+		.605	NA	.73	NA
VOLUME (LITERS)		461.325	5464.49	5464.54	521.493
KGS SOLN		694.294	8329.23	8329.64	794.899
KGS URANIUM		170.198	2081.46	2031.57	198.644
RECEIVED 5001.79 LITERS TRANSFERRED 4943.04 LITERS					
7633.04 KG SOLN 7534.74 KG SOLN					
1910.8 KG U 1882.92 KG U					
PRIMARY TO TAYLOR LEVEL					
	-1.763	-4.89	-4.915	-1.837	
TJR TO TI TEMPERATURE					
	5.83	4.13	4.21	4.79	
TAYLOR TO TAYLOR DENSITY					
	NA				
PRIMARY TO TAYLOR DENSITY					
	.0043	.0052			
LAB @ 25 TO PRIMARY DENSITY					
	NA				
LAB @ 25 TO TAYLOR DENSITY					
	NA				
LAB @ T TO PRIMARY DENSITY					
	.0042	.0032			
LAB @ T TO TAYLOR DENSITY					
	.0085	.0081			
AT TO BR SOLUTION					
	2.306				
BS TO AS SOLUTION					

FIGURE 15-25

SUMMARY OF MEASUREMENT POINT STANDARD DEVIATION
29-Aug-79 02:05 PM

<u>STANDARD DEVIATION</u>	<u>TANK 02003 BATCHES 206-315</u>	<u>TANK 02007 BATCHES 72-186</u>	<u>TANK 02023 BATCHES 159-253</u>	<u>TANK 02028 BATCHES 564-740</u>
Combined for Measurement Point	75.0032	140.219	4.81561	15.7669
Net Kilogram Solution Measurement: Random	3.97322	4.06	2.68	3.81
Net Kilogram Solution Measurement: Systematic	2.33238	3.96989	20	11.6387
Sampling and Analysis: Random - First Method	.616441	.99	.17	1.3
Sampling and Analysis: Random - Second Method	1.3	1.3	.17	1.3
Analysis: Systematic - First Method	0	0	.01772	.0696707
Analysis: Systematic - Second Method	.01772	.01772	.01	.01
Sampling: Systematic	.00004	.00029	.01	.01

FIGURE 15-26

LIMIT OF ERROR SUMMARY
29-Aug-79 02:06 PM

<u>MATERIAL BALANCE COMPONENT</u>	<u>TOTAL KGU</u>	<u>LIMIT OF ERROR (KGU)</u>	<u>LIMIT OF ERROR (% OF INPUT)</u>
Beginning Inventory	11118.	100.	.0567991
Input (02003) Batches 206-315)	176059.	150.006	.0852024
Product (02007) Batches 72-186	185777	280.439	.159287
Waste (02023) Batches 159-253	251.309	9.63121	.00547045
Waste (02028) Batches 564-740	572.397	31.5338	.0179109
Ending Inventory	531	18	.0102238
Total (Inventory Difference)	45.3715	335.498	.19056

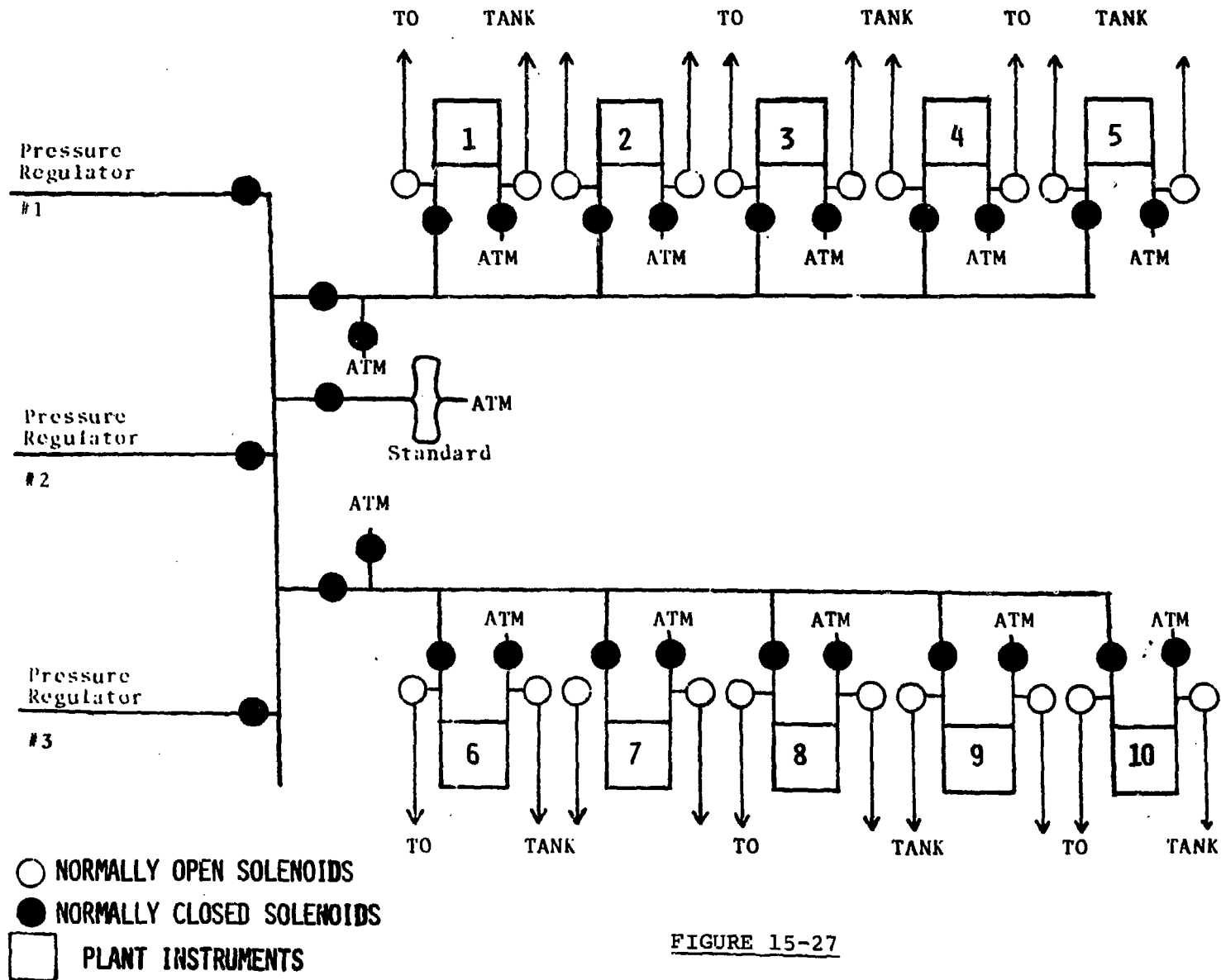
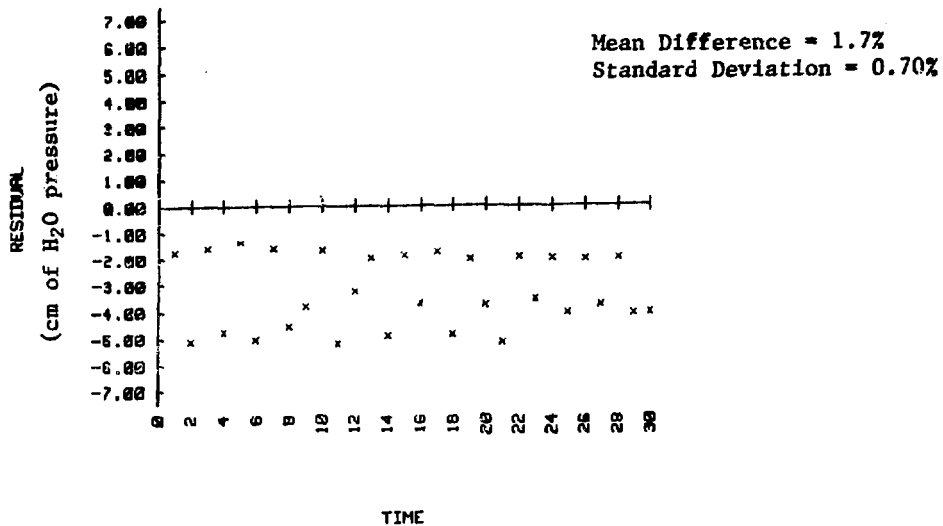
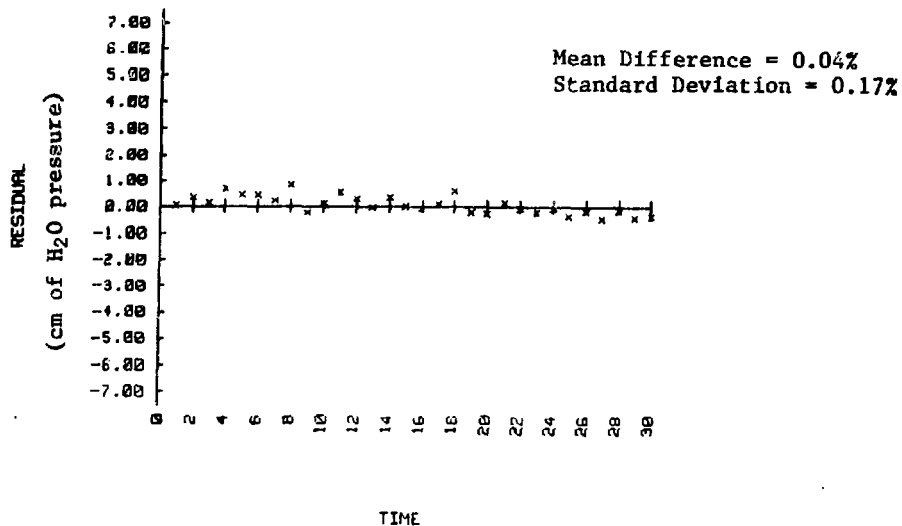


FIGURE 15-27

SCHEMATIC OF AUTO CALIBRATION EQUIPMENT



COMPARISON OF UNCORRECTED PLANT INSTRUMENT
TO REFERENCE STANDARD



COMPARISON OF CORRECT PLANT INSTRUMENT
TO REFERENCE STANDARD


```

RUN WASTE
OOT:TT0
_6
WHICH OF THE FOLLOWING FUNCTIONS ARE TO BE RUN?

    1 = PACKAGING NEW CONTAINERS
    2 = UPDATE OF PREVIOUS RECORDED CONTAINERS
    3 = CONTAINER DISPOSAL
    4 = MEASUREMENT AND SEC DATA
    5 = TRANSFER BETWEEN AREAS
    6 = LOCATION CHANGE WITHIN AN AREA
    7 = OFFSITE SHIPMENT

ENTER NUMBER OF FUNCTION > 1

WHICH AREA IS THE WASTE FROM? (CR FOR LIST OF AREAS)

ENTER AREA > 2A

THE NEXT TEN CONTAINER SERIAL NUMBERS ARE:
2A  2A  2A  2A  2A  2A  2A  2A  2A  2A
26  27  28  29  30  31  32  33  34  35

NOTE: IDENTIFY EACH CONTAINER WITH BOTH AREA CODE AND SERIAL NUMBER.

DO YOU WANT A LIST OF QUESTIONS? (Y OR N DEF. N) > Y

HOW MANY CONTAINERS DO YOU HAVE? >

WHAT IS THE CONTAINER'S LOCATION? >

    *** CONTAINER DATA ***

WHAT TYPE OF CONTAINER IS IT?
ENTER 1=DRUM, 2=CAN, 3=BOTTLE, 4=BOX OR 5=BAR >

WHAT IS THE CONTAINER MADE OF?
ENTER 1=METAL, 2=PLASTIC, 3=GLASS, 4=PAPER, 5=WOOD OR
6=FIBERBOARD >

GIVE UNITS THAT CONTAINER VOLUME IS MEASURED
ENTER C=GALLON, O=CU. FT., OR L=LITER >

ENTER NO. OF VOLUME UNITS >

    *** PHYSICAL FORM ***

ENTER 1 IF COMPLETELY DRY SOLIDS,
    2 IF LIQUIDS SOLIDIFIED IN CONCRETE,
    3 IF LIQUIDS IN ADSORBENT MATERIAL,
    4 IF LIQUIDS,
    OR 5 IF SLURRY. >

ANY NONCOMPACTIBLES SUCH AS AEROSOL CANS, LARGE PYRAMID
BOTTLES, OR LARGE PIECES OF METAL, WOOD, PAPER, ETC. Y OR N >

    *** RADIOISOTOPES ***

IS MATERIAL CONTAMINATED WITH NATURAL URANIUM? Y, N, OR D >

ANY OTHER RADIOISOTOPES PRESENT? Y, N, OR D >

```

FIGURE 15-29

WASTE PACKAGE DATA ENTRY DIALOG

FIGURE 15-30

PHYSICAL INVENTORY STATUS

DATE: 9/22/80 TIME: 12:18

Feed Stopped At: 9/10/80 9:0

VESSEL NAME	VESSEL I D NUMBER	SAMPLE		RESULTS DENSITY	MONITORING		RE-INV	CUMULATIVE INVENTORY KG U
		REQUEST TIME	BY ACID		BEGAN	BY		
1 BU REC TK	21-D-210	9/18/80 9:57	RED	1.00	9/18/80 12:45	RED		0.048
2A COL	32-C-301	MANUAL INPUT	WFF	1.02	9/16/80 15:16	WFF		0.033
2B COL	32-C-302	MANUAL INPUT	WFF	1.00	9/17/80 9:54	LCG		0.154
PU REAK TK	32-D-301	9/17/80 14:51	RED	1.02	9/18/80 9:59	RED		0.002
1 BP SURG TK	32-D-307	9/11/80 14:37	RED	1.11	9/15/80 13:18	WFF		0.090
3A COL	33-C-303	MANUAL INPUT	WFF	1.04	9/16/80 14:24	WFF		0.007
3B COL	33-C-306	MANUAL INPUT	WFF	1.04	9/17/80 9:55	LCG		0.008
3S COL	33-D-309	MANUAL INPUT	RED	1.02	9/17/80 9:54	LCG		0.005
PU PROD CH TK	34-D-302	MANUAL INPUT	WFF	1.19	9/16/80 11:10	WFF		0.000
PU PROD SPL TK	34-D-303	9/16/80 11:13	WFF	1.17	9/16/80 11:19	WFF		1.150
3P CONC	34-E-310	MANUAL INPUT	WFF	1.19	9/16/80 11:19	WFF		0.060
1 PU PROD ST TK	35-D-304	9/18/80 8:33	WFF	1.34	9/18/80 8:35	WFF	WFF	51.120
2 PU PROD ST TK	35-D-305	MANUAL INPUT	WFF	1.46	9/15/80 13:54	WFF	WFF	121.415
3 PU PROD ST TK	35-D-306	MANUAL INPUT	WFF	0.66	322.20	WFF	WFF	115.114
HW CH TK	41-D-404	MANUAL INPUT	WFF	1.45	9/19/80 14:35	RED	RED	0.344
HW SPL TK	41-D-405	MANUAL INPUT	WFF	1.07	9/17/80 11:31	WFF		0.480
HW SURG TK	41-D-417	9/19/80 12:58	RED	1.09	9/19/80 14:15	RED		9.408
IS COL	42-C-401	9/18/80 11:32	RED	0.36	9/18/80 13:19	RED		1.053
SOL STRP TK	42-D-401	9/19/80 14:26	WFF	1.04	9/19/80 15:25	RED		3.271
LAN CONC FD TK	42-D-406	9/19/80 9:17	RED	1.02	9/19/80 10:20	RED		1.848
1 SF TK	42-D-433	9/19/80 15:18	RED	0.51	0.97			0.207
LANB CK TK	42-D-434	MANUAL INPUT	WFF	0.20	9/19/80 16:10	WFF		0.926
LAN CONC	42-C-461	MANUAL INPUT	WFF	1.05	7.80	WFF		9.492
MO2 ABSORBER	45-C-490	MANUAL INPUT	WFF	1.00	7.80	WFF		0.003
1 I SCRB	45-K-425	9/17/80 11:13	LCG	0.02	9/17/80 13:49	WFF		0.028
1R COL	51-C-503	9/17/80 10:37	RED	1.54	9/18/80 8:30	WFF		1.426
1 SOL FD TK	51-D-502	9/19/80 9:16	RED	0.12	9/17/80 13:38	RED		27.445
ACID FRACT	54-C-550	9/16/80 12:57	WFF	0.82	9/19/80 10:19	RED		-0.000
AF ACCUM	54-D-505	9/16/80 13:48	WFF	1.20	9/17/80 9:53	LCG		-0.001
REC ACID ST TK	62-D-605	9/16/80 12:58	WFF	1.00	9/17/80 9:53	LCG		-0.005
0.01 HNO3 RU TK	62-D-620	9/15/80 14:11	JP	1.28	9/16/80 15:39	WFF		0.028
UFG REC ACID TK	62-D-621			1.00	9/16/80 15:18	WFF		
HS COL	21-C-201	MANUAL INPUT	RED	0.55	9/17/80 15:29	RED		0.622
GPC FD TK	43-D-408			1.01				

CUMULATIVE INVENTORY TOTAL KILOGRAMS OF URANIUM:

346.193

FIGURE 15-31

PHYSICAL INVENTORY SUMMARY REPORT

DATE: 9/22/80 TIME: 11:36

Feed Stopped At: 9/10/80 9: 0

MEAS. POINT NUMBER	VESSEL NAME	VESSEL I D NUMBER	LEVEL RTD CHAN	ALARM LIMIT (in H2O)	ALARM FLAG	LEVEL READING (in H2O)	TANK TEMP (Cdes C)	ACID	DENSITY (g/ml)	UCONC (g/l)	VOLUME (liters)	INVENTORY URANIUM (kg U)
02032	1 BU REC TK	21-D-210	39	2.00		19.59	25.00		1.00	0.1	415.37	0.05
02109	2A COL	32-C-301	153	2.00	***	67.39	25.00	0.64	1.02	0.1	256.93	0.03
02110	2B COL	32-C-302	147	2.00	***	327.61	25.00	0.19	1.00	0.4	357.10	0.00
02008	PU REWK TK	32-D-301	140	2.00		7.47	24.40	0.56	1.02	0.5	3.78	0.00
02017	1 EP SURG TK	32-D-307	131	2.00		2.25	28.04	1.58	1.11	0.3	1.26	0.00
02111	3A COL	33-C-303	180	2.00	***	90.40	25.00	1.53	1.03	0.1	211.69	0.00
02112	3B COL	33-C-306	170	2.00		543.43	25.00	0.34	1.01	1.1	458.32	0.25
02113	3PS COL	33-C-309	182	2.00		0.23	25.00	0.64	1.02	1.2	2.17	0.00
02054	PU PROD CH TK	34-D-302	169	2.00		8.98	24.83	0.14	1.19	0.0	16.12	0.00
02010	PU PROD SPL TK	34-D-303	161	2.00		26.23	25.42	4.69	1.17	16.9	68.23	1.15
02122	3P CONC	34-E-360	173	2.00		0.18	25.00	6.14	1.19	0.0	13.55	0.00
02011	1 PU PROD ST TK	35-D-304	163	2.00		133.22	25.77	1.60	1.34	162.3	314.91	51.12
02012	2 PU PROD ST TK	35-D-305	164	2.00		166.98	25.66	0.68	1.46	330.2	367.70	121.41
02013	3 PU PROD ST TK	35-D-306	198	2.00		160.86	25.90	0.66	1.45	322.2	357.27	115.11
02056	HAU CH TK	41-D-404	256	2.00		19.30	23.56	1.97	1.06	1.0	334.68	0.34
02023	HAU SPL TK	41-D-405	262	2.00		22.59	26.64	2.08	1.07	0.8	571.48	0.48
02034	HAU SURG TK	41-D-417	238	2.00		107.05	25.16	2.73	1.09	3.5	2,688.08	9.41
02114	15 COL	42-C-401	265	2.00		301.12	25.00	0.36	1.01	0.8	1,298.39	1.06
02021	SOL STRP TK	42-D-401	212	2.00		49.19	36.73	1.08	1.04	8.1	406.33	3.27
02035	LAW CONC FD TK	42-D-406	274	2.00	***	67.54	24.72	0.51	1.02	1.0	1,913.28	1.85
02004	1 SF TK	42-D-433	261	2.00		40.85	25.00	0.20	1.01	0.4	472.49	0.21
02024	LAWB CK TK	42-D-434	281	2.00		6.79	29.20	1.10	1.05	7.8	118.72	0.93
02124	LAW CONC	42-E-461	269	2.00		0.58	29.33	1.10	1.05	7.8	1,216.88	9.49
02129	M02 ABSORBER	45-E-490	297	2.00		7.50	28.15	0.02	1.00	0.0	310.81	6.00
02037	1 I SURB	45-K-425	292	2.00		18.62	27.97	1.56	1.04	0.1	321.19	0.03
02117	1R COL	51-C-503	225	2.00		35.16	25.00	0.12	1.01	0.5	2,923.33	1.43
02015	1 SOL FD TK	51-D-502	248	2.00		84.30	25.51	0.82	0.82	2.5	10,978.00	27.45
02130	ACID FRCT	54-C-550	277	2.00		0.15	31.25	6.49	1.20	-0.0	0.39	-0.00
02062	AF ACIDH	54-D-505	273	2.00		36.07	27.86	10.26	1.00	-0.0	770.94	-0.00
02025	REC ACID ST TK	62-D-605	1	2.00		148.44	35.80		1.28	-0.0	12,230.30	-0.00
02044	0.01 HNO3 MU TK	62-D-620	19	2.00		64.43	25.00		1.00	0.0	30,317.40	0.03
02042	UP-6 REC ACID TK	62-D-621	5	2.00								
02103	HS COL	21-C-201	35	2.00		526.71	25.00	0.55	1.01	0.4	1,569.12	0.62
02036	GPC FD TK	43-D-408	345	2.00								

CUMULATIVE INVENTORY TOTAL KILOGRAMS OF URANIUM:

346.19

FIGURE 15-32

NUCLEAR MATERIAL ACCOUNTING
MATERIAL BALANCE REPORT FOR PERIODS 10 - 10
DATE OF REPORT 05-Sep-79
TIME OF REPORT 05:38 PM

		DETAIL			MBR		
FROM/TO	CODE	LITERS	KG SOL	KG U	LITERS	KG SOL	KG U
***** BEGINNING INVENTORY *****							10529.000
***** INPUT *****							
02003	ACCT TK						
	2001 F	19471.8	19694.5	12.741			
	2003 F	-23.6	-5.5	1.106			
	2007 F	194510.0	286573.0	65968.900			
10 12	272 THRU 10 13 315						
TOTAL FOR MBA		213958.0	306262.0	65982.800	213958.0	306262.0	65982.800
***** OUTPUT *****							
02007	U PROD SPL TK						
	2003 F	194258.0	286510.0	66041.700			
	2007 F	3.2	3.6	.031			
	4001 F	42691.2	58153.0	9560.650			
10 11	140 THRU 10 12 187						
TOTAL FOR MBA		236953.0	344667.0	75602.400	236953.0	344667.0	75602.400
***** OUTPUT *****							
02023	HWW SPL TK						
	2425 F	71731.1	93934.5	153.970			
	2029 RF	30125.9	40395.8	360.967			
10 11	205 THRU 10 12 253						
TOTAL FOR MBA		101857.0	134330.0	514.938	71731.1	93934.5	153.970
***** OUTPUT *****							
02028	BPW CK TK						
	2425 F	47563.3	52987.9	359.182			
	2021 RF	1297.0	1426.1	23.437			
	2029 RF	3619.9	4322.9	233.200			
	2036 RF	293.0	373.6	1.998			
	2125 RF	0.0	0.0	0.000			
	2127 RF	487.7	640.0	0.000			
10 11	658 THRU 10 12 740						
TOTAL FOR MBA		53260.9	59750.5	617.818	47563.3	52987.9	359.182
***** ENDING INVENTORY *****							
							396.277

FIGURE 15-33

NMC - ACCOUNTING
 INPUT/OUTPUT REPORT FOR MEASUREMENT POINT 02003
 DATE OF REPORT 05-Sep-79
 TIME OF REPORT 12155 PH

									QUANTITY RECEIVED			QUANTITY TRANSFERED			DEST		
LOT	BATCH	C	AS	LOG	P/F	BATCH	REC	U-CONC	LITERS	KG	U-CONTENT	LITERS	KG	U-CONTENT			
NO	NO		DATE	NO		NO	FROM	MG-U/G		SOLUT			SOLUT				
***** BEGINNING INVENTORY *****									5380.8	7854.3	1677.910						
12	272	C	20	6	79	29058	F	272	2003	213.920	-23.6	-5.5	1.106	2178.0	3191.1	682.640	2005
12	273	C	25	6	79	29058	F	140	2007	213.920	0.0	-1.8	-1.165	2696.7	3950.4	845.061	2006
12	274	C	24	6	79	29265	F	141	2007	196.960	5183.5	7389.3	1443.220	5074.1	7248.9	1427.740	2006
12	275	C	26	6	79	29326	F	142	2007	210.420	6183.5	8992.0	1903.490	5996.8	8707.2	1832.160	2006
12	276	C	26	6	79	29392	F	143	2007	226.030	5682.4	8368.4	1909.220	5860.9	8617.0	1947.700	2006
12	277	C	27	6	79	29425	F	144	2007	231.680	4818.3	7137.5	1658.610	4978.0	7368.1	1707.030	2005
12	278	C	27	6	79	29513	F	145	2007	236.890	5101.4	7670.4	1820.480	5077.9	7626.0	1806.520	2006
12	279	C	28	6	79	29537	F	146	2007	231.560	4695.5	6986.8	1614.150	4676.6	6964.6	1612.720	2005
12	280	C	28	6	79	29614	F	147	2007	205.100	5598.9	8079.3	1638.050	5479.0	7926.3	1625.650	2006
12	281	C	29	6	79	29668	F	148	2007	211.740	3925.7	5852.1	1202.560	4082.7	5801.7	1245.400	2005
12	282	C	29	6	79	29735	F	149	2007	215.190	4893.3	7126.1	1535.680	4721.5	6869.6	1478.270	2006
12	283	C	30	6	79	29758	F	150	2007	220.250	6524.5	9526.8	2102.820	6520.8	9518.6	2096.470	2005
12	284	C	30	6	79	29792	F	151	2007	222.150	5456.1	7967.2	1771.630	5586.2	8157.0	1612.080	2006
12	285	C	30	6	79	29825	F	152	2007	223.780	4146.5	6078.3	1361.350	4046.7	5929.7	1326.940	2005
12	286	C	1	7	79	29861	F	153	2007	231.500	5009.7	7443.0	1729.740	5003.0	7422.2	1718.240	2006
12	287	C	1	7	79	29897	F	154	2007	236.790	5309.4	7884.7	1871.720	5454.2	8098.9	1917.730	2005
12	288	C	1	7	79	29941	F	155	2007	236.960	4690.3	6937.2	1642.760	4591.2	6760.5	1608.590	2006
12	289	C	2	7	79	29971	F	156	2007	236.060	5925.3	8738.9	2062.160	5846.9	8625.1	2036.030	2005
12	290	C	2	7	79	30011	F	157	2007	225.730	5362.1	7748.4	1739.450	5414.8	7842.0	1770.160	2006
12	291	C	2	7	79	30053	F	158	2007	228.170	5770.7	8411.0	1921.100	5778.3	8417.1	1920.520	2006
12	292	C	3	7	79	30090	F	159	2007	227.410	6578.9	9680.4	2200.780	6537.6	9585.0	2179.720	2005
LOT TOTAL 12 272 292									100852.0	147806.0	33120.000	105002.0	154735.0	34597.400			
13	293	C	5	7	79	30231	F	160	2007	229.580	5786.0	8456.2	1943.380	5806.7	8489.1	1948.920	2006
13	294	C	5	7	79	30296	F	161	2007	225.400	5203.4	7558.0	1699.840	5330.2	7747.5	1746.280	2005
13	295	C	5	7	79	30322	F	162	2007	227.600	5301.9	7688.5	1751.450	5173.6	7503.9	1707.880	2006
13	296	C	6	7	79	30353	F	163	2007	224.660	5363.2	7744.4	1737.250	5543.0	8007.8	1799.030	2005
13	297	C	6	7	79	30422	F	164	2007	221.875	5401.6	7890.4	1746.730	5369.3	7627.7	1735.770	2006
13	298	C	7	7	79	30452	F	165	2007	229.540	5476.3	8026.2	1847.520	5499.8	8057.3	1849.460	2005
13	299	C	7	7	79	30484	F	166	2007	232.340	4961.0	7292.1	1696.050	4938.0	7256.4	1685.950	2006
13	300	C	7	7	79	30518	F	167	2007	229.880	5858.2	8567.0	1967.700	5700.2	8325.8	1913.930	2005
13	301	C	7	7	79	30538	F	168	2007	229.420	5305.3	7770.5	1782.270	5454.4	7916.5	1832.270	2006
13	302	C	8	7	79	30579	F	169	2007	235.000	5102.1	7590.1	1787.630	5112.3	7555.1	1784.850	2005
13	303	C	8	7	79	30611	F	170	2007	245.360	5133.0	7737.0	1905.630	5142.1	7747.2	1899.380	2006
13	304	C	8	7	79	30653	F	171	2007	244.870	4812.1	7236.9	1771.760	4684.7	7046.1	1725.380	2005
13	305	C	9	7	79	30686	F	172	2007	246.290	4921.7	7420.2	1828.790	5044.3	7602.9	1872.530	2006
13	306	C	9	7	79	30707	F	173	2007	245.620	4757.7	7178.3	1762.670	4652.4	7019.0	1724.010	2005
13	307	C	9	7	79	30743	F	174	2007	244.130	4982.3	7497.4	1829.050	5093.1	7666.1	1671.510	2006
13	308	C	10	7	79	30771	F	175	2007	248.540	5001.5	7633.0	1900.180	4742.7	7534.7	1872.680	2005
13	309	C	10	7	79	30818	F	176	2007	250.240	5127.2	7801.6	1953.620	4892.1	7444.9	1853.010	2006
13	310	C	10	7	79	30855	F	177	2007	250.890	5130.3	7683.7	1928.520	5285.2	7933.6	1970.460	2006
13	311	C	12	7	79	31060	F	0	2001	75.430	2252.8	2240.3	10.777	2641.5	3127.6	235.933	2005
13	312	C	13	7	79	31104	F	0	2001	-771	1999.6	2067.7	-537	1537.2	1610.8	1.242	2006
13	313	C	13	7	79	31223	F	0	2001	1149	7659.7	7743.5	1850	7681.5	7773.9	1.156	2005
13	314	C	16	7	79	31230	F	0	2001	114	4910.4	4953.3	1547	4883.0	4928.4	1.556	2006
13	315	C	16	7	79	31251	F	0	2001	1024	2649.4	2689.6	1025	2755.9	2795.7	1.067	2002
LOT TOTAL 13 293 315									113106.0	158456.0	32852.800	113383.0	159022.0	33063.300			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000			

FIGURE 15-34

NMC - SUMMARY
 INPUT/OUTPUT REPORT FOR MEASUREMENT POINT 02028
 DATE OF REPORT 05-Sep-79
 TIME OF REPORT 12:45 PM

LOT NO	BATCH NO	C	AS DATE	LOG NO	P/F	BATCH NO	REC FROM	U-CONC MG-U/G	QUANTITY RECEIVED			QUANTITY TRANSFERED			DEST
									LITERS	KG SOLUT	U-CONTENT	LITERS	KG SOLUT	U-CONTENT	
***** BEGINNING INVENTORY *****									97.2	75.9	.062				
***** LOT TOTAL 7 564 602 *****									22025.4	28069.9	323.090	22092.8	28110.1	322.782	
***** LOT TOTAL 8 603 610 *****									4805.4	6138.1	29.204	4784.9	6111.5	29.402	
***** LOT TOTAL 9 611 623 *****									6886.9	8817.9	22.266	6821.5	8782.1	22.320	
***** LOT TOTAL 10 624 657 *****									20387.1	24848.4	136.053	20494.2	24937.0	136.066	
***** LOTS 7 10 *****															
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000	
***** SUB TOTAL *****									0.0	0.0	0.000	0.0	0.0	0.000	
***** SUB TOTAL *****									43126.5	53919.3	207.519	42904.9	53768.6	213.215	2425
***** SUB TOTAL *****									43126.5	53919.3	207.519	42904.9	53768.6	213.215	
***** SUB TOTAL *****									6266.0	7964.6	208.722	6769.1	8474.7	236.616	2021
***** SUB TOTAL *****									583.9	784.3	44.212	-1.1	-1.5	-0.079	2028
***** SUB TOTAL *****									3493.3	4521.3	46.563	3783.6	4885.3	51.764	2029
***** SUB TOTAL *****									635.1	684.8	3.596	736.9	813.7	9.054	2036
***** SUB TOTAL *****									10978.2	13955.0	303.094	11288.4	14172.2	297.354	
***** TOTAL *****									54104.7	67874.3	510.613	54193.4	67940.8	510.570	
***** ENDING BALANCE *****												8.5	9.4	.105	

FIGURE 15-35

IPI DETERMINATION SUMMARY

NUMBER 133

TIME 3611

(= 1 : 0)

DATE 17-Jun-80

FOR TANKS

	PUPROD	PU CTH	1 PU STG	2 PU STG	3 PU STG	PU RAK	1DP	1 SOL FB	3P CONC
MP	2010	2054	2011	2012	2013	2000	2017	2015	2122
LR	85.0811	22.9235	21.0086	21.182	15.2438	55.7739	79.1199	62.3269	117.84
BR	15.080	14.7509	13.4954	12.8904	13.8152	11.4247	11.5209	8.09045	14.2222
T	31.1704	31.1704	31.2319	27.4515	28.0157	24.9631	24.85	25.0426	0
O	0	0	0	0	0	0	0	0	0
H+	1.615	0	1.655	1.665	1.595	3.161	2.953	.072	0
BW	1.49695	0	1.49455	1.41105	1.49135	1.1441	1.1729	.0325	0
U CONC	.33488	.26322	.33416	.27046	.33303	.03747	.02501	.0048	.26322
VOL	172.963	27.186	49.084	37.3791	42.5587	587.33	1012.44	7511.75	73.4503
O	0	0	0	0	0	0	0	0	0
O	.33688	0	0	0	0	.0381	.0559	0	145.003
O	0	0	0	0	0	0	.02826	0	0
KBU	58.2678	7.1559	16.4019	10.1096	14.1733	22.0073	25.3211	51.0799	19.3336

FOR COLUMNS

	2A	3A	2B	3PS	3D
MP	2109	2111	2110	2113	2112
LR	19.6448	18.6813	9.28186	10.2417	6.37534
BR	8.87805	8.98181	8.19324	7.7558	8.58441
BR	450.837	460.386	345.765	147.721	583.409
LI	12.1945	13.5963	0	10.6903	10.8613
SOLV FLOW	217.316	86.3119	0	0	-35.5599
SCRUB FLOW	31.913	12.9328	78.5432	0	174.135
SCRUB H+	1.29166	1.29166	.156859	0	.156859
FEED FLOW	449.592	57.9675	217.316	0	86.3119
FEED CONC	.04595	.0363	.0571536	0	.0567068
PROD FLOW	0	0	78.5432	0	174.135
PROD CONC	.0547734	.0599768	.0366	-.00542	.0366
KBU	16.5277	24.2426	9.22566	4.76732	33.7832

TOTAL MEASURED INVENTORY = 312.4 KGS U (EXCLUDING NEGATIVES)

TOTAL SYSTEM INVENTORY = 482.6 KGS U

UNMEASURED INVENTORY = 170.2 KGS U

FIGURE 15-36

MINT RIN 5

THE PLOT OF UNIS (NOTH WITH(W) AND WITHOUT(O) COLUMN KG U FSIMATES ADDED IN)

THE SCALE IS 5KG U PER EACH *

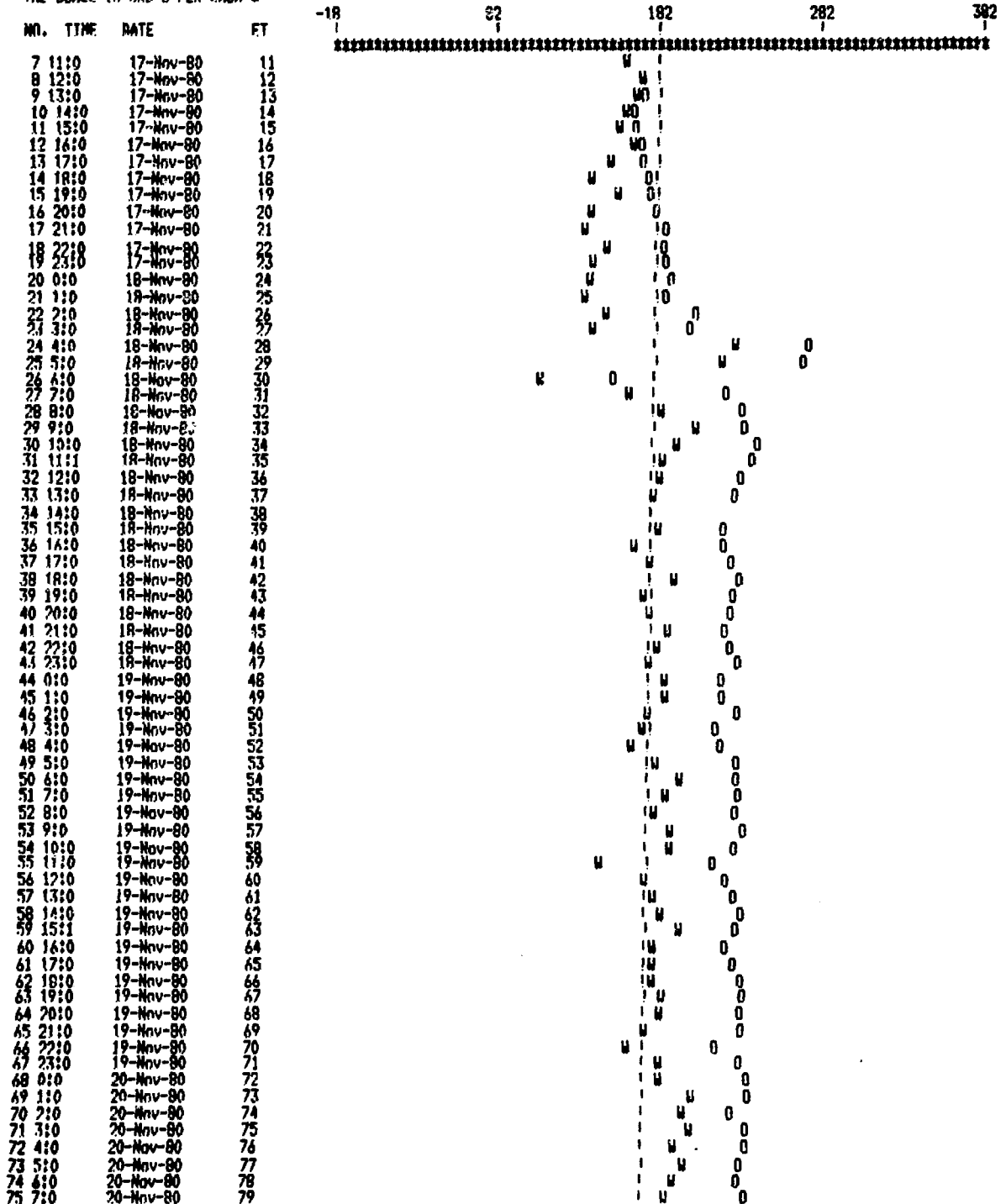


FIGURE 15-37

NEAR-REAL-TIME COLUMN MATERIAL BALANCE SUMMARY

THIS IS A PLOT OF THE 2A COLUMN HOLDUP CALCULATED FROM MASS IN/MASS OUT MEASUREMENTS AS DESCRIBED BY A.C.FERMAK
 THE DATA ARE FROM NHTT RUN NO.
 FROM NO. 38 AT 07:15 AM ON 03-Sep-80
 TO NO. 100 AT 10:45 PM ON 03-Sep-80

THE 2A MASS IN IS REPRESENTED BY AN (I) IN KGS/HR
 THE MASS OUT BY AN (O) IN KGS/HR
 AND THE CUMULATIVE HOLDUP BY AN (H) IN KGS

	CUM HOLDUP KGS	MASS IN KG/HR	MASS OUT KG/HR	INTEG I-O KGS	HDP SCALE T/O SCALE 1	10	3	20	5	30	7
03-Sep-80											
38 07:15AM	.6	4.9	.4	.6	IH O					I	
39 07:30AM	1.7	5.2	.4	1.2	I HO					I	
40 07:45AM	2.9	5.1	.5	1.2	I OH					I	
41 08:00AM	4	4.6	.3	1.1	I O H					I	
42 08:15AM	5.1	4.8	.4	1.1	I O H					I	
43 08:30AM	6.3	5.8	.4	1.2	I O H					I	
44 08:45AM	7.7	5.7	.5	1.3	I O H					I	
45 09:00AM	9	6.2	.4	1.4	I O H					I	
46 09:15AM	10.5	6.3	.5	1.5	I O H					I	
47 09:30AM	11.7	4.1	.5	1.2	I O H					I	
48 09:45AM	12.5	4	.6	.9	I O H					I	
49 10:00AM	13.4	4.3	.6	.9	I O H					I	
50 10:15AM	14.3	4.2	.8	.9	I O H					I	
51 10:30AM	15.2	4.8	.9	.9	I O H					I	
52 10:45AM	16.1	4.6	1.1	.9	I O H					I	
53 11:00AM	16.9	4.5	1.7	.8	I O H					I	
54 11:15AM	17.6	4.6	2	.7	I O H					I	
55 11:30AM	18.2	4.4	2.3	.6	I O H					I	
56 11:45AM	18.8	4.7	2.7	.5	I O H					I	
57 12:00PM	19.2	4.5	3.1	.4	I O H					I	
58 12:15PM	19.5	4.6	3.3	.3	I O H					I	
59 12:30PM	19.8	4.6	3.7	.3	I O H					I	
60 12:45PM	20	4.7	3.9	.2	I O H					I	
61 01:00PM	20.2	4.6	4.1	.2	I O H					I	
62 01:15PM	20.3	4.6	4.3	.1	I O H					I	
63 01:30PM	20.3	4.7	4.5	.1	I O H					I	
64 01:45PM	20.4	4.7	4.6	0	I O H					I	
65 02:00PM	20.4	4.7	4.7	0	I O H					I	
66 02:15PM	20.4	4.8	4.7	0	I O H					I	
67 02:30PM	20.4	4.9	4.7	0	I O H					I	
68 02:45PM	20.5	4.8	4.7	0	I O H					I	
69 03:00PM	20.5	4.9	4.8	0	I O H					I	
70 03:15PM	20.5	4.5	4.8	0	I O H					I	
71 03:30PM	20.4	4.7	4.8	-1	I O H					I	
72 03:45PM	20.4	4.9	4.8	0	I O H					I	
73 04:00PM	20.4	4.6	4.8	0	I O H					I	
74 04:15PM	20.4	4.8	5	0	I O H					I	
75 04:30PM	20.3	4.4	4.9	-1	I O H					I	
76 04:45PM	20.2	4.8	4.9	0	I O H					I	
77 05:00PM	20.2	4.7	4.9	0	I O H					I	
78 05:15PM	20.2	4.8	4.9	0	I O H					I	
79 05:30PM	20.1	4.8	4.9	0	I O H					I	
80 05:45PM	20.1	4.7	4.9	0	I O H					I	
81 06:00PM	20.1	4.7	4.9	-1	I O H					I	
82 06:15PM	20	4.5	4.9	-1	I O H					I	
83 06:30PM	19.9	4.7	4.8	-1	I O H					I	
84 06:45PM	19.9	4.7	4.8	0	I O H					I	
85 07:00PM	19.9	4.7	4.7	0	I O H					I	
86 07:15PM	19.9	4.9	4.7	0	I O H					I	
87 07:30PM	19.9	4.8	4.7	0	I O H					I	
88 07:45PM	20	4.8	4.8	0	I O H					I	
89 08:00PM	20	4.9	4.8	0	I O H					I	
90 08:15PM	20	4.6	4.8	0	I O H					I	
91 08:30PM	19.9	4.8	4.8	0	I O H					I	
92 08:45PM	19.9	4.8	4.8	0	I O H					I	
93 09:00PM	19.9	4.8	4.8	0	I O H					I	
94 09:15PM	19.9	4.7	4.9	0	I O H					I	
95 09:30PM	19.9	4.8	4.8	0	I O H					I	
96 09:45PM	19.8	4.3	4.9	-1	I O H					I	
97 10:00PM	19.7	4.7	4.9	-1	I O H					I	
98 10:15PM	19.7	4.7	4.8	0	I O H					I	
99 10:30PM	19.7	4.8	4.8	0	I O H					I	
100 10:45PM	19.7	4.8	4.8	0	I O H					I	

SUMMARY OF TANK TRANSFERS

```

FROM 01:00 AM TO 01:15 AM ON 04-Sep-80 (NO. 301 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 01:15 AM TO 01:30 AM ON 04-Sep-80 (NO. 302 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 01:30 AM TO 01:45 AM ON 04-Sep-80 (NO. 303 )
FEED 2 (306) SHOWS TRANSFER OF 169.8
PU REMARK SHOWS CHANGE OF 357.5 DURING THE SAME TIME

FROM 01:45 AM TO 02:00 AM ON 04-Sep-80 (NO. 304 )
24.2 LITERS OF PU CATCH WERE TRANSFERRED
RECEIPT IN PRODUCT TANK DOES NOT MATCH AT 29.2

FROM 02:00 AM TO 02:15 AM ON 04-Sep-80 (NO. 305 )
PU REMARK INDICATES LEAK, DIVERSION OR OTHER CHANGE OF 20.7

FROM 02:15 AM TO 02:30 AM ON 04-Sep-80 (NO. 306 )
PU REMARK INDICATES LEAK, DIVERSION OR OTHER CHANGE OF 1.40002

FROM 02:30 AM TO 02:45 AM ON 04-Sep-80 (NO. 307 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 02:45 AM TO 03:00 AM ON 04-Sep-80 (NO. 308 )
CATCH TANK SHOWS A LEAK OR DIVERSION OF 6.6

FROM 03:00 AM TO 03:15 AM ON 04-Sep-80 (NO. 309 )
LEAK, DIVERSION OR OTHER CHANGE OF 1 DETECTED IN PRODUCT TANK

FROM 03:15 AM TO 03:30 AM ON 04-Sep-80 (NO. 310 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 03:30 AM TO 03:45 AM ON 04-Sep-80 (NO. 311 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 03:45 AM TO 04:00 AM ON 04-Sep-80 (NO. 312 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 04:00 AM TO 04:15 AM ON 04-Sep-80 (NO. 313 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 04:15 AM TO 04:30 AM ON 04-Sep-80 (NO. 314 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 04:30 AM TO 04:45 AM ON 04-Sep-80 (NO. 315 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 04:45 AM TO 05:00 AM ON 04-Sep-80 (NO. 316 )
145.8 LITERS OF PU PRODUCT SAMPLE WERE TRANSFERRED
RECEIPT IN INPUT TANK (304) DOES NOT MATCH AT 176.7

FROM 05:00 AM TO 05:15 AM ON 04-Sep-80 (NO. 317 )
34.6 LITERS OF PU CATCH WERE TRANSFERRED
RECEIPT IN PRODUCT TANK DOES NOT MATCH AT 23.3
LEAK, DIVERSION OR OTHER CHANGE OF .399994 DETECTED IN INPUT (304)

FROM 05:15 AM TO 05:30 AM ON 04-Sep-80 (NO. 318 )
PU REMARK SHOWS TRANSFER OF 146.3
IDP SHOWS A CHANGE OF 141.193 DURING THE SAME TIME

FROM 05:30 AM TO 05:45 AM ON 04-Sep-80 (NO. 319 )
PU REMARK SHOWS TRANSFER OF 291.6
IDP SHOWS A CHANGE OF 317.578 DURING THE SAME TIME

FROM 05:45 AM TO 06:00 AM ON 04-Sep-80 (NO. 320 )
PU REMARK SHOWS TRANSFER OF 178.2
IDP SHOWS A CHANGE OF 197.554 DURING THE SAME TIME

FROM 06:00 AM TO 06:15 AM ON 04-Sep-80 (NO. 321 )
PU REMARK SHOWS TRANSFER OF 194.8
IDP SHOWS A CHANGE OF 204.68 DURING THE SAME TIME

FROM 06:15 AM TO 06:30 AM ON 04-Sep-80 (NO. 322 )
PU REMARK SHOWS TRANSFER OF 135.7
IDP SHOWS A CHANGE OF 135.439 DURING THE SAME TIME

FROM 06:30 AM TO 06:45 AM ON 04-Sep-80 (NO. 323 )
NO TRANSFERS OR SIGNIFICANT CHANGE

FROM 06:45 AM TO 07:00 AM ON 04-Sep-80 (NO. 324 )
NO TRANSFERS OR SIGNIFICANT CHANGE

```

FIGURE 15-39

MEASUREMENT PROGRAM STATUS

AS OF 18-Nov-80 02:07 PM

TANK ID	BATCH #	INITIAL	DR	DS	SAMPLE	AS	TRANSFER	AT
02011	80	F	F					
02010	67	F	NA	F				
02007	208	F	NA	F	F	F		
02028	972	F	NA					
02036	18	F	NA	F	F	F	F	F
04001	37	F	NA	F	F	F	F	F
02024	18	F	NA	F	F	F	F	F

>RUN VOLCHN

>

VOLCHN X81.00 02:09 PM 18-Nov-80

Tank Volume Calculation Program
RTP Channel Readings Version

Enter Vessel Number? 02010

More tanks (Y/N)? Y

Enter Vessel Number? 02011

PU PROD SPL TK

1 PU PROD ST TK

RTP Readings: Channel	Value cm H2O	(Sp. Gr.)
LR-326R 2002	163.61	
LR-326 161	167.066	
DR-374R 2003	32.85	1.29535
DR-374 162	33.0057	1.30149

RTP Readings: Channel	Value cm H2O	(Sp. Gr.)
LR-301R 2000	32.19	
LR-301 165	34.1832	
DR-304R 2001	30.75	1.36026
DR-304 160	31.1825	1.37939

Overflow Volume	Present Volume	Difference
215.889 liters	152.632 liters	63.257 liters

Overflow Volume	Present Volume	Difference
414.43 liters	35.6212 liters	378.809 liters

15-47

FIGURE 15-40

DATA BASE EDIT LOG

```

#####
DATA BASE EDIT LOG                INITIALIZED 07:53 PM 09-JUN-80
#####

MEAS. PT. NO.  FILE  RECORD  CODE  OLD VALUE  NEW VALUE  TIME AND DATE  WHO
-----
04001          B      3      2      0.0000    188.0000    15: 9  9/25/80  CJ
04001          B      4      2      0.0000    189.0000    15: 9  9/25/80  CJ
04001          A      2      8      0.0000    201.8300    15:11  9/25/80  CJ
04001          A      2      9      0.0000    201.9900    15:11  9/25/80  CJ
04001          A      2     10      0.0000    201.8400    15:11  9/25/80  CJ
04001          A      2     11      0.0000    202.4800    15:11  9/25/80  CJ
04001          A      2     12      0.0000      2.0000    15:12  9/25/80  CJ
04001          A      2     13      0.0000      2.0000    15:12  9/25/80  CJ
04001          A      2     14      0.0000      2.0000    15:12  9/25/80  CJ
04001          A      2     15      0.0000      2.0000    15:12  9/25/80  CJ
04001          A      3      8      0.0000    197.0900    15:13  9/25/80  CJ
04001          A      3      9      0.0000    196.8000    15:13  9/25/80  CJ
04001          A      3     12      0.0000      2.0000    15:14  9/25/80  CJ
04001          A      3     13      0.0000      2.0000    15:14  9/25/80  CJ
04001          A      4      8      0.0000    196.4500    15:15  9/25/80  CJ
04001          A      4      9      0.0000    196.5500    15:15  9/25/80  CJ
04001          A      4     12      0.0000      2.0000    15:16  9/25/80  CJ
04001          A      4     13      0.0000      2.0000    15:16  9/25/80  CJ
02024          R      4     11     29.9100    169.6300     9:55  9/29/80  CCJ
02024          R      4     15     29.1694    172.3600     9:55  9/29/80  CCJ
02024          R      4     22      1.3779      1.1957     9:56  9/29/80  CCJ
02024          R      4     23      1.2158      1.1953     9:56  9/29/80  CCJ
02024          R      4     24      1.2158      1.1956     9:56  9/29/80  CCJ
02024          R      4     27      1.1021      1.1827     9:57  9/29/80  CCJ

```

KEY:FILE:

B = Batch File
 A = Analytical File
 R = Raw Data File

CODE:

2 = Batch Number in Source Tank
 8, 9, 10, 11, = H Concentrations Reported
 12, 13, 14, 15 = Analytical Methods for 8, 9, 10, 11

FIGURE 15-41

PROCESS STATUS AT 08:12 AM												ON 08-Sep-80		(NO. 514)	
TANKS	PT	LR	DR	T	P.S.	INDEX	Ht	BN	U	VOL	KG U				
INPUT	2011	146.344	11.2362	31.1006	8.937	11	.744	1.4613	0	366.9	0				
PRODUCT	2010	7.84424	7.10791	30.1049	9.984	10	.702	1.4654	227.5	32.9	11				
FEED 1	2012	9.37012	9.74935	29.3912	9.11	12	1.042	1.27275	141.47	37.8	6.8				
FEED 2	2013	14.5045	13.409	29.3758	8.886	13	.706	1.4573	224.4	42	13.7				
PU RMK	2008	20.4529	11.5747	29.594	9.93	8	2.944	1.1717	57.9	40.5	2.3				
1BP	2017	78.4955	11.7701	31.9339	10.22	14	3.019	1.1702	60.2	975	50.7				
PU CATCH	2054	50.3414	14.4286	47.0452	9.921	40	.702	1.4654	227.5	54.2	18.1				
1 SOL FD	2015	68.7964	8.04517	27.8245	9.9	14	.018	.8235	.5	8604.1	4.3				
3P CONC	2122	116.9	13.8156	93.8330	9.91	97	.702	1.4654	227.5	76.6	25.5				
COLUMNS	WR	LR	LI	BR	VOL										
2A	457.399	18.6951	11.9107	9.02508	707										
3A	466.145	20.1435	12.475	9.1012	575										
2B	363.492	9.08309	31.6505	8.29456	490										
3B	567.232	8.95994	10.3534	8.31702	539										
3PS	120.73	21.2382	.16449	4.58228	54										
FR AND CR	Z	RNG	FLMSHT	RUSKA	RAW	ZERO	ADJ TO CH.								
3AS-FR618	33	30	36	2000	36678	5	366.73								
3BX-FR619	31	110	104	2001	33853	9	338.44								
3BS-FR541	-25	-79	25	2002	8549	1	85.48								
3AX-FR542	43	137	110	2003	3542	0	55.42								
2AX-FR543	30	100	160	2004	3200	45	22.8								
2AG-FR638	50	61	60	2005	5087	57	35.36								
2BX-FR639	18	146	150	2006	53	53	0								
3AF-FR633	50	85	40	2007	0	0	0								
1BP-FR205	43	101	142												
3AG-CR631	56	.57	1												
2AS-CR446	55	1.02	1												
2BX-CR447	6	.11	.01												
1BP-CR440	72	3.2	3												
LATEST ANALYTICAL DATA															
	L.N.	DATE AND TIME		Ht	REN	U CONC	FLUENT	HP. NO.							
FOR	38920	9 / 8	14 : 0	0	.8232	.144	---	2162							
1BP SURGE	38506	9 / 7	22 : 51	3.019	1.1702	60.2	60	2017							
2AW	38507	9 / 8	0 : 1	1.9	1.0421	.0979	TRACE	2152							
2AP	38515	9 / 8	0 : 9	.847	.8965	49.6	53.1	2151							
2BW	38506	9 / 8	0 : 2	0	.8236	.4	TRACE	2154							
2BP	38516	9 / 8	0 : 9	.105	1.0354	27.7	56.6	2239							
3AF	38509	9 / 8	0 : 3	.103	1.0369	27.1	44.7	2156							
3AW	38510	9 / 8	0 : 4	3.059	1.0951	.113	TRACE	2157							
3BW	38511	9 / 8	0 : 5	0	.8233	.1	TRACE	2160							
1SF	38512	9 / 8	0 : 6	2.144	1.0677	.505	TRACE	2004							
3AP	38514	9 / 8	0 : 8	.08	.9095	63.2	77	2220							
3BP	38519	9 / 8	2 : 41	.098	1.0481	35.8	80	2161							
PU RMK	38521	9 / 8	4 : 23	2.944	1.1717	57.9	60	2008							
2AG/3AG	37975	9 / 3	4 : 18	1.052	1.0272	0	---	2150							
2BX/3BX	37139	4 / 16	8 : 17	.087	0	0	---	2195							
1 SOL FD	38513	9 / 8	0 : 6	.018	.8235	.5	TRACE	2015							
LANF	38995	9 / 7	16 : 5	2.093	1.0682	.48	TRACE	2035							
LANB	37982	9 / 3	9 : 2	1.754	1.0575	2.4	---	2024							
PU PROD	38517	9 / 8	0 : 31	.702	1.4654	227.5	232N6/6	2010							
INPUT	0	0 / 0	0 : 0	.744	1.4613	225.3	232N6/6	2011							
FEED 1	38039	9 / 5	1 : 39	1.042	1.27275	141.47	232N6/6	2012							
FEED 2	38520	9 / 8	4 : 31	.706	1.4573	224.4	232N6/6	2013							
REC Ht STG	38976	9 / 7	9 : 57	10.929	1.3145	.00163	---	2025							
AND THERE IS STILL PLENTY OF STEAM															

AND THERE IS STILL PLENTY OF STEAM

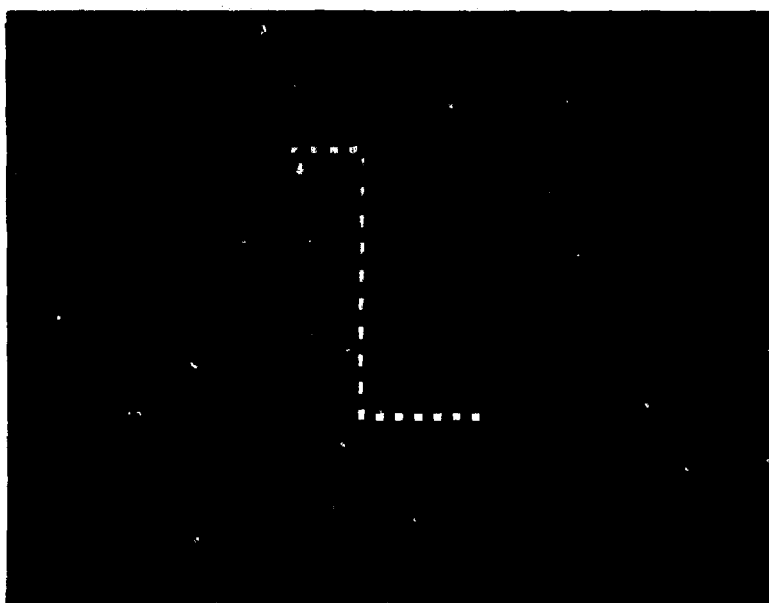
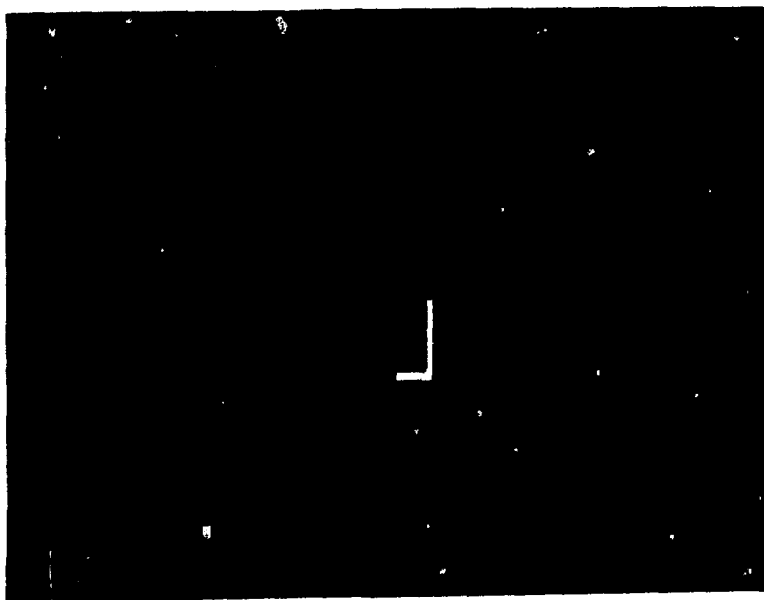


FIGURE 15-42

AGNS PROCESS COLOR-GRAPHIC DISPLAYS

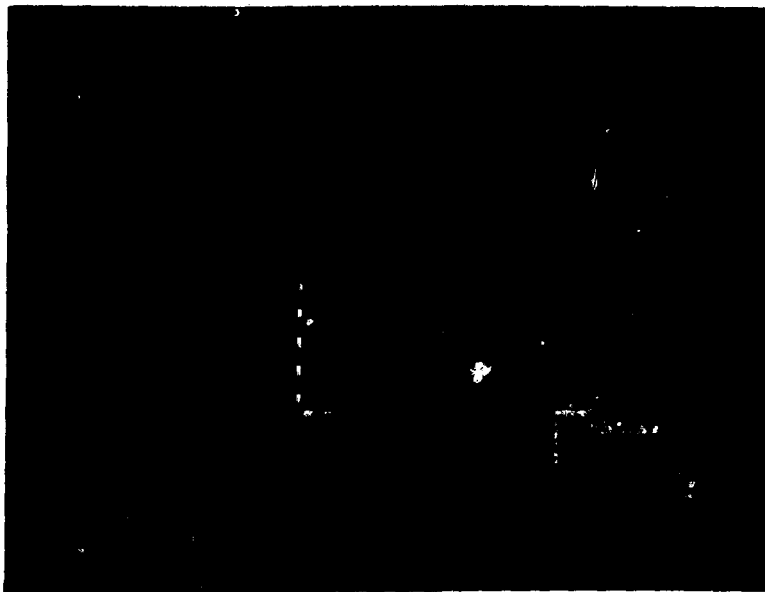


FIGURE 15-43

AGNS PROCESS COLOR-GRAPHIC DISPLAYS

FIGURE 15-44

BLEND PROGRAM
FOR MAKING 60 G/L U IN PU REMORK
FROM PRODUCT STORAGE TANK STUFF (305 OR 306)

IS THE SOURCE 305 OR 306 (TYPE IN "305" OR "306") ? 306

CURRENT MEASURED DATA ARE:

306 LR = 134.739 = 71 %
306 DR = 11.148 = 35 %
306 T = 30
REMORK LR = 40.036 = 27 %
REMORK DR = 11.6555 = 41 %
REMORK T = 28.3948

THERE IS NOT ENOUGH IN THE STORAGE TANK TO MAKE A FULL 1700 LITER BATCH
WHAT IS IN THE TANK DOWN TO A MEASURABLE HEEL IS USED IN THE CALCULATION

- (A) THERE ARE CURRENTLY 353 LITERS IN THE PRODUCT STORAGE TANK
IT HAS DENSITY = 1.2252
ACID = .805
U CONC = 150.08 G/L
- (B) THERE IS CURRENTLY 324 LITERS IN THE PU REMORK TANK
IT HAS DENSITY = 1.1784
ACID = 3.139
U CONC = 64.3 G/L
- (C) CURRENT 42 MULTIPURPOSE FEED TANK STUFF IS:
ACID = 3.438
DENSITY = 1.1038
- (D) ADD 493 LITERS OF 3.5 MOLAR ACID TO THE PU REMORK TANK
THIS WILL GIVE A FINAL LEVEL IN THE PU REMORK TANK OF:
46 % OF CHART
- (E) THEN ADD 313 LITERS FROM PRODUCT STORAGE TANK
THIS SHOULD BE TO A FINAL CHART READING OF 6 % IN THE STG TANK
AND A FINAL CHART READING OF 61 % IN THE REMORK TANK
- (F) THE FINAL PU REMORK TANK CONTENT SHOULD BE:
VOLUME = 1130
LEVEL = 61 %
ACID = 2.6
DENSITY = 1.1588
U CONC = 60 G/L
- (G) SAMPLE THE PU REMORK AFTER YOU ARE DONE
AND CHECK THAT IT IS CLOSE TO 60 G/L

AS A SUMMARY.....FOR 306 BATCH NUMBER 37

	TIME	OP. INIT.
(1) ADD 3.5 N ACID TO REMK TK TO 46 %	<u>1000</u>	<u>WJH</u>
(2) ADD PRODUCT TANK TO REMK TO 61 % (PRODUCT TANK WILL READ 6 %	<u>1011</u>	<u>WJH</u>
(3) THEN REQUEST PU REMORK TANK SAMPLE	<u>1130</u>	<u>WJH</u>

TABLE 15-1

NDAS CHANNEL DEFINITIONS AS OF 09:55 AM 31-JUL-80

INSTRUMENT	CHAN	SCAN		GAIN	RANGE		ALARM LIMITS		INHIBIT ALARMS
		MODE			LOW	HIGH	LOW	HIGH	
<DR646>	0	3		4	10.000	15.000	NONE	NONE	NO
<LR617>	1	3		4	0.000	345.000	34.500	310.000	NO
<CR666>	2	3		4	0.000	100.000	NONE	NONE	NO
<CR667>	3	3		4	0.000	100.000	NONE	NONE	NO
<DR678>	4	1		4	10.000	15.000	NONE	NONE	NO
<LR623>	5	1		4	0.000	149.000	42.000	78.000	NO
	6								
	7								
<DR101>	8	1		4	10.000	19.000	NONE	22.600	NO
<LR101>	9	1		4	0.000	235.000	NONE	169.000	NO
	10								
<DR160>	11	1		4	5.000	10.000	NONE	NONE	NO
<LR105>	12	1		4	0.000	330.000	NONE	135.300	NO
<DR615>	13	1		4	10.000	15.000	NONE	NONE	NO
<LR607>	14	1		4	0.000	150.000	30.000	105.000	NO
	15								
<LR611>	16	1		4	0.000	80.000	NONE	60.000	NO
<LR604>	17	1		4	0.000	115.000	24.000	NONE	NO
	18								
<LR612>	19	3		4	0.000	103.000	NONE	NONE	NO
<FR633>	20	3		4	0.000	100.000	NONE	NONE	NO
<CR648>	21	3		4	0.000	100.000	NONE	NONE	NO
<FR630>	22	3		4	0.000	100.000	NONE	NONE	NO
<FR639>	23	3		4	0.000	100.000	NONE	NONE	NO
	24								
	25								
	26								
	27								
	28								
	29								
	30								
	31								
	32								
<L1210>	33	1		4	0.000	41.000	10.000	NONE	NO
<LR205>	34	1		4	15.500	24.000	NONE	NONE	NO
<WR200>	35	1		4	0.000	575.000	NONE	NONE	NO
	36								
<DR209>	37	1		4	7.000	11.000	NONE	NONE	NO
<FR241>	38	2		4	0.000	50.000	NONE	NONE	NO
<L1209>	39	3		4	0.000	61.000	NONE	55.000	NO
<WR224>	40	1		4	0.000	520.000	NONE	NONE	NO
<FR205>	41	3		4	0.000	100.000	13.000	NONE	NO
<LR216>	42	1		4	14.000	23.400	NONE	NONE	NO
<AR201>	43	3		4	0.000	100.000	NONE	NONE	NO
<DR223>	44	1		4	7.000	11.000	NONE	NONE	NO
<WR215>	45	1		4	0.000	165.000	NONE	NONE	NO
<WR227>	46	1		4	0.000	425.000	NONE	NONE	NO
<LR212>	47	1		4	6.000	13.000	NONE	NONE	NO
<L1241>	48	1		4	0.000	40.000	3.000	NONE	NO
<FR242>	49	1		4	0.000	0.000	NONE	NONE	NO

TABLE 15-2NON-RADIATION ON-LINE MONITORS

<u>PARAMETER</u>	<u>MEASUREMENT TECHNIQUE</u>
Nitrogen Dioxide (Nitrite)	Photometric
Uranium	Photometric
Nitric Acid	Conductivity
Density	Oscillating Cell

TABLE 15-3ON-LINE NITROGEN DIOXIDE (NO₂) MONITOR

Type of Stream	-- Liquid Stripped with Air
Type of Instrument	-- DuPont Model 400 Photometric Process Analyzer
Location of Monitor	-- In-Line with a Sampler Stream
Wavelength Selection	-- Filter
Measuring Wavelength	-- 436 nm
Reference Wavelength	-- 546 nm
Sample Cell Length	-- 20 cm
Range	-- 0 - 2000 PPM in the Air Stream
Sensitivity	-- 30 PPM
Calibration	-- On-Line by Analysis of Line Samples

TABLE 15-4
ON-LINE URANIUM MONITOR

TYPE OF STREAM	- LIQUID
LOCATION OF ANALYZER	- IN-LINE WITH A SAMPLER STREAM
TYPE OF INSTRUMENT	- DUPONT MODEL 400 PHOTOMETRIC PROCESS ANALYZER
CELL LENGTH	- 2.0 INCHES
WAVELENGTH SELECTION	- FILTER
MEASURING WAVELENGTH	- 405 NM
REFERENCE WAVELENGTH	- 546 NM
READ-OUT	- STRIP CHART RECORDER, G U/ℓ
RANGE	- 1 - 16 G U/ℓ
SENSITIVITY	- 0.5 G U/ℓ
ACCURACY	- ±5% RELATIVE
CALIBRATION	- ON-LINE WITH STANDARDS
ROUTINE CHECK	- COMPARED TO STREAM SAMPLES ANALYZED IN THE LABORATORY
PROBLEM	- VARYING NITRIC ACID CONTENT CAUSES SOME BIAS EVEN WITH THE BEST SELECTION OF WAVELENGTHS

TABLE 15-5

ON-LINE CONDUCTIVITY MONITORS AS NITRIC ACID MONITORS

TYPE OF STREAM	- LIQUID
LOCATION OF ANALYZER	- A) ON-LINE WITH A SAMPLER PROCESS STREAM B) IN-LINE ON RECOVERED HNO_3 PROCESS STREAMS
TYPE OF INSTRUMENT	- ELECTRODE AND ELECTRODELESS CELLS
READ-OUT	- STRIP CHART RECORDER AND/OR COMPUTER INTERFACE
RANGE	- 0.1 - 4.0 M HNO_3 , DEPENDING ON STREAM
SENSITIVITY	- 0.05 M - 1% OF FULL SCALE
ACCURACY	- 5%,
CALIBRATION	- BENCH STANDARDIZATION WITH STANDARDS
ROUTINE	- COMPARED TO STREAM SAMPLES ANALYZED IN THE LABORATORY

TABLE 15-6

ON-LINE DENSITY MONITOR

TYPE OF STREAM	- LIQUID
TYPE OF INSTRUMENT	- A) METTLER DPR412YWS B) DYNATROL CL-10HY
MEASUREMENT PRINCIPLE	- MEASUREMENT OF PERIOD OF OSCILLATION OF FILLED TUBE
READ-OUT	- DIGITAL, RECORDER AND/OR COMPUTER INTERFACE
RANGE	- A) METTLER, 0.0011 - 2.0 g/ML (USED AT 0.8 - 1.4 g/ML) B) DYNATROL, 1.0 - 1.2 g/ML FOR A URANIUM STREAM C) DYNATROL, 1.00 - 1.13 FOR HNO ₃ STREAM
SENSITIVITY	- A) METTLER - 0.0001 g/ML B) DYNATROL - 0.0005 g/ML
ACCURACY	- A) METTLER - 0.0005 g/ML B) DYNATROL - 0.001 g/ML
PROBLEMS	- A) ENTRAINED GAS (AIR) BUBBLES B) REQUIRES GOOD TEMPERATURE CONTROL
CALIBRATION	- ON BENCH WITH AIR, WATER AND LIQUID STANDARDS
ROUTINE CHECK	- COMPARED TO STREAM SAMPLES ANALYZED IN THE LABORATORY

TABLE 15-7PROCESS MONITORING/PROCESS SURVEILLANCE PROGRAMS AND MODULES

<u>Name</u>	<u>ID</u>	<u>Purpose</u>
<u>Quantity Transferred Versus Received Program:</u>		
1. Main Program installed as:	PQTVRC QTVRC	To coordinate and monitor a vessel-to-vessel transfer, collect, and store measurement data, and print transfer comparison and summary report.
2. Calculation Module	CALCQT	Make instrument and solution comparisons, convert RTP readings, calculate liquid level, volume (via TVOL), and solution quantities, initialize batch parameters, mark option and marginal indicators.
3. Volume Calculation Module	TVOL	Calculates solution volume given level and density.
4. Password Module	PASQT	Determines if an entered supervisor password is valid.
5. Operator Initials Module	QPIQT	Requests and stores the operator's initials at each step of the measurement sequence.
6. Branch Option Module	OPTQT	Based on operator decision, performs a branch to the desired step in the measurement sequence. (Example: If, for any reason, an invalid measurement is taken, the operator can decide to remeasure.)
7. Initialization Module	INITQT	Initializes the temporary data file and common area at the start of each transfer.
8. Measurement Data Collection Module	RTPQT	Assembles measurement request parameters and initiates measurement requests and receives measurement data from the preprocessor (RTP system).
9. PNSA Ruska Transducer Units Module	RUSKA 2	Transforms units of data received from the PNSA Ruska Universal Controller into standardized units.
10. Reading Summary Module	RUSQT	Summarizes measurement readings for operator approval.
11. Response Module	RESQT	Get a "YES" or "No" response from the terminal.
12. Vessel Input Module	VESQT	Get a vessel ID from the terminal and store it in the temporary data file.



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



April 27-May 12, 1981

Session Objectives

SESSION 16: PERFORMANCE EVALUATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS.

Examples are given illustrating the application of near-real-time accounting concepts and principles to actual nuclear facilities. Experience with prototypical systems at the AGNS reprocessing plant and the Los Alamos plutonium facility are described using examples of actual data to illustrate the performance and effectiveness of near-real-time systems.

After the session, participants will be able to:

1. identify the major components of near-real-time accounting systems,
2. describe qualitatively the advantages, limitations, and performance of such systems in real nuclear facilities,
3. identify process and facility design characteristics that affect the performance of near-real-time systems,
4. describe qualitatively the steps necessary to implement a near-real-time accounting and control system in a nuclear facility.



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



April 27-May 12, 1981

SESSION 16: PERFORMANCE EVALUATION OF NEAR-REAL-TIME ACCOUNTING SYSTEMS

D. D. Cobb and J. J. Malanify
Safeguards Systems Group Q-4
Los Alamos National Laboratory
and

J. H. Ellis, Manager
Nuclear Materials Control
Allied-General Nuclear Services

I. INTRODUCTION

The previous days' sessions have largely concentrated on new developments in measurement technology for safeguards and materials accounting. Today's sessions (14-16) are concerned more with the integration of various safeguards technologies into systems for in-plant nuclear materials accounting and control.

A key aspect of the development of near-real-time accounting and control systems is the analysis of measurement data for losses and diversion. A closely related idea is the ability to quantify the effectiveness and performance of the system.

In Session 14 Dr. Shipley talked about measures of system performance: false-alarm probability, detection probability, detection time, and detectable quantity. These measures are useful both from the point of view of analyzing the data for diversion (that is, data analysis as part of a near-real-time accounting system) and for analyzing the performance and effectiveness of the system (that is, data analysis as part of designing the system).

Basically there are two ways of getting the information that is necessary to analyze system performance. One is through computer-based modeling and simulation. The other is through test loops and experiments at host facilities. The two methods are complementary and, in general, both are needed for designing a good system.

In Session 15 John Ellis described the process measurement and data acquisition systems at AGNS. In this session we will extend this discussion to the analysis of near-real-time data and the performance of near-real-time systems. Examples of real data will be given from two prototype systems at actual nuclear facilities, the AGNS reprocessing plant and the plutonium facility at Los Alamos.

After this session, you should be able to:

1. Identify the major components of near-real-time accounting systems.
2. Describe qualitatively the advantages, expected performance, and operational difficulties associated with applying such systems in real nuclear facilities.
3. Identify some of the generic process and facility design characteristics that affect the performance of near-real-time systems.

4. Describe qualitatively the steps necessary to develop and implement a near-real-time accounting and control system in a nuclear facility.
5. Describe qualitatively the data sets required for near-real-time accounting.

II. AGNS MINIRUN DESCRIPTION

A. Background

A description of the AGNS Computerized Nuclear Material Control and Accounting System (CNMCAS) was presented in Session 15. Development and testing of this system started in 1977 and has continued under AGNS' research and development contract with the US Department of Energy.

Initial work on CNMCAS involved the entire AGNS solvent extraction system and was centered on computerization of measurement, measurement control, and accounting procedures for "conventional" accounting. ("Conventional" accounting is the measurement of inputs and outputs for a materials balance area, coupled with periodic cleanout and physical inventory to close the balance.)

Between 1977 and 1979, almost 500 metric tons of natural uranium were cycled through the process and measured using CNMCAS. During this period, data from over 1790 batch measurements and 10 physical inventories were collected and analyzed. A summary of the results of these tests is presented in Table 16-I. As can be seen from this test result summary, significant improvements were achieved in successive years. These improvements, as previously discussed in Session 15, were a result of adopting the Ruska electromanometer as the primary accountability measurement device and applying a vigorous computerized measurement control program.

TABLE 16-I

CNMCAS FULL-PLANT TEST RESULTS

<u>Year</u>	<u>MTU Processed</u>	<u>ID^a</u>	<u>LEID^b (2σ)</u>
1977	83	0.29% (241 kg U)	0.98% (813 kg U)
1978	82	0.04% (33 kg U)	0.28% (229 kg U)
1979	301	0.007% (21 kg U)	0.19% (572 kg U)

^aID = Inventory Difference. This is the difference between inputs and outputs after adjustment for beginning and ending inventory quantities. This quantity is also referred to as MUF or Materials Unaccounted For.

^bLEID = Limit of Error of the Inventory Difference. This is the uncertainty of the materials balance for the inventory period.

Beginning in 1976, the AGNS plant had been adopted by the Los Alamos Safeguards Systems Group as the baseline facility in a series of safeguards studies to develop the necessary concepts for near-real-time accounting systems for future large reprocessing plants.^{1,2} The plutonium purification process (Fig. 16-1) received special attention in these studies because this is where separated plutonium solutions would be processed to the final, concentrated nitrate product.

As measurement techniques and computer programs were improved, AGNS began to experiment with near-real-time accounting in which routine measurements of process variables were used to estimate the quantity of material in-process. These experiments were initially conducted for the entire process with computerization of the program by 1979.

In 1980, reduced funding levels required AGNS to find a less costly mode of testing. Because of the widespread and continuing interest in developing computerized nuclear materials control and near-real-time accounting methods, the minirun concept was devised. This concept involves cycling uranium solutions through the plutonium purification process in a closed loop, supported only by the solvent recycle system, the acid recovery/condensate recycle systems, and the process off-gas system. During 1980 and continuing through 1981, a series of these minirun experiments is being performed jointly by AGNS, Los Alamos, and Oak Ridge.

B. Process and Equipment Description

The minirun cycle, as shown on the simplified process diagram (Fig. 16-1), consists of four pulsed-column contactors (2A, 2B, 3A, and 3B); one packed column (3PS); a product evaporator (3P concentrator); and seven product, feed, and blending tanks. Support systems include aqueous waste tanks, a waste evaporator and an acid fractionator, a solvent surge and recycle tank, an off-gas system, and associated process and chemical distribution systems. This represents a good cross section of routinely used plant equipment for development of improved materials control and accounting methods.

A modified Purex solvent extraction flowsheet, using 30 volume percent tributyl phosphate (TBP) in a refined kerosene diluent, is used. Unirradiated natural uranium is used in place of plutonium for the system tests.

Uranium feed for the process is provided by recycling the concentrated uranium product solution. Product batches are blended to 60 g/L and about 3M HNO_3 in the plutonium rework tank and batch transferred to the 1BP surge tank as needed. Feed to the process is continuously transferred to the 2A column from the 1BP surge tank at about 100 L/hr.

Uranium is extracted into the organic phase and scrubbed with nitric acid in the 2A column. In the 2B column, the uranium is then stripped back into the aqueous phase using dilute HNO_3 . An acid adjustment is made in-line downstream of the 2B column, and the above operations are repeated in the 3A and 3B columns, respectively.

Aqueous wastes (2AW and 3AW) from each minirun period are accumulated in a waste evaporator for the entire run period. Samples are taken every 8 h and analyzed for uranium to permit order-of-magnitude estimation of waste losses. The contents are measured and analyzed at the end of each run to quantify the waste loss. An on-line x-ray fluorescence analyzer (XRFA) has recently been installed

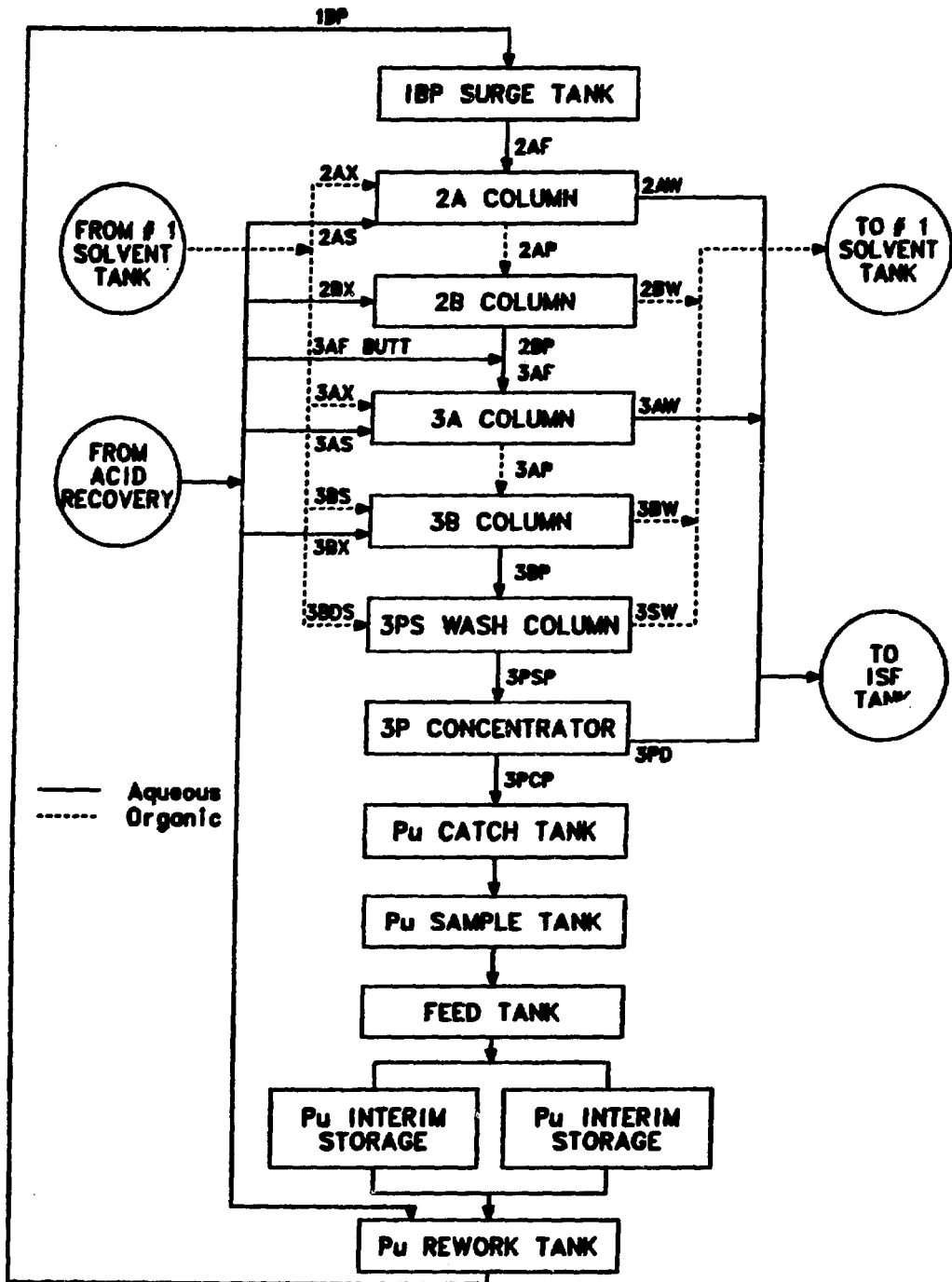


Fig. 16-1. Minirun cycle (modified coprocessing flowsheet).

on the 2AW and 3AW streams to provide continuous measurement of the waste losses. These instruments permit near-real-time estimation of the waste losses. Used solvent from the process (2BW and 3BW) is sent back to the solvent feed tank without treatment. The used solvent streams were also recently equipped with XRFA systems to measure the uranium removal rate.

Product aqueous solution is scrubbed with diluent in the 3PS column (to remove dissolved TBP), evaporated to 250-300 g/l in the 3P concentrator (the concentrator is operated in a continuous overflow mode), and collected in the plutonium catch tank. The material is then batch transferred to the plutonium sample tank, measured for product accountability, and moved to the feed tank. The material is then remeasured for input accountability in the feed tank and moved to one of the interim storage tanks.

The normal starting inventory for each run was 400-500 kg of uranium. After attaining equilibrium, a "process holdup" (pulsed columns, lines, product evaporator) of about 70-75 kg was observed with the remaining material distributed among product tanks. Waste losses from the system varied from run to run, averaging something on the order of 100 kg for each run.

C. Test Descriptions

Five minirun tests are described in this session. Each run was seven days in duration, except for minirun No. 5, which was five days long. Table 16-II summarizes the purpose and activities of each of the runs. AGNS has prepared a videotape presentation of the minirun activities. This tape shows the plant and the typical operations that took place during the miniruns. Following this videotape presentation, the results of the miniruns and subsequent data evaluation will be presented.

III. EVALUATION OF MINIRUN DATA

A. Conventional Accounting

Table 16-III is a materials balance summary of the five miniruns based on conventional accounting. A total of 3340 kg of uranium was processed during the runs at a nominal rate of 150-200 kg of uranium per day. The cumulative ID for the five runs was 13.3 kg of uranium (0.4% of throughput) with a 2σ uncertainty of 11.7 kg (0.35%).

The relative percent values for ID and LEID are not as good as 1978 and 1979 results. This is due in part to the fact that waste losses, which are normally difficult to measure precisely, were large compared to throughput (15% of throughput during the miniruns as compared to 1% of throughput for full-plant runs). As a result, waste measurements had a significant degrading effect on the minirun overall materials balance performance. (It should be noted, however, that in full-plant operation, these minirun "waste losses" would actually be internal recycles and would not significantly impact full-plant data evaluation.)

The minirun ID slightly exceeds the LEID, which is not desirable. This has been traced to an upset in Run No. 1. The first minirun was very erratic in terms of system/column operation. Inventory data showed a considerable loss of organic from the minirun system, likely caused by column upsets and overflows. The materials balance data reflect the quantities associated with this loss.

TABLE 16-II

AGNS MINIRUN SUMMARY

<u>Number</u>	<u>Purpose</u>	<u>Special Test Activities</u>
1	Shakedown	- Program debugging; column inventory experiment
2	Shakedown/baseline run	- Accumulation of steady-state data
3	Announced diversions (all parties informed of diversion timing)	- 17 abrupt (batch) diversions ranging from 5 kg of uranium to 0.25 kg of uranium - 4 protracted removals, 16-hour duration each, rates from 0.2 kg of uranium to 0.6 kg of uranium per hour
4	Unannounced diversions (accounting personnel not informed of timing)	- 3 abrupt removals, 0.3 kg of uranium from a storage tank, 0.5 kg of uranium, and 1.2 kg of uranium from LBP surge tank - 2 protracted removals, 0.5 kg of uranium per hour, ~12-hour duration
5	DOE contractor demon- stration	- 1 abrupt removal, 0.25 kg of uranium from storage tank - 1 protracted removal, 0.85 kg of uranium per hour for 16 hours; column inventory experiment
---Process and Program Enhancements Installed---		
6	Enhancement tests	- Additional steady-state data - 4 protracted removals, 0.5 kg of uranium to 0.2 kg of uranium per hour, 16-hour duration each

Subsequent runs finally recovered most of this material indicating that the "missing" organic was probably distributed as undetected layers on peripheral minirun storage tanks.

Thus, inventory measurement procedures must consider the possibility of two-phase solutions at all measurement points. The results also point to constraints on measurement technology and implementation due to plant design. The minirun system is an isolated portion of the fuel reprocessing plant. The full plant is interconnected with recycle pathways, and it is difficult to isolate a portion of the plant and monitor all possible routes of material in and out. An effective safeguards system must consider the full plant.

TABLE 16-III

MINIRUNS MATERIALS BALANCE SUMMARY

	With Input/Output (kg U)		Without Input/Output (kg U)	
Run No. 1	BI	7.00	BI	7.00
	Input(1-21)	1173.58	Input	501.37
	Product (1-15)	671.03	Waste	126.88
	Waste (S.C.)	126.88	EI	339.08
	EI	339.08		
	ID	43.59	ID	42.41
Run No. 2	BI	339.08	BI	339.08
	Input (22-41)	1080.64	Input	169.59
	Product (18-35)	914.74	Waste	121.69
	Waste (1-5)	121.69	EI	398.62
	EI	398.62		
	ID	-15.33	ID	-11.64
Run No. 3	BI	398.62	BI	398.62
	Input	699.07	Input	88.31
	Product	608.81	Waste (LAWB)	194.94
	Waste (LAWB 6-11)	194.94	(GPW)	1.09
	(GPW)	1.09	EI	296.13
	EI	296.13		
Run No. 4	ID	-3.28	ID	-5.23
	BI	296.13	BI	296.13
	Input	924.69	Input	193.30
	Product	726.11	Waste (LAWB)	134.65
	Waste (LAWB 12-18)	134.65	(HWW)	2.49
	(HWW)	2.49	EI	368.26
Run No. 5	EI	368.26		
	ID	-10.68	ID	-15.97
	Cumulative (Runs 1-4)	14.37		9.57
	BI	368.26	BI	368.26
	Input	416.27	Input	--
	Product	421.67	Waste (LAWB)	71.76
Run No. 5	Waste (LAWB 19-25)	71.76	EI	292.18
	EI	292.18		
	ID	1.08	ID	4.32
	Cumulative (Runs 1-5)	13.29		13.89

B. In-Process Inventory Determinations

During the course of the five miniruns, about 1000 in-process inventory determinations were made at the rate of one per hour. Figure 16-2 is a summary of a typical in-process inventory determination, which includes current liquid level, solution density, temperature, and solution composition data for each process vessel. Volumes and total uranium contents are calculated for each vessel and summed up to give the total measured inventory. This total is subtracted from the total system inventory (which is either the current difference between accumulated inputs and outputs or the total beginning inventory of uranium in the minirun loop) to give an unmeasured inventory (UMI). This UMI was not zero in the minirun tests because raffinate waste losses and line holdups were not measured or estimated.

Evaluations performed by AGNS personnel involved monitoring of the UMI values to detect unauthorized removals and to explain significant changes in the data. Figures 16-3, 16-4, and 16-5 are typical UMI vs time plots that were generated as part of the data evaluation effort.

It is evident from these plots that improvements were achieved in the stability of the data with each successive test. A number of factors contributed to this improvement. First, Run No. 1 was most unstable because a continuous in-line dilution system was used for the feed. A batch-blend system was adopted for succeeding runs and the stability of the system was greatly improved. Second, the data reflect fluctuations caused by the initial inhomogeneity of each feed batch. In the future, an estimated value will be used for the uranium concentration until tank mixing is complete. Third, partially plugged dip-tubes caused erroneous readings when not corrected. This problem was overcome by installing purge-air humidifiers on the troublesome dip-tubes. Also, following Run No. 3, several pressure transmitters were tied into an automated calibration system in which the calibrations of process instrumentation were periodically compared with a high-precision digital manometer. This modification alone reduced the uncertainty of level and density readings by almost an order of magnitude.

C. The Pulsed Columns

Under normal process conditions it is not possible (or at least not very convenient) to measure the in-process inventory of nuclear material in the pulsed columns. However, estimates of the in-process inventory can be obtained if near-real-time measurements are available on the column inlet and outlet streams.

The Los Alamos studies of near-real-time accounting^{1,2} showed that estimates of the AGNS column inventories to 10% or better should be adequate for sensitive detection of losses. Under the sponsorship of the Los Alamos Safeguards Systems Group and with participation by the nuclear industry (AGNS and General Atomic) and universities (Iowa State and Clemson), techniques for estimating the inventory in contactors were developed.

Figure 16-6 is a schematic diagram of a pulsed column. Flow rates of all inlet streams normally are monitored to control the columns. For improved control of the columns and for nuclear materials accounting and control, it is also desirable to measure the concentrations of nuclear materials in the feed, product, and waste streams.

IPI DETERMINATION SUMMARY

NUMBER 134

TIME 7229

(= 2 : 0)

DATE 17-Jun-80

FOR TANKS

	PUFROB	PU CTH	1 PU STG	2 PU STG	3 PU STG	PU RIK	1BP	1 SOL FB	3P CONC
MP	2010	2054	2011	2012	2013	2008	2017	2015	2122
LR	84.9618	45.418	21.0229	12.1963	15.3163	55.7624	71.2445	62.7637	118.743
DR	15.8905	14.7108	13.4956	12.9025	13.8784	11.4247	11.531	8.18516	14.1783
T	30.9661	30.9661	31.5538	27.6213	28.0184	25.1027	24.7972	25.7272	0
O	0	0	0	0	0	0	0	0	0
HA	1.936	0	1.655	1.665	1.595	3.161	2.953	.041	0
BN	1.4972	0	1.49455	1.41105	1.49135	1.1441	1.1729	.0325	0
UCONC	.33	.25605	.33416	.27046	.33303	.03753	.02572	.0118	.25605
VOL	172.69	48.6032	49.1117	37.3855	42.5643	587.149	882.531	7531.93	74.0968
O	0	0	0	0	0	0	0	0	0
O	.33	0	0	0	0	.0381	.0559	0	146.088
O	0	0	0	0	0	0	.02898	0	0
KGU	56.9878	12.4449	16.4112	10.1113	14.1752	22.0357	22.6987	88.8767	18.9725

FOR COLUMNS

	2A	3A	2B	3PS	3B
MP	2109	2111	2110	2113	2112
LR	19.4101	18.9444	9.23238	18.1686	6.37534
DR	8.85809	9.08398	8.19916	7.7674	8.45068
WR	445.999	464.588	371.88	146.973	599.149
LI	11.9446	13.0655	0	10.5511	10.6445
SOLV FLOW	217.288	79.1758	0	0	-35.5599
SCRUB FLOW	31.9043	12.9328	78.5815	0	173.656
SCRUB HA	1.29014	1.29014	.155785	0	.155785
FEED FLOW	440.778	58.5903	217.288	0	79.1758
FEED CONC	.04669	.0452	.0531293	0	.0666817
PROD FLOW	0	0	78.5815	0	173.656
PROD CONC	.0531293	.0705637	.0488	-.0054	.041
KGU	9.83537	28.9611	17.6901	4.55025	49.373

TOTAL MEASURED INVENTORY = 373.17 KGS U (EXCLUDING NEGATIVES)

TOTAL SYSTEM INVENTORY = 482.6 KGS U

UNMEASURED INVENTORY = 109.43 KGS U

Fig. 16-2.
In-process inventory determination summary.

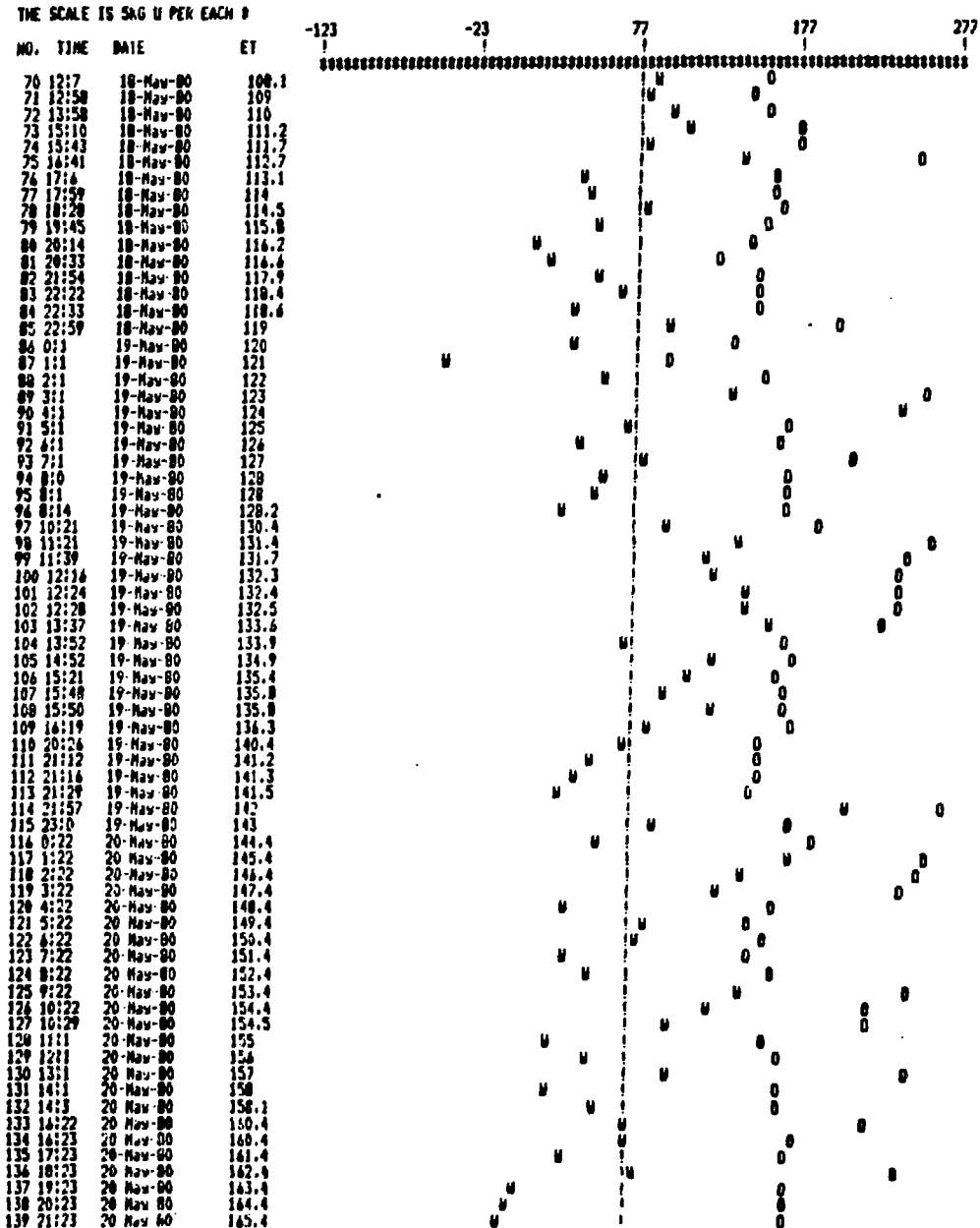


Fig. 16-3.

Minirun No. 1. Unmeasured inventory plot with (W)
and without (U) column inventory estimates.

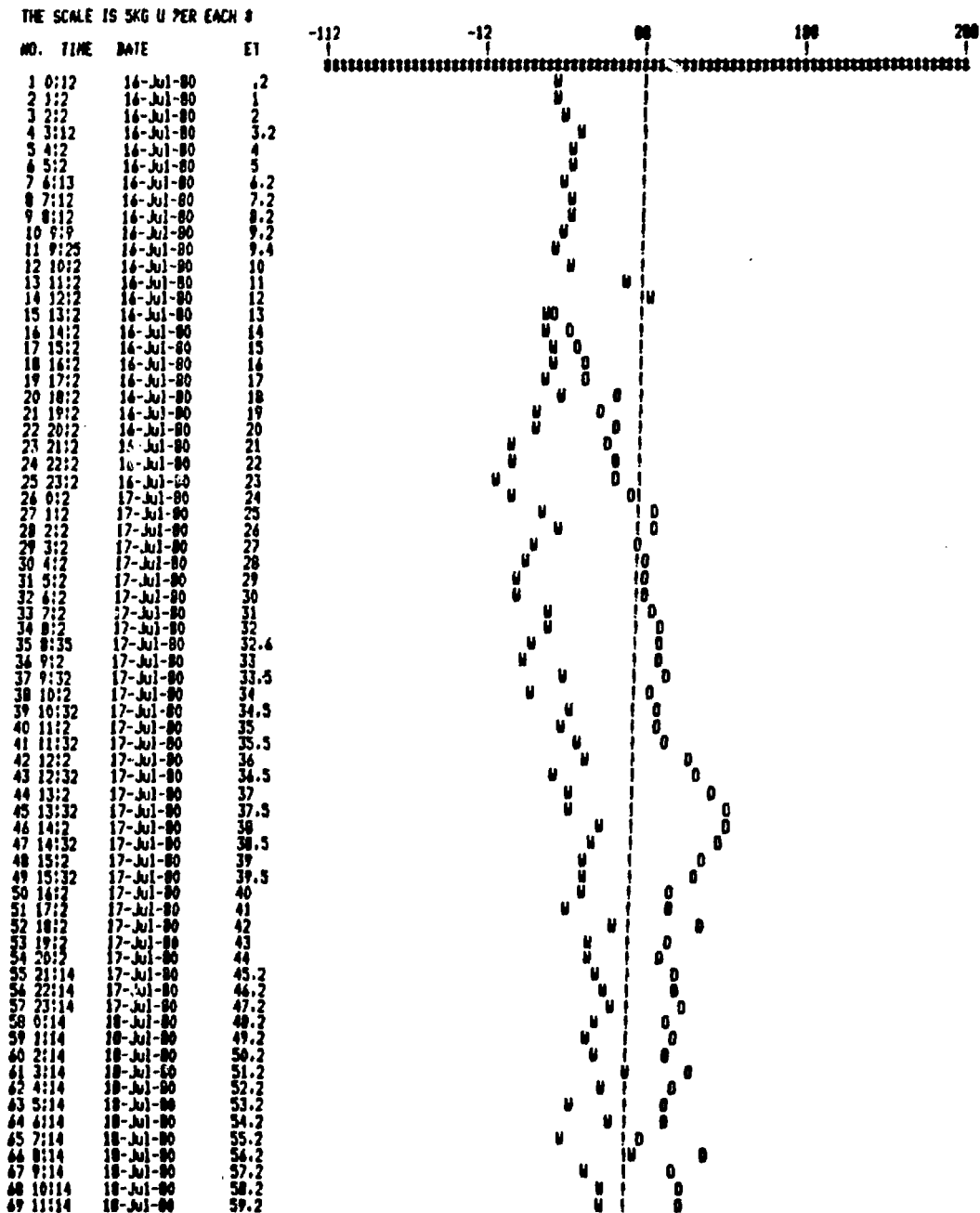


Fig. 16-4.

Minirun No. 3. Unmeasured inventory plot with (W) and without (O) column inventory estimates.

THE SCALE IS SKR U PER FACH *

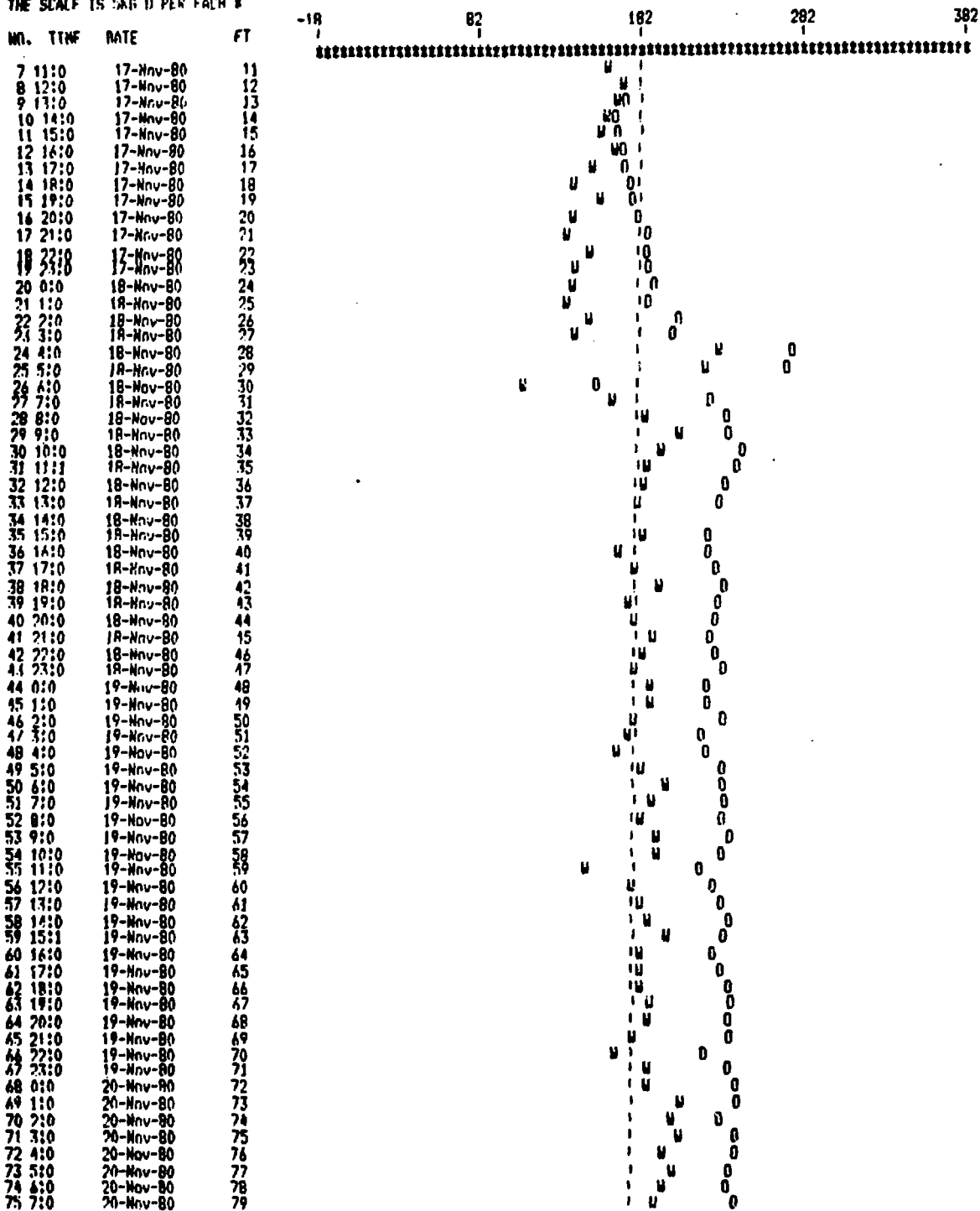


Fig. 16-5.

Minirun No. 5. Unmeasured inventory plot with (W)
and without (O) column inventory estimates.

"A" Column

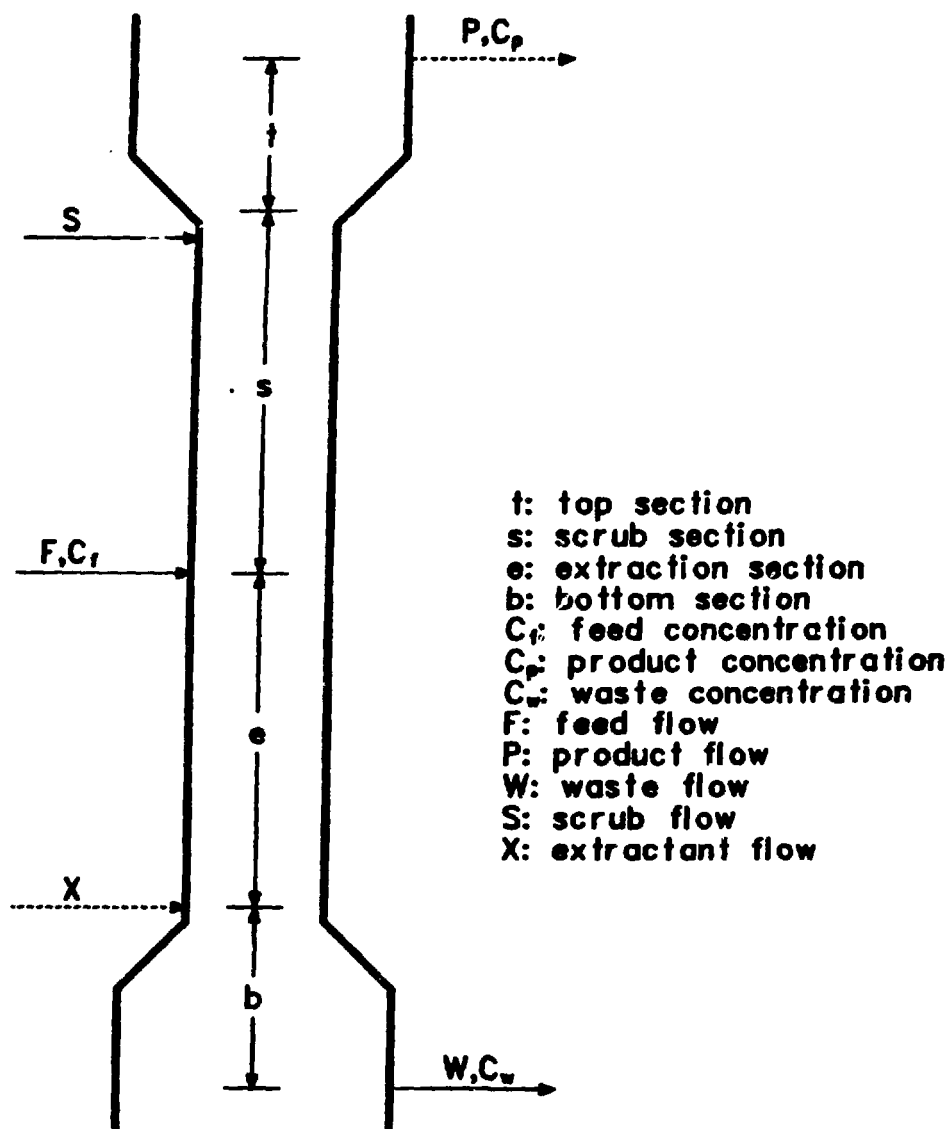


Fig. 16-6.
Pulsed-column diagram.

These same measurements can be used to estimate the in-process inventory of nuclear materials in the columns. The form of the estimator is given by³

$$H = H_f C_f + H_p C_p + H_w C_w, \quad (1)$$

where H is the total column inventory; C_f , C_p , and C_w are measured concentrations in feed, product, and waste streams; and H_f , H_p , and H_w are constants determined experimentally and through engineering models of specific contactor systems.

Experiments at AGNS during the miniruns indicate that the column inventory estimates are good to 5 to 25% for individual columns and to about 10% for the total inventory in all four pulsed columns during smooth operation of the process. These experiments consisted of draining the columns into holding tanks at the end of the minirun. The contents of the holding tanks were sampled and analyzed for uranium, and the measured uranium inventory was compared with the inventory estimated for the columns.

D. Decision Analysis

The AGNS minirun data were analyzed using the Los Alamos decision analysis techniques previously described by Dr. Shipley in Session 14. Several unit process accounting areas (UPAAs) with overlapping boundaries were defined. This was possible because at certain points in the process there are redundant measurements; for example, the LBP tank drop-out rate and the 2AF stream head-pot flow meter both measure the feed flow rate. Likewise the product solutions can be measured both in the catch tank and the product sample tank. Materials-balance data from overlapping UPAAs and redundant measurements were very useful in detecting and localizing losses and in maintaining continuity when there were measurement problems.

Data from each UPAA were examined using a two-step scan-search procedure. In the scan mode, materials-balance and cusum (cumulative materials balance) plots were produced for selected time intervals, along with tables and plots of measurement data from selected instruments. These scan data were examined for evidence of significant outliers or trends. If significant losses were indicated, a search of the data was performed in which an alarm chart was generated. In the search mode, the most significant sequence of materials balances was identified, and the amount, time, and location of the apparent loss were determined.

Four Los Alamos computer codes were implemented at AGNS for analyzing data from the miniruns. The MESSAGE and DECANAL codes were developed previously to apply the decision analysis techniques to near-real-time accounting data. The code RADAR was developed specifically to read the AGNS measurement data. The code FUNNEL was an executive program that selected the particular UPAA and data sets for analysis, aggregated the measured values, and calculated net transfers, in-process inventories, and their statistical uncertainties. These results were transmitted to MESSAGE and DECANAL and analyzed for unmeasured losses.

Figures 16-7 through 16-11 show data from steady process operation during minirun 4 (September 4-8, 1980). The data sets were collected and analyzed every hour.

Figure 16-7 shows the total in-process inventory of uranium estimated for the pulsed columns. The inventory is slowly varying,

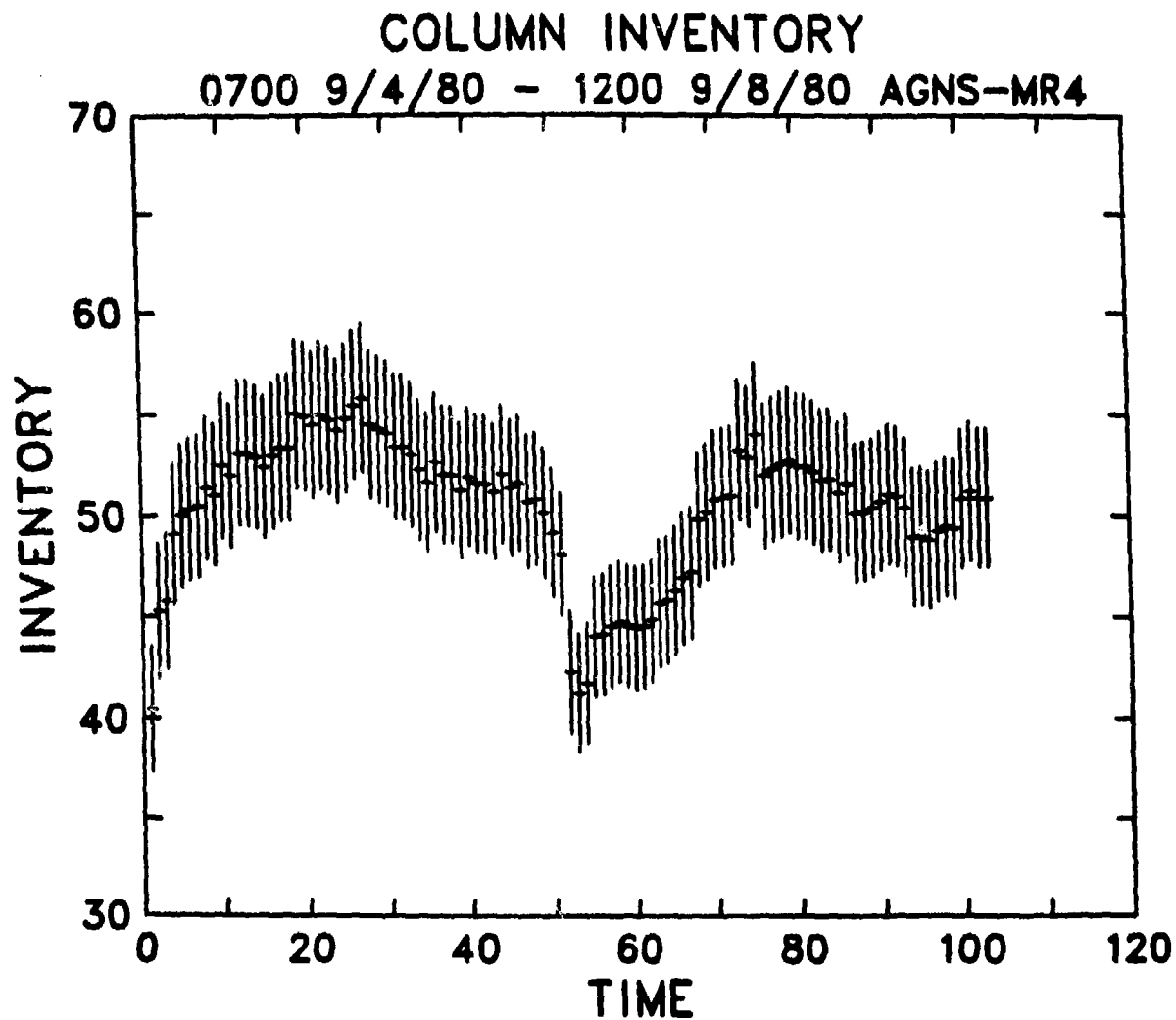


Fig. 16-7.
Estimated in-process inventory in the pulsed columns.

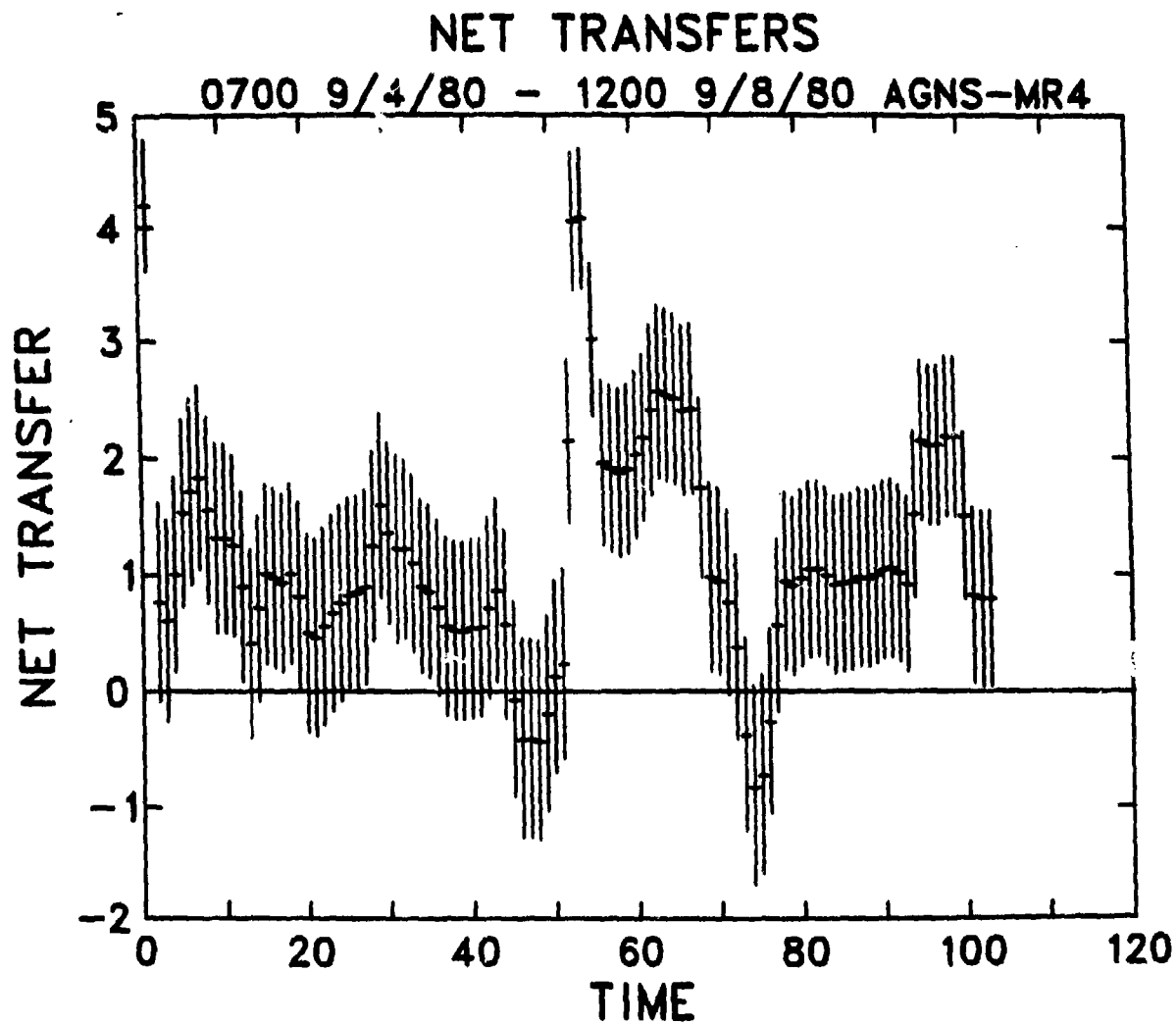


Fig. 16-8.
Net transfers (inputs minus outputs) across the columns.

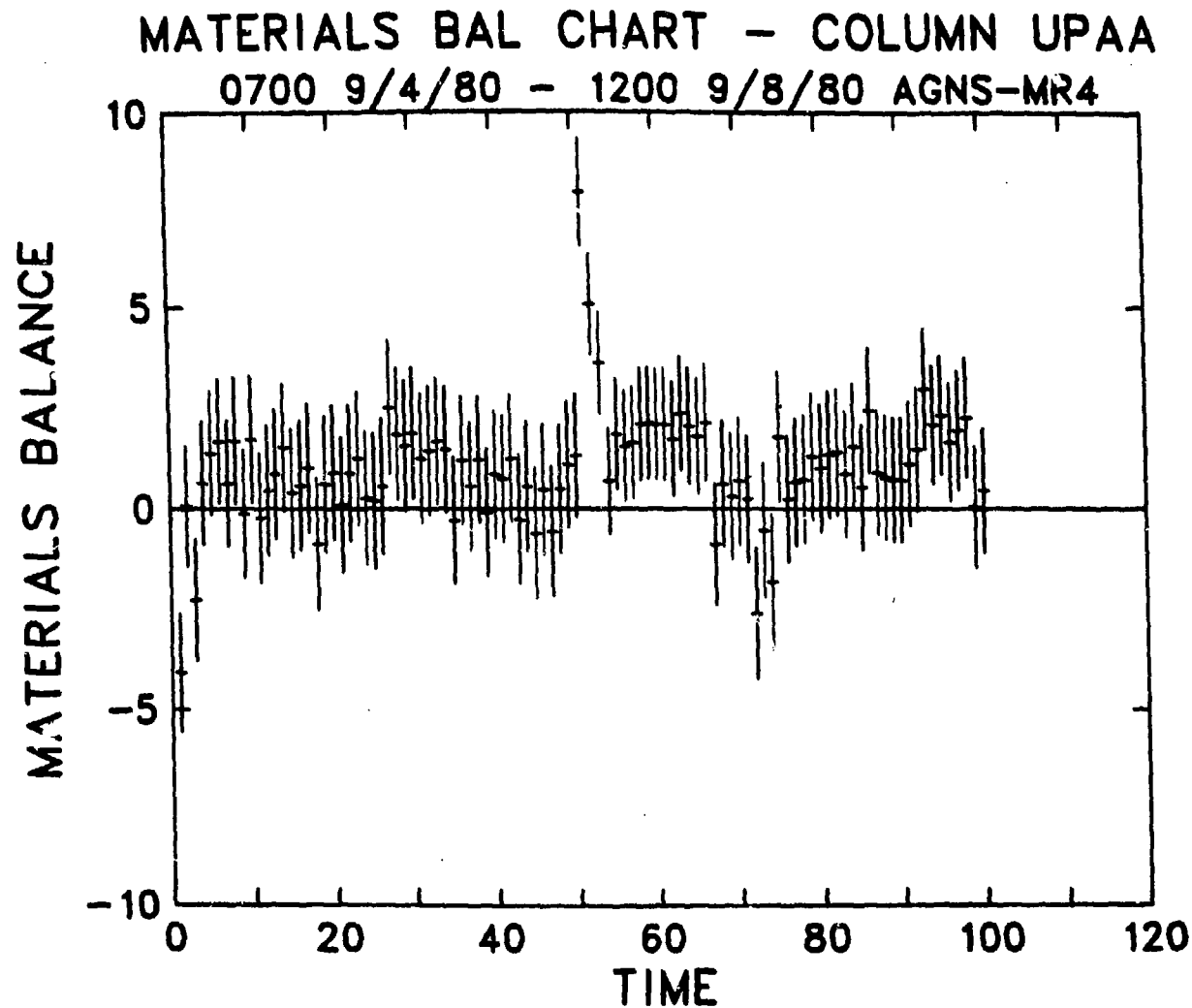


Fig. 16-9.
Plot of materials balances during minirun 4.

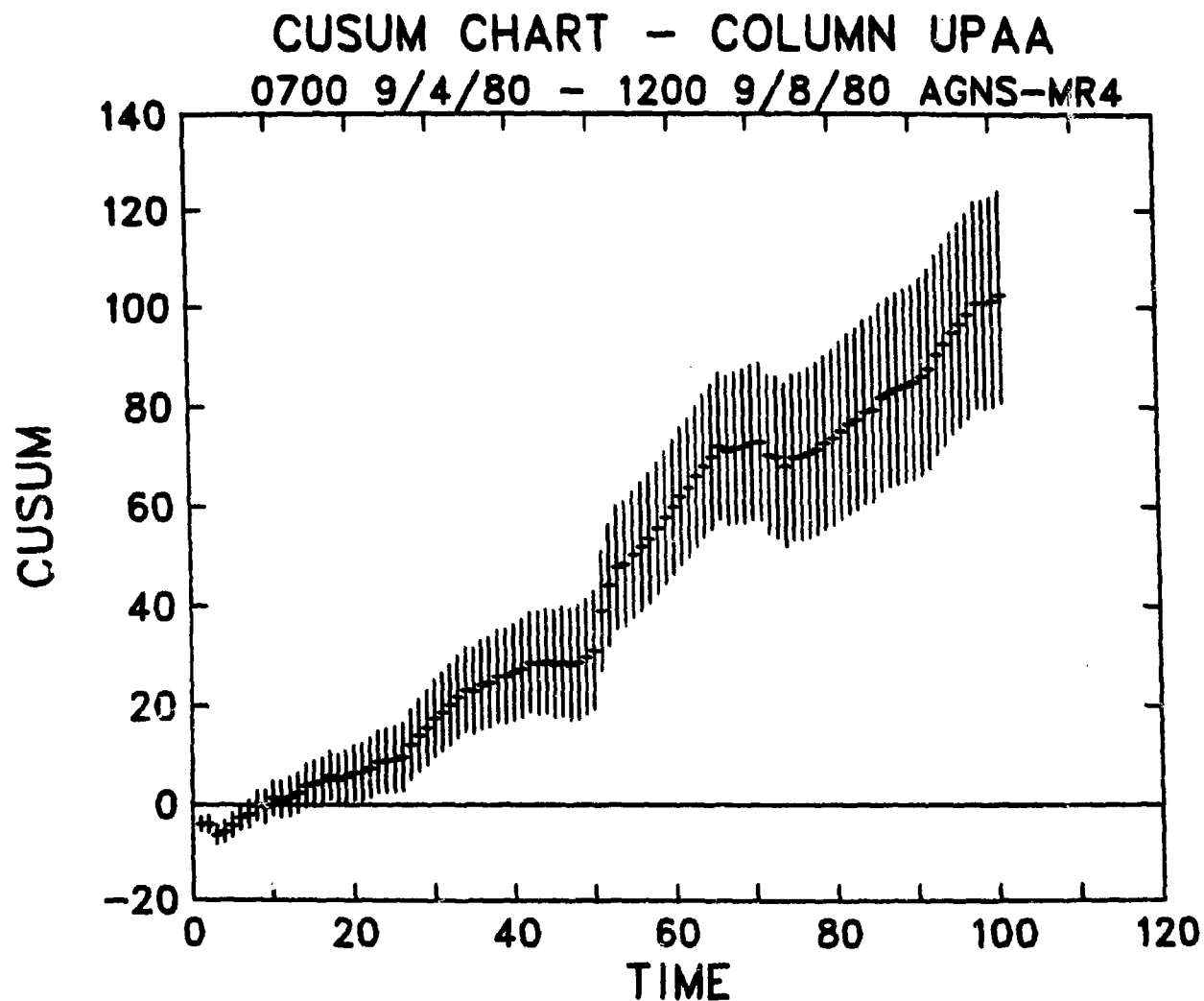


Fig. 16-10.
Cumulative summation of materials balances during minirun 4.

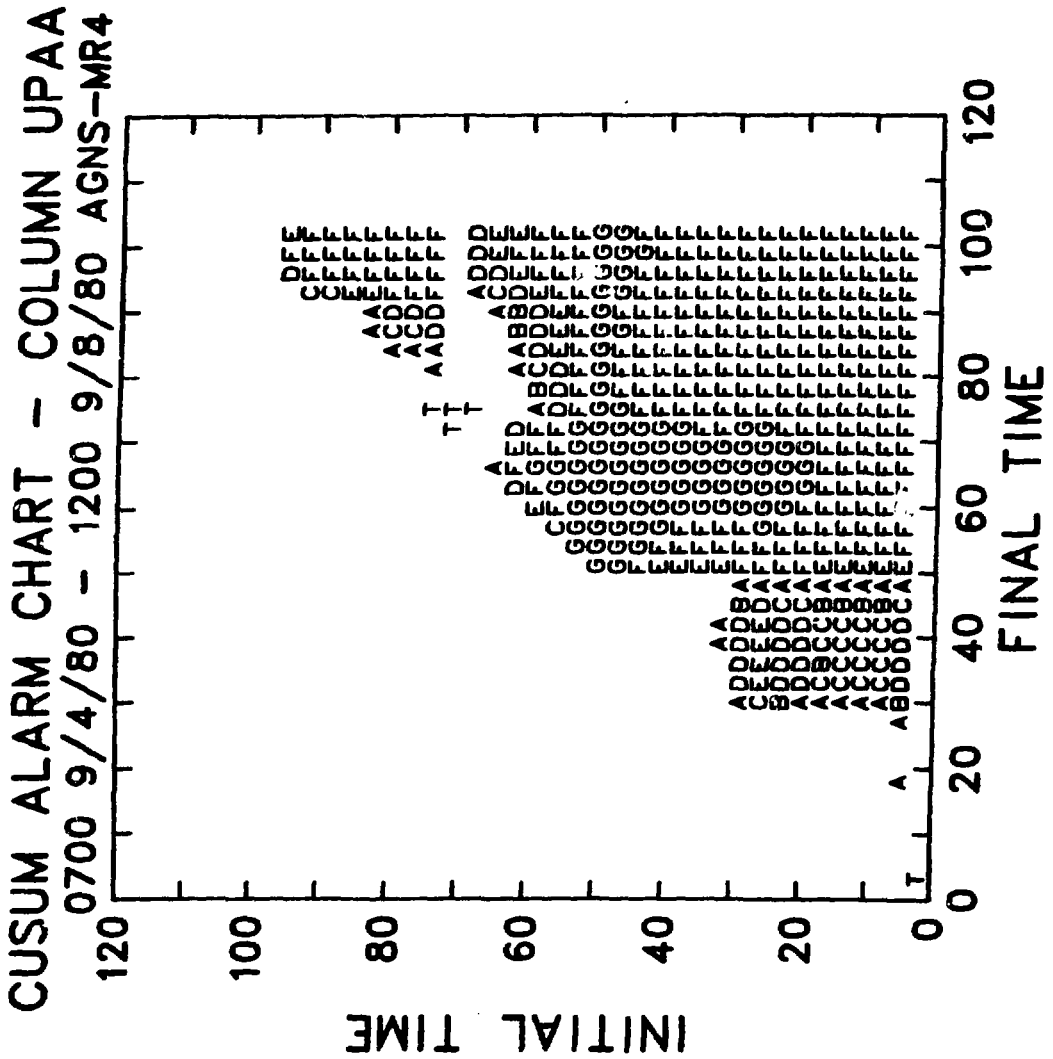


Fig. 16-11.
Alarm chart corresponding to the materials-balance data of minirun 4.

except near balance number 50 where there was an abrupt shift caused by an abnormally low uranium analysis.

Figure 16-8 shows the net-transfer data (inputs minus outputs) across the columns and the Product Concentrator, that is, from the LBP tank to the Product Catch Tank. Figures 16-9 and 16-10 show materials-balance and cusum plots obtained by combining the in-process inventory and net-transfer data. Three separate trends are apparent in the cusum plot, corresponding to two protracted diversion tests from intermediate product streams (balance numbers 20 to 40 and 80 to 100) and an unexpected rapid loss of uranium to waste (balance numbers 50 to 70).

Figure 16-11 is the alarm chart corresponding to the cusum plot of Fig. 16-10. Note that all three trends produce highly significant alarms (F and G) and clusters of many alarms. This is clear evidence that unmeasured losses are occurring and that an investigation is required.

E. Lessons Learned

1. Near-real-time accounting for nuclear materials is sensitive to losses from the process area of a large nuclear fuels reprocessing plant.
2. Timely measurements of process streams and in-process inventories are necessary. The in-process inventory measurements may be relatively imprecise and inaccurate compared with the stream measurements.
3. Analysis and display methods geared to ease of understanding and interpreting the data are necessary components of near-real-time systems.
4. Overlapping UPAAAs and redundant measurements are helpful for system reliability and for localization and detection of losses.
5. The facility is an integrated whole, and the safeguards system must address the entire facility. Statements concerning the overall sensitivity of the safeguards system must recognize this fact.

IV. DESCRIPTION OF LOS ALAMOS DYMAC SYSTEM

As nuclear materials safeguards research and development projects mature, it becomes essential that the improved instrumentation and techniques be applied in an operating plant environment. Only then can the resulting advantages and disadvantages be judged. The Los Alamos National Laboratory has developed a near-real-time, advanced nuclear materials accountability system, DYMAC, at its Plutonium Processing Facility.^{4,5} This system will demonstrate the applicability of these techniques and provide a basis for evaluating wider implementation.

The processing system and the accountability system have been installed and developed in parallel. At this time, the facility is virtually complete. The responsibility for continued routine operation and maintenance of the accountability system has been transferred from the Safeguards Research and Development staff to the Operational Safeguards staff.

DYMAC embraces the concept of maintaining a materials balance around a unit process by measured values (see Fig. 16-12). The unit process may be a glovebox or part of a glovebox, or two or more

SCHEMATIC OF A DYMAC UNIT PROCESS

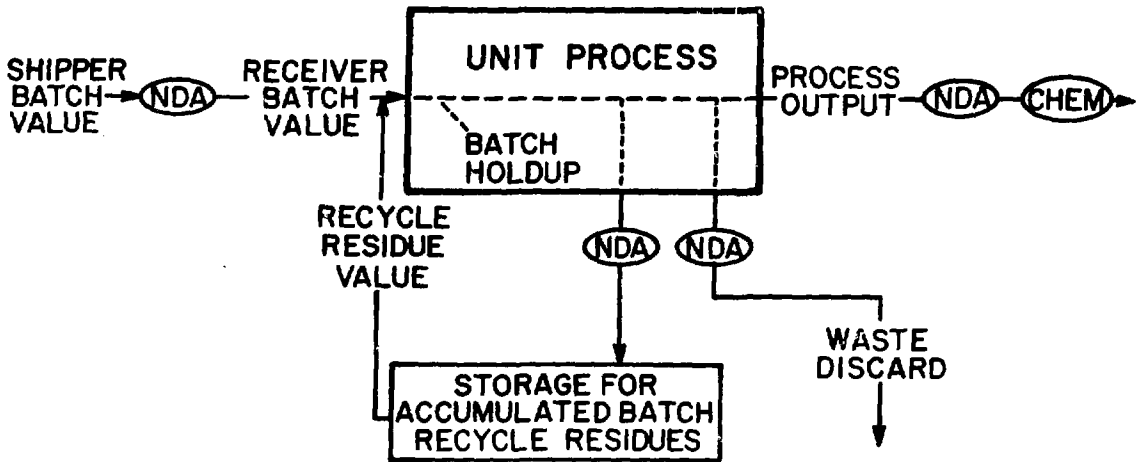


Fig. 16-12.

Based on in-line NDA instruments, DYMAC maintains a materials balance around each unit process.

adjoining gloveboxes. This approach provides good information on the location of the material. Furthermore, some unit processes may be able to complete their batches and have time to perform a clean-out. This allows the removal of scrap and holdup, to reduce the material in process (MIP) in that area to a minimum, thereby improving the balance accuracy. These cleanouts can be performed for a localized area without having to wait for a total shutdown.

The heart of the DYMAC system is a dedicated minicomputer, which receives information on activities and transactions within the Plutonium Processing Facility, and can provide at any time the location, quantity, and composition of all special nuclear material (SNM). Nondestructive assay (NDA) instruments are located strategically throughout the plant. Measurements made with this instrumentation are sent to the computer, either directly or by operator intervention, at computer terminals located throughout the plant (see Fig. 16-13).

The fundamental requirement of DYMAC is that whenever a significant change is made in a batch, or when a batch moves from one area to another, the computer is notified of this action and information is sent to the computer to characterize the change. The computer uses this information to generate a computer transaction. No movement of the sample, nor change in its character, takes place without the computer being notified, or without the computer generating a transaction indicating the change.

At each unit process all the data needed to prepare an inventory file, a transaction file, and an in-transit file are provided. Some data are entered by the process operator and some by the computer. Just what is entered by each depends on the kind of process being carried out. Each process area has a transaction list that the

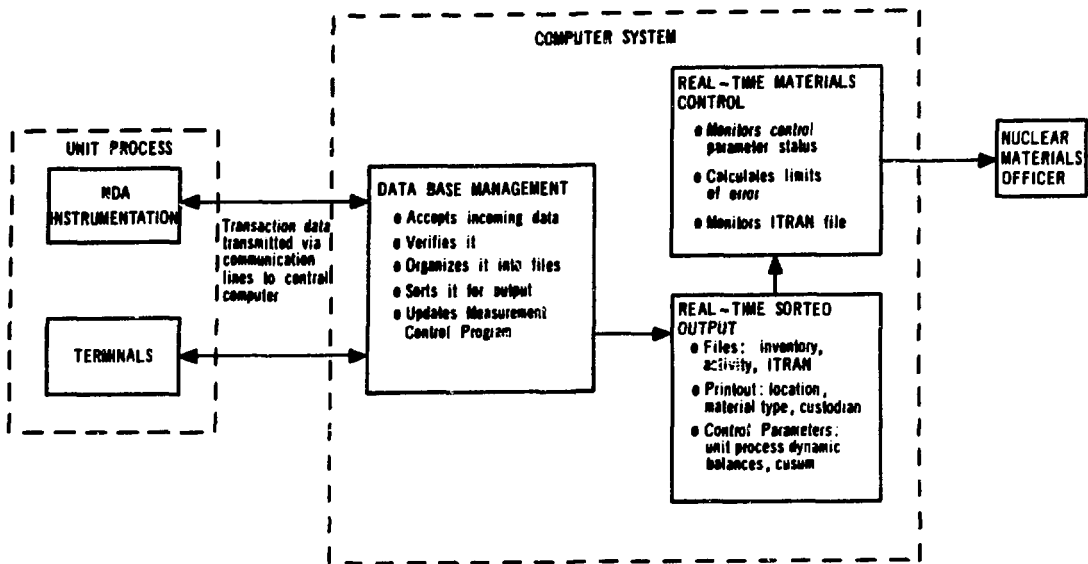


Fig. 16-13.
The DYMAC system configuration.

operator can call up on the display of his computer terminal. After a transaction has been selected from the list, a sequence of questions will appear on the terminal screen. The operator answers them one by one. At the end of the questioning, a full display will appear on the screen to show the operator what he has entered. A sample display is shown in Table 16-IV. This is the operator's opportunity to check the entries to be sure the data are correct before notifying the computer to update the transaction file and the inventory file.

In addition to detecting errors, DYMAC tries to minimize the opportunities to make them. Whenever it is possible to let the instrument provide the input, or when the computer can generate or transfer data, this is done in preference to allowing human input. Some instrument measurement results are automatically read by the system, and diagnostics are performed on the data to ensure their integrity and to guarantee that the transmission has been error-free. To provide the computer with the precoded information, each process in the facility has been analyzed to determine materials flow and measurement points. For each step in the process, the computer has been precoded to know whether the item's name is changing, whether it is to be divided to form new items, or combined with another item. The computer also knows what type of material is involved, what verification is needed, what calculations to perform with the measured data, and whether completion of a process step indicates that a materials balance can be drawn.

Accountability personnel regularly assess the inventory information to determine whether safeguards criteria are being met. They examine the balance of material that remains in an area after a batch is processed to ensure that no SNM has been diverted (see Fig. 16-14). On detecting an anomaly, an investigation is initiated.

TABLE 16-IV

TRANSACTION NUMBER 045N9
 TRANSACTION MADE ON 9/19/78 AT 10:48
 FROM PERSON: HGM TO PERSON:
 NUMBER ***** FIELD ***** FROM ***** TO *****

1,2	ITEM ID	FS5301	SC5301
3,4	ACCOUNT	711	711
5,6	RECEIPT AREA	OB	OB
7,8	PROJECT	413	413
9,10	SPECIAL DESIGNATOR	S1	S1
11,12	LOCATION	G133	G133
13,14	SHELF		
15,16	ITEM DESCRIPTION	CA1	DA9
17	"FROM" REMARKS: FEED STOCK IN OXIDE BLENDING		
18	"TO" REMARKS: SCRAP FROM OXIDE BLENDING		
19	DESTINATION:		
20,21	SNM AMOUNT: 4.0 G OF TYPE 54	BULK AMOUNT:	29.00 G
22	ENRICHMENT: 11.74%	ISOTOPIC WEIGHT:	4. G
23,24	IMPURITY .00% OF	MEASUREMENT CODE:	F10
25,26	SEAL NUMBER:	COEI NUMBER:	748
27	ISOTOPIC A: .0006, B: .8651, C: .1174, D: .0149, E: .0020		

RESULTS

711/54/FS5301	NM VALUE: 366.00 G,	BULK VALUE: 2471.00 G
711/54/SC5301	NM VALUE: 4.00 G,	BULK VALUE: 29.00 G

TRANSACTION OK? (Y...YES, N...NO)

Such a system constitutes a deterrent to covert nuclear materials diversion by facility personnel. The improved timeliness and sensitivity also complements the facility's physical security system.

The goals of the DYMAC system are to demonstrate the reliability and operational feasibility of NDA instrumentation in a production environment, to generate inventory data efficiently and accurately, to be sensitive to detection of missing materials, and to be compatible with production control and quality assurance in a cost-effective manner. As DYMAC meets these goals, it will demonstrate the feasibility of applying its techniques to other processing environments.

V. EVALUATION OF DYMAC SYSTEM PERFORMANCE

The concepts of a DYMAC System have been espoused on many occasions (see Refs. 6-9), but have never been reported in any one document. Briefly, these concepts require adoption of the following principles:

1. The processing plant is divided geographically into non-overlapping, contiguous materials balance areas (MBAs), each of which is divided into unit processes. No area of the plant where SNM may reside is excluded. Each unit process is completely contained within one MBA.
2. Each item of SNM is assigned a unique name. A central computer keeps track of each item by its name.
3. No material crosses a unit-process boundary or changes chemical character without a transaction being performed to update the book inventory that resides in the central computer.

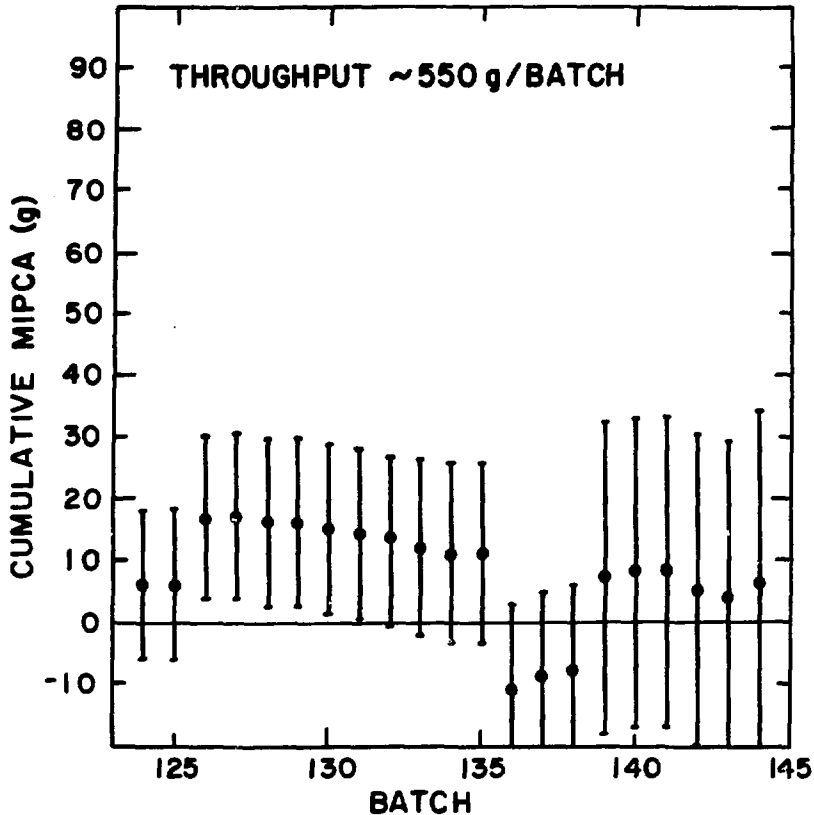


Fig. 16-14.

A cumulative sum chart for the dynamic materials balances of a unit process.

4. Measurements are made in near-real-time on each item as it enters and as it leaves a unit process. All items, even waste and scrap, are measured.
5. All measurements are made nondestructively with instruments that are certified daily by comparison to standards traceable to the National Bureau of Standards.
6. All NDA instruments transmit measurements directly to the central computer without process-technician intervention.
7. Two persons are always involved in the transfer of an item from one unit process to another: one person to measure and send it, the other to receive and measure it. The sender and receiver may together perform a measurement on a single instrument to satisfy this requirement.
8. The person who makes a measurement is responsible for making the related transaction. Transactions must be made immediately upon transfer of an item or a change in its chemical character.

9. A Nuclear Materials Officer (NMO) is responsible for accountability of all the SNM in the plant. The NMO reports to an organization that does not have immediate responsibility for plant production. The effectiveness of a DYMAC System depends on the effectiveness of the NMO. However, the NMO cannot be effective without timely and reliable data concerning the SNM content and location of every item in the plant. A DYMAC system can and must supply this information.
10. The accounting system and associated records must be auditable in the usual sense; for example, it must be possible to develop a detailed history of the passage of an item through the facility.

The system installed at the Los Alamos plutonium facility (PF/LASS) does not embody all of the DYMAC principles. Several compromises were necessary. Some were made in the interest of process efficiency; others were made because it was not technologically possible to fulfill all of the DYMAC precepts. Thus it is appropriate to differentiate the conceptual system (DYMAC) from its application at the plutonium facility (PF/LASS).

The main features of PF/LASS as documented in the DYMAC Phase II report¹⁰ are listed here. PF/LASS is a system for near-real-time accountancy of SNM. The system incorporates NDA instrumentation--some on-line, some off-line--for analyzing and verifying SNM content, with a set of instructions for handling and measuring SNM as it passes through the facility. These measurements are either typed on a terminal or transmitted directly to the computer over communication lines that connect some of the electronic balances to the central computer. For each transaction, the computer uses the measurement data and the information supplied by the process technician to update its inventory. The inventory data base may then be queried by process technicians and supervisors to obtain up-to-date information on the location and status of any item in the plant.

PF/LASS departs from DYMAC in the following ways:

1. Not all measurements are made on certified instruments. For example, when a PF/LASS balance is out of service, a technician sometimes uses a process balance to obtain the measurement data but reports to the central computer that a PF/LASS balance was used. While this practice is undesirable in principle, it is justifiable in terms of processing efficiency. Because process balances are calibrated and a check weight is performed before a measurement is made, no problems have resulted.
2. Many material transfers involve only one individual who often carries the material across a unit-process boundary to continue processing. In addition, only one measurement is made as material crosses a boundary, rather than the two required by DYMAC principles. Since DOE regulations do not now require double measurement, and since process efficiency would suffer if such a rule were adopted, the single measurement approach is used. No associated problems have resulted.
3. Some determinations of SNM content must be inferred rather than measured, primarily because not all residues are amenable to measurement on current instrumentation. For example, at present there are no NDA instruments in the PF/LASS system for assaying PuF_4 , although experimental models of such an instrument are undergoing trials.

4. Not all of the NDA instruments are tied directly to the computer. At present, only 18 balances are directly connected. Thus, most measurements are reported to the PF/LASS computer by process technicians. This is a violation of the tenets of DYMAC, but is allowed by DOE regulations.
5. The NMO is responsible to the plant manager. This is a violation of DYMAC precepts, but is acceptable under DOE regulations.
6. Many features of the present software system are not transportable. The record structure is unique, the packets containing the interactive dialogue are unique, and the method of keying records is unique. Thus the software developed for the Los Alamos plutonium facility cannot be directly useful at other installations unless exactly the same computer (a Data General Eclipse C330), the same operating system--the Advanced Operating System (AOS), and the same file structure are used.

Many anticipated benefits of PF/LASS have been realized. Some impact primarily on safeguards, others on process control. These benefits, and features of the system that bring them about, are outlined below. They include quick inventory, decreased error rate, timely accountability, on-line instrumentation, instrument reliability, instrument measurement accuracy, system reliability, system flexibility, improved reporting, improved process control, and process-technician satisfaction.

1. Quick Inventory. The most conspicuous success of PF/LASS has been the decrease in the amount of time required for inventory. Preparing book inventory reports with PF/LASS is so quick and easy that a book inventory report is routinely prepared on the last working day of each week for each glovebox in the reprocessing wing; the report is then confirmed by the individual responsible for the area.

2. Decreased Error Rate. Except for the plutonium facility, the Los Alamos National Laboratory uses a standard paper-entered accounting system. Although mistakes in entering and transcribing data on forms are infrequent, much time and effort is expended in detecting and rectifying these errors. Before PF/LASS, the production control office at the plutonium facility made about 80 corrections per month to 8-10 000 transactions in the data base just to correct item names. With PF/LASS, although few of the computer's potential verification capabilities have been incorporated, the error rate has decreased dramatically. (At present, little is done beyond checking whether the item identification number actually exists in the data base before allowing the transaction; even this simple check catches many errors.) The production control office estimates that four additional employees would be needed to detect and rectify errors if the error rate equaled that existing before PF/LASS was initiated.

3. Timely Accountability. Because of reduced errors and a more up-to-date book inventory, the accountability of the plant is greatly improved over that of the previous facility. Although not all aspects of certain inventory differences are fully understood, and although not all of the NDA instruments are connected directly to the computer, the timely nature of the data base is a clear improvement over the old paper system.

4. On-Line Instrumentation. While it has been determined that all of the NDA instruments are capable of transmitting their measurement results directly to the computer, only 18 balances have been coupled directly to the computer. For all the other NDA instruments, the process technician must note the reading and then enter it as part of a transaction on a PF/LASS terminal. This not only slows processing but increases the opportunity for error.

Another difficulty arises from failure to have the instruments on-line. Rather than take the time to certify an instrument before making a measurement, some process technicians make measurements with one instrument and report that they were made with another. To reduce the tendency of process technicians to avoid using the proper instrument, the responsibility for certifying each NDA instrument each working day has been assigned to a single individual.

5. Instrument Reliability. The past year of PF/LASS operation has seen much improvement in NDA instrument reliability.

6. Instrument Measurement Accuracy. Measurements made with the NDA instruments are accurate. For example, the solution assay instrument (SAI) measurements are considered so trustworthy by facility personnel that many samples, particularly more concentrated ones, are no longer routinely sent for chemical analysis. The availability of the SAI measurement data not only speeds the processing at decision points, but obviates the need for making a second entry to the accounting system when the results of the chemical analysis are known. Before the availability of the SAI, average values were determined for each step and were carried by the accounting system until the results of chemical analysis were obtained about two weeks later. Then the deviations from the average for 5 or 10 samples were credited (or debited) to the appropriate MIP account. The present method is a clear improvement.

7. System Reliability. The computer itself has been quite reliable since it has been turned over from development to operations. During the three-month period of April through June 1980, there were no software failures, although some minor problems continued to be identified and corrected in the transaction packets. This followed a period of frequent failures during the conversion to a new operating system. Hardware availability has averaged between 90 and 95%.

8. System Flexibility. A serendipitous feature of PF/LASS is the manner in which it assumes the responsibility of accounting for silver, gold, platinum, and other precious metals in the facility. The system coding was designed to keep track of SNM using a two-digit code for material type. The 9X series of material type (user designated) has been assigned to accountable precious metals. The process technicians simply transfer and account for precious metals in the same manner that they account for SNM--by using PF/LASS transactions. This same approach is also used to account for nonfissile radioactive sources and to keep track of subaccountable amounts of SNM.

9. Improved Reporting. PF/LASS assists in the determination and reporting of shipper/receiver differences. Scrap lots are usually shipped with a receipt showing the net SNM content. When they

arrive at the facility, the contents are sorted into sublots of similar scrap type. Each subplot is assayed using the best method available for that subplot, and the total SNM content for the sublots is compared to the shipper's claim. The timely and convenient reports generated from PF/LASS data greatly simplify this complex process.

10. Improved Process Control. PF/LASS also provides more timely, more effective, and easier process control. Nondestructive assay allows timely determination of solution concentrations or fissile content so that decisions may be made at branch points in a batch process. Before the installation of PF/LASS, these decisions could not be made until the results of wet-chemical analysis were known, causing a delay of almost two weeks. Materials had to be returned to the vault and processing had to be halted on that item. Now, because of the NDA instruments, production need not be halted.

11. Process-Technician Satisfaction. The majority of persons at Los Alamos who have worked on both a process line with PF/LASS and on one with the standard paper system much prefer the computer-based system. This view is doubly gratifying because, as in any undertaking of this type, problems can develop because processing goals differ from safeguards goals. As indicated, compromises were sometimes necessary between the demands of efficient processing and the stringencies of a good safeguards program. That an effective system with process technician acceptance is now in place suggests that this experiment has been successful.

This first DYMAC experiment has been a success, but not necessarily in the way expected. The benefits to the processor were perhaps underestimated by the developers and thus not necessarily optimized. More discussion with the management of target processes could enhance this outcome and perhaps lead to concomitant increases in system safeguards.

Not enough attention appears to have been given initially to the "people" problems that, in retrospect, we know were bound to occur. Much was known and allowed for in instrument design; similarly, steps were taken to make the dialogue between the computer and the process technician transparent and simple. Little was anticipated and allowed for, however, in the sociology of the interaction between the two organizations involved--processing and safeguards, organizations that have different missions, backgrounds, types of employees, and personalities. The next DYMAC experiment must pay more attention to this concern and recognize that a tight safeguards system is usually perceived as inimical to efficient processing, even if the safeguards system is optimally designed. Since this conflict is inevitable, care must be taken to minimize it and to provide benefits to the processor that outweigh the detriments. More effort must be spent by system designers, not only in understanding the needs and concerns of the customer and the peculiarities of the particular operation, but in providing a safeguards system that takes these needs, concerns, and peculiarities into account. PF/LASS has clearly shown that benefits to the processor are significant. These benefits need to be communicated effectively to other facilities.

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



April 27-May 12, 1981

Session Objectives

SESSION 17: REVIEW, DISCUSSION, AND CONSULTATION WITH TECHNICAL EXPERTS

This session will be opened to general discussion and answering of questions and comments from course attendees on the material presented in Sessions 1-16. Specific problem areas will be reviewed and explained as required. Technical experts in various areas of safeguards technology and practical implementation will be available for individual consultation and follow up on special problems that individual attendees may have.



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



April 27-May 12, 1981

Session Objectives

SESSION 18: BRIEF PLANT DESCRIPTION

The plant layout will be described in relation to the key measurement points.

After the session, participants will be able to:

1. understand the relationships between plant layout, material flows, and key measurement points,
2. more fully understand later presentations on details of the measurement and accounting systems,



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



April 27-May 12, 1981

SESSION 18: BRIEF PLANT DESCRIPTION

K. P. Galbraith
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 gaudometer laboratories are located in the Specialty Fuels Building.



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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, participants will be able to:

1. understand the relationships between plant layout, material flows, and key measurement points,
2. more fully understand later presentations on details of the measurement and accounting systems,



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



April 27-May 12, 1981

SESSION 19: GENERAL PLANT TOUR

K. P. Galbraith and R. A. Schneider
Exxon Nuclear

A walk-through tour of the plant site 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 which can be seen without having to enter areas requiring protective clothing.

The tour begins at the main West Gate and proceeds down the road past the UO_2 Building to the UF_6 cylinder storage area. The participants are shown the UF_6 scale, the UF_6 cylinder handling equipment, and the places where the UF_6 cylinders enter the process building.

The tour then proceeds past the solar evaporation ponds to the scrap storage warehouse and then to the waste barrel storage area. The next stop is the Shipping and Receiving area where fuel bundle shipping containers and trucks loaded with fuel bundle shipping containers are often present.

The tour then enters the UO_2 Building showing the fuel bundle packaging and storage area, the bundle assembly area, and the fuel rod loading and pellet column weighing station. The tour then enters the area adjacent to the pellet preparation area where the pellet pressing, sintering, grinding, inspection, and weighing operations may be viewed.

The tour then leaves the UO_2 Building going out through the Analytical Laboratory and back to the main West Gate.



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April 27-May 12, 1981

Session Objectives

SESSION 20: MODEL PLANT KEY MEASUREMENT POINTS

The key measurement points for the model low enriched fuel fabrication plant are described as well as the measurement methods. These are the measurement points and methods that are used to complete the plant's formal material balance.

After the session, participants will be able to:

1. understand the basis for each key measurement,
2. understand the importance of each measurement to the overall plant material balance.



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



April 27-May 12, 1981

SESSION 20: 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 1. 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 1. 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 1. (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	Storage	
	MBA-2 Pellet Preparation	MBA-3 Rod Loading	Warehouse & Trailers
MBA-4 Analytical Laboratory	Rod Storage and Bundle Assembly ICA-2		

UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

FIGURE 1. Inventory Locations



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



April 27-May 12, 1981

Session Objectives

SESSION 21: BASIS OF ACCOUNTABILITY SYSTEM

Session 21 describes the criteria, principles, and operation of the accounting systems used in the model plant.

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,
2. understand the principles of materials accounting used to account for element and isotope in the model plant,
3. understand how the computer-based accounting system operates to meet the above objectives,



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



April 27-May 12, 1981

SESSION 21a: 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 (2σMUF). 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
- $\sigma^2_{MUF} = \sigma^2_{B1} + \sigma^2_{Rec} + \sigma^2_{Rem} + \sigma^2_{El}$
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 1.

The first two columns in Table 1 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 1 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 1 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, σ 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 discards, 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, "Procedures 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.

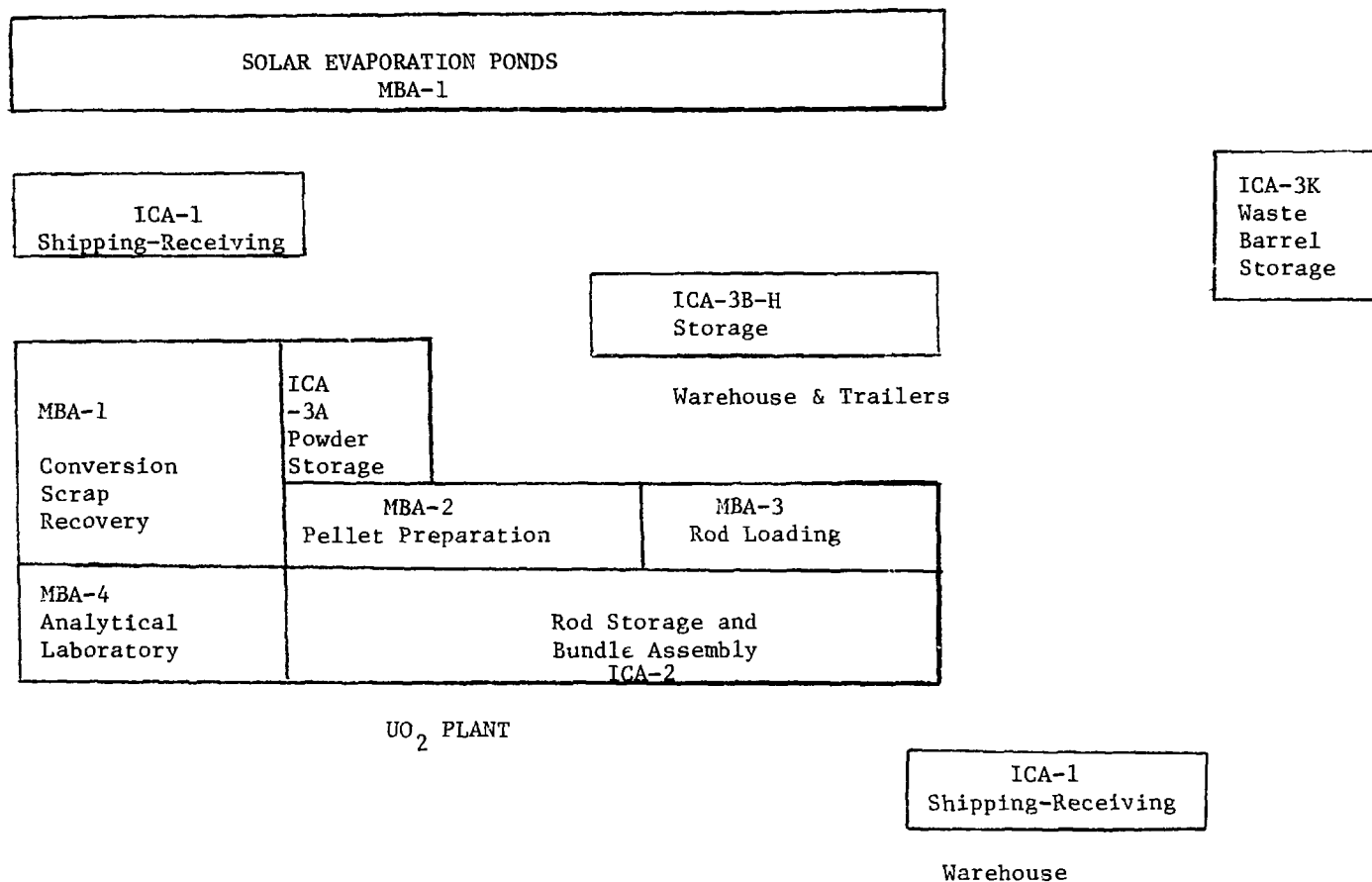


FIGURE 3. Model Plant Material Control Areas

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 in Workshop I and in Workshop II.

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-0006, 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).



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



April 27-May 12, 1981

SESSION 21b: MODEL PLANT ACCOUNTING SYSTEM

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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 21c.

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. & C. Merriam Co., 1979.

Note that the key words in the definition are recording, summarizing, analyzing, verifying, and reporting. Accounting in itself is not concerned with the development of an event or activity, but rather the accurate recording and reporting of the event or activity.

The recording function must be completed on a timely basis with a high degree of accuracy. Timely means as soon as possible. The development of real time computer systems has greatly improved timeliness. Accuracy includes not only the transmission of data from a measurement, but also involves the measurement itself. Again, modern computer systems capture the source data as close to the origination point as possible and make the data immediately available for summarization, calculation, and reporting. A basic source of recording errors stems from long elapsed times between the event or activity and its recording, or the transfer of data from one record form to another. This is especially true if pencil and paper are involved as a recording media.

In nuclear materials accounting one of the largest recording errors is the non-recording of an event or activity. Accuracy in recording must also be concerned with completeness. Once an event is recorded, accuracy can be checked in various ways; some examples are described later. But, the assurance that all events or activities have been recorded is much more difficult and presents a major challenge.

The reporting function must also be accurate and complete. It is paramount that data base integrity is always maintained. Report

titles should describe the data presented and the time or period covered should always be indicated. Timeliness in reporting is also a factor. Diagnostic or edit reports should be issued so that timely action can be taken to correct discrepancies.

The above key accounting functions are discussed further in the remainder of this lecture on nuclear materials accounting.

III. 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 bookkeeping;
2. Subsidiary accounts for each material balance area and item control area;
3. Records showing:
 - a. Date and time tamper-indicating seals are applied, unique identification of tamper-safed items, location and quantity of items, and source and description of items;
 - b. Quantities of material added to or removed from the process;
 - c. Quantity of material in process;
 - d. Unique identification of items or containers of material in process; identity, location and quantity of material contained; and source and disposition of the items or containers;
 - e. Identity and quantity of material transferred between material balance areas; and
 - f. Signatures authorizing each transfer between material balance areas.
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 material owned by customers as well as provide the quantity records in support of the company assets. The model plant accounting system also satisfies these requirements.

IV. ACCOUNTING SYSTEM DESIGN CONSIDERATIONS

A. Double-Entry Bookkeeping

Although a requirement, double-entry bookkeeping is a technique used 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:

- 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.
- 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.
- 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.
- 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.
- 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 alpha and numeric 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.

B. Reporting Requirements. The accounting system must contain sufficient reference data within a transaction record to facilitate various reporting requirements. Since the basic reporting unit is element weight or isotope weight, the following associated references are added and become part of the transaction record:

Transaction Date:

Year, Month, Day, Time of Day

Transaction Codes:

B Beginning Inventory
R Receipt
S Shipment
D Measured Discard
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 general job or activity 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.

Summarization of data can be handled at any desired level. Transactions can be grouped around any given criteria to achieve the desired result.

The data must be generated at the operating level. Corresponding identification must be physically made on containers for traceability.

IV. GENERAL PRINCIPLES

A. MBA and ICA Control

Material Balance Area (MBA) and Item Control Area (ICA) control is used to help localize losses within a plant. MBA control utilizes mass quantity balances. As material moves into the MBA, the quantity is increased. Material moving out of the MBA decreases the quantity. At any point in time, all transactions are posted, a physical inventory is taken, and the book versus physical inventory difference is calculated.

In an ICA, a quick check against the ICA listing is made to verify that all items physically exist. Since the measurements of the ICA items are protected by tamper-safing, the quantities can be quickly summed to determine total inventory quantities.

The selection of MBA's and ICA's in a facility should be determined carefully for optimum control. MBA's should be set up in process areas where some physical or chemical change is made in the material. ICA's should be set up to hold material awaiting further processing or shipment. Items should be recorded upon receipt to the plant and when they remain in storage long enough to be tamper-safed. In-process items should be retained in an MBA quantity balance.

B. Computer Based System Versus Manual System

A computer based system generally is used whenever large quantities of data must be processed, or where the processing must be done quickly and accurately. Most modern nuclear material accounting systems are partly computerized, and partly manual. The level of computerization generally is determined by the number and complexity of the transactions processed.

C. Separation of Functions--Accounting and Custodians

The separation of functions is one of the basic principles of internal control. Transactions are generated by custodians and processed by accounting. The custodians are responsible for the accuracy of the data which are processed. Accounting maintains the overall record, but has no custodial control. A double-entry accounting system requires that the addition of a quantity to one balance or control area must be identically offset by a corresponding subtraction. When the custodians agree on the quantities to be transferred and submit the transaction, accounting makes the entry into the accounting record. Through this independence and by having one group check the accuracy of the other, greater data reliability is assured.



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



April 27-May 12, 1981

SESSION 21 c (Part 1): DESCRIPTION OF COMPUTER BASED SYSTEM

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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 UO_2 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.



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



April 27-May 12, 1981

SESSION 21c (Part 2): DESCRIPTION AND EXAMPLE OF RECORDS, REPORTS AND FORMS

A. J. McGinnes
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 two listed forms are regulatory forms utilized in accordance with instructions provided by the U.S. Nuclear Regulatory Commission (NRC). Form 741 is completed and distributed for each transfer and receipt of any special nuclear material or source material of 1 gram or more of contained uranium-235, uranium-233, or plutonium; 1000 kilograms or more of source material; or 1000 curies (0.1 gram) or more of tritium. For shipments, the shipper must dispatch the form on the same day the material is shipped. For receipts, the receiver must acknowledge receipt of shipments within ten days of receipt of material. If delayed measurements are to be made Form 284 is completed. Following this action Form 741 must be completed within thirty days after receipt of each shipment.

The Exxon Nuclear designed forms are printed in three parts consisting of an original and to 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. Key punched
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 AEC-284 - CS Material Transfer Receipt
- *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.(a-b)	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) were distributed to course participants. Copies are available from Exxon Nuclear Company, Incorporated.

REQUEST FOR CHANGES IN NICS & NMRS FACTOR DATA BASE

NICS SYSTEM

NMRS SYSTEM

PROJ #	FACTOR		XN-50	ACTION		DELETED FACTOR FILE	PROGRAM CHANGED						DONE BY	FACTOR TABLE			ACTION		DONE BY
	NOMINAL	AVERAGE		A/D	DATE		ENCDS	JAWE	PUMP	PUPT	ENCDS	YUDE		PUMP	PUPT	NO	N5	N6	
1.																			
2.																			
3.																			
4.																			
5.																			
6.																			
7.																			
8.																			
9.																			
10.																			
11.																			
12.																			
13.																			
14.																			
15.																			
16.																			
17.																			
18.																			
19.																			
20.																			

A-1

Reason for change _____

Requested by _____ on _____ Approved by _____ on _____

Approved by GAO
B 180225 (R0040)
Expires 12-31-81

A-3

[illegible][illegible]

15 USC SECTION 501, ACT OF JULY 3, 1946, 60 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.

UNITED STATES
ATOMIC ENERGY COMMISSION

A-4

SS MATERIAL TRANSFER RECEIPT

SS MATERIAL ON TRANSFER	FROM (STATION SYMBOL)	TO (STATION SYMBOL)	NO.
	SHIPPING DATE		DATE RECEIVED
MATERIAL HAS BEEN VERIFIED AS FOLLOWS (CHECK ONE):			
PIECE COUNT ☐ CONTAINER COUNT ☐ GROSS WEIGHT CHECK ☐			
OTHER: _____			
SHIPPER'S WEIGHTS AND SS CONTENTS ARE ACCEPTED PENDING FINAL VERIFICATION MEASUREMENTS AND COMPLETION OF FORM AEC-101.			
BY _____ (ACCOUNTABILITY REPRESENTATIVE)			

☐ R RECEIPT ☐ S SHIPMENT

NUCLEAR MATERIAL TRANSACTION

						Not Required For Shipments				A-5
CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP	ELEMENT WT.	ISOTOPE WT.	ELEMENT FACTOR	ISOTOPE 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
21										21
22										22
23										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.			

DISTRIBUTION: WHITE & CANARY - NM Accounting PINK - S/R ICA

LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

FROM		TO		RECEIVING CUSTODIAN			
FROM MDA		TO MDA		RECEIVING CUSTODIAN			
DATE	TIME	PROJECT NO	ROUTE COMP	GROSS WT	TARE WT	NET WT	REMARKS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

DISTRIBUTION

WHITE (70%)

YELLOW (30%)

RED (10%)

NOTES

REPORT NO

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																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
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.

UF₆
INVENTORY RECORD

No. _____

Item I. D. _____

Material Form _____

Enrichment _____

Gross Weight Lb. _____

Tare Weight Lb. _____

Net Weight Gm U _____

Inventory Date _____ By _____

UF₆ 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

A-10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

DATE			TC	741 REFERENCE				REF NO	OWN	RPT CAT		M T	ENRICH- MENT	MAT'L COMP	PROJECT	COMMENTS	AMOUNT (GRAMS)	
MO	DAY	YR		FROM RIS	TO RIS	/	c										ELEMENT WT	ISOTOPE WT
1			7	9	12	15	19	20	24	27	31	35	36	41	44	48	61/62	72
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

ANALYTICAL REQUEST & REPORT FORM

SERIAL NO.	TYPE SAMPLE	ENRICHMENT	LOT NO.	CAN NO.	PROJECT	APPROVAL
☐ BET	☐ H ⁺	☐ Pu LOW LEVEL	☐ U. TITR	☐ UO ₂ POWDER REL		
☐ C	☐ H ₂ O	☐ Pu TITR	☐ GAS REL	☐ UO ₂ PELLET REL		
☐ CL	☐ M. SPEC	☐ RARE E	☐ H ₂	☐		
☐ E. SPEC	☐ N ₂	☐ SO ₄	☐ O ₂	☐		
☐ EBC	☐ O/U	☐ SPG	☐ TOT. SOL.	☐		
☐ F	☐ pH	☐ U. GRAV	☐ S	☐		
☐ Fe	☐ PS	☐ 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 _____

A-1.3

☐ E TYPE METAL SEAL.

[illegible]

A-14

(Fuel)

Column

Date

Removed From Hood:

Rod Serial Nos.

Weight

Time

Weld

Time

Date:

Oper:

ROD FABRICATION FOLLOWER CARD

REACTOR:

Group No.

Rod Type

Enrichment

Card No.

of

Line No.

Responsible Organization

S = Shop Operations

Q = Quality Control

S Enter Release Numbers

Upper End Cap

Tube

Connector

(B)

Seg. Spring

(B)

Lower End Cap

Filler Rod

(A)

Pellet

(uranium amounts in grams)

A-15

[illegible]

FROM 07/01/79 TO 07/30/79

MATERIAL CAT				MAT	NRC=DOE	FLEMENT ISOTOPE	
T/C COMP. DATE				741 REF.	REF.	OWNER	WT(GM) WT(GM)
JOB 0001 REACTOR RELOAD 1							
E=03.000	N	NC	000	7/25/79	BWA=YUD=1=0	0001	FNC 2.000 60
	N	NV	UUF	7/25/79	BWA=YUD=1=0	0001	RPC 1,348,000 41,940
E=03.000	N						1,400,000 42,000
	S	SP	UUD	7/25/79	YUD=XVZ=1=0	0001	RPC -499,967 -14,999
E=03.000	S						-499,967 -14,999
	P	PT	UMA	7/25/79	000=000=0=0	0000	ENC 60,007 1,803
E=03.000	P						60,007 1,803
	M	MM	UMB	9/30/79	000=000=0=0	0000	ENC -67,421 -2,025
	M	MM	UMB	9/30/79	000=000=0=0	0001	FNC -1 -1
E=03.000	M						-67,422 -2,024
	E	EE	UHS	9/30/79	000=000=0=0	0000	000 -529 -16
	E	EE	UOU	9/30/79	000=000=0=0	0000	000 -55 -2
	Z	EE	UPD	9/30/79	000=000=0=0	0000	000 -365,296 -10,999
	E	EE	UPD	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 _____

B-4

(Quantities in Kilograms)

	Depleted	Natural	Thorium	Enriched		Plutonium	
				U	U-235	Element	Fissile
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-1062-1

**Per Federal License # SNM-1227, Amendment # 14, Dated 10/26/78

Distribution:

Prepared By: _____

Date:

B-5

FORM NRC/ERDA-742

(6-76)

10 CFR 70/ERDA-7421

(Previous editions are obsolete)

U.S. NUCLEAR REGULATORY COMMISSION
AND
U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

MATERIAL STATUS REPORT

1 NAME AND ADDRESS Fuel Fabrication Plant Richland, Washington		2 LICENSE NUMBER RIS SNM - XXXX		3 REPORT IDENTIFICATION SYMBOL 'RIS' YUD
		4 REPORT PERIOD FROM 4/1/79 TO 9/30/79		5 MATERIAL TYPE (Submit separate report for each type) 20 - Enriched
MATERIAL ACCOUNTABILITY				
6. QUANTITY BY ELEMENT AND ISOTOPE WEIGHT		A ELEMENT WEIGHT		B ISOTOPE WEIGHT
8. BEGINNING INVENTORY ERDA OWNED				
9. BEGINNING INVENTORY NOT ERDA OWNED		-0-		-0-
RECEIPTS				
11. PROCUREMENT FROM ERDA FROM:		RIS		
13. PROCUREMENT - OTHER				
14. DOD RETURNS - USE A				
15. DOD RETURNS - USE B				
16. DOD RETURNS - OTHER USES				
21. PRODUCTION				
22. FROM OTHER MATERIALS				
30. RECEIPTS REPORTED TO NRC/ERDA ON FORM NRC/ERDA-741 (Not listed elsewhere) FROM: BWA - YUD - 1		RIS		
		1,400,000		42,000
40. TOTAL		1,400,000		42,000
REMOVALS				
41. EXPENDED IN SPACE PROGRAMS				
42. SALES TO ERDA TO:		RIS		
43. SALES TO OTHERS FOR THE ACCOUNT OF ERDA TO:		RIS		
44. DOD - USE A				
45. DOD - USE B				
46. DOD - OTHER USES				
47. EXPENDED IN ERDA TESTS				
48. ROUTINE TESTS				
49. SHIPPER-RECEIVER DIFFERENCE				
51. SHIPMENTS REPORTED TO NRC/ERDA ON FORM NRC/ERDA-741 (Not listed elsewhere) TO: YUD - YYZ - 1		RIS		
		499,967		14,999
71. DEGRADATION TO OTHER MATERIALS				
72. DECAY				
73. FISSION AND TRANSMUTATION				
74. NORMAL OPERATIONAL LOSSES/MEASURED DISCARDS		-0-		-0-
75. ACCIDENTAL LOSSES				
76. APPROVED WRITE OFFS				
77. MATERIAL UNACCOUNTED FOR Loss		1,215		35
80. ENDING INVENTORY ERDA OWNED				
81. ENDING INVENTORY NOT ERDA OWNED		898,818		26,966
82. TOTAL		1,400,000		42,000

(See Reverse Side)

(11)

2 REPORTING
IDENTIFICATION
SYMBOL YUD
(79)

3.A. MATERIAL TYPE		NON-ERDA OWNED INVENTORY		J.B. ENRICHMENT LEVEL	
20 (10-11)				E-1 (For U-235) (10 11)	
4 INVENTORY COMPOSITION CODE (12 14)	DESCRIPTION	ELEMENT WEIGHT (15 27)	ISOTOPE WEIGHT (28 40)		
860	IN REACTORS AND CRITICAL ASSEMBLIES				
861	IN COOLING				
862	IN CONVERSION AND FABRICATION PROCESSES	875,536	26,267		
863	IN RECOVERY PROCESSES	55	2		
864	MATERIAL NOT IN PROCESS	22,627	679		
865	UNIRRADIATED SCRAP AWAITING RECOVERY				
866	UNIRRADIATED SCRAP AWAITING DISPOSAL	600	18		
899	TOTAL <i>(Total must agree with quantity on line 81, "Ending Inventory Not ERDA Owned," on front side of Form 742. For U-235, sum of separate total quantities by enrichment level must agree with line 81.)</i>	898,818	26,966		

(Refer to ERDA Manual Appendix 7401C for reporting instructions)

[illegible]

DATE	SIGNATURE	TITLE
10/15/79		Vice President, General Manager

FORM NRC/FRDA 742 (6-76)

☒ 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	R-6a
1	EX800	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											

FROM: 41 REFERENCE:		FROM: TO LOCATION:		NOTES:	
BWA YUD 1		Enrichment Plant		Receipt of full UF ₆ Cylinder	
DATE (mm/dd/yy)	TIME (24 hr clock)	MCA	S R ICA CUSTODIAN	NM ACCOUNTING	REPORT NO.
7/25/79	1400	101	Signature Required	Signature Required	00071

DD FORM 741
REV 10-70 DP
TOLER 20, 30, 50, 70, 150

U.S. DEPARTMENT OF ENERGY AND U.S. NUCLEAR REGULATORY COMMISSION
NUCLEAR MATERIAL TRANSACTION REPORT

Approved by GAO
180775-1R0040
Expires 12-31-81

[illegible]

1. SHIPPER'S DATA										2. SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED				3. REMARKS	
UNIT NO. (SHIP)	UNIT NAME (SHIP)	MATERIAL (SHIP)	QUANTITY (SHIP)	ORIGIN (SHIP)	USE (SHIP)	PROPERTY (SHIP)	PROPERTY (SHIP)	GROSS WEIGHT (SHIP)	NET WEIGHT (SHIP)	ELEMENT WEIGHT (SHIP)	WEIGHT IN (SHIP)	ISOTOPE WEIGHT (SHIP)	ELEMENT (SHIP)	ISOTOPE (SHIP)	
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
01	EX 800	20	103	G	US	1	USUS0000	5,961	4,559	1,398,000	3.0000	41,940	1314	45	
SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED															
4. RECEIVER'S DATA										5. SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED				6. REMARKS	
UNIT NO. (SHIP)	UNIT NAME (SHIP)	MATERIAL (SHIP)	QUANTITY (SHIP)	ORIGIN (SHIP)	USE (SHIP)	PROPERTY (SHIP)	PROPERTY (SHIP)	GROSS WEIGHT (SHIP)	NET WEIGHT (SHIP)	ELEMENT WEIGHT (SHIP)	WEIGHT IN (SHIP)	ISOTOPE WEIGHT (SHIP)	ELEMENT (SHIP)	ISOTOPE (SHIP)	
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
01	EX 800	20	100	G	US	1	USUS0000	5,968	4,566	1,400,000	3.0000	42,000	2352	160	
SIGNATURE OF AUTHORIZED OFFICIAL AND DATE SIGNED															

IN U.S. DISTRICT COURT ACT OF 1956, IN 1968 (28 USC 176) MADE IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OF ANY MATTER WITHIN THE JURISDICTION OF THE DISTRICT COURT OF THE UNITED STATES, SUCH AS:

900 915.81.

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mm/dd/yyyy)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1415	ICA-1	Signature Required	MBA-1	Signature Required

B-6c

[illegible]

0.575, 2.310

1. NAME
 2. ADDRESS
 3. CITY

NOTE:

Transfer of full UF_6 cylinder from cylinder storage to conversion area.

REPORT NO

000:3

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.) 7/25/79	TIME (24 hr. clock) 1430	FROM MCA MBA-1	SHIPPING CUSTODIAN Signature Required	TO MCA ICA-3A	RECEIVING CUSTODIAN Signature Required	B-60

CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP.	GROSS WT.	TARE WT.	URANIUM FACTOR	
PD 00001	E00001	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00002	E00005	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00007	E00011	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00008	E00012	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00009	E00013	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00010	E00014	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00011	E00015	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00012	E00016	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00013	E00017	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00014	E00018	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00015	E00019	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00016	E00020	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00017	E00021	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00018	E00022	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00019	E00023	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00020	E00024	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00021	E00025	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00022	E00026	E	300	0001	UPD	21905.0	2500.0	87600	
PD 00023	E00027	E	300	0001	UPD	21905.0	2500.0	87600	

DISTRIBUTION:
WHITE NUCLEAR
CANADIAN
NICKEL

NOTE:

Transfer of green powder buckets from
conversion area to powder storage area

REPORT NO.

00000

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (m. day, yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN	B-6e
7/25/79	1445	ICA-3A	Signature Required	MBA-2	Signature Required	

[illegible]

DISTRIBUTION
 Mr. T. A. [illegible]
 [illegible]
 [illegible]

transfer 13f green powder bucket from powder storage area to pellet preparation area.

REPORT NO
00004

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo., day, yr.) 7/25/79	TIME (24 hr. clock) 1500	FROM MCA MBA-2	SHIPPING CUSTODIAN Signature Required	TO MCA MBA-3	RECEIVING CUSTODIAN Signature Required	B-64

CONTAINER NO	SEAL NO	MATL TYPE	NOMINAL EL. CHMT	PROJECT NO	MATL COMP	GROSS WT.	TARE WT.	URANIUM FACTOR	
TRAY 0001		E	300	0001	USP	9310.0	2500.0	88100	
2						.	.		
3						.	.		
4						.	.		
5						.	.		
6						.	.		
7						.	.		
						.	.		
						.	.		
10						.	.		
11						.	.		
12						.	.		
13						.	.		
14						.	.		
15						.	.		
16						.	.		
17						.	.		
18						.	.		
19						.	.		
20						.	.		

DISTRIBUTION

1. TO MCA
 2. TO MCA
 3. TO MCA

transfer of sintered pellet tray from pellet preparation area to rod loading area

REPORT NO

00015

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mm/dd/yyyy)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1515	MBA-3	Signature Required	ICA-2	Signature Required

B-69

[illegible]

DISTRIBUTION
DATE: 10/10/68
CLASS: 10/10/68
TIME: 5:00 PM

transfer of loaded rods from rod loading area to rod/bundle storage area

REPORT NO
000-12

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo. day, yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN	B-6h
7/25/79	1530	ICA-2	Signature Required	ICA-1	Signature Required	

[illegible]

DISTRIBUTION
 SOUTH AFRICAN GOVT
 GALLAGHER HOUSE
 111 S. SUMMIT

- transfer of finished bundle from rod/bundle storage area to shipping/receiving area

REPORT NO.

000007

☐ R RECEIPT ☒ S SHIPMENT

NUCLEAR MATERIAL TRANSACTION

B-61

CONTAINER NO.	SEAL NO.	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO.	MATL COMP	ELEMENT WT.	ISOTOPE WT.	ELEMENT FACTOR	ISOTOPE FACTOR
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									
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21									
22									
23									
24									
25									
26									
27									
28									
29									
30									

FORM 741 REFERENCE		FROM LOCATION		NOTE	
YUO 1 XYZ 1		Reactor Power Co.		Shipment of finished bundle	
DATE (m/d/y)	TIME (24 hr. clock)	MCA	S/RICA CUSTODIAN	NM ACCOUNTING	REPORT NO.
7/25/79	1600	101	Signature Required	Signature Required	00008

DOE/NRC FORM 741
REV. (10-78) OF
10 CFR 30.40, 50, 70, 150

U.S. DEPARTMENT OF ENERGY AND U.S. NUCLEAR REGULATORY COMMISSION
NUCLEAR MATERIAL TRANSACTION REPORT

Approved by I&J
% APR 26 1964
F. J. P. 12 10 21

[illegible]

25. SUMMARY OF DATA													26. REMARKS								
UNIT NO.	CONTAINER NUMBER	DATE OF INSPECTION	COMPL. DATE	INSPECTION DATE	INSPECTION TIME	INSPECTION PLACE	INSPECTION METHOD	INSPECTION RESULTS	INSPECTION COMMENTS	INSPECTION DATE	INSPECTION TIME	INSPECTION PLACE	INSPECTION METHOD	INSPECTION RESULTS	INSPECTION COMMENTS	INSPECTION DATE	INSPECTION TIME	INSPECTION PLACE	INSPECTION METHOD	INSPECTION RESULTS	INSPECTION COMMENTS
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
01		29	309	J		1	USUS0000	6,800	1,251	499,967	3,0000	14,999	560	132							

10. USA v. F. J. HALL, ACT OF 1927, 42 U.S.C. § 1927 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OF INFORMATION TO ANY FEDERAL AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

2010 09 25 09:25

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mm/dd/yyyy)	TIME (24 hr clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN
7/25/79	1445	MBA-1	Signature Required	ICA-3K	Signature Required

B-6K

CONTAINER NO	SEAL NO	MATL TYPE	NOMINAL ENRICHMT	PROJECT NO	MATL COMP	GROSS WT	TARE WT	URANIUM FACTOR
DRUM 0001	E00004	E	300	0000	UDW	400.0	0.0	99999
FILT 0001	P00001	E	300	0000	UFW	200.0	0.0	99999
3						.	.	
4						.	.	
5						.	.	
6						.	.	
7						.	.	
8						.	.	
9						.	.	
10						.	.	
11						.	.	
12						.	.	
13						.	.	
14						.	.	
15						.	.	
16						.	.	
17						.	.	
18						.	.	
19						.	.	
20						.	.	

DESCRIPTION

WHITE A. 1000mg
CANAR 1000mg
1000mg Scrap

NOTE

transfer of one barrel and one filter from
conversion area to scrap storage area

REPORT NO

00003

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			
2	0007	E	303	LAGOON	ULW	1700.0	0.0	99999			
3	0008	E	301	LAGOON	ULW	1900.0	0.0	99999			
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											

TO	PROJECT NO.	MATL. TYPE	NOMINAL ENRICHMT	NOTES
	0000	E	300	
LOT NO. —		BLEND NO. —		transfer of liquid waste to solar evaporation ponds (lagoon)

DATE (mo/day/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

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	H5 0001	UHS	26340.0	2500.0	88100	1
2	0003	E	AD 0001	UAD	17670.0	1000.0	60000	2
3	0004	E	GS 0001	USL	16000.0	1000.0	80000	3
4	0005	E	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		
DATE	TIME (hr clock)	MB	MBA CUSTODIAN	NM ACCOUNTING	REPORT NO
7/25/79	1430	MBA-1	Signature Required	Signature Required	0001

DISTRIBUTION: WHITE NM Accounting, PINK MBA Custodian

T LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE (mo./da./yr.)	TIME (24 hr. clock)	FROM MCA	SHIPPING CUSTODIAN	TO MCA	RECEIVING CUSTODIAN	B-6n
7/25/79	1445	MBA-1	Signature Required	MBA-4	Signature Required	

[illegible]

DISTRIBUTION
WHITE: 100% (100%)
BLACK: 100% (100%)
HISPANIC: 100% (100%)

Transfer of material samples from Conversion Area to Analytical Lab

REPORT NC

00012

LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE	QUANTITY	FROM	SHIPPING CUSTODIAL	TO	RECEIVING CUSTODIAL	
7/25/79	1500	MBA-11	Signature Required	ICA-11	Signature Required	B-600

B-60

[illegible]

DISTRIBUTION

1. $\mathcal{L}(\mathbf{X}, \mathbf{Y}) = \mathbb{E}[\ell(\mathbf{X}, \mathbf{Y})]$
 2. $\mathcal{L}(\mathbf{X}, \mathbf{Y}) = \mathbb{E}[\ell(\mathbf{X}, \mathbf{Y})]$
 3. $\mathcal{L}(\mathbf{X}, \mathbf{Y}) = \mathbb{E}[\ell(\mathbf{X}, \mathbf{Y})]$

Transfer of empty UF_6 cylinder (heel) from Conversion Area to Cylinder Storage Area

REPORT NO.

20013

LOCATION TRANSFER

NUCLEAR MATERIAL TRANSACTION

DATE RECEIVED	TIME	FROM	SHIPPING CUSTODIAN	TO	RECEIVING CUSTODIAN	B-6P
5/25/79	1520	ICA-2	Signature Required	MBA-3	Signature Required	

[illegible]

DISSEMINATION

Transfer of rods from rod/bundle storage area to rod loading area (Bundle transfer program)

REPORT NO.

10054

T

NUCLEAR MATERIAL TRANSACTION

B-69[illegible]

DISTRIBUTION

Transfer of bundles from rod loading area to rod/bundle storage area (bundle transfer program)

REPORT NO
00015



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



April 27-May 12, 1981

SESSION 21c-3: ASSIGNMENT OF ELEMENT AND ISOTOPE FACTORS

E. R. Herz
Exxon Nuclear

I. INTRODUCTION

As discussed previously by Tony Kraft and Spike McGinnes, 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. There may be more than one nominal enrichment for a given project account. As explained earlier by Spike McGinnes, 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 UF₆ 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 Spike McGinnes.

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,

CHART 1. Sample NICS Factor Tables

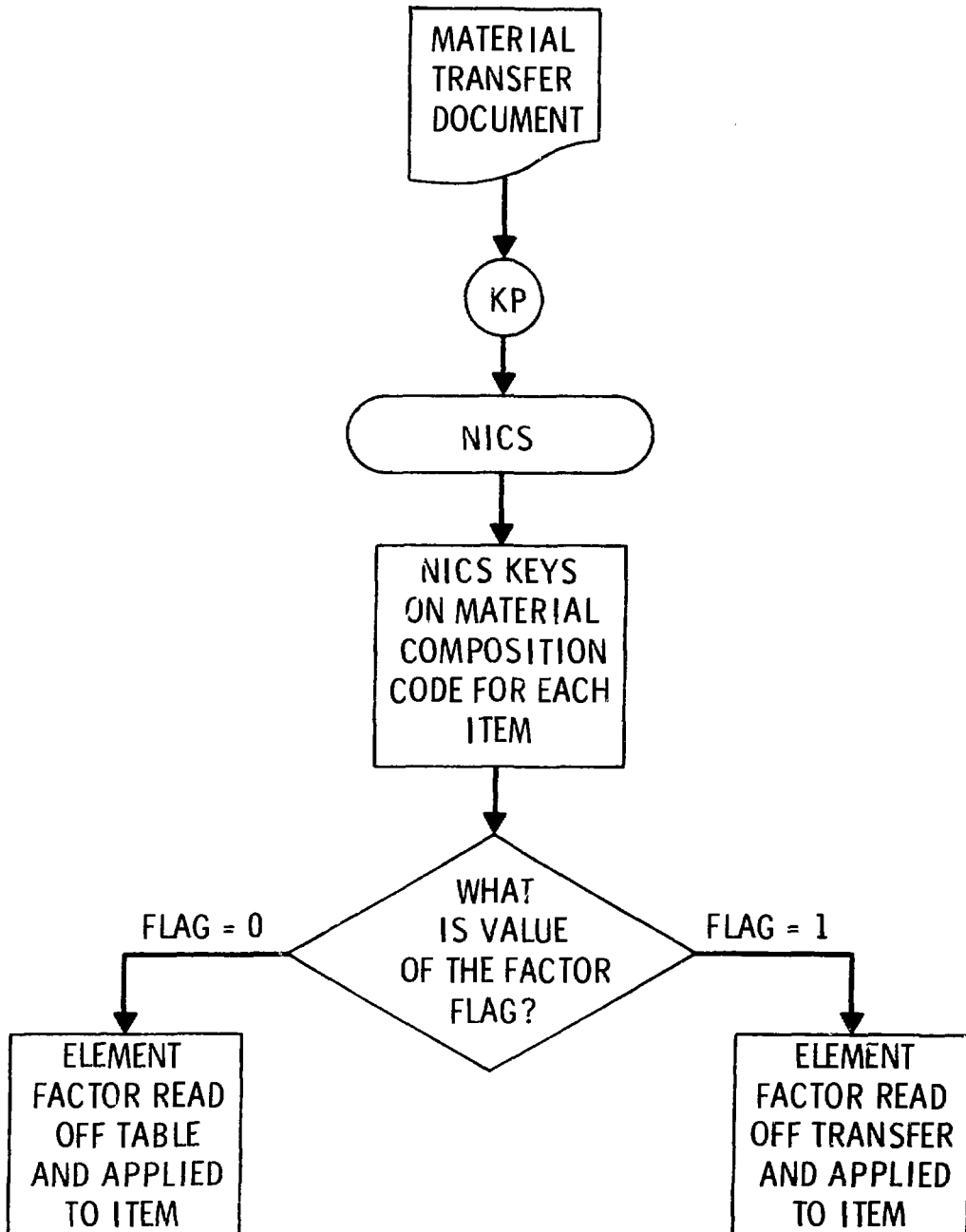
NICS - NUCLEAR INVENTORY CONTROL SYSTEM

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

NICS assigns the value 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 plant element and isotope factors. The project and nominal 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

***** H 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	2499.55	74.99
ROD00011	300	.030000	.88095	2837.00	2499.26	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	2499.78	74.99
				-----	-----	-----
			TOTAL	14188.00	12499.29	374.98

BUNDLE = BUNDLE03

741 REPORT SUMMARY

NOM	U-235	ELEMENT	NET	ELEMENT	ISOTOPE
ENR	FACTOR	FACTOR	WEIGHT	WEIGHT	WEIGHT
---	-----	-----	-----	-----	-----
300	.030000	.88090	14188.00	12499.29	374.98

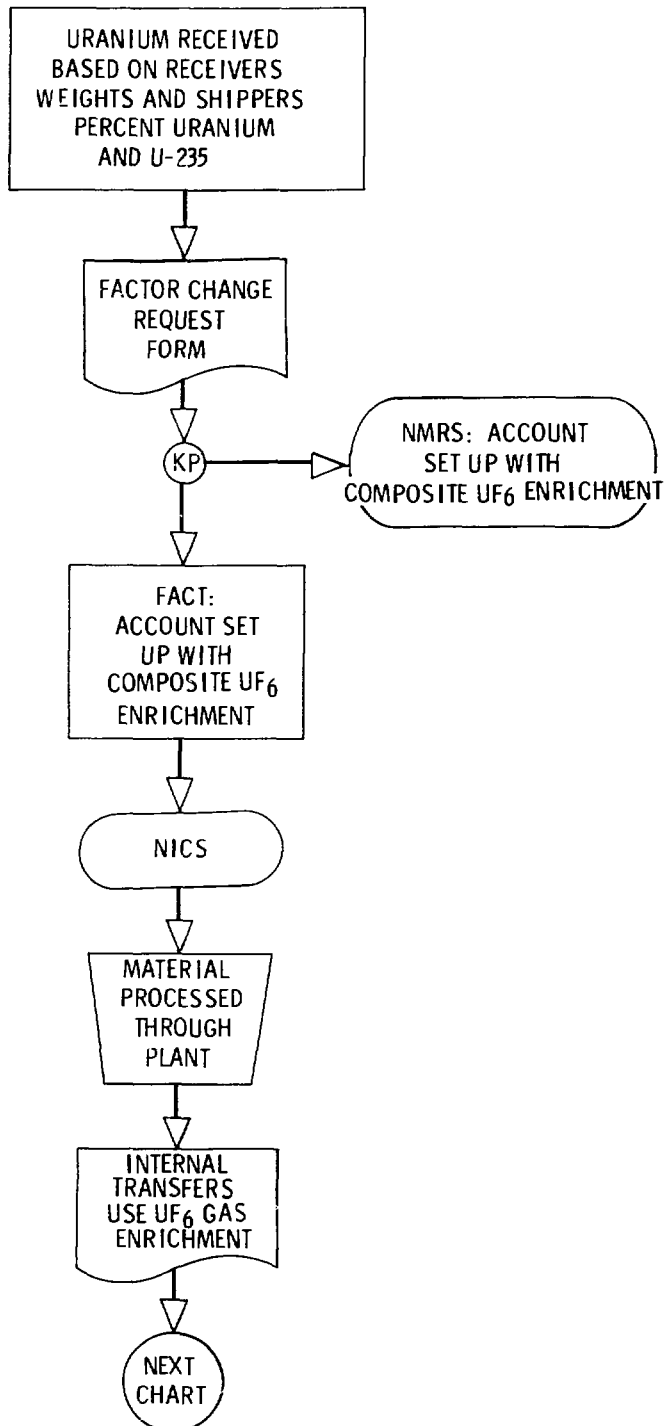
CHART 4. Assignment of Isotope Factors

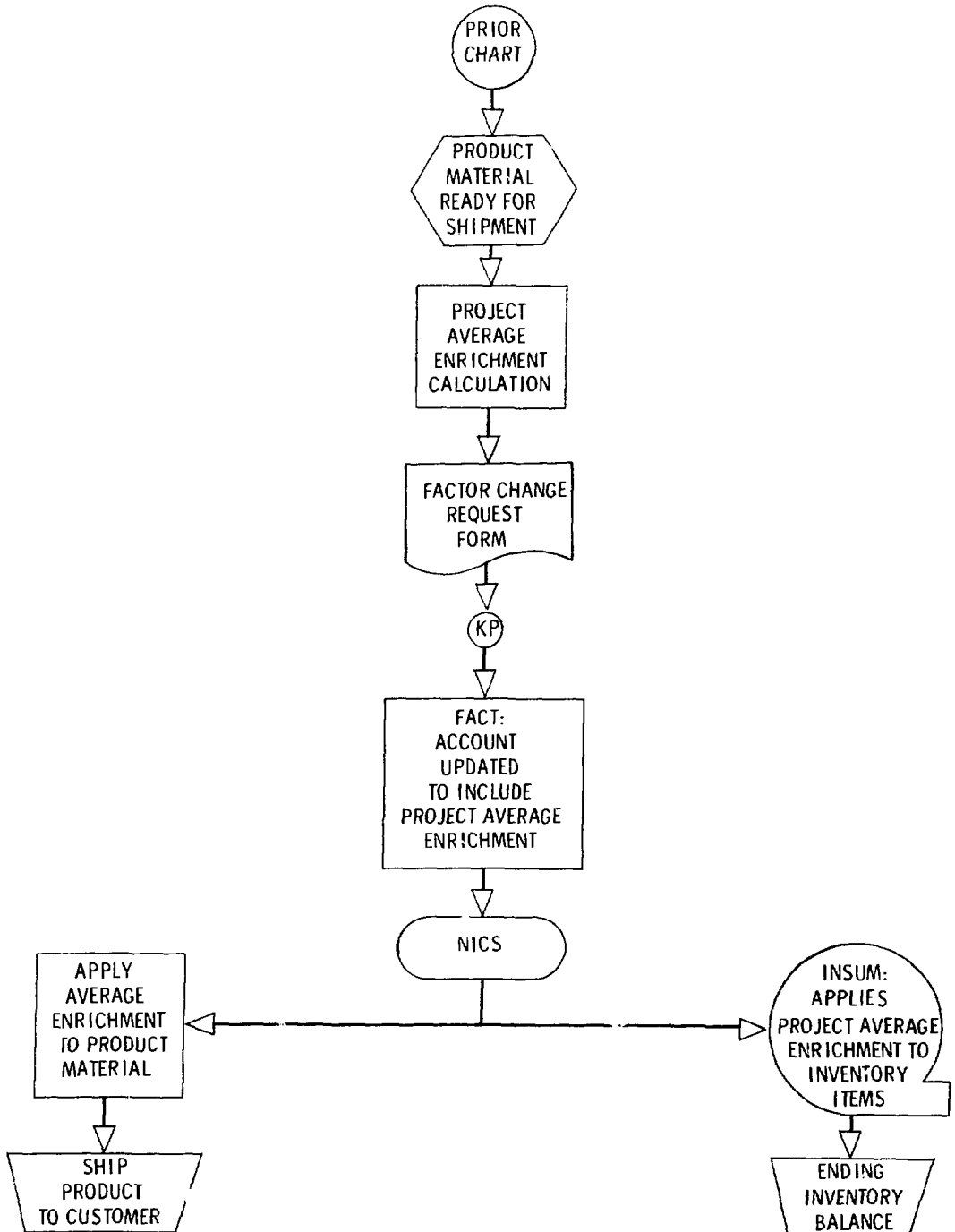
CHART 5. Assignment of Isotope Factors

CHART 6. Project Average Enrichment

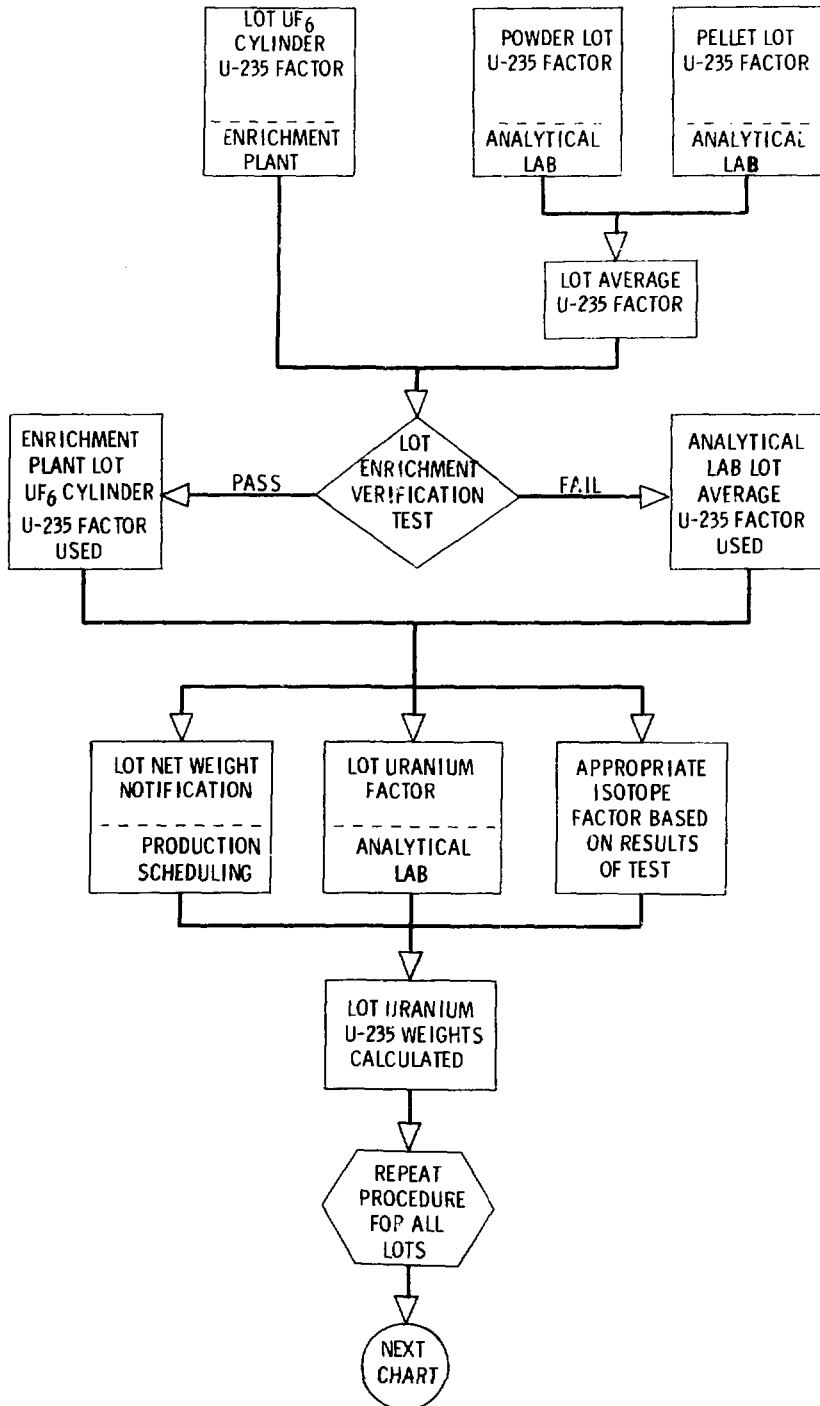
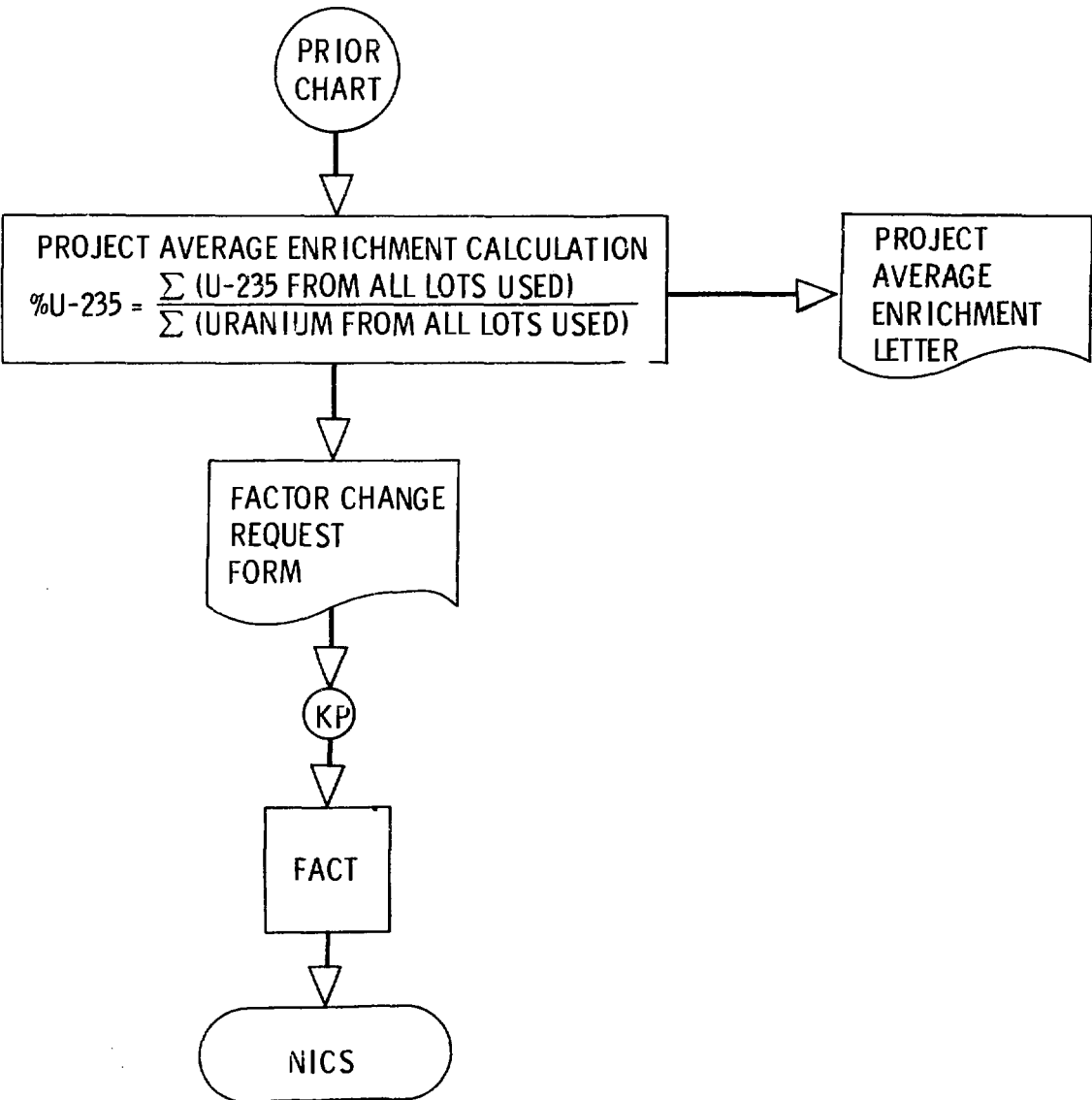


CHART 7. Project Average Enrichment



NUCLEAR MATERIAL TRANSACTION

[illegible]

NICS - NUCLEAR INVENTORY CONTROL SYSTEM

PROJECT CODE	ENR	ISOTOPIC FACTOR

0	E300	0.030000
1	E300	0.030000
2	E296	0.029600
3	E299	0.029900

<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	0.84500
OU	0	

CONTAINER
NUMBER

PD 00002

URANIUM
FACTOR

0.87600

U-235 FACTOR

0.030000

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.

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



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



April 27-May 12, 1981

Session Objectives

SESSION 22: TOUR OF THE CONVERSION AREA

The general plant tour of Session 19 is followed by this more detailed tour of the conversion process area. This includes the liquid waste tanks and solid waste assay systems.

After this tour, participants will be able to:

1. better understand the relationship between the conversion process and the measurement system,
2. better understand the liquid and solid waste measurement systems.



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



April 27-May 12, 1981

SESSION 22: TOUR OF CONVERSION AREA

K. P. Galbraith
Exxon Nuclear

The tour of the conversion area includes the UF_6 to UO_2 conversion process; the scrap oxidation process for converting scrap to U_3O_8 ; U_3O_8 dissolution to UNH and recovery by ammonium diuranate (ADU) precipitation, calcination, and reduction to UO_2 ; the liquid waste measurement tanks; and the solid waste assay system.

The UF_6 conversion process is traced from the UF_6 vaporization chests on the ground floor to the hydrolyzer tank where the UF_6 is reacted with water, to the ammonium hydroxide precipitation tank and then through centrifuge systems which removes the ADU. The ADU is dried, calcined and reduced to UO_2 powder. The powder is blended, treated mechanically, and sampled and weighed into buckets.

The scrap oxidation process is used to convert uranium (IV) scrap materials to U_3O_8 for later dissolution in nitric acid and recovery through the ADU process and conversion back to UO_2 .

The tour emphasizes the key measurements which are carried out in the conversion area. The participants are shown the liquid waste collection and measurement tanks where the liquid waste volumes are measured and each batch sampled for uranium assay. Powder and scrap sampling is also illustrated. The solid waste assay unit which is located on the ground floor is operated during the tour to demonstrate to the participants the measurement of solid waste in barrels (contaminated trash) and HEDA filters.



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



April 27-May 12, 1981

Session Objectives

SESSION 23: MEASUREMENT METHODS USED AT PLANT

The general description of Session 20 on measurement methods is followed by a detailed presentation of each of the accountability measurement methods in use at the model plant. These include bulk measurements (weighing, volume, and sampling), wet chemistry analytical methods, and nondestructive assay methods.

After the session, the participants will be able to:

1. understand the principles and practical aspects of the bulk measurement methods,
2. understand the principles and practical aspects of wet chemistry analytical methods,
3. understand the principles and practical aspects of the nondestructive assay methods.

(See Session 20 for discussion of Session 23a, bulk measurements.)



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



April 27-May 12, 1981

SESSION 23b: ANALYTICAL METHODS USED AT PLANT

N. S. Wing
Exxon Nuclear

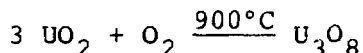
I. GRAVIMETRIC URANIUM ANALYSIS

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)

$$\% \text{ U} = \frac{F \left[W_2 - (W_2 \times I_m \times 10^{-6}) \right]}{W_1} 100$$

WHERE

$$F = \frac{3 \text{ ATOMIC WT URANIUM}}{(3 \text{ ATOMIC WT URANIUM}) + (8 \times 15.9994)}$$

$$W_2 = \text{WEIGHT } \text{U}_3\text{O}_8 \text{ AFTER IGNITION}$$

$$W_1 = \text{WEIGHT OF SAMPLE TAKEN}$$

$$I_m = \text{NON-VOLATILE IMPURITY OXIDES EXPRESSED AS PARTS OXIDE PER MILLION PARTS } \text{U}_3\text{O}_8$$

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	235.538	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

2. 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

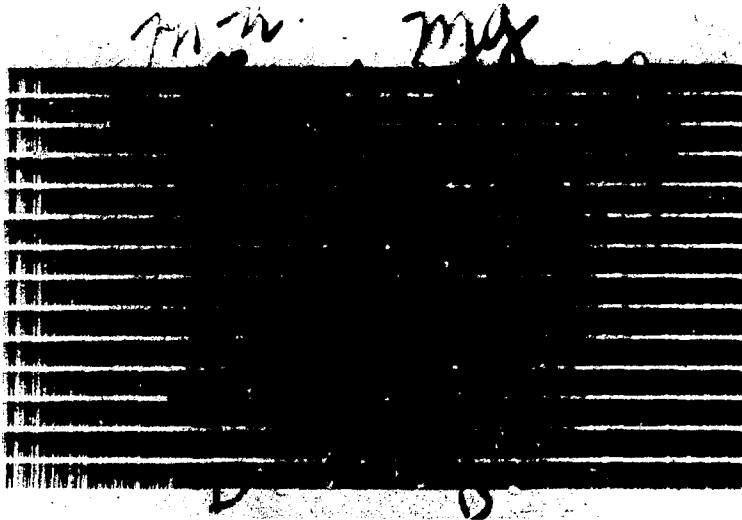


FIGURE 21. Example of a Complex Spectra

APPLIED RESEARCH LABORATORY QUANTOMETER

1. TWO-METER FOCAL LENGTH
2. 960 LINES PER MM GRATING (24,400/INCH)
3. $5.4 \text{ \AA/MM}$ DISPERSION
4. RANGE 1966 TO $8750 \text{ \AA}$ FIRST ORDER
5. THIRTY-NINE ELEMENTS IN PROGRAM
6. FOUR SLIT FRAMES
 - a. Hg PROFILE EACH FRAME
7. TIMING CIRCUITS

FIGURE 22. Spectrometer Description

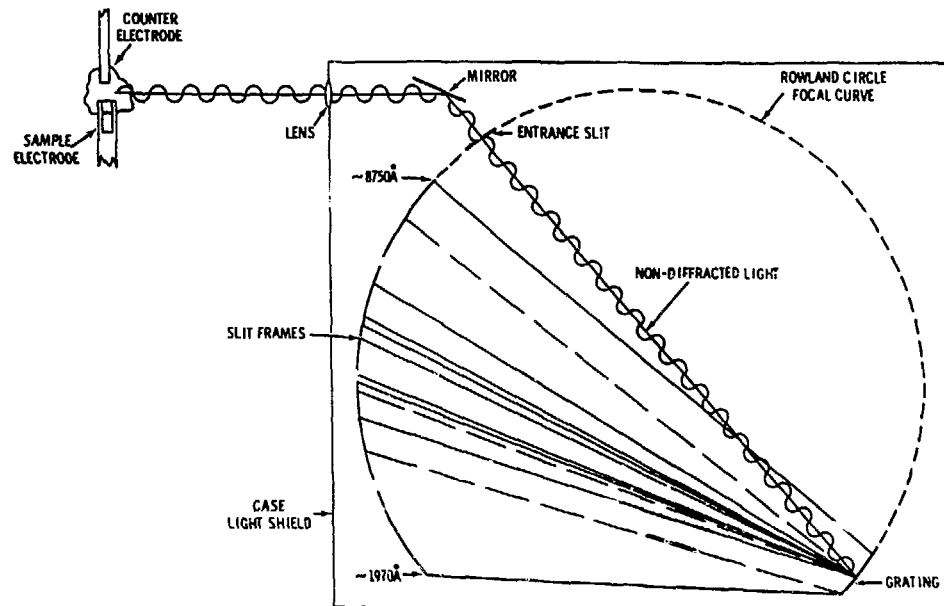


FIGURE 23. Emission Spectrometer Schematic

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

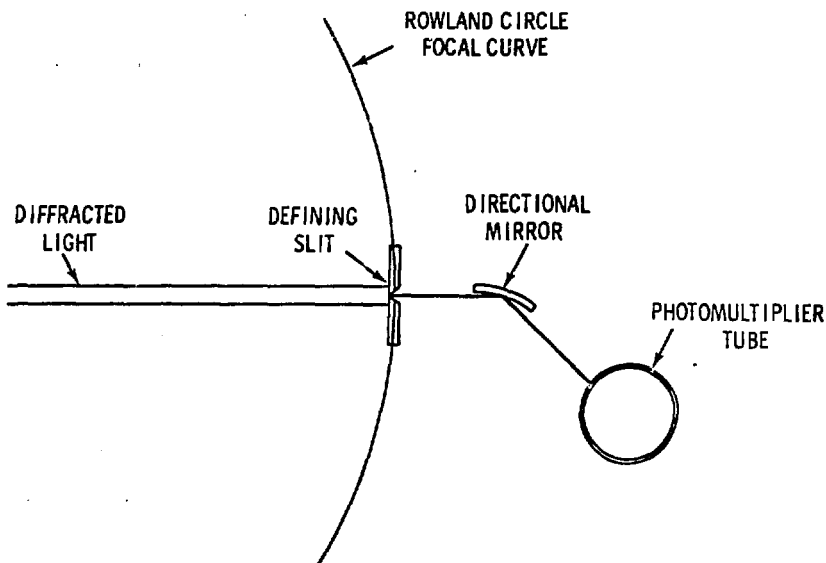


FIGURE 24. Typical Detection System

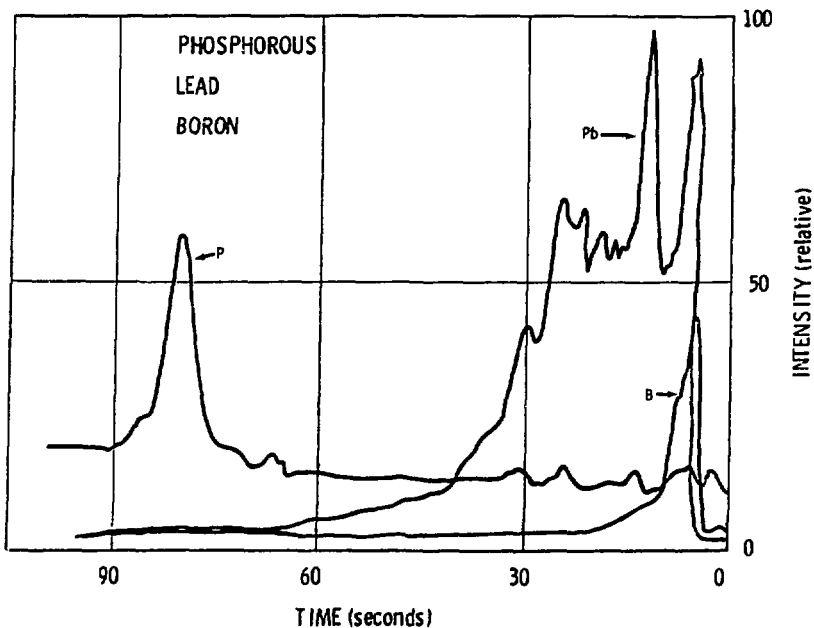


FIGURE 25. Excitation Profiles in U₃O₈

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 U₃O₈, 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 HNO₃. 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.

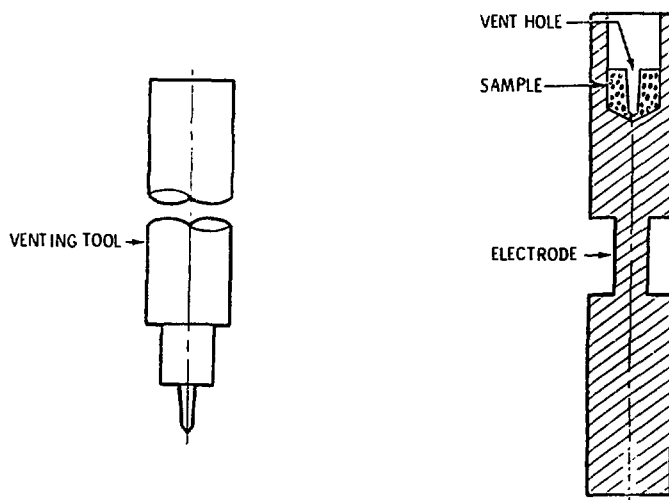


FIGURE 26. Sample Tamper Illustration

- 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

5. REFERENCES

1. Schneider, R. A., and Harmon, K. M., "Fluorimetric Determination of Uranium," USAEC Document HW 53368, 1957
2. Kofoed, R. J., Schneider, R. A., "Emission Spectrographic Methods," USAEC Document HW 53368, 1957.
3. ASTM, "Standard Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear Grade Uranium Dioxide Powder and Pellets," C696, pp. 206-242, Part 45, 1978.
4. Stephens, F. B., et al., "Methods for the Accountability of Uranium Dioxide," NUREG 75/010, UC-16, 1975.
5. Rodden, C. J., "Analysis of Essential Nuclear Reactor Materials," Chapter 1, 1964.

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



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



April 27-May 12, 1981

SESSION 23c: NDA METHODS USED AT PLANT

K. O. Johnson
Exxon Nuclear

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

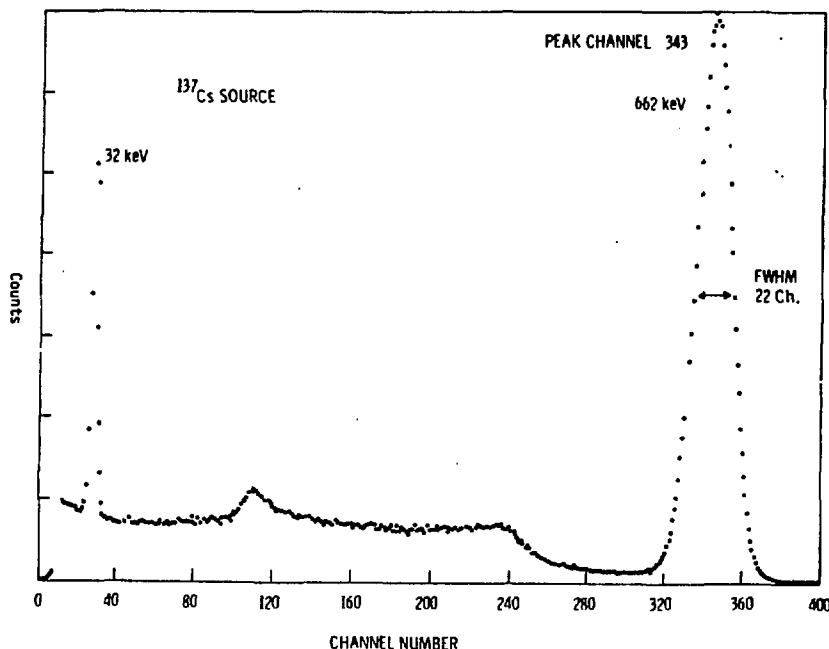


FIGURE 1. Typical NaI Energy Spectrum from a ^{137}Cs Source

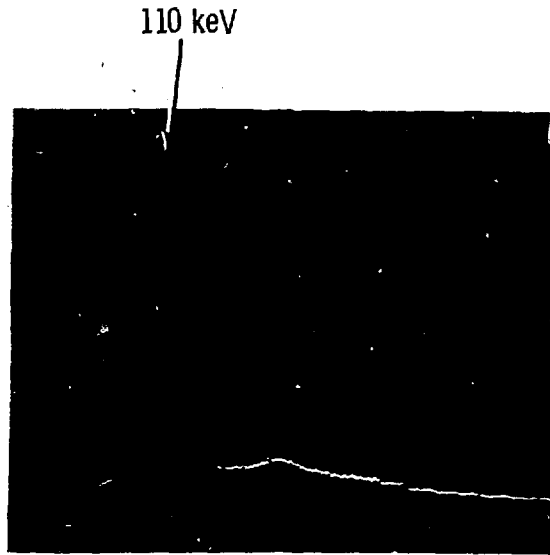


FIGURE 2. Low Energy Spectrum from Depleted Uranium

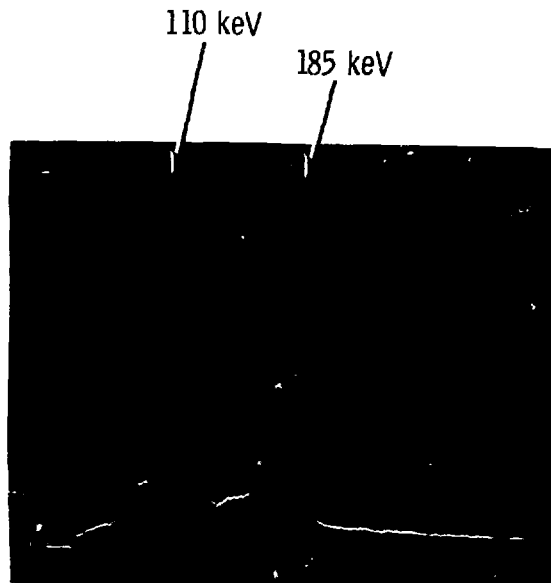


FIGURE 3. Low Energy Spectrum from 3% Enriched Uranium

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:

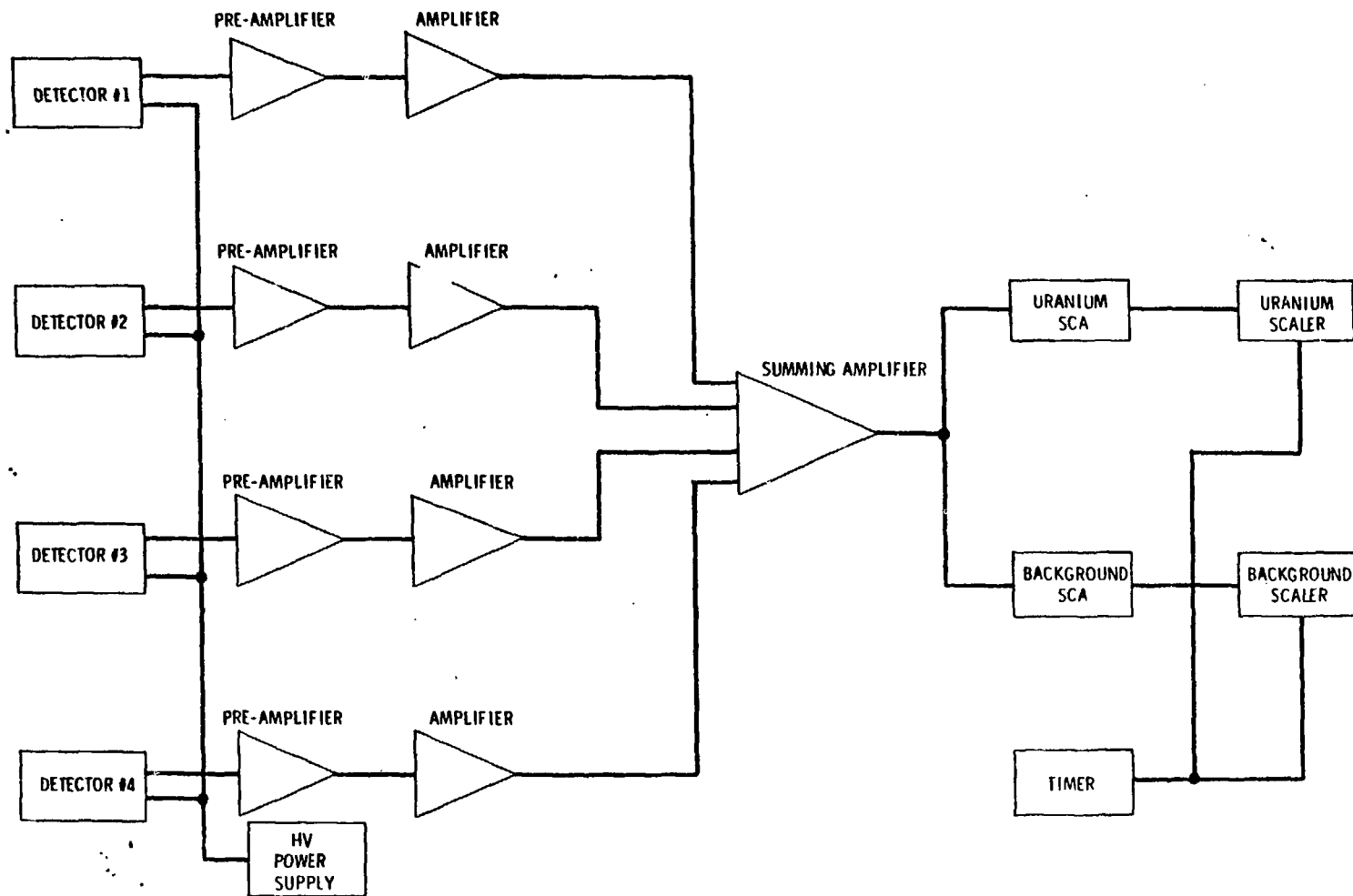


FIGURE 4. Block Diagram of Waste Assay Electronics

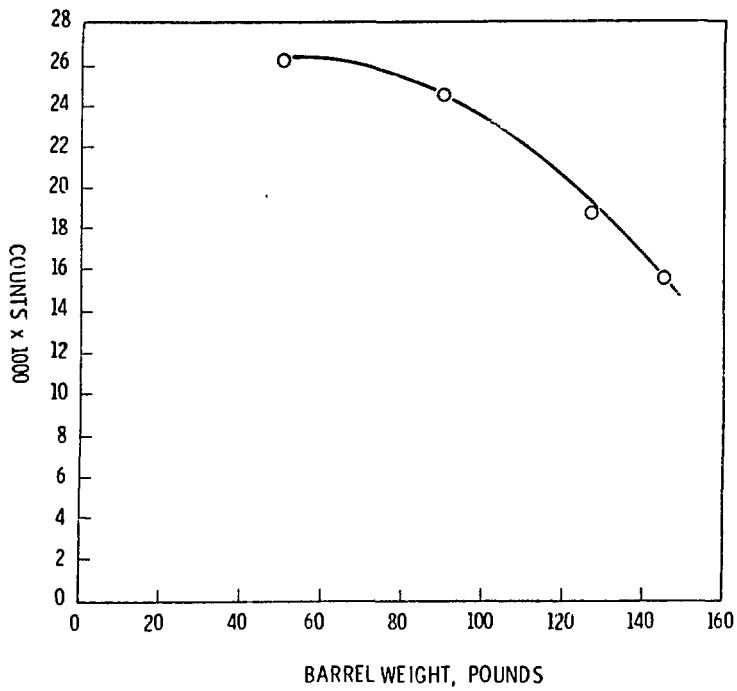


FIGURE 5. Variation of Count with Barrel Weight

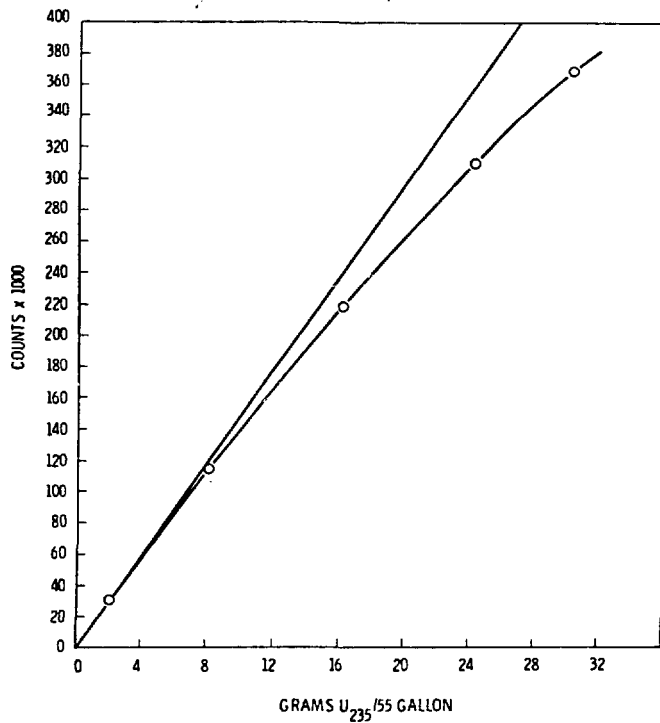


FIGURE 6. Variation of Count with ^{235}U Concentration

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 .

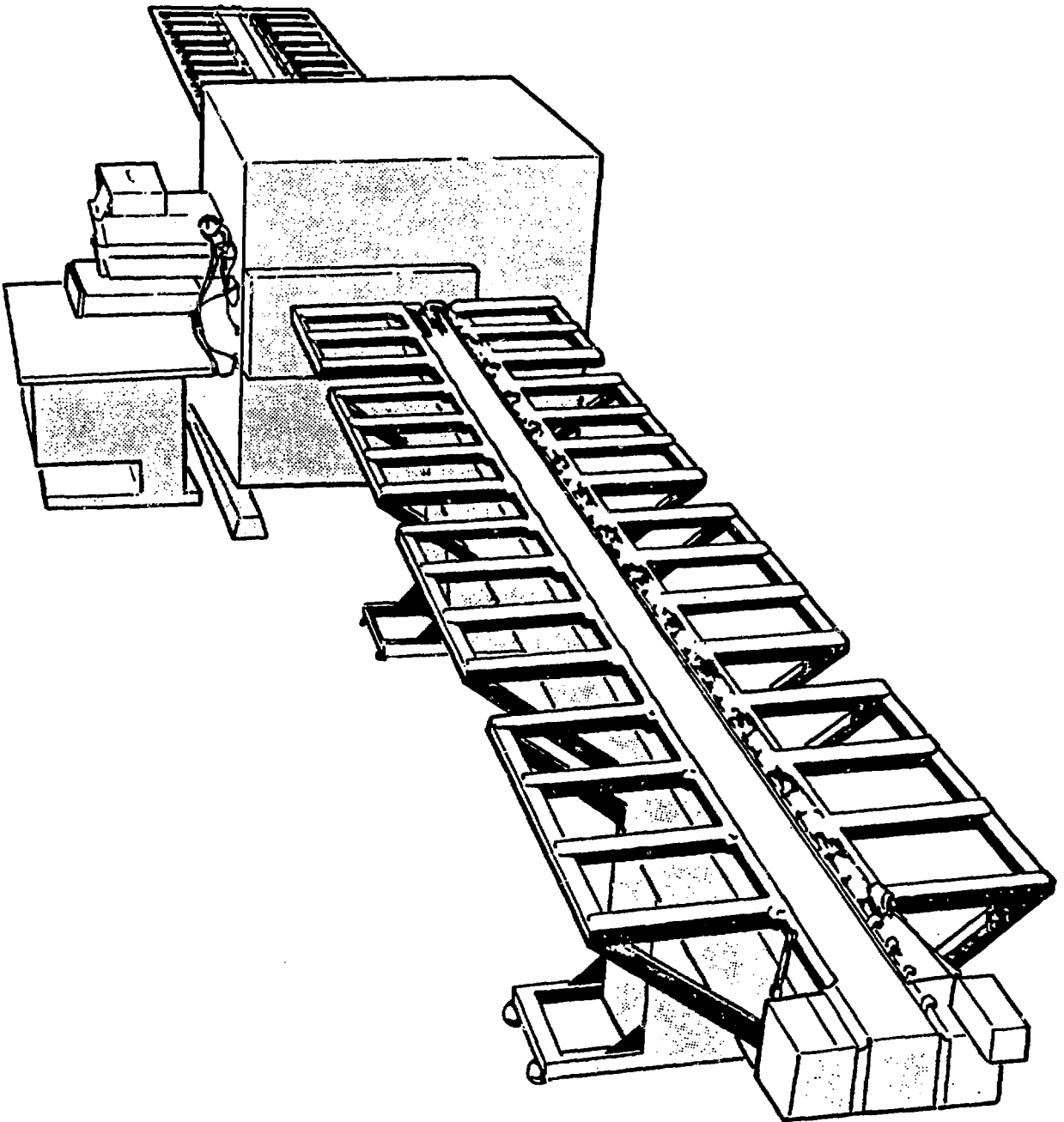


FIGURE 7. Rod Assay Unit



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



April 27-May 12, 1981

Session Objectives

SESSION 24: PROCESS MONITORING

Many of the measurements and observations made in a nuclear processing facility to monitor processes and product quality can also be used to monitor the location and movements of nuclear materials. In this session information will be presented on how to use process monitoring data to enhance nuclear material control and accounting (MC&A). It will be seen that SNM losses can generally be detected with greater sensitivity and timeliness and point of loss localized more closely than by conventional MC&A systems if process monitoring data are applied.

After the session, the participants will be able to:

1. identify process unit operations that could improve control units for monitoring SNM losses,
2. choose key measurement points and formulate a loss indicator for each control unit,
3. describe how the sensitivities and timeliness of loss detection could be determined for each loss indicator.



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



April 27-May 12, 1981

SESSION 24: PROCESS MONITORING

Richard J. Brouns
Pacific Northwest Laboratory

I. INTRODUCTION

In recent developments related to control and accounting of strategic nuclear materials, considerable emphasis has been placed on improving the timeliness of loss detection and the ability to localize a loss to a small part of the facility's operations. Traditional material accounting has limited capability in these areas because the time span between tests for loss (i.e., material balance tests) is long. In addition, the whole plant, or at least a large part of it, is within one material balance area so loss alarms are not localized.

Material control and accounting systems aimed at frequent tests for material losses and small accountability control units ("miniature material balance areas") have been under study for several years. Various names that have been applied to these systems are Dynamic Materials Accounting, Controllable Unit Accounting, Near-Real-Time Material Control and Process Monitoring Technique. All of these are based on the same general principles although their methods vary to some extent. All entail frequent, such as daily, tests for material deficiencies and the use of many tests for control points throughout the process.^(a) They have been shown in modeling studies on paper to have much better sensitivity, localization and timeliness of loss detection than the conventional material balance accounting method and they do not require a process shutdown to establish a material balance test.

References 1 through 4 summarize recent studies sponsored by the Nuclear Regulatory Commission to test the feasibility of applying these techniques to some existing licensed facilities. Studies of applications to other types of facilities and several variations in the techniques used are described in the reports listed in the attached bibliography. Detailed descriptions of the methodology are given in some of these reports.

This paper describes the general methods used and some results from a study of the applicability of the process monitoring technique to two specific strategic nuclear material (SSNM) manufacturing facilities.⁽²⁾ The term "process monitoring technique" reflects an emphasis on using primarily routinely collected process monitoring data to supplement material accounting data for SSNM loss detection. Additional measurement points and improved measurement capabilities are introduced only as necessary to achieve specific goals of loss

(a) Various terms are used to identify the portion of the process around which a loss detection technique is applied. Examples of these terms are unit process accounting area, controllable unit, process monitoring unit, control unit, and in-process control area.

detection. Two recent studies compared the loss detection sensitivity and timeliness of several modifications of an SSNM control and accounting system made by adding more measurements and different control unit arrangements to enhance material control.(3,4)

II. DESIGN APPROACH

Process monitoring data refers to production control, process control, quality control and effluent monitoring data. Examples of process control data are flow rate, pH, and specific gravity, and examples of quality control data are chemical and NDA measurements used to insure product quality. Production control data, which consist primarily of results derived from bulk measurements such as process yields and in-process inventories, are generally most useful for monitoring SSNM in batch operations, while process control data are most useful in continuous flow operations. Quality control data are most useful for detecting diversion concealed by a mass or isotopic substitution. Effluent monitoring data generally provide confirmatory data on waste discards.

The production control system is used by the production managers to order and authorize processing of material, by production personnel to record and report the processing that is finished, and by the production management staff to monitor the reports and compare actual production with the plan, and to recommend modifications or adjustments as necessary. The system is a bookkeeping system based on forms for work schedules and work completion records. These records usually include batch numbers and weights of each batch and container and the nuclear material contents of the batches and containers. The value of production control for process monitoring lies in the batch weight data which can be used to detect mass discrepancies. These data are usually very timely.

The quality controls are checks of the characteristics of the material between process steps to insure that the eventual product will meet specifications. The checks are usually laboratory analyses of a small sample of material from a batch. The results are compared to rigid specifications before further processing is permitted. The quality control data can be used to detect a substitution of other material for the uranium-bearing material. The purpose of such a substitution would be to conceal diversion from the mass checks.

The process controls are checks of the operating characteristics of the processes or process equipment. The checks are made by reading process instruments or by observing control settings. There appears to be little safeguards value to process control data in the case of batch processes, primarily because the process will often operate correctly without any material in it, and almost always will operate with a non-nuclear material used as a substitute for diversion concealment purposes.

A material accounting system using selected portions of a facility's process monitoring data and other measurement data that may be required can be designed to achieve specific loss detection goals. The performance goals for material control systems enumerated in a 1978 NRC task force report have been a guide for the studies.(5) Goals particularly relevant to this purpose are:

MC8--Detect within 24 hours a loss of five formula kilograms of SSNM in bulk form accessible to theft from the process.(a)

MC9--Maintain procedures and information sufficient to evaluate process conditions and material records so that they may provide for assessment of alarms within one hour.

MC10--Assure detection of the cumulative loss of five formula kilograms of SSNM from the process within the interval between physical inventories.

A further goal is to design the system to provide separation of functions so that employees with access to the material are not the ones responsible for detecting diversion. One must also consider the threat of employees acting in collusion as adversaries.

It is also worthwhile to consider strategies of diversion that may affect the system effectiveness. The principal strategies are:

- simple removal of the quantity desired at one time from one location in the facility
- removal with substitution of other material that would help mask the diversion
- removal of enriched uranium with substitution of uranium of lower enrichment to mask the diversion
- removal of the goal quantity in smaller amounts from a single location over a period of time (called protracted or "trickle" diversion)
- removal of the goal quantity in smaller amounts from several locations in the facility
- removal with use of records manipulation or falsification of data to mask the diversion
- removal with collusion of persons having access to records, measurement instrumentation, or alarm system equipment.

III. METHODOLOGY

A generalized and systematic approach to the design and evaluation of the SSNM loss detection system is outlined here. The evaluation is an integral part of the design, providing feedback on effectiveness and allowing an interactive design process. The approach is:

-
- (a) The following definition is from the glossary of the MC&A Task Force report: "Five Formula Kilograms of SSNM--A quantity of 5,000 grams of the isotope uranium-235 (contained in uranium enriched to 20% of more in the uranium-235 isotope), uranium-233, or plutonium alone or in any combination, computed by the formula: grams = (grams contained uranium-235) + 2.5 (grams uranium-233 + grams plutonium)."

1. Describe and diagram the process as a series of unit operations.
2. Identify all measurement and control points for production, process, and quality control and accountability. Describe the information and data collected, the schedule or frequency, and the accuracy of measurement results.
3. Identify the target materials for diversion in each unit operation. It is also useful to grade them according to high, medium, or low potential for diversion on the basis of material attractiveness and accessibility for diversion.
4. Define a set of loss monitoring units (control units) based on the measurement and process monitoring points such that, if possible, each unit operation and every target material is included in at least one of the control units.
5. Determine the effectiveness of the loss monitoring system.
6. Modify the design to achieve greater effectiveness where necessary and feasible.

One should try to design the control units to achieve short time spans, such as a day or less, and few unit operations between loss monitoring points. This enhances detection timeliness and good localization of loss alarms.

The kinds of monitoring checks that are used to detect losses are mass balances, yields, isotopic ratios, quality, purity, visual observations, and other properties of the materials containing SSNM. They are made as follows:

- Weight checks of the amount of material in a container are determined and comparisons made to a previously recorded value of the mass based on a previous weighing. Sensitivity is typically ten grams or less per container.
- Mass balance checks occur when the mass taken out of a process is compared to the mass or masses going in. A conversion formula for the differences in chemical composition is used when applicable.
- Uranium yield checks can be made in which the quantity of uranium going in is compared to the quantity of uranium product. If this does not include measurements of the uranium coming out of the process in the side streams, such as waste streams, the variability of the side stream quantity (process variance) will be part of the loss detection sensitivity variance.
- Property checks are mainly the quality control checks of the properties of the materials relative to the specifications. The measurements are quantitative and a comparison to specifications results in a quantitative comparison. (However, these quantities may bear no relation to the amount of the diversion and there could be a case where all the uranium

is diverted and the substitute so closely matches the material removed that the check does not detect it.)

- Uranium concentration checks are comparisons of the concentration of uranium in a material to the expected value based on past performance of the process or on analyses of the input batches. (This check differs from the quantitative uranium yields mentioned above.)
- Isotope checks are verifications of the ^{235}U enrichment of the uranium. They are made to detect isotopic substitution to mask diversion.
- Visual checks of the material may be made by the process operators who are familiar with the expected appearance. The check is qualitative but may have the power to detect the results of a process malfunction or a substitution of material to mask a diversion.

A. Evaluation

The material accounting system is evaluated by calculating the effectiveness of using the process data to detect a loss under various diversion modes. The effectiveness in detecting each diversion is measured in terms of detection timeliness, mass sensitivity, and degree of localization obtained from the process monitoring and accountability measurements at each process step. A timeliness determination is made by calculating the average time lapse from the postulated loss to the time when all measurements required to close the balance have been performed, recorded and evaluated. Sensitivity of loss detection is calculated by:

- estimating the standard deviation of the detection parameter, e.g., mass balance yield, or SSNM concentration ratio
- choosing an alarm set point for the parameter that corresponds to an acceptable false alarm rate, generally from 0.01 to 0.05
- calculate the quantity of SSNM loss that would be detected at an acceptably high probability such as 0.95.

The alarm set point will be the product of the standard deviation and a factor (from the tables of a normal distribution) that determines the probability of false alarms. Calculating the standard deviation includes consideration of measurement errors, estimated process variance, estimated holdup variability, and variability of the scrap and waste generation rates. The sensitivity is then defined as an amount of SSNM loss that would have a 95% probability of causing an alarm.

Localization effectiveness of the system can be characterized as either the number of target materials or the number of process operations that would need to be investigated if a particular alarm occurred. Each control unit will have a characteristic localization number. Small numbers indicate good localization. The localization of conventional material balance accounting based on the inventory difference test against the limit of error of the difference (i.e.,

MUF versus LEMUF) is characterized by a large number, because all target materials (or all process operations) in the material balance area would need to be investigated if an alarm occurred.

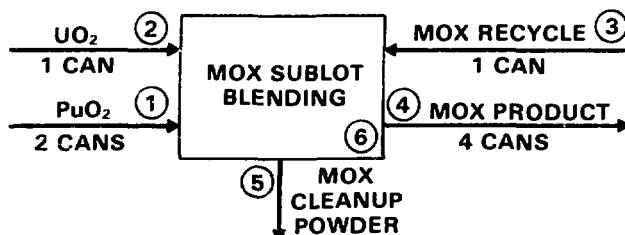
B. Example Applications

An example of a loss detection unit (control unit) is given in Figure 1. This control unit compares one typical unit operation, blending sublots of plutonium-uranium oxides. The feed materials, UO_2 and PuO_2 , have known chemical compositions based on previous analyses. Five measurement points for weighings and an estimate of the holdup in the gloved box and equipment after cleanup are utilized. Cleanup after each MOX lot consists of removing visible holdup and spilled powder in the equipment and on the floor of the gloved box. The equipment is not disassembled for this cleanup.

The control unit is monitored for each complete lot of MOX powder, which consists of two sublots. The loss monitoring equation is:

$$\sum_{i=1}^4 \text{NW}_{1i} + \sum \text{NW}_{2i} + \sum \text{NW}_{3i} - \sum \text{NW}_{4i} - \text{NW}_5 - \text{H}(\text{dNW}_6) = \Delta$$

where $\text{H}(\text{dNW}_6)$ is the estimated change in the holdup and Δ is the mass balance difference. ($\text{dNW}_6 = \text{NW}_{6b} - \text{NW}_{6e}$ for the beginning (b) and end (e) of the lot processing.)



MEASUREMENT POINT	DATA COLLECTED
1	NW OF PuO_2 IN EACH CAN (NW_1)
2	NW OF UO_2 (NW_2)
3	NW OF MOX RECYCLED FROM PREVIOUS LOTS (NW_3)
4	NW OF MOX IN EACH CAN (NW_4)
5	NW OF MOX CLEANUP POWDER COLLECTED AFTER TWO SUBLOTS (NW_5)
6	ESTIMATED AMOUNT OF HOLDUP OF MOX AND PuO_2 IN THE BLENDING SYSTEM AND GLOVED BOX

FIGURE 1. Example Control Unit A. PuO_2 - UO_2 Mixed Oxide (MOX) Blending

The detection sensitivity is based on an estimate of the standard deviation of the mass balance, s_{Δ} , and the loss alarm would be set at a multiple of s_{Δ} , such as $2s_{\Delta}$. The s_{Δ}^2 is estimated as follows: (a)

$$4s_1^2 + 2s_2^2 + 2s_3^2 + ds_4^2 + s_5^2 + s_H^2 + 4^2s_{1c}^2 + 2^2s_{2c}^2 + 2^2s_{3c}^2 + 9^2s_{4c}^2 = s_{\Delta}^2$$

where $s_1, s_2, \dots, s_5$ are the standard deviations of net weighings at measurement points 1 through 5, s_H is the standard deviation of the estimated change in the in-process holdup, and $s_{1c}, s_{2c}, \dots, s_{4c}$ are the calibration standard deviations of the weighing systems used. NW_4 and NW_5 are on the same scale. Therefore the coefficient of the variance term is $(8 + 1)^2 = 9^2$. All values of s are expressed in absolute units, such as grams of MOX. It is assumed that most measurements involved in the control unit are independent and possible correlations between them are ignored except in obvious cases such as where the same instrument or scale is used for more than one measurement point.

Other loss monitoring units were evaluated in a similar manner. Figure 2 shows a typical control unit in an enriched uranium scrap recovery process. The unit operation consists of a solvent extraction and interstage concentration cycle. The process is semicontinuous with evaporation by batches and continuous, uniform flow through the extraction columns. The boundaries of the control unit were chosen at measurement points that permit completion of uranium balances over short time intervals. The time interval chosen for a control unit balance is one day. A uranium balance is based on recorded flow and uranium concentration measurements made hourly at each measurement point. The standard deviation of Δ and the loss alarm level are estimated in a manner similar to that of Example A. The material balance equation for this control unit is:

$$\sum U_{1i}F_{1i}t_{1i} - \sum U_{2i}F_{2i}t_{2i} - \sum U_{6i}F_{6i}t_{6i} - \sum V_{7i}U_{7i} - H(dU_3) \\ - H(du_5) + (V_4U_4)_b - (V_4U_4)_e = \Delta$$

where

$U_1, U_2, \dots$ = the hourly uranium concentration measurements at points 1, 2, $\dots$ respectively, (They were ^{235}U concentration measurements by NDA.)

$F_1, F_2, \dots$ = the hourly flow rate measurements at points 1, 2, $\dots$ respectively

$t_1, t_2, \dots$ = the time intervals of flow corresponding to $F_1, F_2, \dots$ respectively

V_7 = the volume of a batch discharged from the evaporator

(a) Calculating the variance of Δ in this manner is done for design and evaluation. After gaining operating experience, s_{Δ}^2 can be reevaluated from the historical data collected during periods of "no loss" from the control unit.

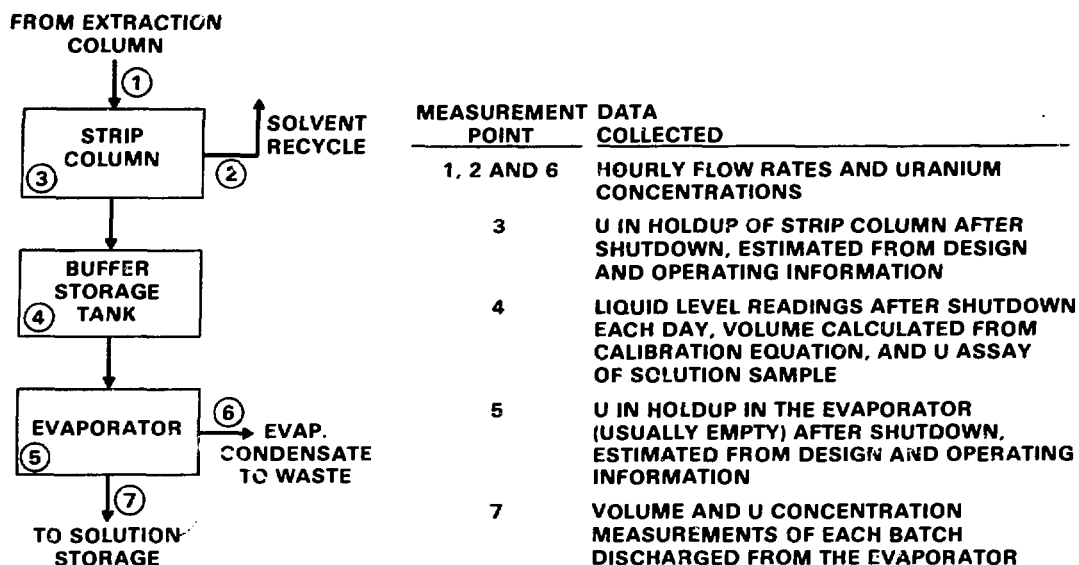


FIGURE 2. Example B, Uranium Extraction in a Scrap Recovery Process

$H(dU_3)$ and $H(dU_5)$ = the estimated differences in the quantities of uranium in the strip column and evaporator holdups at the beginning and end of the day's run

$(U_4V_4)_b$ and $(U_4V_4)_e$ = the inventories of Tank 4 at the beginning and end of the day's run

C. Diversion Modes

One of the diversion scenarios considered was substitution of other material for plutonium or high enriched uranium. In that case simple mass balance monitoring, as shown in Example A, would not detect the diversion. However, where assays are performed, as in Example B, substitution would not mask the diversion and the detection capability would not be affected. Since the uranium assays in this case are ^{235}U determinations, isotopic substitution would also be detected. In cases analogous to Example A, control units based on monitoring plutonium assay data are used to detect diversion with mass substitution. The detection sensitivities in those cases are estimated by evaluating the variance of the ratio of the input and output assays. The input assay values could be either previous feed assays, nominal values, or historical average lot values.

Multiple losses that occur over more than one loss detection interval, called trickle losses, would usually be detectable using the process monitoring data before the cumulative loss reaches the level of detectability of the current material accounting system. To detect a trickle loss when the rate of loss is too small to be detected in a single interval, a study should be made of sequential data utilizing loss rate indicators, such as cumulative sums.^(6,7) Although sufficient information on the statistical characteristics of the loss indicators based on process monitoring data is generally not available in the design stage to perform statistical evaluations of sequential

data, a cursory analysis of the trickle loss detection capability can be performed for each target material. To perform this analysis the variances of the cumulative loss indicators could be assumed to be affected predominantly by the random measurement and process errors. However, the sensitivities estimated in this manner are likely to be optimistic because correlated errors that have a trivial effect on short-term (24 hr) variances may have a pronounced effect for data collected over a week or so.

In the study reported by Brouns, et al.,⁽²⁾ two loss levels were chosen for testing the effectiveness of detecting a trickle loss: one in which the cumulative loss would equal the high probability detection capability of the current material balance accounting system, i.e., approximately twice the facility Limit of Error of Inventory Difference (LEID or LEMUF), and the other in which the cumulative diversion would equal five formula kilograms in two months. To determine if there is a high probability of an alarm from a trickle loss within a two-month period, two tests were performed. The first test calculated the time period until there was a high probability of an alarm for at least one SSNM loss in the series. The second test was based on estimates of the control limits for the cumulative sum of the losses, assuming that all process variance is random. If either of the tests indicated that the trickle loss would be detected within two months, the result was classified as a possible detection, and if both tests indicated that the trickle loss would be detected the result was classified as capable of detecting the trickle loss. (Several of the reports given in the Bibliography contain more detailed discussion about methods of evaluating loss indication data.)

IV. EXAMPLE OF SOME EVALUATION RESULTS (a)

Examples of the evaluation results for the study by Brouns, et al., are shown in the following figures. Figure 3 shows the sensitivity of loss detection for a simple loss as a function of the target material attractiveness^(b) for a high-enriched uranium (HEU) fuel fabrication facility. The number beside each point indicates the number of target materials that have those characteristics. The sensitivity for each target material is shown as a fraction of the sensitivity for the current SNM accountings system based on LEID.

Figure 4 shows the detection sensitivities for the HEU facility as a function of the timeliness of detection. Average delays of

-
- (a) It should be noted that the effectiveness evaluation results in this case are for a SSNM control system based on utilizing only existing measurement points. Sensitivities, timeliness, and localization capabilities could be improved at many points by adding more frequent measurement or different types of measurements.
 - (b) The attractiveness of the target material to a potential adversary is used to interpret the evaluation results. The numeric attractiveness values were based on three characteristics: 1) location, including accessibility to the target material, 2) form, which includes type, purity, and fissile fraction of the material, and 3) mobility, which considers size, weight, containment, transportability, and ease of concealment. The overall numeric attractiveness value is the simple product of the three values.

SENSITIVITY FOR NO SUBSTITUTION CASE

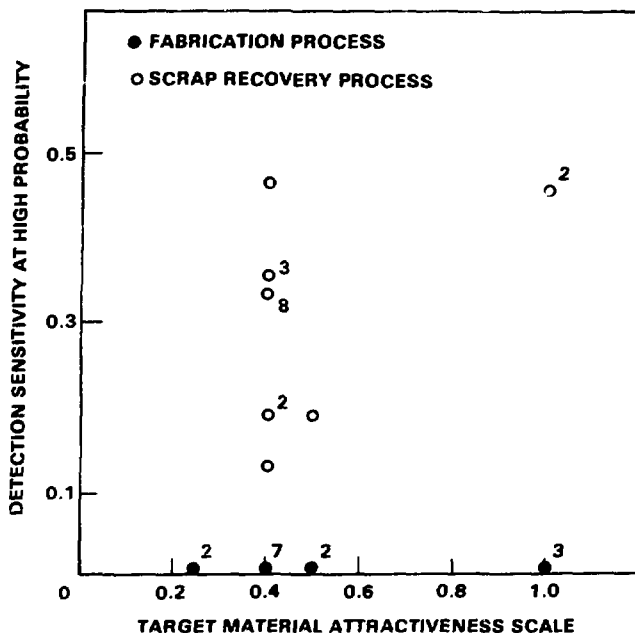


FIGURE 3. Detection Sensitivity versus Target Material Attractiveness; HEU Plant. (attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

20 days occur for several target materials in fabrication because a holding period is required to await release by quality control before further processing.

For diversion concealed by substitution of other material, the sensitivities changed only slightly but the detection times increased appreciably, generally by about two weeks. For the HEU facility, Figure 5 shows the detection sensitivity as a function of timeliness for detection of diversion when concealed by mass substitution.

Data manipulation would further delay detection in many cases but with only small effects on sensitivity. Some falsification scenarios could prevent detection by this technique in certain process steps if record audits and internal control were not thorough. In many target material locations the collusion of two or more plant personnel would be required to successfully falsify data without prompt detection.

For the high-enriched uranium fuels fabrication facility, 58 of 59 target materials are included in the process monitoring data. The target material not included is a low-concentration recycle solution in the scrap recovery process. The average timeliness of the proposed system, based on process monitoring data for the case of a single loss without concealment, was less than 24 hr for 43 target materials and less than one week for six target materials. The detection sensitivity for the proposed system, where process data are available, is a

DIVERSION WITHOUT SUBSTITUTION

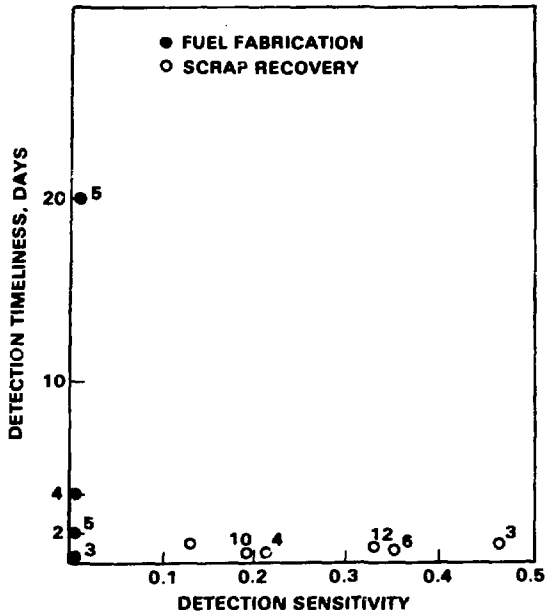


FIGURE 4. Detection Sensitivity versus Timeliness; HEU Plant. (sensitivity expressed as a fraction of the facility LEID)

SENSITIVITY FOR MASS SUBSTITUTION CASE

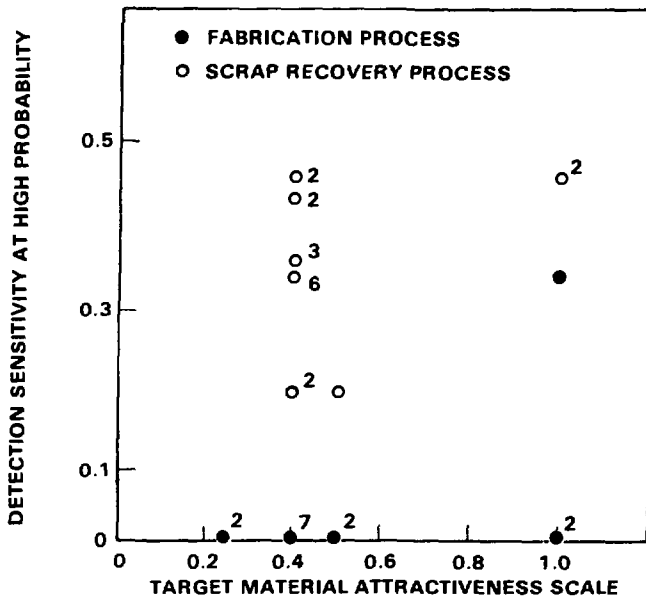


FIGURE 5. Detection Sensitivity for Diversion With Mass Substitution versus Target Material Attractiveness; HEU Plant. (attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

factor of two better than current accounting for all target materials, and for 30% of the target materials the improvement is more than a factor of ten better.

The detection effectiveness of the process monitoring technique for the MOX fuel fabrication plant is shown in Figures 6, 7, and 8. The data are displayed in a manner similar to those for the previous facility. For this facility, 61 of 73 target materials are included in the process monitoring data; the other target materials are clean-out, wastes, and product materials where the measurements are performed for accountability. For all but five of the 73 target materials, the average time from a loss to detection by the current materials accounting system would be 30 days (maximum 60 days). The average timeliness of the proposed system, based on process monitoring data for the case of a diversion without concealment, was less than 24 hr for 37 target materials and less than one week for 24 target materials. Of the 12 remaining, five have low attractiveness (e.g., low concentration wastes), five are controlled as sealed items, and the other two are cleanout materials. The detection sensitivity for the proposed system (i.e., the grams of SSNM loss that would be detected with high probability) is a factor of at least two better

DIVERSION WITH NO SUBSTITUTION

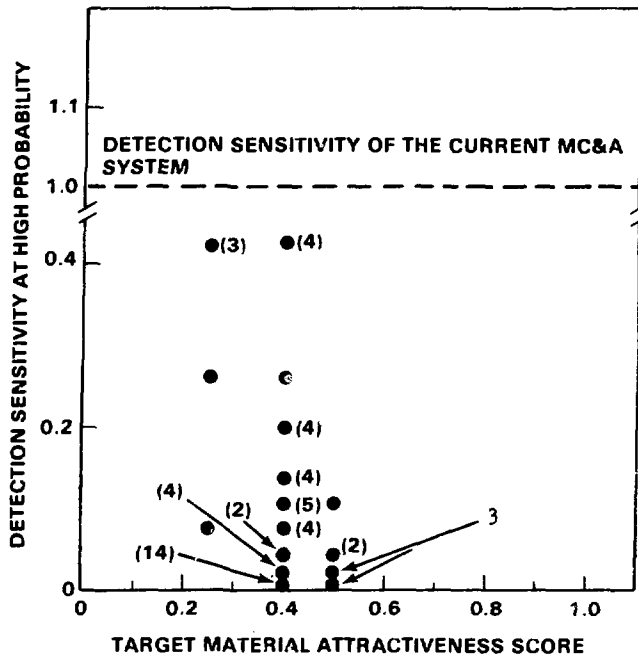


FIGURE 6. Detection Sensitivity versus Target Material Attractiveness; MOX Plant. (attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

DIVERSION WITH NO SUBSTITUTION

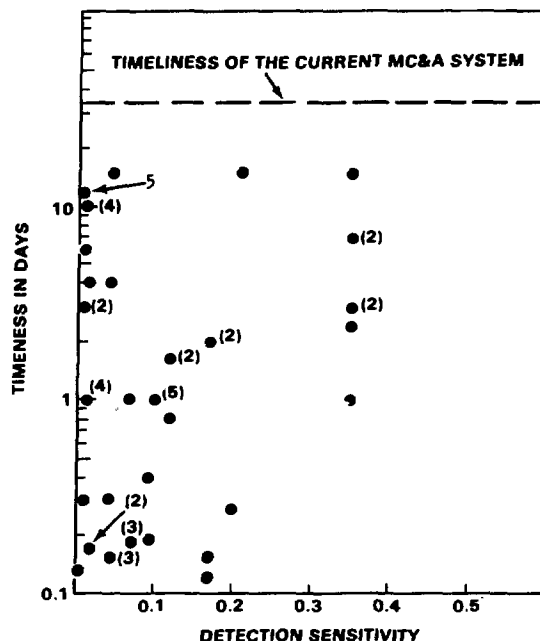


FIGURE 7. Detection Sensitivity versus Timeliness: MOX Plant.
(sensitivity expressed as a fraction of the facility LEID)

than the current accounting system for all applicable target materials, and for 60% of the target materials the improvement is more than a factor of ten better.

The ability to identify the process location or target material from which a loss or diversion occurred when an anomaly is observed is referred to as localization capability. An example of typical localization capabilities is shown in Table 1 using data for the MOX plant. The results for the HEU plant are similar. Localization of diversion alarms is shown by target material in Part a and by unit operation in Part b of Table 1. In the second and third columns the number of diversion monitoring measurement points are given for which an alarm could be localized to only one (1), two (2), three (3), etc., target materials and unit operations, as given in the first column. For example, in the no-substitution case there are seven monitoring points for which an alarm would be uniquely associated with a single target material and nine for which an alarm would be associated with just two target materials. Note that the mass substitution scenario results in poorer localization than the no-substitution case. In the worst case an alarm at one of the monitoring points would require consideration of 22 possible target materials and 17 possible unit operations as potential sources of a diversion.

DIVERSION WITH MASS SUBSTITUTION

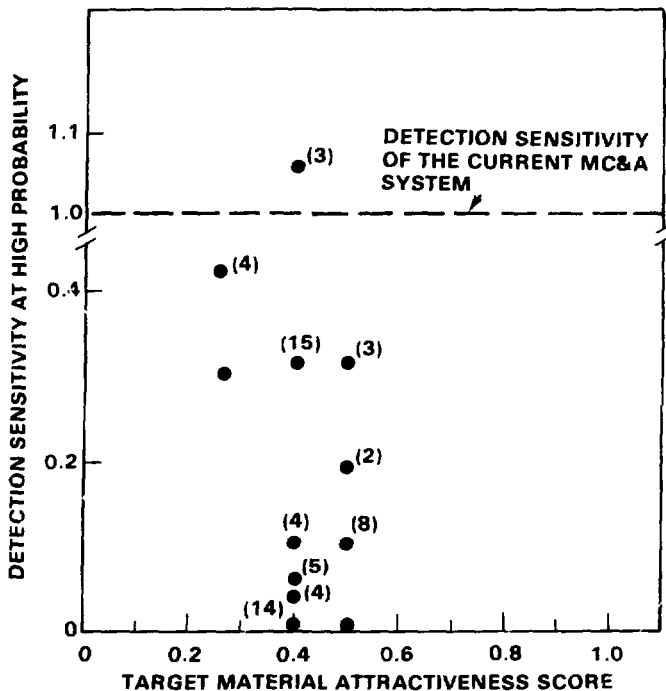


FIGURE 8. Detection Sensitivity for Diversion with Mass Substitution versus Target Material Attractiveness. (attractiveness values <0.25 omitted; sensitivity expressed as a fraction of the facility LEID)

V. INVESTIGATION OF ALARMS

An important cost element in the inclusion of the process monitoring technique into SNM accountability would be the investigation of alarms. Alarms due to innocent causes only may result from:

- A random deviation of the process sufficient to cause a loss indicator value that exceeds the control limit. The frequency is predictable from the process variance, and raising the control limit will reduce the frequency of false alarms. However the detection sensitivity will be poorer.
- A random deviation of a measurement result sufficient to cause a loss indicator value that exceeds the control limit. The frequency is predictable from the measurement variance, and raising the control limit will reduce the frequency although detection sensitivity will be reduced.
- A nonrandom process deviation for which a specific cause usually can be found. The alarm may be anticipated by close observation of the process operation.

TABLE 1. Localization Effectiveness of the Process Monitoring Technique

Number of Target Materials or Units Monitored at the Diversion Monitoring Point	Number of Diversion Monitoring Measurement Points	
	<u>Without Substitution</u>	<u>With Mass Substitution</u>

Part a. Localization by Target Material

1	7	2
2	9	3
3	4	2
4	3	1
5	2	1
6	2	-
10	1	-
13	-	1
17	-	1
22	-	1

Part b. Localization by Unit Operation

1	10	3
2	8	3
3	5	3
4	1	-
5	1	-
6	2	-
9	1	-
13	-	1
14	-	1
17	-	1

- A nonrandom measurement deviation caused by an out-of-control situation. A good measurement control program can maintain the frequency of such events to a negligible level.
- Human errors in performing measurements. The opportunities for a false assay result due to a human error are numerous but the frequency of weighing errors should be quite small.
- Human errors in recording and copying measurement data and information.

Human errors in performing measurements and recording data are expected to be the major source of alarms. Some of these alarms will be resolved quickly by review of recorded data and calculations, while others will require checks of labels, criticality safety sheets, or remeasurements of items still in the process line. Because of the timeliness of process monitoring it is expected that this type of alarm will usually not be difficult to evaluate. Alarms due to unusual process variability may be much more difficult to evaluate. Additional measurements of process material, holdup measurements, assay of scrap and recycle material, or improved measurements may resolve these alarms, but because of the localization of process data

these are not expected to affect the whole process. Resolution will also be useful to production and quality control and should coincide with normal operating practices.

VI. CONCLUSIONS

Loss monitoring effectiveness of the process monitoring technique for the target materials in bulk material processing is usually uniquely affected by the specific processing operation. Generalizations of the sensitivity, timeliness, and localization are not feasible, except that for the vast majority of the target materials in these two facilities loss detection effectiveness is better than the capabilities of the current SSNM accounting systems. Loss detection time periods are usually a few days in contrast to many weeks, and target material sensitivities are usually a small fraction of the typical facility LEID, largely as a consequence of the short time spans involved between measurements. In addition, loss alarms would generally localize the trouble point to a small part of the process area. Because of the inability of the current SSNM accounting system to distinguish between block and trickle losses within the two-month period, the process monitoring technique is generally more sensitive to early detection of trickle losses. Even though the process monitoring technique may not detect a trickle loss, it should be noted that in the event of an excessive inventory difference (ID or MUF), the investigation could be concentrated on those detection units where sensitivities are insufficient to detect the trickle loss within the material balance period.

Because the sensitivity evaluations were based on low false alarm rates and high probability of detection, there will also be evidence that can be used to test specific hypotheses about the source of the ID, only at some lower probability than that used in this system. Also, the system will gain effectiveness from limitations on frequency of access to the process, presence of other personnel that might deter the diversion, and the benefits of the physical security system.

The process monitoring data are currently monitored by the staff in many licensed facilities. If a sufficient loss occurred at any of the monitored points in the process, an anomaly in the process data would be observed and an investigation would undoubtedly follow. However, formalization of the system and involvement of safeguards personnel would probably improve loss detection timeliness and the overall effectiveness of safeguards procedures.

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



April 27-May 12, 1981

Session Objectives

SESSION 25: DEMONSTRATION OF MEASUREMENT TECHNIQUES

Following the Session 23 presentation, this session will actually illustrate the application of the analytical methods, the SAM-2 enrichment meter, and pellet weighing and sampling techniques.

After the session, participants will be able to:

1. understand how the analytical methods are performed in actual practice,
2. understand how the SAM-2 performs on actual production materials,
3. understand how pellets are actually weighed and sampled.



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



April 27-May 12, 1981

SESSION 25: DEMONSTRATION OF MEASUREMENT TECHNIQUES

N. S. Wing, D. J. Hill (Analytical Methods)

K. O. Johnson (NDA Methods)

Roger Sharp (Pellet Sampling and Weighing onto Trays)

J. W. Key (Fuel Rod Loading)

Exxon Nuclear

In Session 25, the participants come to the plant for demonstrations of the measurement methods described in classroom Session 23. Demonstrations are given at three locations within the UO₂ plant. These are the Analytical Laboratory, the area near the rod scanner, and the rod loading area.

At the Analytical Laboratory, demonstrations of the gravimetric, fluorimetric, and Davis-Gray methods for uranium assay are given. The equipment is shown and the various operations are described and illustrated.

At the area near the rod scanner, the participants are shown the operation of the SAM-2 enrichment meter using buckets of UO₂ of different enrichments. The operation of the rod scanner is also described and typical instrument readouts are shown. While the participants are still in the same area, they can observe the demonstrations of pellet sampling and the weighing of pellets on trays.

The last demonstration is given at the rod loading area where the weighing of pellet columns into fuel rods is demonstrated.



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



April 27-May 12, 1981

Session Objectives

SESSION 26: 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.



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



April 27-May 12, 1981

SESSION 26: PROCEDURE FOR TAKING PHYSICAL INVENTORIES

A. J. McGinnes
Exxon Nuclear

This session is intended to apprise you of the various aspects of procedures and routines that Exxon Nuclear uses with respect to its nuclear materials physical inventory program.

I. GENERAL

Chart 1 summarizes the overall physical inventory program encompassing regulatory requirements, accountability and custodial responsibilities, planning activities, physical counting, reconciliation processes, and finally, required reporting.

II. FORMS

Chart 2 shows the two principal forms used for recording actual counts of rod/bundles and other nuclear materials of varying compositions in the production areas. Sample copies of the forms are available upon request. Use of the forms will be discussed in detail later in the session.

III. REPORTS

Chart 3 is a composite listing of the various inventory reports (computer tabulations) totaling 11 that are used in conjunction with the physical inventory program. Sample copies of these reports are available showing physical inventory data on a model plant.

IV. PROGRAMS AND PROCEDURES

Physical inventories are taken quarterly. The entire plant is shut down and inventoried. Each process area is shut down so all process equipment can be cleaned out. Movement of nuclear material is restricted until completion of the physical inventory.

Three physical inventory procedures are used. Incorporated in the procedures is the use of serially numbered stickers which are affixed to each item or group of items for control purposes. Colored stickers are used alternately for each scheduled inventory. The charts that follow outline procedural routines involved.

V. ITEM CONTROL AREA (ICA) PROCEDURE

Chart 4 shows the procedure relating to the inventories maintained in ICA areas. All containers listed on the perpetual inventory tabulation (PHIL) for ICAs must be found. During the verification process, it is of utmost importance to assure that all containers are sealed and that the seal number on each container agrees with that on inventory tabulation. Containers with no seal or a broken seal

CHART 1. Nuclear Materials Physical Inventory Program

RULES AND REGULATIONS

FEDERAL REGULATIONS
LICENSING REQUIREMENTS
DOCUMENTED PLANS AND PROCEDURES

RESPONSIBILITY

ACCOUNTANT, NUCLEAR MATERIALS
MATERIAL CUSTODIANS

PLANNING

PRE-INVENTORY REVIEW MATERIAL LOCATIONS
TIME SCHEDULE
MANPOWER ASSIGNMENTS (TWO MAN TEAMS)
WRITTEN INVENTORY PROCEDURES
INVENTORY LISTINGS, SHEETS AND TAGS
DETAILED CHECK LISTS
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
MANAGEMENT

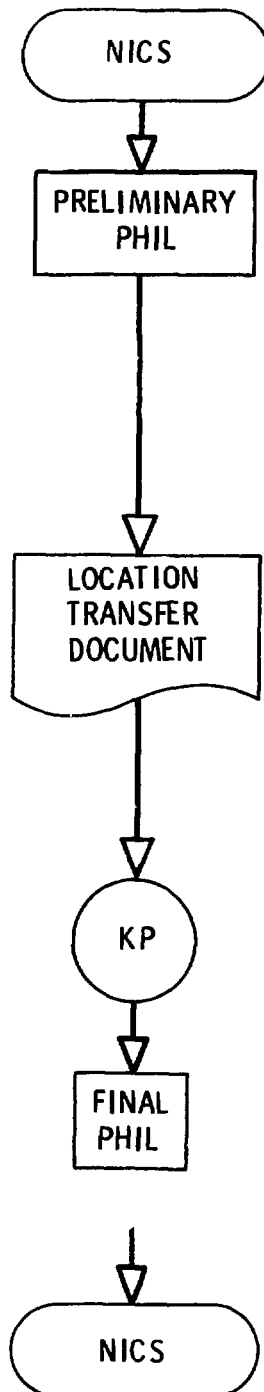
CHART 2. Physical Inventory Forms

<u>SOURCE DOCUMENT</u>	<u>PREPARED BY</u>	<u>VERIFIED BY</u>	<u>PROCESSED BY</u>	<u>TRANSACTION RECORDED</u>
ROD INVENTORY PHYSICAL COUNT SHEET	MBA CUSTODIAN	NM ACCOUNTING	NM ACCOUNTING	ROD/BUNDLE PHYSICAL INVENTORY
MBA PHYSICAL INVENTORY SHEET	MBA CUSTODIAN	NM ACCOUNTING	NM ACCOUNTING	MBA PHYSICAL INVENTORY

CHART 3. NICS Physical Inventory Reports

<u>REPORT</u>	<u>TITLE</u>	<u>DESCRIPTION</u>
MIMS	MATERIAL INVENTORY MAINTENANCE SYSTEM	SHOWS FINAL MBA MATERIAL BALANCES; ELEMENT AND ISOTOPE QUANTITIES ARE SHOWN FOR EACH MBA BY MATERIAL TYPE, PROJECT, AND NOMINAL ENRICHMENT ACCOUNTS. INDIVIDUAL CONTAINERS ARE LISTED FOR EACH ICA INVENTORY.
PHIL	ICA PHYSICAL INVENTORY LIST	CONSOLIDATED LISTING OF ALL ITEMS IN ICA INVENTORIES.
MPIS	MBA PHYSICAL INVENTORY LIST	SHOWS DETAIL OF ALL ITEMS INVENTORIED IN EACH MBA.
INSUM	INVENTORY SUMMARY	SHOWS CONSOLIDATED TOTAL OF MBA AND ICA INVENTORIES.
EIS	ENDING INVENTORY SUMMARY	SHOWS DETAIL OF ENDING INVENTORY ACCORDING TO MATERIAL COMPOSITION BY SPECIFIC ENRICHMENT AND RELATED PROJECT NUMBER.
RODIN	ICA-2 ROD INVENTORY	COMPARISON OF BOOK BALANCE WITH PHYSICAL INVENTORY ACCORDING TO ROD SERIAL NUMBER PREFIX.
FACT	ELEMENT AND ISOTOPE FACTOR TABLE	SHOWS UPDATED ELEMENT AND ISOTOPE FACTORS.
WEIT	DUPLICATE CONTAINER LIST	SHOWS IF DUPLICATE CONTAINERS ARE INCLUDED AS RESULT OF PHYSICAL INVENTORY.
MBMUF	MBA MUF CALCULATION	COMPARES BOOK BALANCE WITH PHYSICAL INVENTORY SHOWING RESULTING MUF BY PROJECT AND ENRICHMENT.
TRAP	TRANSACTION FILE LIST	SHOWS ALL TRANSACTIONS PROCESSED DURING THE MATERIAL BALANCE PERIOD. TRANSACTIONS ARE SEGREGATED BY EACH MBA AND ICA.
SCRAP	SCRAP MATERIAL PHYSICAL INVENTORY	SUMMARIZES BY MATERIAL COMPOSITION ALL ITEMS IN THE SCRAP INVENTORY.

CHART 4. Physical Inventory Procedure Item Control Areas



must be remeasured to be included in the inventory. Seal number variances must be satisfactorily resolved. Location transfer documents are processed for any container discrepancy so as to correct inventory tabulations. No MUFs are allowed within ICA inventories.

Chart 5 covers the procedure for inventorying rods. This is a specially designed procedure. It provides for inventorying rods in quantities according to their assigned prefix letters rather than by verifying each numbered rod. The form used on which to record the physical count is designed to show preassigned inventory sticker numbers and coinciding numbers of each storage bin. The count sheets are segregated into predetermined groups according to storage area and assigned to physical inventory teams. The computer program is designed to provide a reconciliation type report which shows the following results by rod prefix:

Book Inventory	XXX
Actual Count	<u>XXX</u>
Inventory Difference	-0-

Reported differences for an assigned rod prefix must be resolved before finalizing the inventory. In other words, a difference in one rod prefix cannot be used to offset a difference in another prefix.

VI. MATERIAL BALANCE AREA (MBA) PROCEDURE

Chart 6 shows the steps taken to inventory nuclear materials in production areas. All containers of material; generally in buckets, boats, trays, etc., are recorded on an MBA physical inventory sheet.

The tag number column is serially numbered to coincide with the serially numbered stickers assigned to the inventory team. During the recording process, it is of utmost importance to assure that all containers are sealed. Containers with no seal or a broken seal must be remeasured to be included in the inventory. Pertinent data with respect to each container inventoried is taken from a material record card that accompanies each container. Data for the solar evaporation ponds is taken from the so-called lagoon inventory log. Sample copies of the inventory sheet, material record card and lagoon inventory log are available upon request. After all necessary adjustments have been resolved, a final MPIS listing is produced which details all items inventoried in each MBA.

VII. POST PHYSICAL INVENTORY

Chart 7 shows the final steps involved to conclude the physical inventory process; that is, the inventory data produced by the nuclear inventory control system (NICS) are made available for inclusion in the nuclear materials reporting system (NMRS).

VIII. RECONCILIATIONS

Reconciliation of physical inventory data to the book inventory encompasses several facets of audits, reviews and analyses. In summary, our course of action is geared to assure ourselves that all such

CHART 5. Nuclear Materials Physical Inventory Procedure
Rod Storage/Bundle Assembly

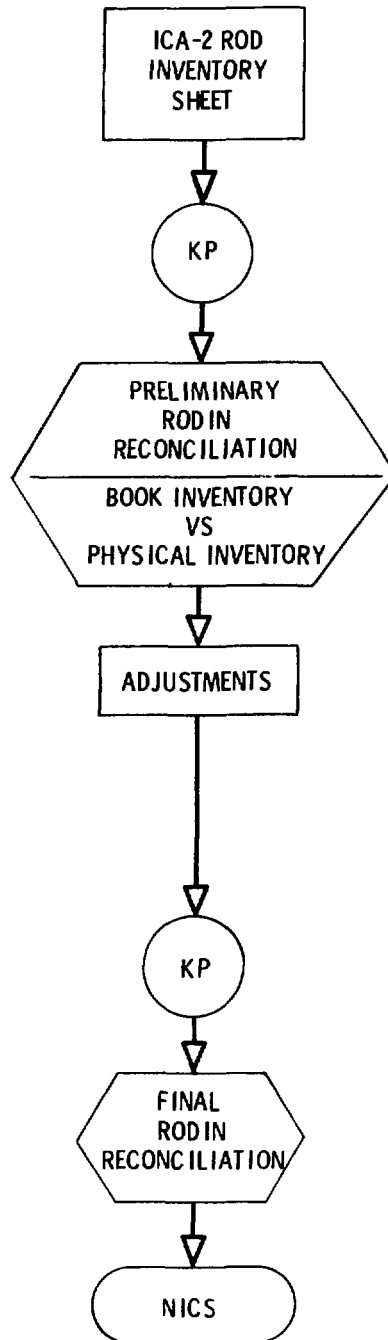


CHART 6. Nuclear Materials Physical Inventory Procedure
Material Balance Areas

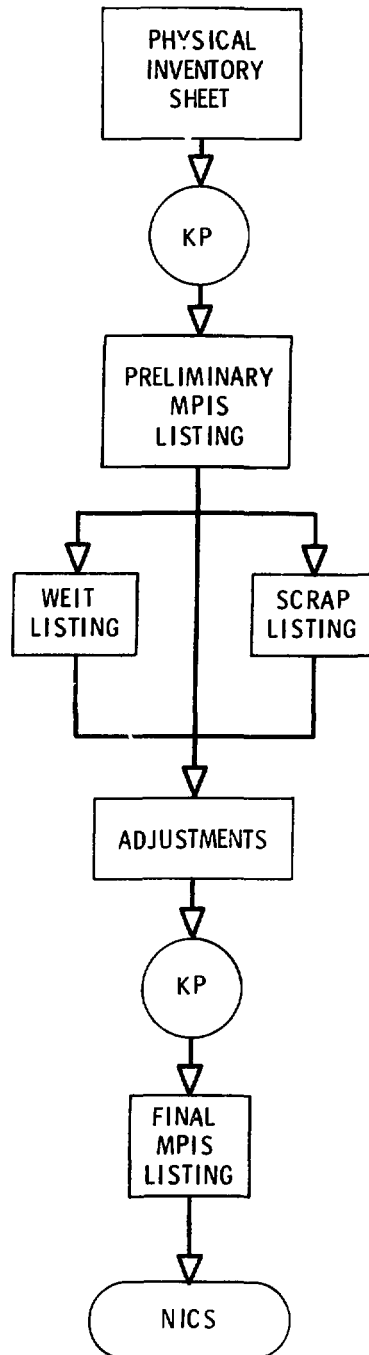
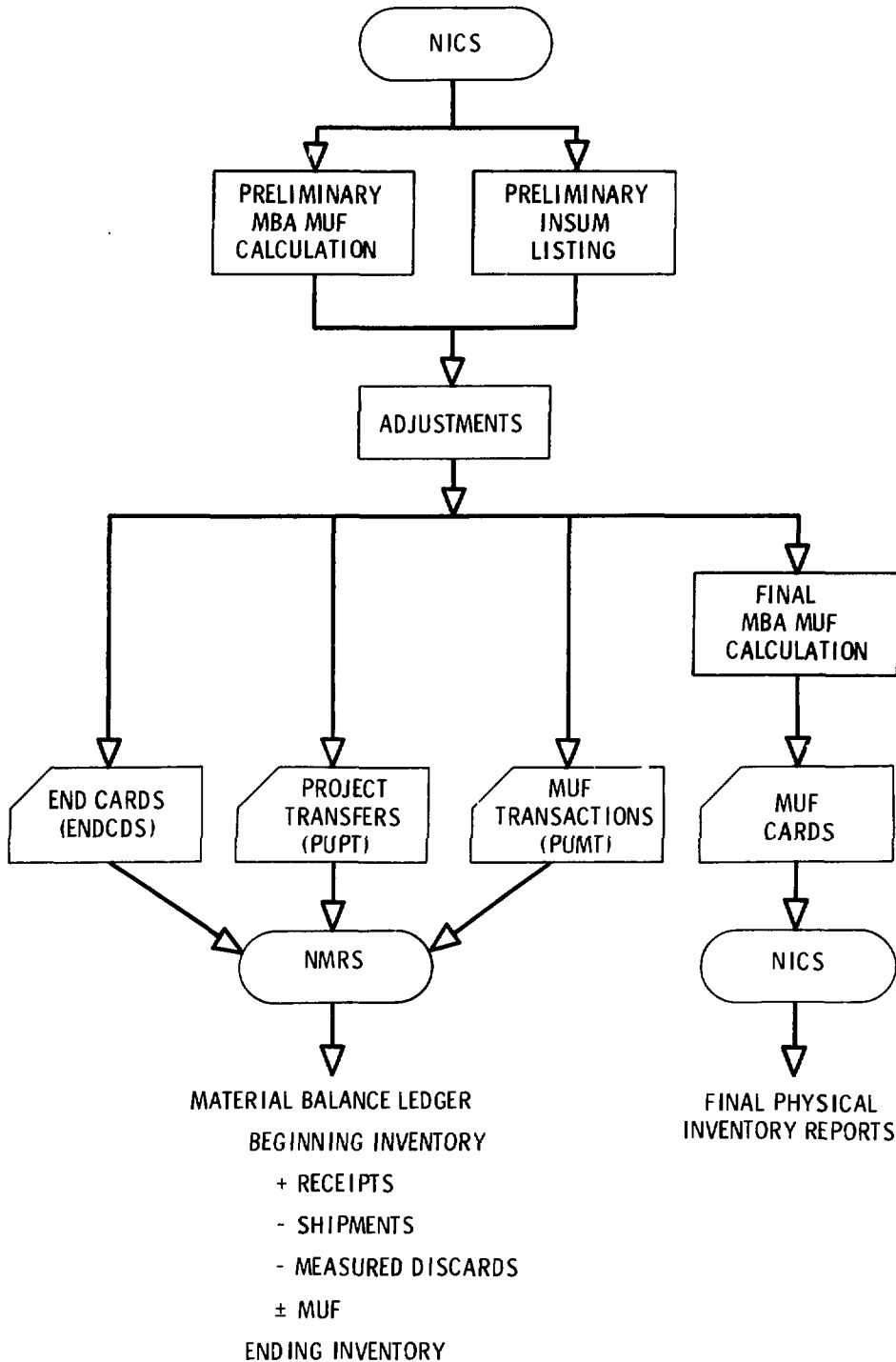


CHART 7. Nuclear Materials Post-Physical Inventory Procedure

data at hand is not unusual, is devoid of duplications, has been coded properly, keypunched accurately and that required adjustments or corrections were properly processed.

IX. REPORTS

Regulatory reports are prepared and distributed according to regulatory requirements. Management-type reports are also prepared to apprise management of pertinent aspects of nuclear materials inventory levels and activities.



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



April 27-May 12, 1981

Session Objectives

SESSION 27: MATERIAL CONTROL

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,



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



April 27-May 12, 1981

SESSION 27 (Part 1): SEAL CONTROL AND PROCUREMENT PROGRAM

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Exxon Nuclear

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	00001	00020	FILL IN NAME	MBA-1	SIGNATURE	INITIALS
7-25-79	00021	01000	980						

27-1-2

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	00001	00020	FILL IN NAME	MBA-1	SIGNATURE	INITIALS
7-25-79	00021	01000	980						

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			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
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



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



April 27-May 12, 1981

Session Objectives

SESSION 28: MEASUREMENT CONTROL PROGRAM

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.



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



April 27-May 12, 1981

SESSION 28: MEASUREMENT CONTROL PROGRAM

R. A. Schneider
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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 1. 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

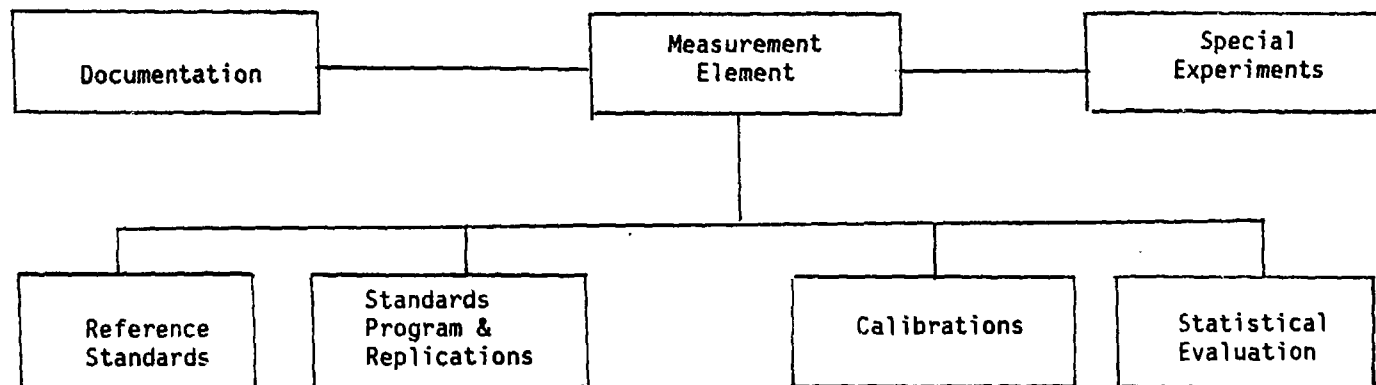


FIGURE 1. Measurement Control Program Focus

TABLE 1. 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 2. 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 2. 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	
	Tare Approximately 1650 Pounds	Recertify 2 Years.
	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 2 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 3. 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 3. Analytical Standards

Measurement	Standard	Certification
% 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 4. 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 4 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 4, 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 4. 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.

VII. STATISTICS

A. General

The scope of the statistical aspects of the measurement control program is shown in Table 5. 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 5. 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 tank 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 6.

TABLE 6. 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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**ADVANCED INTERNATIONAL TRAINING COURSE
ON STATE SYSTEMS OF ACCOUNTING FOR
AND CONTROL OF NUCLEAR MATERIALS**



April 27-May 12, 1981

Session Objectives

**SESSION 29: PREPARATION OF FUNDAMENTAL NUCLEAR MATERIAL CONTROL
(FNMC) PLAN AND DIQ**

This session describes and illustrates how an FNMC plan is prepared for the model plant. It also describes and illustrates how the DIQ is prepared, and points out the differences between the two documents. An actual example DIQ is completed for the model plant.

After the session, participants will be able to:

1. understand the basis for preparing an FNMC plan for an existing plant,
2. prepare a DIQ for a similar plant.



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



April 27-May 12, 1981

SESSION 29a: PREPARATION OF A FUNDAMENTAL NUCLEAR MATERIAL CONTROL PLAN

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I. INTRODUCTION

The general features of U.S. Regulations and the general provisions for low enriched uranium were discussed in Session 5. The general requirements for materials accounting and the corresponding approach taken to meet each general requirement were covered in Session 21a. This session extends the work of those previous sessions 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 the first part of this session and the preparation of a DIQ in the second part. The example DIQ describes in detail the low enriched uranium fuel fabrication plant which is the Model Plant of the course.

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 21a. The design criteria discussed in Session 21a, "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 1. Example descriptions of safeguards functions are given in Table 2.

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 3.

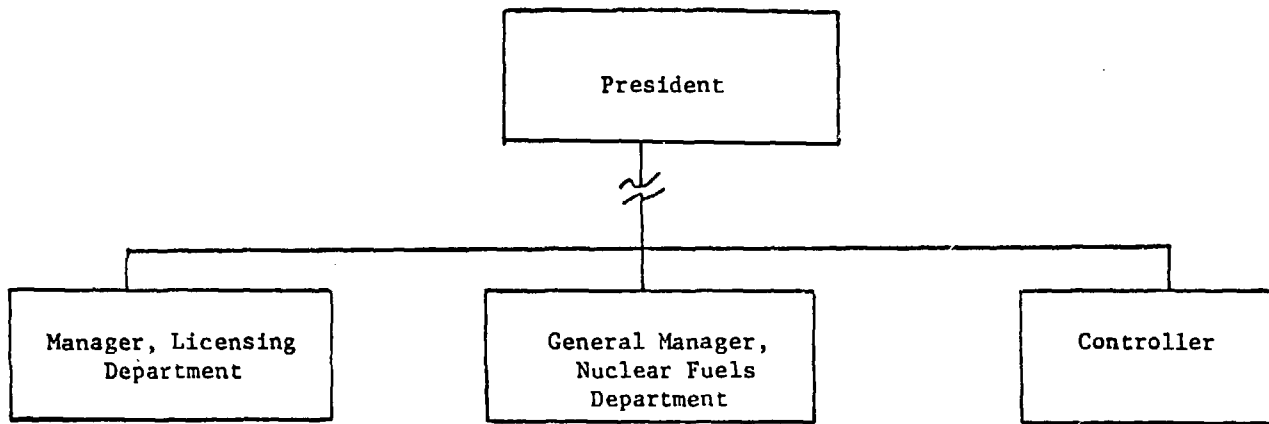
E. Chapter 4--Material Control Areas

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 21a 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

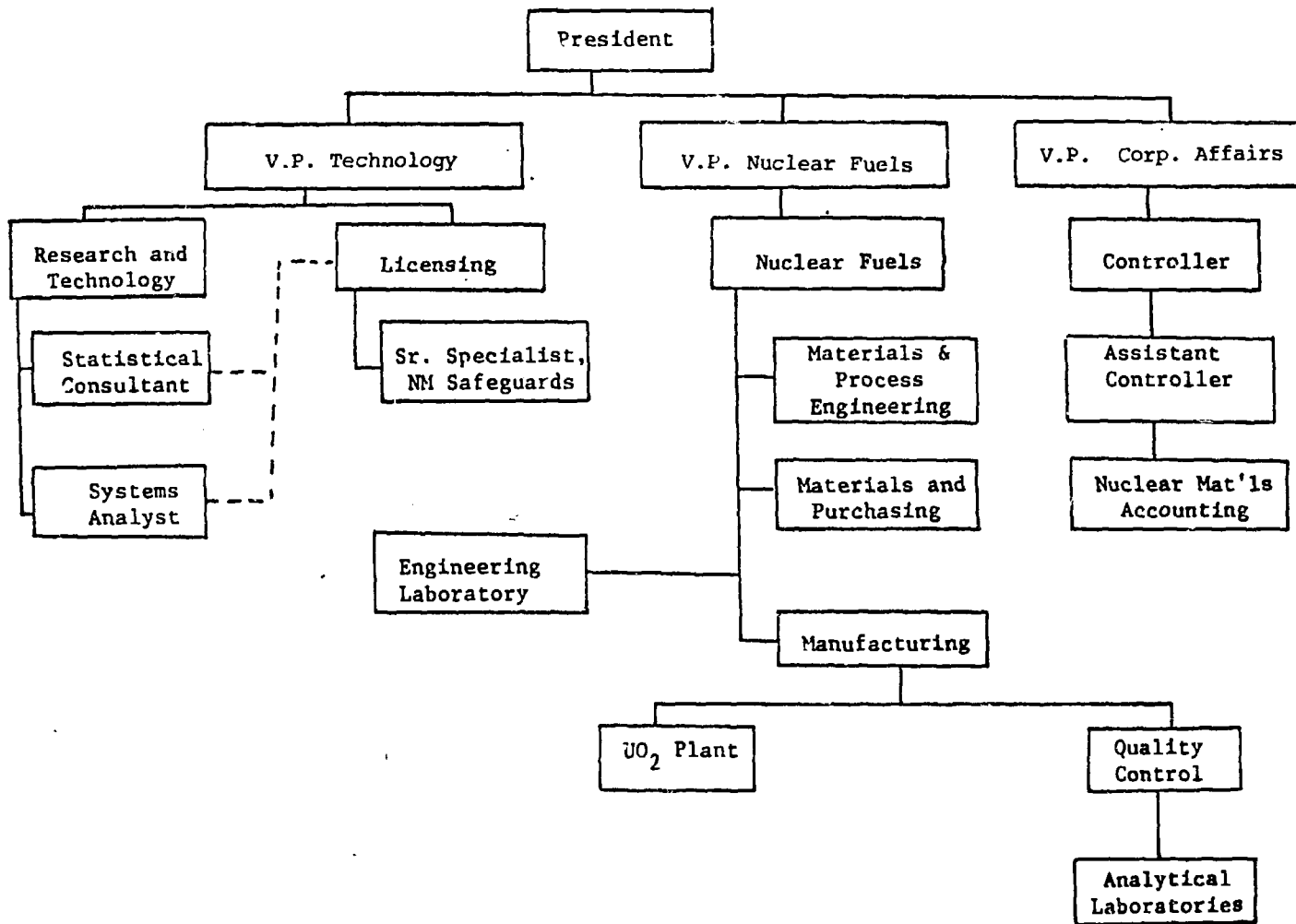


FIGURE 2. Model Plant Organizational Substructure of Components and Safeguards Responsibilities

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 1. 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 2. 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.

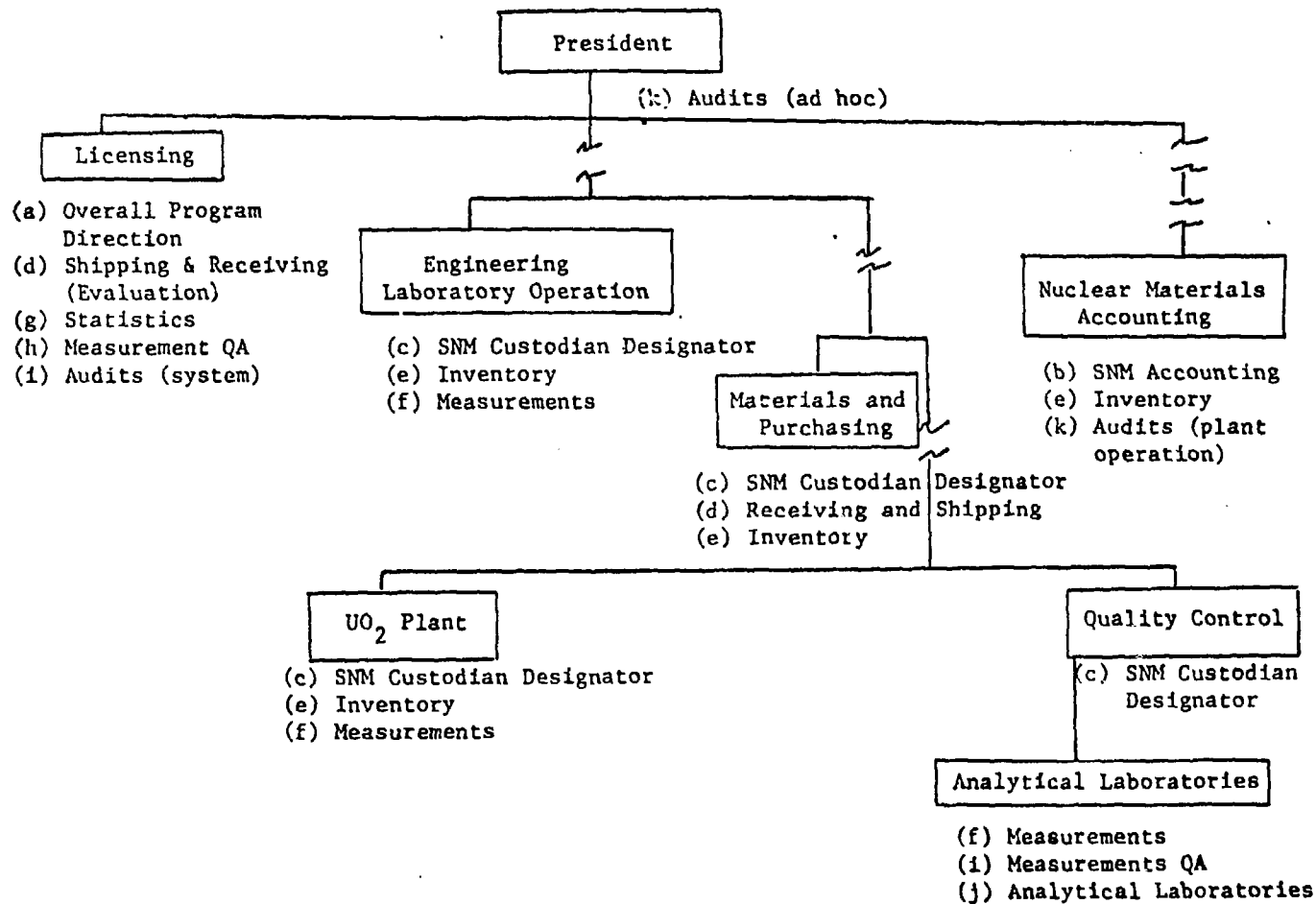


FIGURE 3. Example of Safeguards Functional Responsibilities

TABLE 3. Example of Training Program Description**Analytical 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

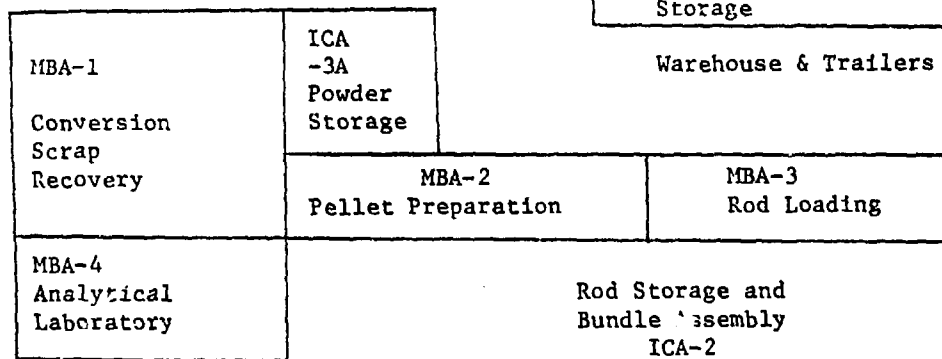
Training of individuals qualified to perform NDA measurements shall be the responsibility of the Manager, Facilities and Equipment Engineering. He shall certify in writing that a given individual is qualified to perform the measurement in question, based on the operator's adherence to the written procedures. 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



UO₂ PLANT

ICA-1
Shipping-Receiving

WAREHOUSE

FIGURE 4. Model Plant Material Control Areas

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 38 and 39. 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 the 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 38 and 39.

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 21a, 21c, and 26.

An example of the topics to be described in Chapter 8 of the Fundamental Material Control Plan are shown in Table 4.

TABLE 4. 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 38 and 39).
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 4. (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 5. 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 6.

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 7.

TABLE 5. Material Accounting Topics for Chaptet 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-Shipent • Location Transfer • Physical Inventory Recording Form
4. Flow Chart	4. See Table 8, page 36 of the Model Plant DIQ, Session 29.
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 5. (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 6. 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 38 and 39.

TABLE 6. (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_3O_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 6. (Contd)

<u>Discussion Topic</u>	<u>Example</u>
<u>Internal Transfers</u>	
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.	
<u>Overchecks</u>	
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.	
<u>Records</u>	
Shipping and Receiving retains the records described in Chapter 9 for a minimum period of five (5) years.	

TABLE 7. 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 7. (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 29-2).

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 38 and 39. 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.



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



April 27-May 12, 1981

SESSION 29b: 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
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Date

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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

EXAMPLE

DESIGN INFORMATION QUESTIONNAIRE
MODEL PLANT FUEL FABRICATION PLANT

DISTRIBUTION LIST

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16	Document Control Library
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18-23	Extra

DESIGN INFORMATION QUESTIONNAIRE
EXXON NUCLEAR FUEL FABRICATION PLANT

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Note: The Roman numeral heading numbers correspond to the Arabic numbered questions of the Design Information Questionnaire.

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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

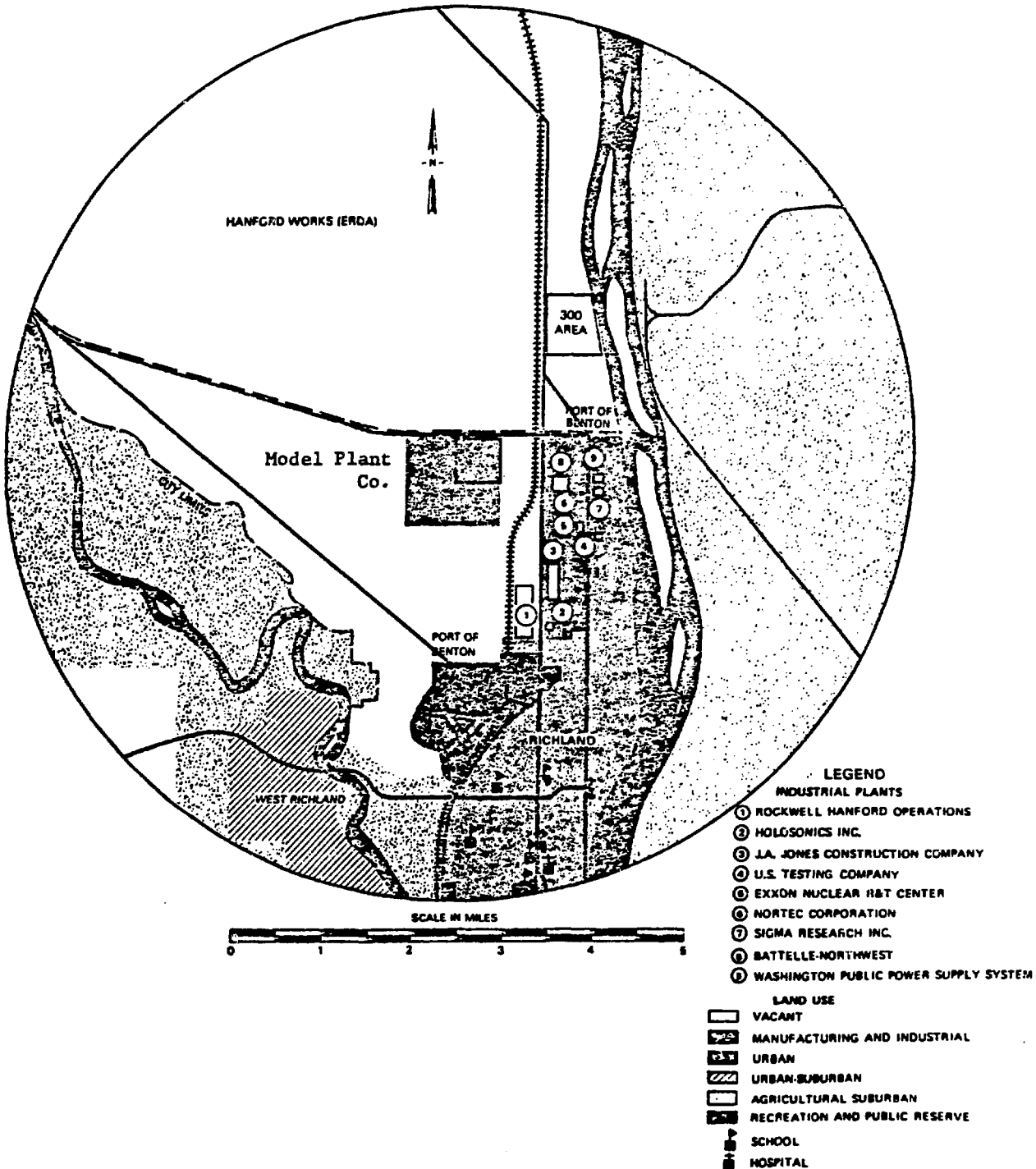


FIGURE 1. Plant Site Location

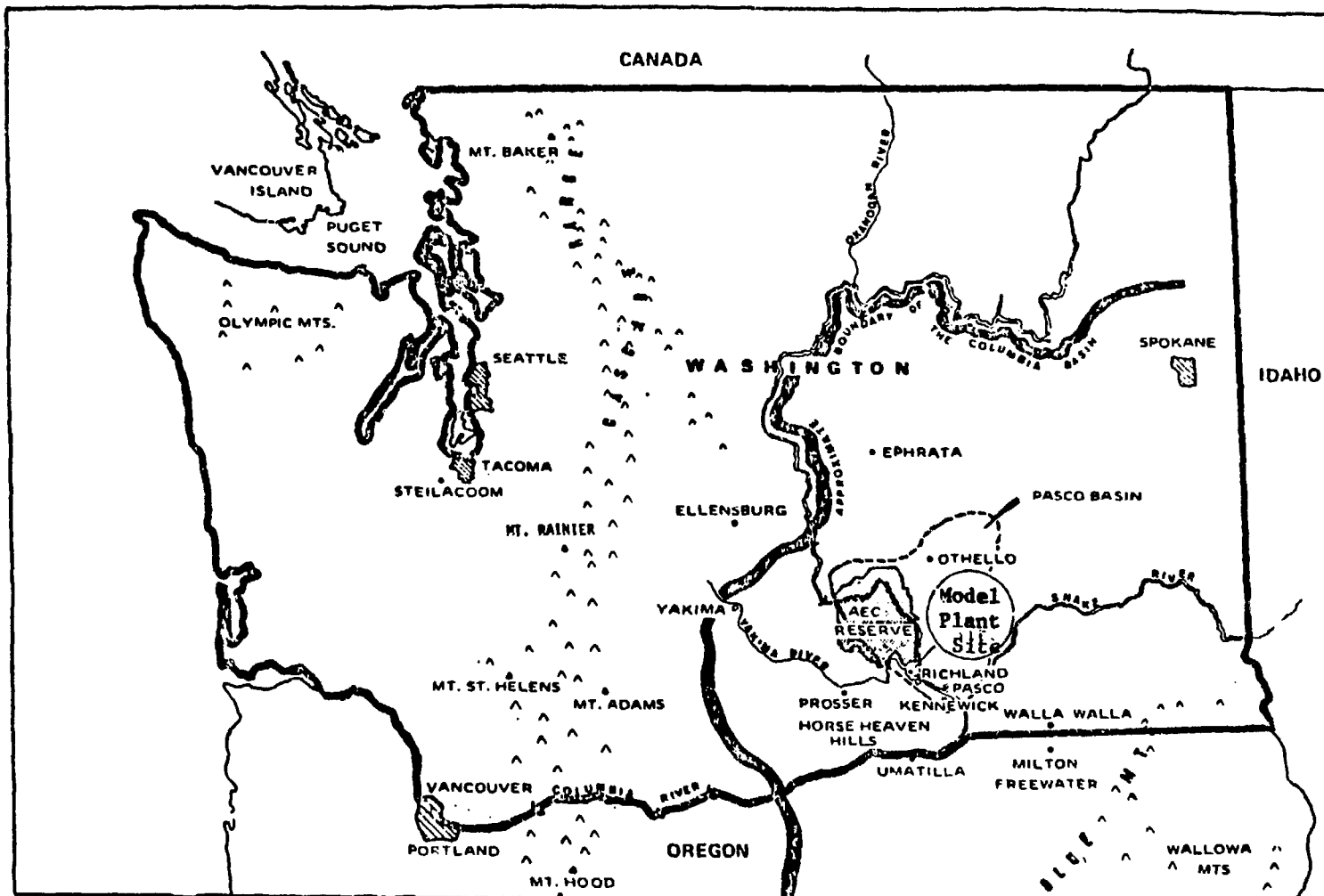


FIGURE 2. Plant Location in State

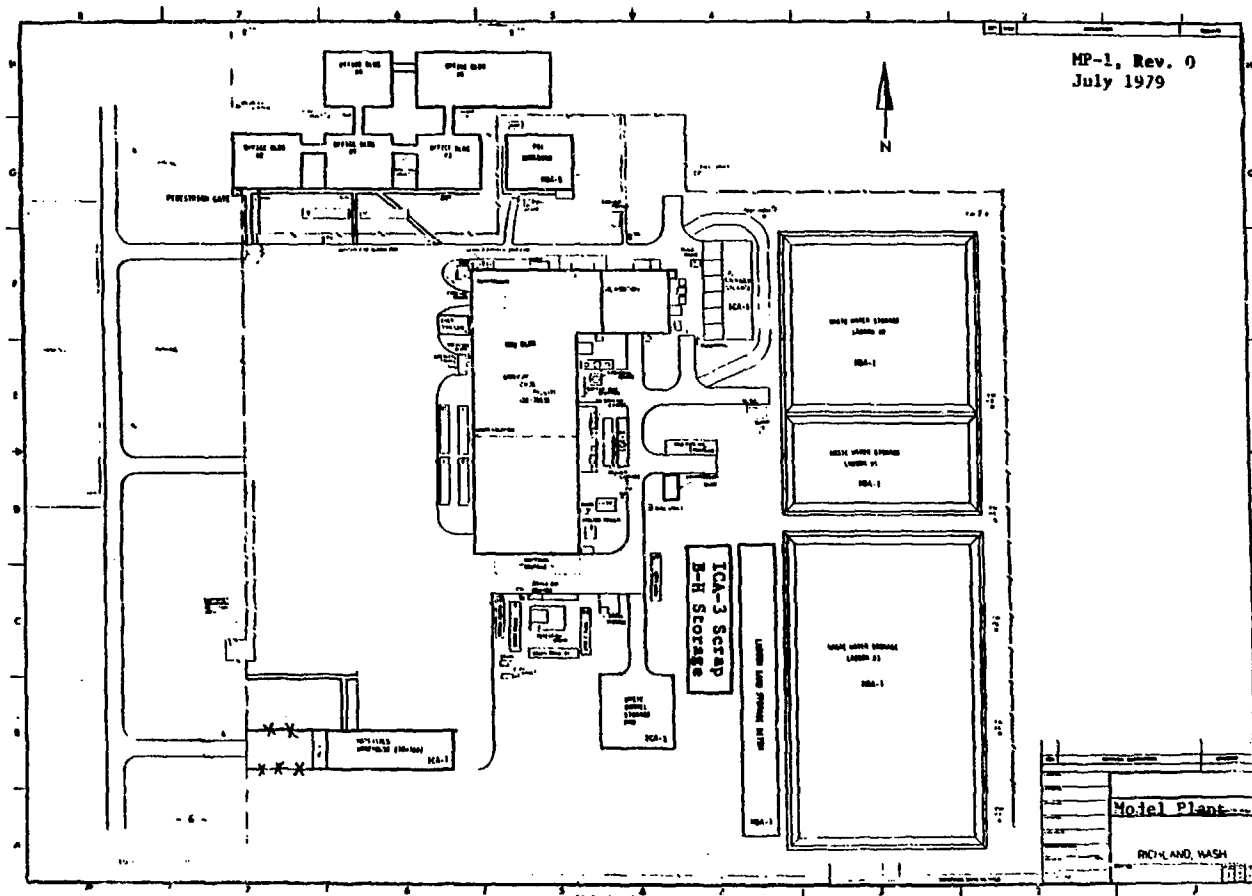


FIGURE 3. Model Plant Fuel Fabrication Facility

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

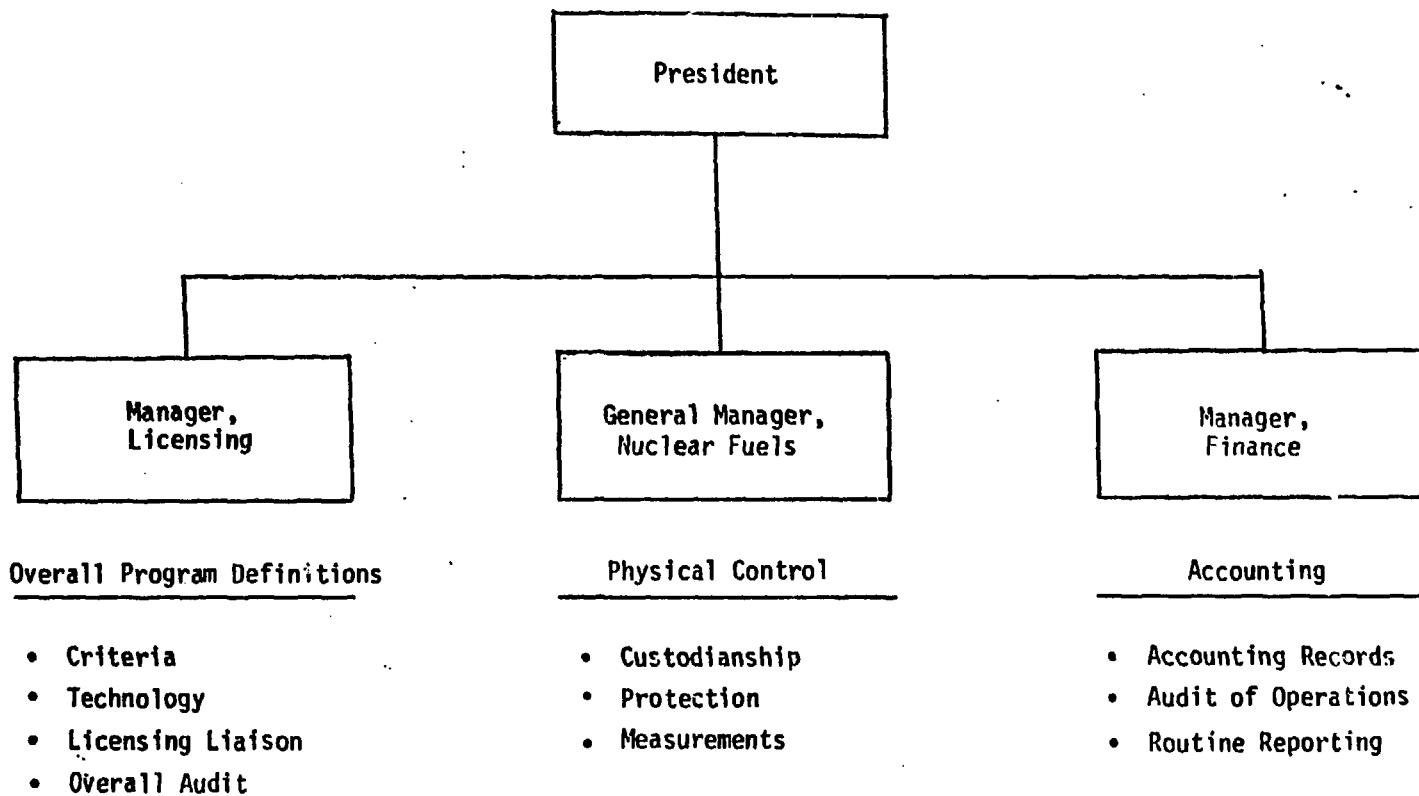


FIGURE 4. Primary Safeguards Responsibility Components

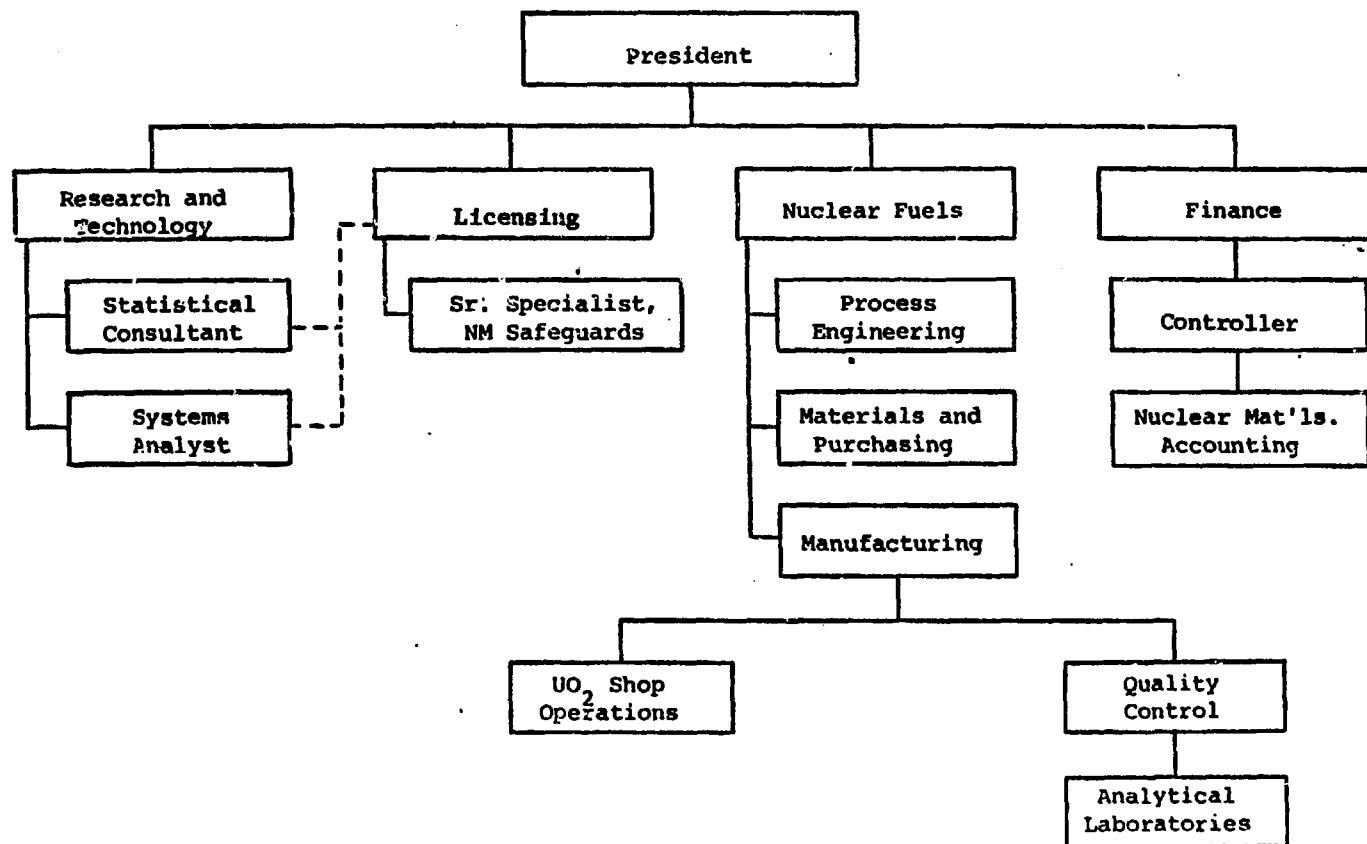


FIGURE 5. Organizational Substructure of Components and Safeguards Responsibilities

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.

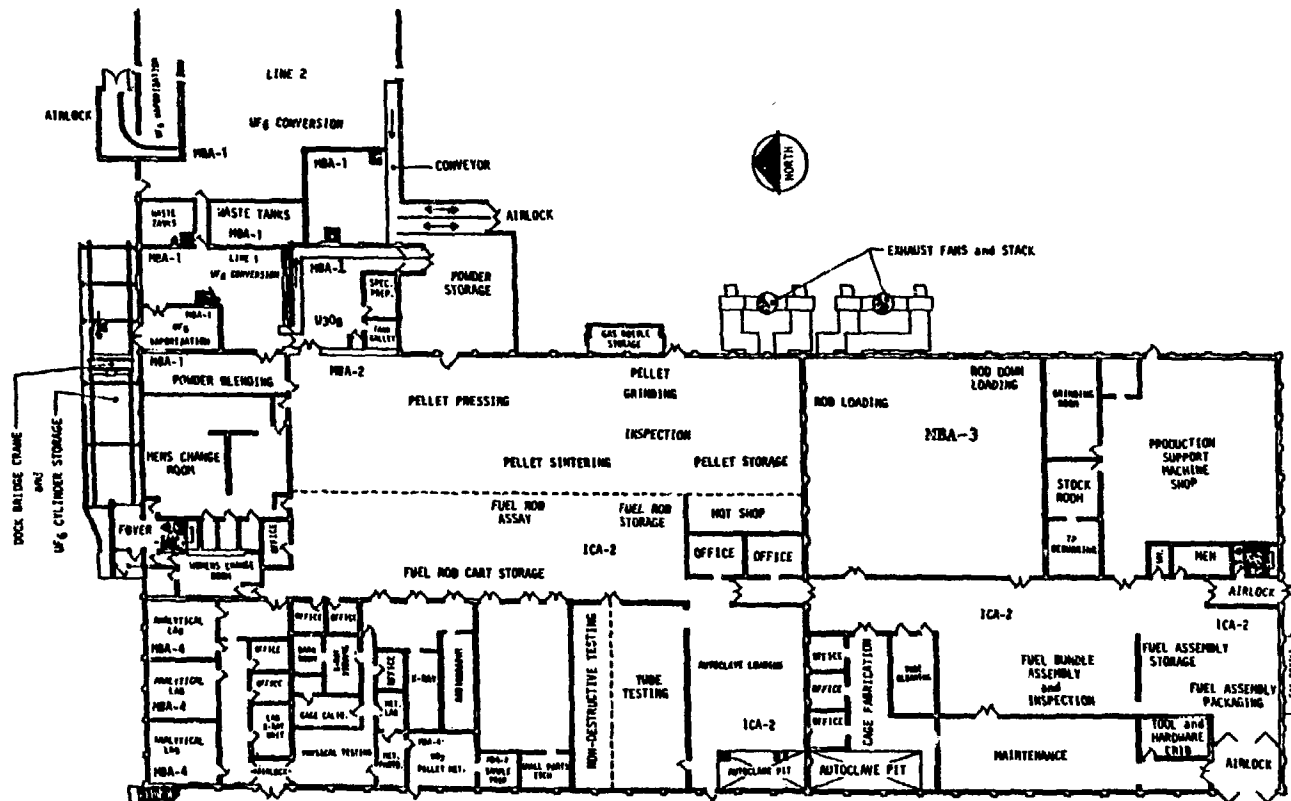


FIGURE 6. Uranium Oxide Fuels Building, First Floor Plan

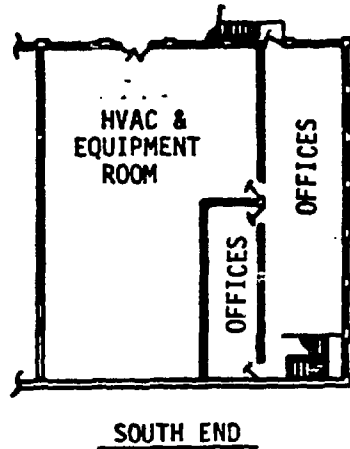
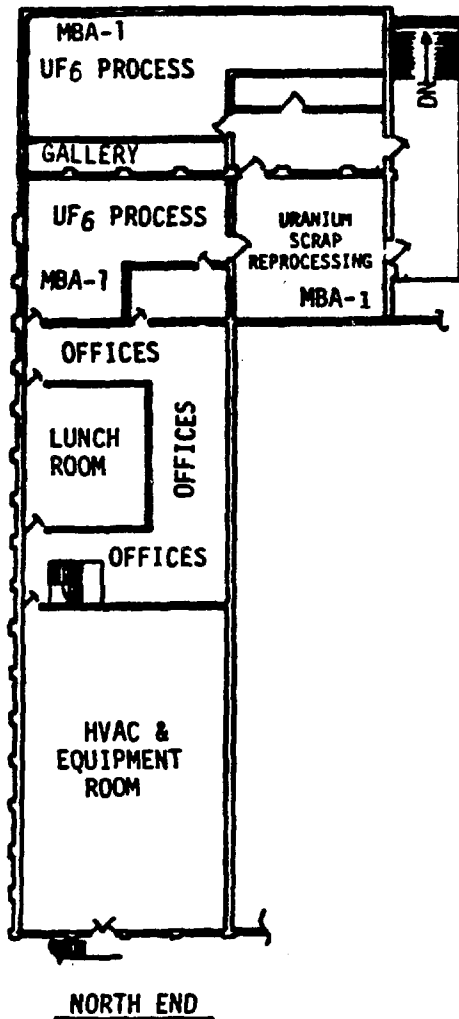
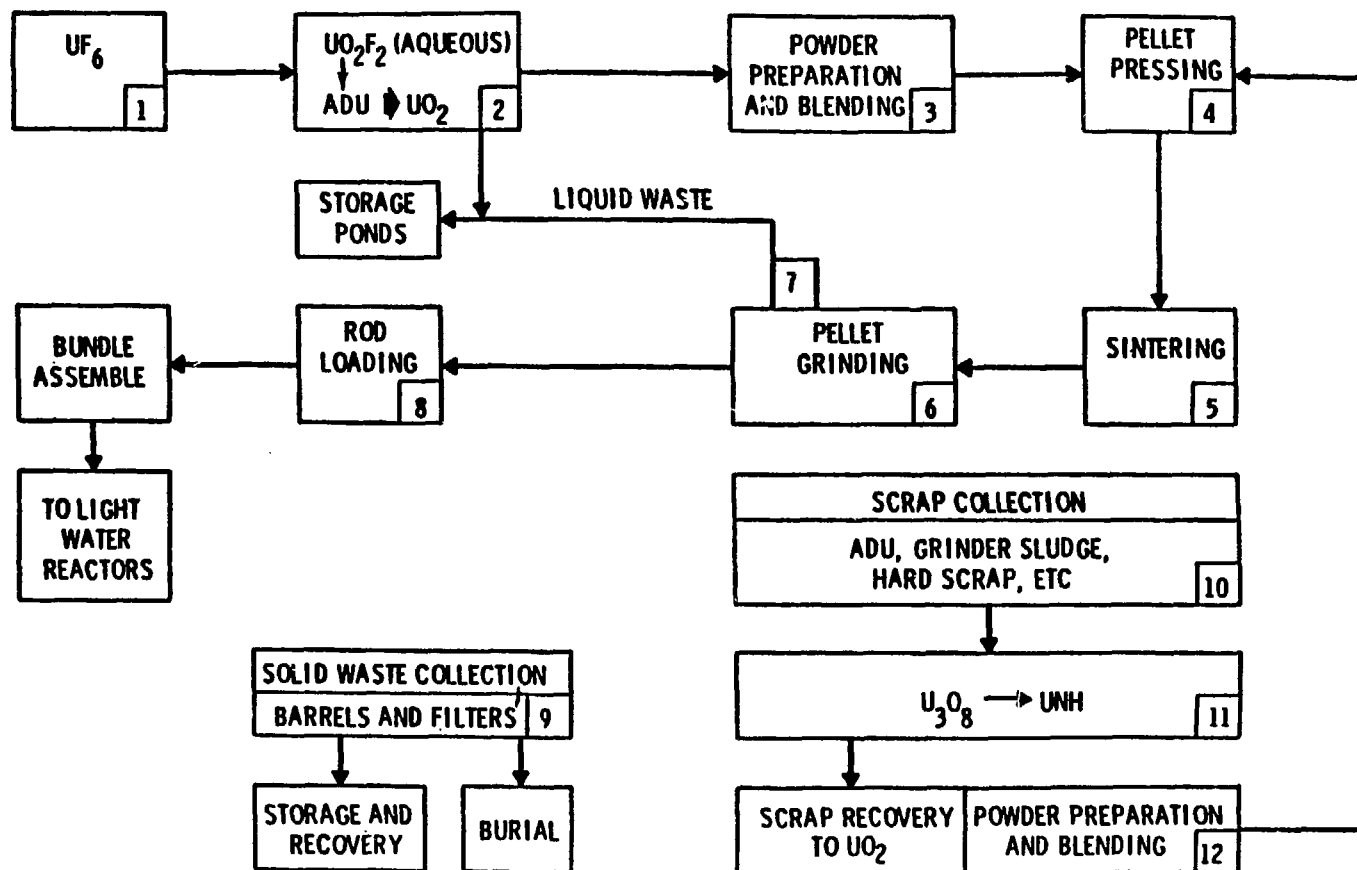


FIGURE 7. Uranium Oxide Fuels Building, Second Floor Plan



KEY MEASUREMENT POINTS

FIGURE 8. Process Flow Diagram for Model Plant

TABLE 1. Description of Key Measurements for Model Plant

Key Measurement Points	Measurement 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.

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 9. Model Plant Material Control Areas

NUCLEAR MATERIAL DESCRIPTION AND FLOWXVII. MAIN MATERIAL DESCRIPTIONChemical 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 UF_6 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 UF_6 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_3O_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.

IXX. 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(1)x3.6(w)x3.8(h) feet
3. <u>Waste</u> Filters	Cardboard boxes ~1(1)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(1)x9(w)x4(h) inches
Sintered Pellets	Pellet trays - flat rectangular tubed metal trays for holding horizontal pellet columns ~24(1)x8(w)x

XX. 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 UO₂ 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.

XXI. MEASURED DISCARDS AND RETAINED WASTEAs 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 UO_2 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 UF_6 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 UF_6 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 holding 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 55-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	Line sample from transfer line
		Filtrate (Centrate Hold Tanks)	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	
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

<u>Measurement Point</u>	<u>Analytical Method</u>	
	<u>Element</u>	<u>Isotope</u>
(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. Svst.	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 kg	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	U ₁	<u>Receipts</u> - UF ₆ Input, Class 1 <u>Removals</u> - UF ₆ Heels, Class 2e	0.013	---	0.005
U-Assay	Gravimetric	U ₂	<u>Removals</u> - Class 2a	0.02	---	0.015
U-Factor	Gravimetric	U ₃	<u>Inventory</u> - Class 3a, 3b	---	0.30	0.015
U-Factor	Gravimetric	U ₄	<u>Inventory</u> - Class 3c, 3d, 3f	---	0.030	0.015
U-Factor	Gravimetric	U ₅	<u>Inventory</u> - Class 3e-U ₃ O ₈	---	0.10	0.10
U-Assay	Gravimetric	U ₆ -U ₈	<u>Inventory</u> - Scrap Class 3g, 3h, 3i	0.04	---	0.10
U-235 Assay	Passive NDA	U-235 ₁	<u>Removals</u> - Waste, Class ~~2b~~ , ~~2c~~ , Barrels and Filers	15.0	---	20.0 ^(d)
U-Assay	Fluorimetric	U ₉	<u>Removals</u> - 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 UF₆ 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 UF₆ cylinders (of the same nominal enrichment) making up the starting 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. Calculation Methods

Material Balance Stratum	Calculation Methods	
	Weight U	Weight U-235
1. <u>Receipts</u>		
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. <u>Inventory</u>		
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
<u>Scrap</u>		
Dirty Powder, Grinder Sludge, ADU	Net weight x U-assay	Weight U x E-factor or assay
3. <u>Product</u>		
Rods	Net weight x U-assay	Weight U x E-factor
Assemblies	Sum of rod U weights	Sum of rod U-235 weights
4. <u>Waste</u>		
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)

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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. Svst. Error
						Random	S.T. Svst.	
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 Travs)	3c	W6	6	6,000	1,000	--	500 Items (b)
Weighing	Sintered Pellets (On Travs)	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	U3O8	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	Dirtv Powder	3i	S3	17	680	40	--	--
Sampling	Liquid Waste	2d	S4	2.0	352	176	--	352 Kgs

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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	--	--

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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. Svst. Error
					Random	S.T. Svst.		
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 UF_6 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:

$$LEMUF = 2\sigma MUF$$

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 UF_6 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 UF_6 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)			$\sigma^{(b)}$			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.
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	0.0002	--	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(b)	8 gm	--	6 gm	Variance Computed		
Weighing	Hard Scrap	3c	W ₂	20	--	10(b)	For Total Weighing On Scale 2					
Weighing	ADU	3g	W ₂	40	--	20(b)						
Weighing	Dirty Powder	3i	W ₂	20	--	10(b)						
				350	--	175(b)	8 gm	--	6 gm	0.023	--	2.21
Weighing	Green Powder	3a	W ₃	270	--	135(b)	8 gm	--	6 gm	Variance Computed For Total Weighing On Scale 3		
Weighing	Hard Scrap	3f	W ₃	20	--	10(b)						
Weighing	ADU	3g	W ₃	40	--	20(b)						
Weighing	Dirty Powder	3i	W ₃	20	--	10(b)						
				350	--	175(b)	8 gm	--	6 gm	0.023	--	2.21
Weighing	Green Powder (Scrap Recovery)	3a	W ₁₀	60	--	30(b)	8 gm	--	6 gm	0.004	--	0.065
Weighing	Green Pellets	3b	W ₄	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.007
Weighing	Green Pellets	3b	W ₅	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.007
Weighing	Sintered Pellets (On Trays)	3c	W ₆	1,000	--	500(b)	8 gm	--	6 gm	0.064	--	18.00
Weighing	Sintered Pellets (On Trays)	3c	W ₇	1,000	--	500(b)	8 gm	--	6 gm	0.064	--	18.00
Weighing	Sintered Pellets (In Boats)	3d	W ₈	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.004
Weighing	Sintered Pellets (In Boats)	3d	W ₉	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.004

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.
Weighing	Grinder Sludge	3h	W11	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.004
Weighing	Grinder Sludge	3h	W12	20	--	10(b)	8 gm	--	6 gm	0.001	--	0.004
Weighing	U308	3c	W13	500	--	250(b)	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	UF6	1	U1	17	--	117,432 Kg (Full Heels)	0.013%	--	0.005%	13.74	--	34.475
U-Assay	UF6 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	U308	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			$\sigma^{(b)}$			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%	7.04	--	792.986
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										97.145	424.571	6314.058
Total $2\text{MUF} = 6835.774 \text{ Kg}^2 \text{ U}$												
Total $\text{MUF} = 82.679 \text{ Kg U}$												

(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

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 accountancy 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>	FLWSHEET(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

18. WASTE MATERIAL

- i) Source and Form
(indicating major contributors; liquid or solid; range of constituents; enrichment range and Pu content, include contaminated equipment)
- ii) Storage Inventory Range, Method and Frequency of Recovery/Disposal

19. CONTAINERS, PACKAGING AND STORAGE AREA DESCRIPTIONS

SEPARATE NOTE TO BE ATTACHED describing for feeds, products and wastes the type and size of containers and packaging used; method of storage; any special identification features.

20. RECYCLE PROCESSES

(briefly describe any such processes giving source and form of material, method of storage, normal inventory, frequency of processing)

21. MEASURED DISCARDS AND RETAINED WASTE

- i) As % of input

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL DESCRIPTION AND FLOW

22. INVENTORY

- i) In-Process
(within plant and equipment during normal operation; indicate quantity, form and main locations and any significant change with time or throughput)
- ii) Other locations
(quantity, form and location of inventory not already specified)

PLANT MAINTENANCE

23. MAINTENANCE, DECONTAMINATION, CLEAN-OUT

SEPARATE NOTE TO BE ATTACHED

describing plans and procedures and defining all sampling and key measurement points associated with:

- i) normal plant maintenance
- ii) plant and equipment decontamination and subsequent nuclear material recovery;
- iii) plant and equipment clean-out.

PROTECTION AND SAFETY MEASURES

24. BASIC MEASURES FOR PHYSICAL PROTECTION OF NUCLEAR MATERIAL

25. SPECIFIC HEALTH AND SAFETY RULES FOR INSPECTOR COMPLIANCE (if extensive, attach separately)

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY

26. SYSTEM DESCRIPTION

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) General

SPECIMEN FORMS USED IN ALL PROCEDURES ATTACHED UNDER REF. NO.

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY

SYSTEM DESCRIPTION CONTINUED

ii) Receipts
(including method of dealing with shipper/
receiver differences and subsequent account
corrections)

iii) Shipments (product and waste)

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.

v) Measured Discards and Retained Waste

vi) Operational Records and Accounts
(including method of adjustment or correction
and place of preservation and language)

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

x) 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

27. FOR EACH KEY MEASUREMENT POINT IDENTIFIED UNDER Q'S 14,23 GIVE THE FOLLOWING:

i) Identification

ii) Chemical and Physical Form of Material

iii) Sampling Procedures and Equipment Used

iv) Measurement/Analytical Method and Equipment Used

v) Source and Level of Random and Systematic Errors
(weighing, volume, sampling, analytical)

vi) Method of Converting Source Data to Hatch Data
(standard calculative procedures, constants used, empirical relationships, etc.)

CONVERSION AND/OR FUEL FABRICATION PLANTS

NUCLEAR MATERIAL ACCOUNTANCY

28. OVERALL LIMIT OF ERROR

Describe procedures to combine individual measurement error measurements to obtain the overall limit of error for:

- i) S/R Differences
- ii) Book Inventory
- iii) Physical Inventory
- iv) MUF

OPTIONAL INFORMATION

27. OPTIONAL INFORMATION

(What the operator considers relevant to safeguarding the facility)

Signature of
Responsible Officer



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



April 27-May 12, 1981

Session Objectives

**SESSION 30: DESCRIPTION OF TYPICAL NRC INSPECTION PROCEDURES FOR
MODEL LEU FUEL FABRICATION 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.



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



April 27-May 12, 1981

SESSION 30: INSPECTION PROGRAM AT A LOW ENRICHED URANIUM FABRICATION 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 SRDL. 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.

D. 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.

G. 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.

J. 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.



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



April 27-May 12, 1981

Session Objectives

SESSION 31: DEMONSTRATION OF MOBILE NDA SAFEGUARDS MEASUREMENT SYSTEM

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.



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April 27-May 12, 1981

SESSION 31: DEMONSTRATION OF A MOBILE NDA SAFEGUARDS MEASUREMENT SYSTEM

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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

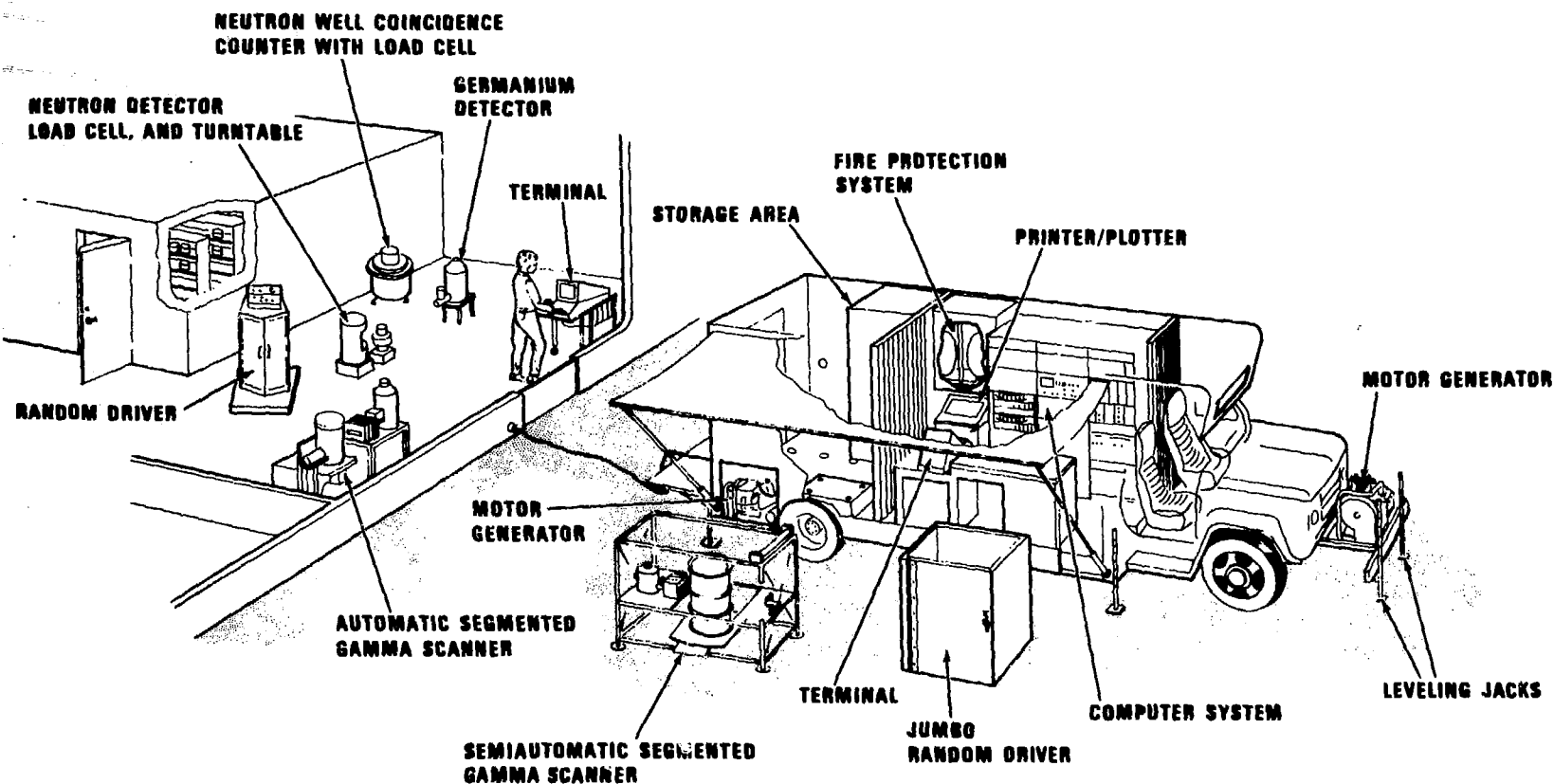


FIGURE 1. Schematic of an Existing Mobile NDA Safeguards System

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

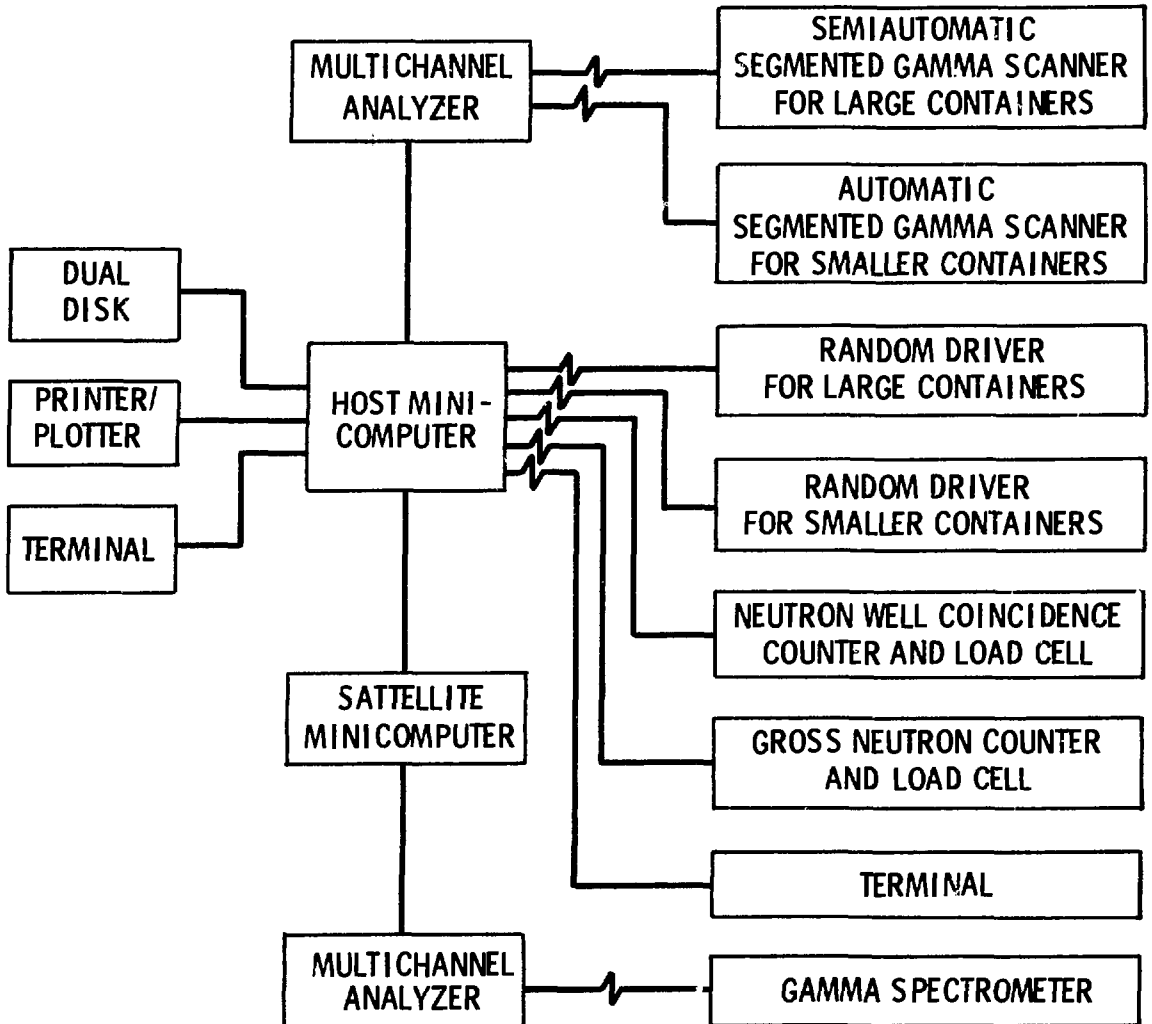


FIGURE 4. Block Diagram of Mobile Nondestructive Assay System

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. Pigtaills 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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ADVANCED INTERNATIONAL TRAINING COURSE ON STATE SYSTEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS



April 27-May 12, 1981

Session Objective

SESSION 32: 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.



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April 27-May 12, 1981

SESSION 32: 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

$$\sigma^2 = \sum_{i=1}^k \left(\frac{\partial \phi}{\partial x_i} \right)^2 \sigma_i^2 + 2 \sum_{i=1}^{k-1} \sum_{j>i} \left(\frac{\partial \phi}{\partial x_i} \right) \left(\frac{\partial \phi}{\partial x_j} \right) \sigma_{ij} \quad (6)$$

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:

$$\text{MUF} = I - O + \text{BI} - \text{EI} \quad (7)$$

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 UF₆ 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.



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April 27-May 12, 1981

Session Objectives

SESSION 33: 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.



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SESSION 33: CALCULATING THE VARIANCE OF THE DIFFERENCE STATISTIC

John L. Jaech
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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 receivers' 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.

$$s_i = X_i \delta_s \theta_s \gamma_s \epsilon_{si} \omega_{sj} v_{sj} \quad (1)$$

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}, v_{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 $\sigma^2 \delta_s, \sigma^2 \theta_s, \dots, \sigma^2 v_s$, 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:

$$\frac{\partial S}{\partial \delta_s} = \frac{\partial S}{\partial \theta_r} = \frac{\partial S}{\partial \theta_s} = \frac{\partial S}{\partial \theta_r} = \frac{\partial S}{\partial \gamma_s} = \frac{\partial S}{\partial \gamma_r} = \sum_{i=1}^{22} x_i \quad (3)$$

$$\frac{\partial S}{\partial \epsilon_{si}} = \frac{\partial S}{\partial \epsilon_{ri}} = x_i \quad (4)$$

$$\frac{\partial S}{\partial \omega_{sj}} = \frac{\partial S}{\partial \omega_{rj}} = \frac{\partial S}{\partial v_{sj}} = \frac{\partial S}{\partial v_{rj}} = x_i \text{ for cylinders having concentration factor } j \quad (5)$$

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 $(MUF - \hat{D})$ 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.



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Session Objectives

SESSION 34: 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.



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SESSION 34: ESTIMATION OF MEASUREMENT VARIANCES

John L. Jaech
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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

$$x_i = \mu_0 + \theta_1 + \varepsilon_i; i = 1, 2, \dots, n \quad (1)$$

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 y_j , defined to be

$$\begin{aligned} \text{MSE}(y_j) &= E(y_j - T_j)^2 \\ &= \theta^2 + \sigma_e^2 \end{aligned} \quad (5)$$

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_x^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^2/n or s^2 estimates $s_1^2 + s_2^2$, the random error variances for methods 1 and 2, respectively. One can, under certain conditions, obtain separate estimates of s_1^2 and s_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_i^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.



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April 27-May 12, 1981

Session Objective

SESSION 35: STATISTICAL SAMPLE 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 35: STATISTICAL SAMPLE PLANS

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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 $\bar{D}$ 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 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 $\hat{D}$. 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.



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



April 27-May 12, 1981

Session Objectives

SESSION 36-37: MEASUREMENT AND MATERIAL CONTROL DEMONSTRATION AND STUDENT PARTICIPATION AT EXXON NUCLEAR PLANT

The students will participate in UF_6 cylinder weighing, performing measurements with the SAM-2 enrichment meter, the weighing of scrap containers, and performing analytical measurements. They will also tour the mass spectrometer and quantometer (uranium impurity analysis) laboratories.

Tamper-indicating seals will be demonstrated and applied by the students to various types of containers. Seal logbook forms, material record cards, material transfer forms, and material inventory sheets will be illustrated, and completed by the students with assistance from the instructors. After the session, participants will be able to:

1. understand the indicated measurements, and perform some of them,
2. better understand the operation of the mass spectrometer used for measuring enrichment,
3. better understand the operation of the quantometer used for measuring impurities,
4. apply the tamper-indicating seals to process containers,
5. understand the use and importance of the various forms used for material control.



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



April 27-May 12, 1981

SESSIONS 36 and 37: MEASUREMENT AND MATERIAL CONTROL DEMONSTRATION AND STUDENT PARTICIPATION AT EXXON NUCLEAR PLANT

Sessions 36 and 37 are a full day of plant measurement demonstration and student participation scheduled on Saturday, May 9, 1981. Four "Classroom" areas are used to present four main subject areas. The subject areas, classrooms, and head instructors are shown below:

<u>Class Number</u>	<u>Subject</u>	<u>Place</u>	<u>Lead Instructor</u>
1	UF ₆ Weighing	UF ₆ Scale	George Mulligan
2	Analytical Chemistry Mass Spectrometry or Wet Chemistry	Analytical Laboratory	Norm Wing
3	SAM-2 Enrichment Testing & Bucket Weighing	Warehouse or Powder Storage	Keith Johnson
4	Use of Seals and Transfer Forms	Training Trailer	Rosann Logsdon and Roger Sharp

For the special Saturday schedule, the students are divided into four groups. Each subject is also presented four times during the day according to the class schedule shown below so that each group attends all four subjects by the end-of-the-day.

<u>Period No.</u>	<u>Time</u>
1	09:10 - 10:25
Coffee Break	10:25 - 11:00
2	11:00 - 12:15
Lunch	12:25 - 14:00
3	14:10 - 15:25
Coffee Break	15:25 - 15:45
4	15:45 - 17:00

UF₆ Weighing

The UF₆ weighing demonstration will start with the weighing of the cylinder cart, zeroing the scale and tare weighing of the cart on the digital scale. The full test cylinder will then be weighed to check the accuracy of the scale platform and then a full cylinder of enriched UF₆ will be lifted off the storage pad and weighed. The weights will be printed on a weigh ticket and compared to weights on the enrichment plant packing slips.

This procedure will then be rerun with the students doing the operating of the equipment except for the crane operation.

SAM-2 Enrichment Measurement and Bucket Weighing

The students will perform verification measurements on four or five powder buckets as well as measurements of some reference standards. We will use a platform scale to obtain the bucket weight and a SAM-2 enrichment meter to obtain a measurement of the powder enrichment. Each student will have the opportunity to perform the measurements and to fill out a data sheet listing the measured values and the data listed on the material record card.

Analytical Chemistry Mass Spectrometry

The preparation of a sample for introduction to the mass spectrometer will be demonstrated. The tune up procedure will be shown and mass scans will be made. The students will make some scans, take the ratio data, and calculate the results. Filament preparation will also be illustrated.

Use of Seals and Transfer Forms

A "hands on" demonstration of seal applications to plastic 5 gallon buckets, metal 5 gallon buckets, filter boxes, E Plant suitcases and 55 gallon drums will be completed with each student.

Viewgraphs displaying various forms used by UO₂ Operations Nuclear Materials Accountability will be displayed. The viewgraphs will include location transfers, project transfers, material record cards and seal logbook forms. Each student will complete each form with assistance from the instructors.

Four experienced technicians from UO₂ Support Operations will be present to assist in seal applications and completing forms documentation.



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



April 27-May 12, 1981

Session Objectives

SESSION 38-39: WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR A FUEL FAB- RICATION PLANT

The workshop has as its goal the development of an FNMC plan. The participants will be divided into four groups and will make recommendations on the following: the measurement and accountability system, the inventory-taking procedures, data analysis and reporting procedures, evaluation of system effectiveness. Example problems will be worked. Following this session, the contributions of the participants will be presented and discussed. These presentations will then be evaluated and critiqued by a Panel of about six participants and a moderator.

After these sessions, the participants will be able to:

1. construct an FNMC plan for a similar type plant,
2. understand the key features of an FNMC plan for any generic plant.



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



April 27-May 12, 1981

Sessions 38,39,40,41: WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR
A FUEL FABRICATION PLANT

R. A. Schneider, Exxon Nuclear and
D. B. Smith, Los Alamos
Workshop Coordinators

The purpose of the workshop was to provide the participants with an opportunity to design the main features of a materials control and accounting (MC&A) system for a low-enriched uranium fuel fabrication plant. The model plant described throughout the text was used also for this workshop as the reference process for which the participants were to design an MC&A system.

The participants were divided into four groups, each of which was to develop independently an outline of the key features that they would recommend for the MC&A system for the reference facility. To aid in the preparation of this outline, ten main subject areas were suggested:

- a. organization,
- b. materials control areas,
- c. measurements,
- d. measurement control program
- e. physical inventory,
- f. materials accounting system,
- g. internal controls,
- h. management,
- i. effectiveness, and
- j. design for IAEA safeguards.

To further aid in preparation of the outline, a package containing possible features to be considered for each of the ten subject areas with references to appropriate portions of the course text was provided. This package is attached. Work sheets for preparing the outline were provided as a separate package.

The four working groups were assigned as follows:

Group 1

M. Akiba (Japan)
Jean Yvan Capovet (Commission of European Communities)
Stanislaw Ciemniewski (Poland)
Avraham Farchy (Israel)
Richard Olsson (Sweden)
Edwin MacKay (Canada)
Yi-Ching Yang (Taiwan)

Group 2

Cheong Won Cho (Korea)
Ghulam Kibria (Pakistan)
Valeria Leonardi (Commission of European Communities)
Chung-Lu Lo (Taiwan)
Suror Mahmoud (Iraq)
Angrzej Pietruszewski (Poland)
Rudi Germano Roenick (Brazil)

Group 3

Viktor Dimic (Yugoslavia)
Ah Auu Gui (Malaysia)
Hafiz R. Higgy (Egypt)
Theodor Hürlimann (Switzerland)
Subhash Chandra Purushotham (India)
Piero Vanni (Italy)

Group 4

Adel Abdullah Al-Fayyad (Iraq)
Arif Isyar (Turkey)
M. Maurel (France)
Muhammad Nawaz (Pakistan)
Porfirio Palafox Garcia (Mexico)
Rifaat El-Shinawy (Egypt)
Gilbert Verstappen (Belgium)

Richard Olsson, Rudi Roenick, Theodor Hürlimann, and Rifaat El-Shinawy were chosen by their respective groups to serve as rapporteurs. In addition, each group was assigned a resource person [John Ellis (AGNS), Charles Hatcher (Los Alamos), Richard Schneider (Exxon), and Darryl Smith (Los Alamos)] from the staff to call upon as much as the group desired.

Session 40 was devoted to reporting the main features of each group's MC&A system design. All of the groups chose to modify (to varying degrees) the organizational structure of the reference MC&A system, but all emphasized the need to separate functions so that employees responsible for production and having access to nuclear material are not also responsible for detecting potential loss of that material. All of the groups wanted highly trained and qualified managers for the several parts of the MC&A system, and Group #3 suggested an international certification program. Five to ten years experience was suggested for the more responsible organizational positions.

The reference process was divided into from two to seven MBAs, but this difference is not as great as it appears because the group (#1) that suggested only two MBAs would subdivide the main process MBA into four smaller accounting areas for internal use. All of the groups accepted, for the most part, the measurement points and techniques of the reference MC&A system. Group #4 proposed extensive use of bar codes to identify containers of material and discrete items.

All of the groups suggested rather greater use of computers than proposed in the reference MC&A system and would adapt as many instruments as possible to transmit measurement results directly to the computer to minimize transcription mistakes. In addition, the course participants recommended tailoring domestic regulations to be consistent with IAEA requirements and to facilitate meeting these requirements. They also recommended that reporting forms for internal use and for national reporting be made consistent with IAEA forms.

After the presentations by the four rapporteurs, Session 41 concluded with an open discussion of the workshop, moderated by Dino Pontes of the IAEA. The discussion included an informal evaluation of workshop results by the workshop coordinators and comments from course participants and staff.



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



April 27-May 12, 1981

SESSIONS 38 & 39: WORKSHOP ON SAFEGUARDS SYSTEM DESIGN FOR A FUEL FABRICATION PLANT

DESCRIPTION OF REFERENCE (MODEL) PLANT

R. A. Schneider, Exxon Nuclear and
D. B. Smith, Los Alamos
Workshop Coordinators

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 designs and in working the example problems that have been prepared. The same basic information has also been incorporated into the Design Information Questionnaire used earlier in the course (of Session 29).

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

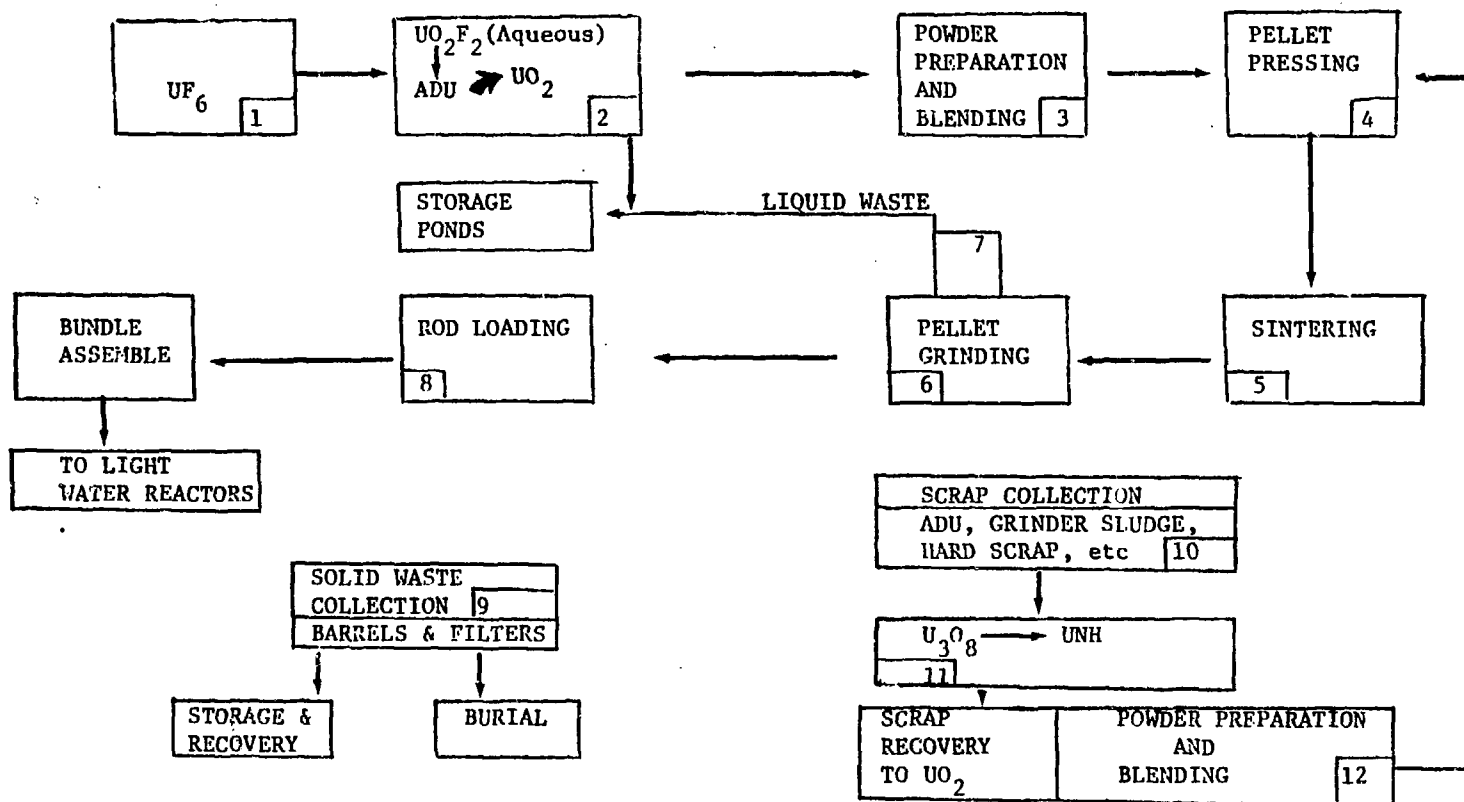
Calcined powder is processed through preparation steps and blended to yield homogeneous lots of green UO₂ powder.

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 1. 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 1. 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 2. A summary of the uranium element and isotopic measurements are given in Table 3 and described briefly below. Sampling methods are given in Table 4.

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 2. 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 2. (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_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.

TABLE 3. 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_3O_8	Gravimetric	Factor
10 Grinder Sludge	Gravimetric or Titration	Factor
9 Solid Waste	Factor	NDA

TABLE 4. Model Plant Sampling Method

Key Measurement Point	Materials	Description
(see Figure 1)		
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 Inven- tory	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-- UF_6 cylinders are weighed on a UF_6 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 5. 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 6.

An example calculation of the uranium element sigma MUF (σ_{MUF}) for a six-month material balance is given in Table 7. The example calculation for σ_{MUF} includes several simplifying assumptions. Long term systematic weighing errors for the UF_6 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 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 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 5. Error Parameter Values for Model Plant Uranium Material Balance

Method	Description	Number	Component and Class (a)	σ , % RSD U (or as noted) (b)		
				Random	S.T. System	L.T. System
Weighing	Scale 1 UF ₆ Scale	W ₁	Additions--UF ₆ Full Cylinders, Class I Removals--UF ₆ Heels, Class 2e	0.40 kg	0.60 kg	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 5. (contd)

Method	Description	Number	Component and Class (a)	σ , % RSD U (or as noted) (b)		
				Random	S.T. System	L.T. System
U-Factor	Gravimetric	U ₁	<u>Receipts</u> --UF ₆ Input, Class 1 <u>Removals</u> --UF ₆ Heels, Class 2e	0.013	---	0.005
U-Assay	Gravimetric	U ₂	<u>Removals</u> --Class 2a	0.02	---	0.015
U-Factor	Gravimetric	U ₃	<u>Inventory</u> --Class 3a,3b	---	0.30	0.015
U-Factor	Gravimetric	U ₄	<u>Inventory</u> --Class 3c, 3d,3f	---	0.030	0.10
U-Factor	Gravimetric	U ₅	<u>Inventory</u> --Class 3e-- U ₃ O ₈	---	0.10	0.10
U-Assay	Gravimetric	U ₆ -U ₈	<u>Inventory</u> --Scrap Class 3g,3h,3i	0.04	---	0.10
U-235 Assay	Passive NDA	U-235 ₁	<u>Removals</u> --Waste, Class ~~2b~~ , ~~2c~~ , Barrels and Filters	15.0	---	20.0 (d)
U-Assay	Fluorimetric	U ₉	<u>Removals</u> --Liquid Waste, Class 2d	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 6. 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	2e	W ₁	2.0	164	84	17	84 Items
Weighing	Heels							
Weighing	Pellet	2a	W ₁₄	2.5	58,500	23,400	--	23,400 Items
	Columns							
	(rods)							
Weighing	Pellet	2a	W ₁₅	2.5	58,500	23,400	--	23,400 Items
	Columns							
	(rods)							
Weighing	Green	3a	W ₂	17	4,590	270	--	135 Items (2)
	Powder							
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	3i	W ₂	17	340	20	--	10 Items (2)
	Powder							
Weighing	Green	3a	W ₃	17	4,590	270		135 Items (2)
	Powder							
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	3i	W ₃	17	340	20		10 Items (2)
	Powder							
								W ₂ = 175 Items (2)
								W ₃ = 175 Items (2)
Weighing	Green	3a	W ₁₀	17	1,020	60	--	30 Items (2)
	Powder							
	(scrap							
	recovery)							
Weighing	Green	3b	W ₄	18	360	20	--	10 Items (2)
	Pellets							

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TABLE 6. (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	
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

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TABLE 6. (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 (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	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	--	117,000 Kgs
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	--	--

TABLE 6. (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 7. Example Calculation of Uranium Sigma MUF for a Six-Month Material Balance

Measurement	Material	Class	Method Number	(a) Items or Quantities Affected by Types of Error			(b) σ			σ^2 Kgs ² U by Method		
				Random	S.T. System		Random	S.T. System		Random	S.T. System	
					L.T. System	L.T. System		L.T. System	L.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%	—	(2.5%) (C)	10.404	—	—
Sampling	Liquid	2d	S ₄	176	—	—	5%	—	15%	1.76	—	2,787.84
							Total Sampling			46.148		2,787.84

TABLE 7. (contd)

Measurement	Material	Class	Method	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 σ^2_{MUF} = 6,835.774 Kgs² UTotal σ_{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). UF₆ 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.

UF₆ cylinders enter the process as a transfer from ICA-1 to MBA-1 (Conversion and Scrap Recovery). Prepared UO₂ 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.

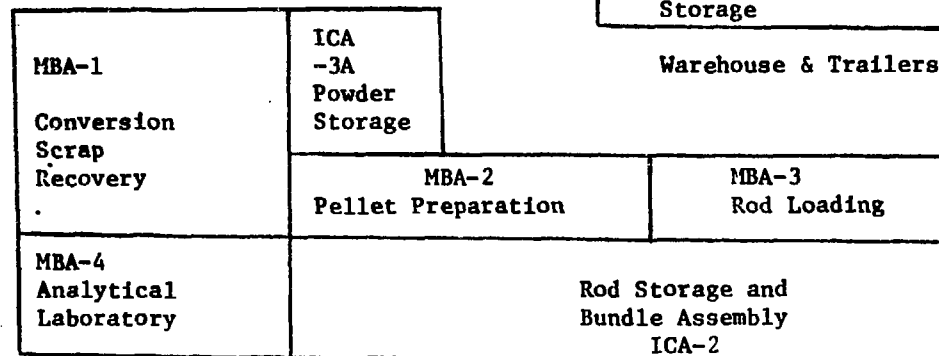
Containers of scrap and intermediate products are transferred from the originating MBA to the various storage ICAs for storage as discrete items. The letter designations for ICA-3 (3A-3K) specifies a particular location within ICA-3 such as the powder storage room, 3A, the radioactive materials warehouse 3B, or one of the storage trailers 3C-3H.

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

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 8. 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 9.

Accounting Reports

A number of accounting reports are generated from the master record accounting system data. An example listing is shown in

TABLE 8. 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 10. 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

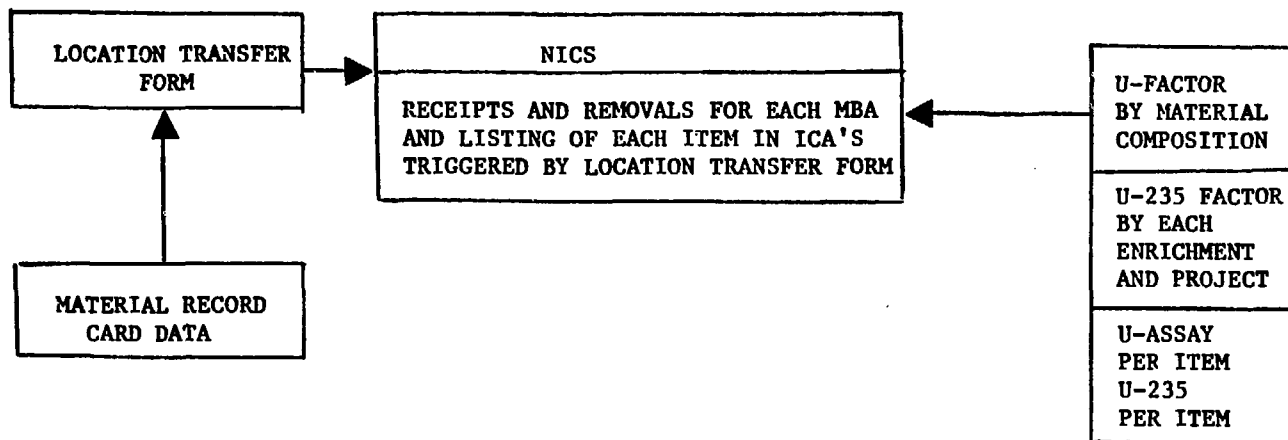


FIGURE 3. Operating Mode of Internal Accounting System

TABLE 9. 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 9. (contd)

<u>Document</u>	<u>Issued by</u>	<u>Maintained by</u>	<u>Retention Period</u>
Detailed Trans- action 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 10. 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.

WORKSHOP ON SAFEGUARDS SYSTEM
DESIGN FOR A FUEL FABRICATION PLANT

Sessions 38, 39, 40

R. A. Schneider, Exxon Nuclear
and D. B. Smith, LASL
Workshop Coordinators

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 Reference or Model plant described in the text for this workshop is used as the model process for which the participants are to design a material control and accounting system.

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 subject areas:

- 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. Work sheets for preparing the outline are provided as a separate package.

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 and providing public assurance that nuclear energy can be used by mankind in a safe and economical manner.

Reference pages 3-10 of text for Session 29a, "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 29a, "Preparation of a Fundamental Material Control Plan".

C. Measurements

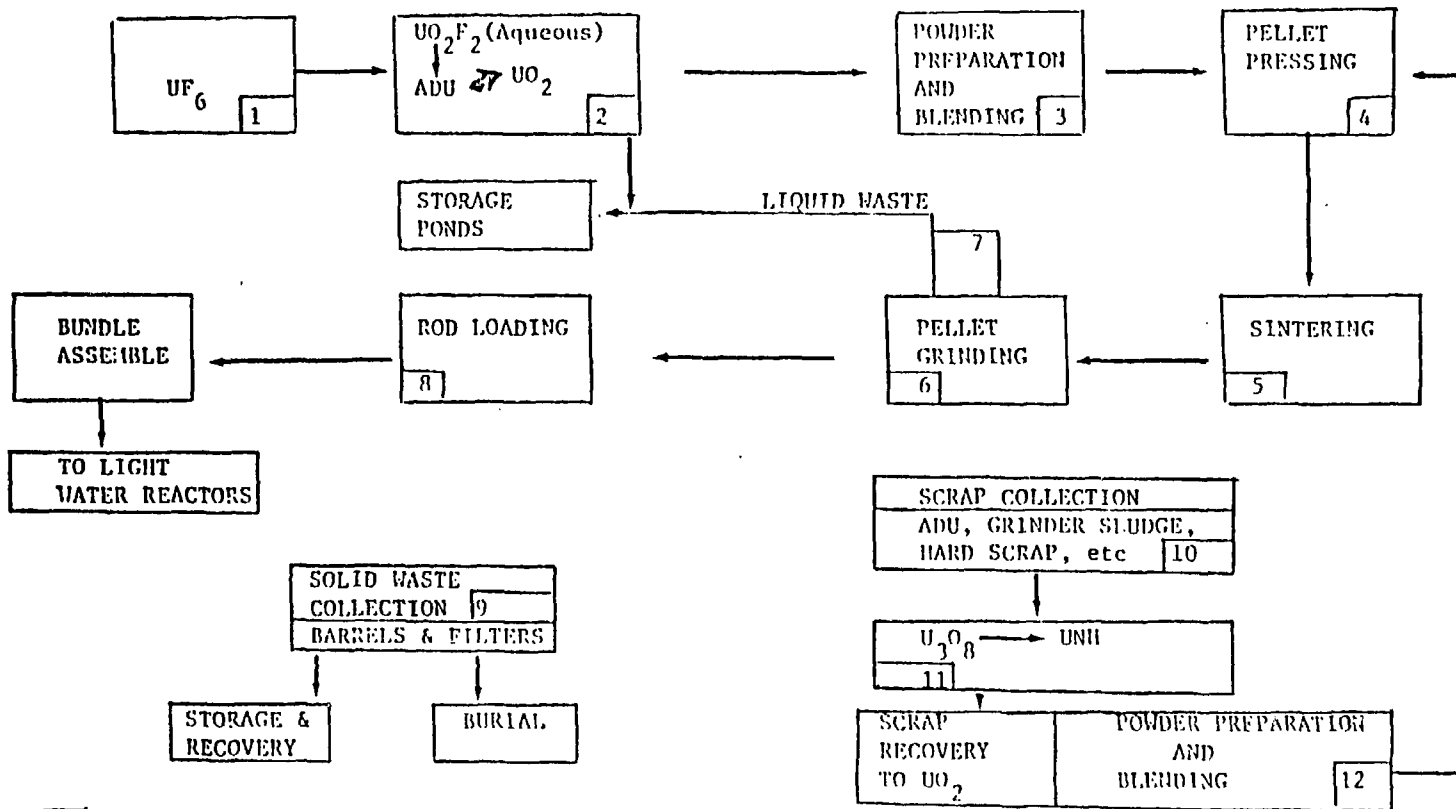
1. Identify on a process flow diagram or plant site layout each key measurement point. Use Figure 1 and/or Figure 2 for a layout sketch.
2. Describe briefly the materials^{present} and measurements made at each point.
3. Describe briefly each measurement method; e.g., volume, analytical, sampling, weighing, and NDA.

Reference see text for this workshop, "Descriptions of Reference (Model) Plant", pages 3, 5, 6, 7, 8, 9, 10, and 11.

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. 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.



X Key Measurement Points

FIGURE 1. Process Flow Diagram for Model Plant

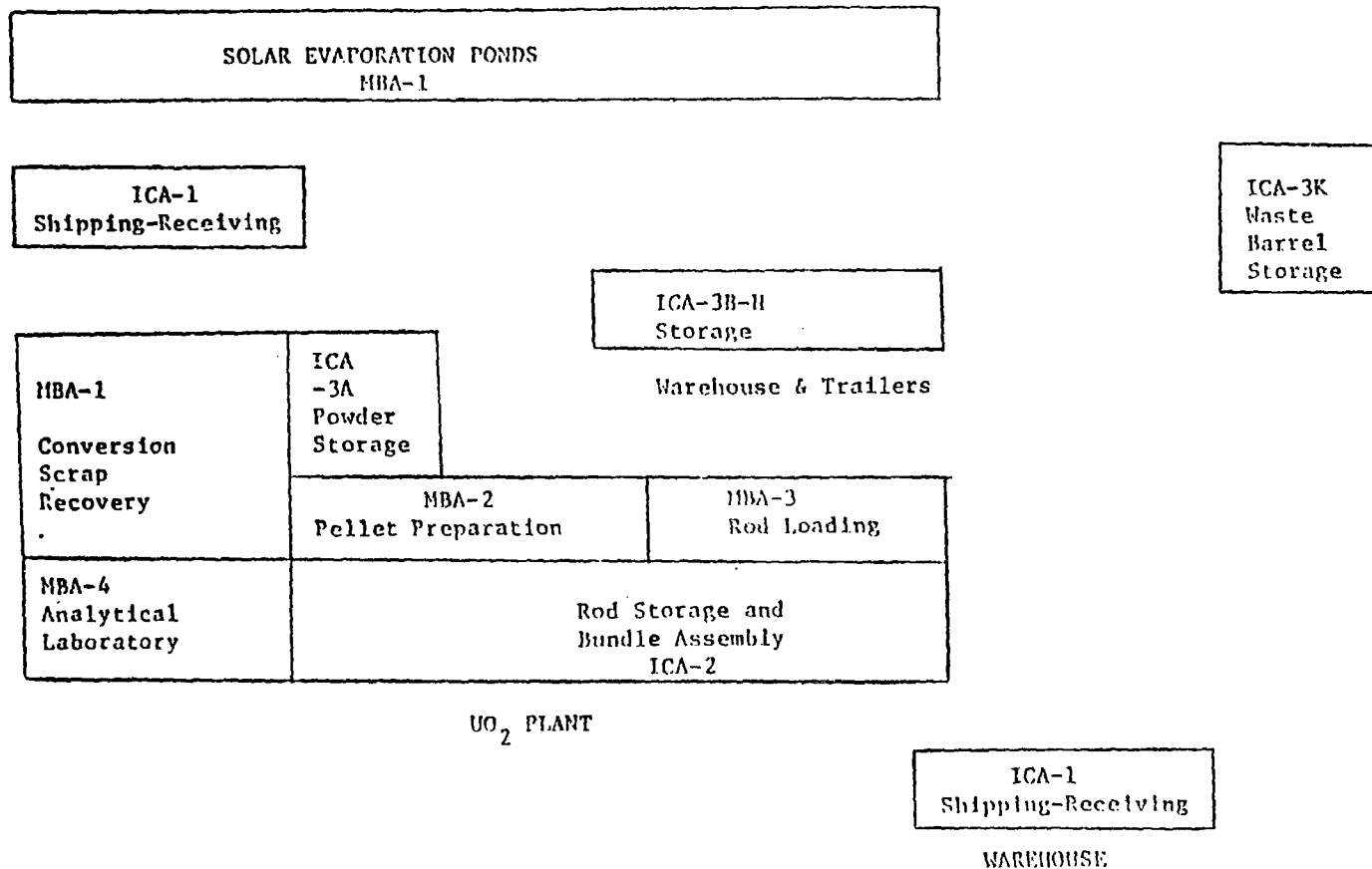


FIGURE 2. Model Plant Material Control Areas

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 1 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 2 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.
2. Use Table 3 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 4 to assist you in your selection of the key features your group recommends for inclusion in your material control and accounting system.

TABLE 1
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 text (see Table I of Reference of Model Plant, Sessions 38 and 39).
8. Prelisting of Inventory	8. ICA listings, rod printout prior to inventory.
9. Cut-off Procedures	9. Written instructions for each area.

TABLE 1 (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 reconciliation 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 2

MATERIAL 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 ° Receipt-Shipment ° Location Transfer ° Physical Inventory Recording Form
4. Flow Chart	4. See Table 8 page 33 of Model Plant DIQ, Session 29.
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 2 (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 37, 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 40-41 of DIQ.
12. Electronic Data Processing	12. Computer services are procured from offsite.
13. Record 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 3

INTERNAL CONTROL TOPICS

<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. (1)
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 3 (Continued)

INTERNAL CONTROL TOPICS

<u>Discussion Topic</u>	<u>Example</u>
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 38 and 39.
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 were shown on Table I of Chapter 8. (page 24 of DIQ also.) 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 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%.

(1) Shipping and Receiving Custodians both sign transfer form.

TABLE 4
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 Chapter 3.
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 4 (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 4 (Continued)

MANAGEMENT TOPICS

Discussion Topic

Example

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.

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 5. 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 10-17 of the Reference (Model) Plant Description, or presented in Session 32, or shown in the relative error propagation example on page 6 of Session 21a. Report your sigma MUF as a percent of plant input as given in Table 5.

TABLE 5. 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.

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.
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.



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



April 27-May 12, 1981

Session Objectives

SESSION 40: REPORTS OF DESIGN WORKSHOP SUBGROUPS -- PLENARY SESSION

A member of each subgroup will present a brief report on safeguards system design characteristics recommended by each subgroup.



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



April 27-May 12, 1981

Session Objectives

**SESSION 41: PANEL DISCUSSION: COMPARISON/CRITIQUE OF SUBGROUP
REPORTS**

Panel will consist of approximately six attendees, with an instructor acting as moderator. Moderator will later open discussion to comments and questions from the floor, and encourage maximum attendee participation and feedback.



**ADVANCED INTERNATIONAL TRAINING COURSE
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AND CONTROL OF NUCLEAR MATERIALS**



April 27-May 12, 1981

Session Objectives

SESSION 42: 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 - DOE, IAEA, Los Alamos, NRC, Battelle/Exxon.



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



April 27-May 12, 1981

SESSION 42: COURSE EVALUATION AND SUMMARY

Course attendees completed a detailed course evaluation form that was designed to provide feedback on the effectiveness and value of the overall course, and to solicit suggestions for improving follow-on courses. A summary of participant responses to the course evaluation form is attached. The responses were generally very favorable with a high level of interest expressed in all course material presented, particularly measurement technology (NDA and DA), the Los Alamos and Exxon tours, statistics, and the safeguards design workshop. The visit to the Exxon fuel-fabrication facility provided practical experience and invaluable insight into plant applications of safeguards.

As can be seen in the attached Summary of Participant Responses, some of the main suggestions for future courses were (1) include more coverage of other (more typical) State systems and their experience in implementation, including interaction with the IAEA; (2) more input from IAEA on their requirements (and experience with) various Member State systems; (3) more information on other types of facilities such as power and research reactors, critical facilities, etc., and relevant state-of-the-art technology for assay/verification of fresh and spent fuels, statistics, and near-real-time accounting approaches.

Participants also suggested allocating more time for individual study and follow-up discussion with lecturers and course staff, more time devoted to demonstration and hands-on experience in the laboratory with new measurement instrumentation, and more time for facility tours and demonstrations. The Workshops were considered very valuable and deserving of additional time, including more direct interaction between attendees and staff and more evaluation of workshop results by course staff. Attendees suggested that future courses cover item-dominant facilities (e.g., power and research reactors) as well as bulk-handling facilities, such as the fuel-fabrication facility covered in the 1981 course.

The parts of the course that were judged of greatest value by attendees were the safeguards measurement techniques and demonstrations, the visits to Exxon and Los Alamos facilities, NDA instrumentation, statistics, and the design workshop. Specific areas suggested for expansion in future advanced courses included the principles and practical applications of NDA and conventional measurements, statistical applications, and the safeguards design workshop.

By way of some general observations on the 1981 course, it is noteworthy, first of all, that the attendees were well-qualified professionals holding positions of major responsibility in R&D, operations and management in nuclear material accounting and control organizations at both the facility and national levels within their respective countries. This helped establish an unmistakable atmosphere of collegiality and professional esprit de corps among all participants -- both students and staff -- and created the necessary environment for productive technical exchange and open dialogue throughout the course.

During the technical sessions and panel discussions, it was recognized that certain professional biases and differences in viewpoint and approach to safeguards can arise quite naturally in the normal course of inspector/inspectee interactions -- whether on the facility, national, or international level. In this connection it was pointed out that in recent years there has been significant progress toward better understanding and mutual appreciation between plant people on the one hand and safeguards people on the other. In some US facilities, for example, in-plant test and evaluation programs of safeguards equipment have led to new awareness on the part of both plant operators and safeguards technologists. Thus with more in-plant test experience, safeguards technologists have acquired a fuller appreciation that the cooperation and understanding of plant people are absolutely essential to effective in-plant implementation of new safeguards techniques and instrumentation. By the same token, many of the plant people who have had involvement with in-plant test and evaluation programs have become increasingly aware of the significant contribution that modern safeguards measurement equipment and systems can make to increased plant operational efficiency and production, and hence to good overall plant economics.

The differences in viewpoint and approach to safeguards issues and problems taken by different facilities and nations were cited as positive evidence of the great need for consensus, international cooperation, and standardization in the implementation of equitable, effective safeguards on both the national and international level. It was further noted that this need is an important underlying factor in the basic thrust and overall purpose of the ongoing series of international training courses on accountancy and control of nuclear materials.

In addition to the formal material presented, participants were able to exchange information and ideas with each other

concerning the actual practice of safeguards in the different countries and organizations represented. These informal exchanges and contacts among responsible safeguards personnel from differing professional and cultural backgrounds provided significant additional benefit to both lecturers and participants. In connection with the overall thrust of the course, the hope was expressed that this advanced training course provided not only technical and procedural details of modern safeguards, but would help each participant, through their extensive interactions and deliberations throughout the course, to achieve a deeper insight and greater knowledge with which to undertake the task of implementing effective safeguards in their own individual countries.

The value of the present series of SSAC Courses, as well as strong interest in continued and expanded advanced SSAC courses (emphasizing the use of modern safeguards technology in the implementation of SSAC systems) has been repeatedly expressed by participants throughout both the 1980 and 1981 SSAC Courses. Thus there appears to be a strong consensus among the safeguards representatives of Member States for a coordinated program of SSAC training courses that would cover modern safeguards requirements, procedures, technology, and practical implementation at both item dominant and bulk-handling facilities. Such a program should take into account the needs and concerns of both the IAEA and of Member States in various stages of development of their nuclear energy programs.

In summary, it is clear that an increasing number of IAEA Member States are beginning to look to the Agency (and major supplier nations) for training and assistance in establishing and improving their own national safeguards systems. The effectiveness of the overall international safeguards regime in the final analysis rests largely on the effectiveness of the State systems, and in turn the operators' systems, whose performance the international system must independently verify. In the increasingly important area of SSAC training and technology transfer, it is thus gratifying that the coordinated efforts of the Agency and nuclear supplier nations now appear to be contributing positively to the technical effectiveness and acceptability of both State systems and IAEA international safeguards. In today's world it is more essential than ever to implement effective safeguards training and technology transfer, while at the same time redoubling our efforts toward the sometimes elusive, yet absolutely essential, goal of international consensus, cooperation, and sense of common professional commitment among safeguards colleagues throughout the world.

SUMMARY OF PARTICIPANT RESPONSES

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

April 27-May 12, 1981

Sante 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 Advanced International Training Course on 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	Average	High	Very High
A. OVERALL COURSE CONTENT: 78% ^a						
1. Degree to which course met stated objectives		1	2	3(5) ^b	4 (19) ^b	5(3) ^b
2. Degree to which course met your needs		1	2	3(5)	4 (21)	5(1)
3. Your satisfaction with course emphasis		1	2	3(3)	4 (21)	5(2)
What changes would you suggest in overall course content? <u>Include lectures on other (more typical) state systems, experience in implementation, interaction with IAEA, etc. More input from IAEA on their requirements and experience with state systems. Brief coverage of other types of facilities such as power reactors, FCAs, Pu facilities etc.</u>						
B. TECHNICAL LEVEL/CONTENT 73%						
1. Degree to which technical level of material met your needs		1	2(1)	3 (6)	4 (14)	5(6)
2. Proportion of material that was new to you		1(2)	2(5)	3 (10)	4 (9)	5
3. Your understanding of technical presentations		1	2(1)	3 (8)	4 (16)	5(2)
4. Estimated practical value of technical presentations		1	2(1)	3 (5)	4 (16)	5(5)
Should the course have greater technical content? If so, in what areas? <u>Most responses did not indicate specifically a need for greater technical content, although several participants suggested more information on verification and/or measurement of spent and fresh fuels, NDA, statistics, and near-real-time accounting.</u>						

(a) Percent of maximum possible score.

(b) Numbers in parenthesis indicate the number of course participants who gave the indicated response.

C. COURSE ORGANIZATION, FORMAT, AND SCHEDULE 74%

1. Your satisfaction with course format and schedule	1	2	3 (10)	4 (15)	5 (2)
2. Satisfaction with amount of discussion allowed after lectures	1	2	3 (3)	4 (21)	5 (3)
3. Satisfaction with planning for free time and independent study	1 (1)	2 (1)	3 (12)	4 (11)	5 (1)

What changes in course schedule and organization would you recommend? _____

Provide more unscheduled time for study and discussion by reducing the number of lecture hours per day.

D. FACILITIES AND ACCOMMODATIONS 83%

1. General helpfulness/cooperation of course staff	1	2	3 (1)	4 (10)	5 (15)
2. Satisfaction with planned social activities	1	2	3 (4)	4 (15)	5 (9)
3. Satisfaction with Santa Fe Hilton hotel accommodations, personnel, services, etc.	1	2 (1)	3 (3)	4 (12)	5 (10)
4. Satisfaction with Holiday Inn (Richland) hotel accommodations, personnel, services, etc.	1	2 (2)	3 (9)	4 (11)	5 (4)

Explanation/Comments: Problems were experienced at Richland with lecture room, luncheon arrangements, organization, and travel changes.

E. SAFEGUARDS EQUIPMENT TOUR AND DEMONSTRATION AT LOS ALAMOS, NM 72%

1. Value to you of equipment tour and demonstration	1	2	3 (5)	4 (17)	5 (4)
2. Your comprehension of equipment tour and demonstration	1	2	3 (7)	4 (15)	5 (3)
3. Value of instrumentation in your national safeguards system	1	2	3 (9)	4 (13)	5 (3)

Explanation/Comments: Need more time for discussion, demonstration, and hands-on experience. The tour should place more emphasis on NDA instrumentation and less on other Los Alamos facilities, such as Omega West and LAMPF. The Los Alamos tour illustrated very effectively the state-of-the-art in NDA technology.

F. TOUR/DEMONSTRATION OF FUEL FABRICATION PLANT AND MEASUREMENT SYSTEMS AT RICHLAND, WA 72%

1. Value to you of plant tour and process demonstration	1	2 (5)	3 (5)	4 (13)	5 (4)
2. Value to you of measurement methods and equipment demonstrations	1 (1)	2 (4)	3 (7)	4 (11)	5 (4)
3. Potential (future) value of modern in-plant material accountancy and control technology in your own nation's facilities	1 (1)	2 (2)	3 (5)	4 (14)	5 (4)

Explanation/Comments: Plant tours and demonstrations were good, but generally too short.

G. WORKSHOP EVALUATION 74%

1. Overall effectiveness of workshop--methods and results	1	2 (1)	3 (4)	4 (17)	5 (5)
2. Estimated value of workshop to you professionally	1	2 (1)	3 (6)	4 (14)	5 (6)
3. Estimated value of workshop in implementing your state system	1 (1)	2	3 (11)	4 (9)	5 (4)
4. Satisfaction with proportion of time/effort devoted to workshop	1 (1)	2 (1)	3 (15)	4 (8)	5

What changes, if any, in the workshop would you suggest? More time should be given to the workshop.

More use should be made of workshops throughout the course. More evaluation of workshop results should be provided by course staff.

H. COMMUNICATION AND UNDERSTANDING 77%^c

1. Degree to which you experienced language difficulties	1 (12) ^d	2 (8)	3 (3)	4 (6)	5 (1)
2. Effectiveness of communication between instructors and attendees	1	2	3 (5)	4 (16)	5 (6)
3. How well your questions about course material were answered	1	2 (1)	3 (5)	4 (18)	5 (3)
4. Usefulness of visual presentations and resource materials in aiding your understanding	1	2	3 (3)	4 (16)	5 (7)
5. Usefulness of videotape monitors in aiding your understanding	1 (1)	2 (4)	3 (6)	4 (9)	5 (4)

(c) Scores on H.1. were reversed to arrive at percent score of 77%.

(d) Includes responses that indicated "no problem with language" but did not circle a number.

H. COMMUNICATION AND UNDERSTANDING Cont'd.

How could we improve communication between instructors and attendees? Arrange workshops in which students and instructors work together. Remind all instructors to speak slowly. Ask instructors to encourage discussion. Couldn't be better.

I. COURSE APPLICABILITY, USEFULNESS 78%

1. Applicability of course material to your work	1	2	3 (6)	4 (16)	5 (5)
2. Applicability to your nation's safeguards system	1	2 (1)	3 (6)	4 (14)	5 (3)
3. Usefulness of course material to colleagues in your country	1	2 (1)	3 (6)	4 (14)	5 (5)

How could the course material be made more useful to you? Include information on facilities other than fuel fabrication and reprocessing, Section A. Provide more information on NDA instruments and methods. Provide follow-up courses and information on specific topics.

J. GENERAL SUGGESTIONS, CRITICISMS, COMMENTS

1. Which parts of the course were of greatest value to you? Measurement techniques and demonstrations, plant visits to Exxon and Los Alamos, NDA, statistics, and the workshop.

2. Which parts of the course should be expanded?

Expand principles and practical applications of NDA and conventional measurements, more time for statistical

3. Which parts of the course should be shortened (or omitted)? applications and workshop.

4. Overall course length was too long 4 too short 7 about right 15

5. In your opinion should the training course be offered again? 26 yes (one did not answer)

6. What changes in the course would you suggest in order to make it more useful?

Include more on facilities such as power reactors and research reactors. Include more on other state systems and IAEA safeguards implementation in those countries.

J. GENERAL SUGGESTIONS, CRITICISMS, COMMENTS Cont'd.

7. General comments/observations not covered above. Greatly appreciate effort to organize course,
prepare lectures, open Exxon Plant, etc. Suggest follow-on courses.

Name (Optional) _____