ORNL/TM-10458
(ISPO-275)

ornl

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Process Monitoring in Support of International Atomic Energy Agency Safeguards

M. H. Ehinger
J. W. Wachter
T. L. Hebble
H. T. Kerr

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04; Microfiche A01

ORNL/TM-10458
ISPO-275
Dist. Category UC-86

Consolidated Fuel Reprocessing Program

PROCESS MONITORING IN SUPPORT OF INTERNATIONAL ATOMIC ENERGY AGENCY SAFEGUARDS

M. H. Ehinger
Engineering Technology Division

J. W. Wachter
Fuel Recycle Division

T. L. Hebble
Engineering Physics and Mathematics Division

H. T. Kerr
Engineering Technology Division

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

PRELIMINARY DRAFT: October 1986
DATE PUBLISHED: August 1987

Prepared for the
Office of Facilities, Fuel Cycle,
and Test Programs

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

ABSTRACT

The introduction of large-scale nuclear fuel reprocessing plants, coupled with an increased concern over nuclear material safeguards, has led to a significant effort to develop new methods and procedures to improve safeguards. One such effort is **Process Monitoring**, in which the wealth of process data from a reprocessing facility is used to enable close surveillance of the nuclear material. The International Atomic Energy Agency, through the International Safeguards Projects Office, is examining the possible use of process monitoring in international safeguards. This report describes the characteristics and historical development of process monitoring. Specific applications of process monitoring to a reprocessing plant are developed in preparation for demonstrations in the Integrated Equipment Test facility of the Oak Ridge National Laboratory. Methods by which processing monitoring can complement and enhance other safeguards activities to provide a comprehensive system for international safeguards are discussed.

1. SUMMARY

Process monitoring is an expression that has traditionally referred to the surveillance of complex processing plant equipment for purposes of operation and control. Recently, process monitoring has been given new attention for a possible role in international safeguards. The International Safeguards Project Office (ISPO) Task C.59 has the goal to identify specific roles for process monitoring in international safeguards.

As the preliminary effort associated with this task, a review of previous efforts in process monitoring for safeguards was conducted, and the findings were reported in *Review of Safeguards Activities* [ISPO-255 (ORNL/TM-10151)]. As discussed in *Review and Safeguards Activities*, previous efforts touched on various concepts and a few specific applications, but none was comprehensive in addressing all aspects of a process monitoring application for safeguards. That report summarized the basic element that must be developed in a comprehensive process monitoring application for safeguards.

As the next step in the investigation of process monitoring for international applications, this report develops prototypical process monitoring concepts that can be incorporated into the International Atomic Energy Agency's (IAEA's) general safeguards approach for fuel reprocessing plants. This effort considers existing approaches, recognizing limitations and needed improvements. Prototypical process monitoring applications are developed and proposed for implementation and demonstration in the Integrated Equipment Test (IET) facility, which is located at the Oak Ridge National Laboratory (ORNL). The specific information needed to accomplish the process monitoring objectives are defined, and the mechanics for obtaining that information are described. Effort is given to the identification and assessment of potential impacts and benefits associated with process monitoring concepts, with particular attention to IAEA, state, and plant operator interests.

In this report, the historical development of process monitoring is described in Sects. 2 through 4. The implications of using process monitoring in international safeguards are discussed in Sect. 5. Specific process monitoring applications for demonstration in the IET facility are developed in Sects. 6 through 14.

2. INTRODUCTION

Existing international safeguards programs are complex institutional efforts by sovereign countries to obtain mutual assurances that nuclear materials are used in accordance with declared peaceful purposes. Those assurances are based, in part, on specific technical approaches that have been carefully formulated and accepted by the governments with nuclear programs. The various technical approaches rely on material-accounting functions as the primary source of assurances and on suitable containment and surveillance functions to ensure the integrity of the material-accounting information. This original philosophy was both logical and highly compatible with existing government systems of material control and accounting (MC&A).

Each sovereign state has strict regulations for nuclear facilities within national boundaries, and these regulations include requirements for material-accounting information for each facility. The facility operators are responsible for implementing and operating an approved material-accounting system and for reporting the appropriate accounting data to the national regulatory body. The international organization has on-site inspectors at each facility to collect independent data and other information to verify state-supplied data. This approach takes full advantage of the state's material-accounting system and minimizes the impact on the facility operators resulting from international safeguards activities.

This general approach to international safeguards has been successfully applied in most commercial nuclear facilities in the world. It does provide some level of assurance that nuclear materials are being used for declared peaceful purposes. However, the levels of assurance are limited by practical consideration of timeliness and sensitivity. With increasing concern about safeguards issues, some improvements are desired.

Large-scale reprocessing plants—that is, those with capabilities in excess of 1,000 Mt of uranium annually—present a significant challenge to the safeguards community. Concern for nuclear material safeguards has increased in recent years. Conventional methods for safeguards involving traditional input/output (I/O) methods and periodic inventory measurement have limited capabilities in these large facilities. Concern for safeguards has led to a significant effort to develop new methods and applications to improve capabilities, and much attention has been given to reprocessing plants. Definition of the problem and a statement of desired detection goals for safeguards have been the subjects of domestic (United States) and international (IAEA) discussions.

The Standing Advisory Group on Safeguards Implementation (SAGSI) has recommended that the definition of goals start with a definition of threshold amounts, the presumed minimum quantity required to fabricate a nuclear weapon. Minimum times for detection of a removal of the goal quantity were tied to estimates of the minimum time to accomplish the removal and fabricate the device, given the physical and chemical form of the material in the process subject to safeguards. SAGSI concluded that the best estimates of the threshold amounts were given in an early United Nations study of fast critical masses (United Nations Document. UN Doc.A/6858, October 1967). For plutonium, the value in the United Nations study was 8 kgs of ^{239}Pu. For conversion times, the SAGSI recommended "the order of 1–3 weeks" for separated plutonium like that found in a typical reprocessing facility.

A typical large-scale reprocessing facility requires 2–3 weeks for a shutdown and physical inventory. This limits material closures and conventional tests to 3–6 months. In a typical 1,500-Mt/year-of-uranium plant processing light water reactor (LWR) fuel, sensitivity of conventional accounting techniques on a six-month interval is on the order of 40–50 kgs of plutonium if a measurement system able to detect a 0.5% change in mass can be maintained. The limitations have led to discussions of possible new approaches for international safeguards. Among these, Near-Real-Time Accounting (NRTA) and process monitoring have received attention as candidate approaches.

This report concentrates on process monitoring as a tool appropriate for international safeguards and develops a relationship between process monitoring, NRTA, and other safeguards measures. It looks also at the development of process monitoring in relation to efforts in NRTA. The goal is to define a role for process monitoring that can complement and enhance other safeguards activities, thus providing a comprehensive system to meet the goals and challenges of international safeguards in large fuel processing facilities.

3. THE HISTORICAL PERSPECTIVE

In perspective, process monitoring and NRTA are both modern extensions of the older MC&A activities, which were administered in operating plants through the years preceding the 1970s. With NRTA, the concept is simply to make material balance closures and analyses more frequently than the previously accepted 2–6 months. Frequent closures gain timeliness. To a degree, sensitivity is improved by the reduction in throughput-dominated factors. This is somewhat offset by the necessity to make frequent in-process inventory measurements. NRTA is an extension of the accounting functions of MC&A.

Process monitoring, in simple terms, can be considered an extension of the "material control" portion of the old MC&A activities. Process monitoring strives for a real-time understanding of activities associated with the control of material as it moves through the process. It makes use of any and all indicators of process activity without concentrating on the strict accounting of nuclear material in process solutions.

Through the 1980s, NRTA has gained considerable acceptance as a safeguards tool. The problems associated with NRTA, particularly the difficulties of on-line, in-process inventory measurement, have been and continue to be investigated, but the procedures for accounting are well developed and in place in most facilities. Once in-process inventory measurement is understood, NRTA is a simple matter of streamlining the flow of accounting information and increasing the frequency of material balance closures. Because most of the procedures are already in place, NRTA is a logical extension of previous efforts, requiring only efforts to speed the flow of accounting information.

Process monitoring has been slow to see the same level of acceptance. There has been a problem in defining a specific role for process monitoring in the context of conventional accounting-based safeguards. Process monitoring requires interface to extensive process information. Few facilities have had process instruments and computer information systems to support process monitoring applications. As a result of this lack of appropriate demonstration facilities, it has been difficult to show that process monitoring works effectively as a safeguards tool.

To characterize process monitoring, consider an operator in a process facility. He has a wealth of information (process control data) available to make judgments about facility operation. He knows from the instruments where material is located and its general characteristics. An experienced operator can generally answer questions about material locations, loss, or other potential problems quickly by interpreting instrument signals that are indirect to actual quantitative measurements. These are the same questions to be answered by an effective real-time safeguards system.

In a sense, process monitoring procedures are material control procedures. Applications represent an attempt to extract the knowledge of an experienced plant operator in interpreting plant signals on the movement and location of material and depositing those interpretations in a computer-based analysis system. In general, only those procedures in support of the old accounting efforts have been documented. The majority fall into the category of operational procedures that are developed only with experience of operations personnel. As such, this information is difficult to extract and translate into computer application. There is also an understandable reluctance to incorporate these efforts into a regulatory function. This has slowed acceptance of process monitoring as a potential safeguards tool as well.

An additional problem with process monitoring involves the overwhelming volume of information that is available for process control. A single operations person is limited in the equipment he can run because of the amount of information he must digest to maintain control. It is only with the recent advances in high-speed, low-cost computer systems that safeguards and operations personnel can begin to think of computerizing process data collection to centralize and facilitate the flow of plant data.

Plant operators are beginning to take advantage of computer systems for operations control and safety. The original problems of interfacing plant data to computers is being overcome. Modern plants have computer-based control systems, and older plants are gradually being retrofitted. As a result, process monitoring may see more rapid development as a safeguards tool.

4. THE EVOLUTION OF PROCESS MONITORING

Process monitoring for safeguards was originally proposed in the late 1970s. It was advanced as a concept that used the wealth of process control data available in an operating plant to make safeguards-related judgments about loss or unauthorized use of material. The concept was contemporary with development of NRTA as a safeguards concept.

4.1 EARLY WORK

The earliest formalized work in process monitoring for safeguards was at the Idaho National Engineering Laboratory (INEL) and the Idaho Chemical Processing Plant (ICPP). This effort was extended to the Tokai Works Reprocessing Plant in Japan through the Tokai Advance Safeguards Technology Experiment (TASTEX). The plant is operated by the Power Reactor and Nuclear Fuel Development Corporation of Japan. The net result was a process monitoring system for plant activities in the plutonium product measurement and storage area.

This early work emphasized one of the basic problems facing process monitoring development. Most of the work at ICPP and, to a degree, in TASTEX concentrated on selecting and implementing instruments to interface process measurements to the computer system. There was limited effort to develop the analysis routines and to integrate process monitoring into the regulatory structure. The problems of retrofitting the application to the control system of the existing plants was the major effort.

The original TASTEX program has expired, but Japan has continued the effort through a similar program, called the Japan Support Program for Agency Safeguards (JASPAS). TASTEX and JASPAS together have been the primary push for the emerging interest within the IAEA for applications of process monitoring for safeguards.

The TASTEX effort, or actually the preliminary efforts within the INEL and ICPP, spurred development of an ongoing process monitoring program at the ORNL and, until it was closed in 1983, at the Barnwell Nuclear Fuel Plant (BNFP), which was operated by Allied General Nuclear Services (AGNS). These programs were directed more at process monitoring for safeguards in a domestic program than as a program applicable to international safeguards. However, interesting results with some application to international safeguards have been obtained.

4.2 THE BNFP MINIRUNS

Spurred by the interest in NRTA and process monitoring generated by the TASTEX program, the BNFP was offered as a test bed to implement and demonstrate the techniques. The BNFP was particularly interesting as an evolutionary step because it represented a significant retrofit of computer interface equipment. The control system was typical panel board, but process signals were transmitted electronically rather than pneumatically as had previously been the standard. As part of the U.S. Department of Energy (DOE)-sponsored activities at the plant from 1977 through 1983, a computerized information system was installed to centralize process information, specifically for safeguards analysis. Because the effort was for safeguards analysis, control of plant process by the system was not permitted under the ground rules established at the time. However, the effort made available a much broader base of plant data than had been available in the earlier efforts at ICPP or Tokai.

ORNL was the major sponsor for seven 1-week test runs at the BNFP during 1980–1981. These have become known as the Barnwell miniruns. For these tests, the plutonium purification cycle was isolated from the rest of the facility and operated on a closed-loop cycle in which natural uranium was processed as a surrogate for plutonium in process flowsheets. Each of these runs realized about 1,000 kg of uranium throughput for the plutonium system during the 1-week run period.

The runs were conducted by the BNFP staff with cooperation of personnel from the Los Alamos National Laboratory (LANL) and ORNL. A safeguards computer system was available at the BNFP that interfaced to plant process control and accountability instruments as well as to the laboratory analytical data computer system to make plant operating data available for safeguards analysis. The BNFP staff developed in-process inventory measurement software that was interfaced to NRTA analysis software supplied by LANL. ORNL brought safeguards process monitoring analysis software and implemented the program on the BNFP computer system. The BNFP staff had also applied their own conventional and NRTA software and process monitoring software.

The test runs included actual removals of solutions in various amounts and from various locations in the system to test and demonstrate removal detection sensitivities. These safeguards process monitoring tests extended the applications beyond the tank-monitoring efforts of TASTEX. They provided valuable insights into process measurement accuracies and the effects of process variations on test sensitivities and capabilities. An important observation from this effort was that all process monitoring and NRTA software was installed on the same computer and accessed a common data base. While an NRTA effort can be implemented with manual collection of data, a computerized effort uses a data base similar to a process monitoring effort.

Results were encouraging. Abrupt removals were made that ranged from a 0.5 L of product solution to tens of liters of intermediate process solutions. Some protracted removals were made which involved "sidepocket" of process streams over several hours. All were detected with a combination of NRTA and process monitoring tests. These tests demonstrated the sensitivity of process monitoring tests to very small removals of material—considerably smaller than goal quantities of international concern. NRTA has limited sensitivity, even when applied hourly. However, analysis of sequential tests becomes sensitive to protracted removals as the sensitivity of process monitoring begins to diminish.

4.3 PROCESS MONITORING AT ORNL

In 1984, the IET facility at ORNL became available for tests and demonstrations. The IET facility is a full-scale test plant for demonstration of advanced reprocessing plant equipment and design considerations. The plant is operable at 0.5 Mt/d of heavy-metal depleted uranium to simulate actual plant conditions and is operable without production or regulatory constraints. This means that test conditions can simulate plant upset or transient conditions without concern for product quality or regulatory requirements.

The IET facility represents a modern, state-of-the-art process plant. It was designed and built with a computer-based distributed data acquisition and control system (DDACS). Plant processes are controlled from computerized operator consoles that replace the traditional panel-board control room. All plant instruments and controls are interfaced to the control and information system in the original design. A safeguards data acquisition and archival system is interfaced to the control system to make process control data available for safeguards analysis.

The facility includes equipment for shear and dissolution of simulated fuel. Accountability and feed adjustment equipment to simulate feed preparation operations is installed. A single cycle of solvent extraction simulates the codecontamination and partition cycle of a typical plant. Centrifugal contactors and a pulsed column are available as solvent extraction equipment.

The IET facility has a waste concentration system that simulates the high-activity waste (HAW) system of an operating facility. Acid recovery and solvent wash cycles are included. Product from the solvent extraction system is concentrated. Collection and accountability measurement tanks are provided.

Shakedown runs in the IET facility were conducted during September 1984 and April 1985. Preliminary safeguards process monitoring tests were developed, and software was implemented. During these runs, valuable data on the behavior of process control data under operating conditions were collected. Several iterations on the safeguards development ensued as a result of increasing knowledge of process parameters and their characteristics.

The IET facility is important to the continued development of process monitoring for safeguards. The information and control system is typical of future plants. Much of the process monitoring software developed in conjunction with the BNFP runs has been transported and implemented in the IET facility. Development has progressed from that point. The most important aspect is that the facility is operable without production and regulatory constraints. Tests that involve actual removals of material can be conducted. Safeguards performance can be evaluated during deliberately induced upset conditions without consideration of production and product quality constraints.

4.4 CURRENT ACTIVITIES IN SAFEGUARDS PROCESS MONITORING

Test runs in the IET facility at ORNL continue with a focus of attention on demonstration of process monitoring for safeguards applications. In September 1985, the facility was operated for a 5-d test run. Safeguards process monitoring software was operational. During the test, 17 prescribed removals of material were made to assess the sensitivity of safeguards tests. These removals ranged from 70 L of feed material to 0.5 L of product material. These quantities contained various quantities of depleted uranium. The quantities involved simulated the removal of 2 kg of plutonium in an operating facility ranging down to the equivalent of 100–200 g of product material in some tests.

These tests provided data on initial sensitivity and false alarm rates. The effects of process variation on test sensitivity were demonstrated. As an example, it was found that the product tank tests show a high false alarm rate when the tank level is within a small range near the top of the tank because of curvature of the tank in the head region. It was found that very sensitive tests for loss or removal from the product tank must consider several related measurements and indicators, including the tank mixer status and tank levels.

Lessons learned during this run resulted in improvements in the process monitor test software. A second test run was conducted in March 1986. This was a 3-d run with no scheduled test removals. The goal was to test functionality of the modified software and investigate alarm rates. This run was preliminary to an April 1986 test run and safeguards demonstration.

The April 1986 run was a special exercise and was conducted in conjunction with a process monitoring workshop. Interested persons from within the safeguards community were invited to ORNL to participate in discussions on safeguards process monitoring applications and witness the process monitoring software in the operating IET facility.

As part of the workshop, three attendees from outside the ORNL staff were asked to act as an adversary team and plan several removals of material from the facility. This team operated with the cooperation of the IET operating staff. The IET safeguards staff had the task to identify, quantify, and isolate the removal locations using the installed process monitoring software. The safeguards staff had no previous knowledge of the adversary team's plans.

The adversary team was given some constraints on the removal plans. A specific 30-h time window was specified in which the team was to accomplish the removals. This time window was established to correspond to timing of the workshop sessions. The team was given quantity constraints that limited removals to quantities that would represent the equivalent of 2 kg of plutonium in an operating facility. The adversary team made five removals. The safeguards team identified three. One unidentified removal was made outside the constraint time window and was only 25% of the minimum quantity. When the safeguards team reviewed test results from the period after the time window expired, this removal had resulted in an alarm.

The fifth removal made by the adversary team involved 25% removal of a solvent extraction process stream over 4 h. Software to test for solvent extraction stream removals was in the early stages of development at the time of the test. An alarm was not produced for this removal. However, process data were reviewed with the group, and the removal was apparent. Test development continues for detection of process stream removals.

4.5 FUTURE DIRECTIONS OF PROCESS MONITORING TESTS

Process monitoring has been discussed and limited experience has been gained with application. However, most of these tests have been developed with applications in a government-controlled system in mind. The tests have considered the facility operator as the user of the applications with the focus of attention based on loss or removal by insider groups or individuals or some level of outsider involvement. Credibility of the facility operator or the state system has not been considered in depth as required for international applications.

There needs to be a statement of the functional objective of the applications that can be directed at international safeguards. From this statement, methods of application and a definition of the data sets required can be identified. A rational discussion of the appropriateness of the data set in terms of operations sensitivity can ensue. It is the purpose of this report to provide evidence that process monitoring can effectively support IAEA goals and to illustrate how process monitoring can be integrated into the framework of international safeguards.

Task objectives are to be met by developing candidate applications, implementing them in the IET facility, and demonstrating their sensitivity and role in relation to established international safeguards activities.

5. INTERNATIONAL SAFEGUARDS—THE ROLE OF PROCESS MONITORING

It is the charter of the IAEA to determine that nuclear materials are used for stated peaceful uses. To this end, the IAEA verifies accounting information supplied by the state. The IAEA adopts methods ranging from direct verification of specific measurements to such measures as containment and surveillance activities that use cameras to monitor activities in control areas of a facility.

Process monitoring represents an innovative new approach to verification activities.

5.1 THE CURRENT ROLE OF PROCESS MONITORING

Most of the process monitoring work at BNFP and ORNL has been directed toward the use of process monitoring for domestic safeguards. Like other domestic applications, it assumes that the program is implemented and administered by U.S. Nuclear Regulatory Commission (NRC)-licensed facilities and that the results are communicated to the domestic regulatory system. The regulatory agency reviews the safeguards plan as part of the licensing procedure and monitors application during limited site inspections. Verification of the data involves checks that proper procedures, including calibration, were implemented and documented.

Safeguards process monitoring in a domestic application can be a stand-alone tool for detecting loss or unauthorized use of material. In its domestic application, process monitoring assumes that the adversary does not include collaboration at the government level. While the interface for process monitoring to a domestic regulatory system is not well defined, it considers the facility operator as maintaining the system with periodic reports to the regulatory agency on status.

5.2 CURRENT IAEA APPROACHES

The role in international safeguards is somewhat different. International safeguards relies on the state system to report material movements and status information. The role of the IAEA is to receive the state-system accounting information and to verify the state-system records. This verification includes independent analysis of some samples, witness of some measurements, and application of some containment/surveillance (C/S) devices such as cameras in storage areas.

In this role, the IAEA safeguards capabilities are limited by the capabilities of the state system. Periodic material balances by conventional accounting methods limit timeliness and sensitivity. NRTA and process monitoring offer the possibility for improvement. However, the traditional approach limiting activities to data verification will have to change to realize the benefits of a process monitoring application (or NRTA).

In the absence of a full-scale commitment to process monitoring, the principles can be applied on a smaller scale in what could be considered a c/s mode. As an example, the program developed and demonstrated at ORNL can be applied to tankage in the feed preparation area of an operating reprocessing plant and be used to verify accountability batch transfers and movements through the area to feed for the solvent extraction system. In this application, process monitoring can be used to substantiate the completeness of accountability data reported through the state system and provide an assurance that undeclared dissolver solutions were not processed.

5.3 PROCESS MONITORING APPLIED TO IAEA SAFEGUARDS

Process monitoring makes safeguards judgments concerning location and use of nuclear materials by extensive analysis of process control data. As such, safeguards process monitoring requires computerized access to process data. The safeguards function alone cannot justify the expense of a computer system installed in an operating facility to meet the needs. However, this function can be integrated with a computerized process control system, which can be designed into modern facilities or retrofitted into older facilities.

There are positive and negative impacts in considerations of implementation of process monitoring systems for international safeguards. The facility operator (or state system) must bear the cost of implementing the majority of the computerized system, and safeguards must pay the price for finalizing the application and the costs associated with collection and analysis of the extensive information that becomes available from these implementations. On the positive side, the international safeguards organization can benefit from increased timeliness and sensitivity for indications of loss or unauthorized use. Implementation of process monitoring for safeguards requires a cooperative effort between the facility operator and the regulatory agency, which must consider the positive and negative impacts of such an implementation.

5.4 FACILITY IMPACTS

The obvious impact to the facility is in the cost of implementation. Retrofitting an older facility can cost millions of dollars, depending on the age and adaptability of the process control instruments to computerization. For new facilities, distributed control systems are state of the art and included in facility design. However, implementation requires considerable effort to adapt commercial software to specific plant processes.

The benefits for enhanced process control, improved product quality, and rapid transfer of management information have been realized and have driven facility design to include distributed control. These benefits generally extend to considerations of improved safety and safeguards. The cost benefits of such an effort are demonstrated by the number of facilities that have programs for upgrade.

Process monitoring is directed at timely and sensitive indications of safeguards problems. An effective application by a facility operator provides a timely indication of those same problems before the operator reaches the inventory closure and material balance analysis period when investigative action becomes a problem. The operator can take advantage of the same timeliness and sensitivity. The same benefits are gained by a state system that encourages applications. Both the operator and the state system that supports the activities are the beneficiaries.

Safeguards costs to the facility begins with superimposing the safeguards function on the control system. Safeguards applications will require condensation of plant data and transfer to a safeguards analysis and data storage computer. Commercially available distributed control systems do not usually support this type of function. Costs and responsibilities for this implementation may have to be distributed between the operator and safeguards organizations.

Also, there is a concern that operators or member states will not be willing to provide the detailed information required for effective process monitoring. The reluctance stems from a concern that process control information can reveal sensitive process design or operations data. The relationship of safeguards to process operation must be detailed in a facility agreement before implementing the safeguards application in terms of when and how data are collected and distributed.

5.5 AGENCY SAFEGUARDS IMPACTS

The advantage of a process monitoring application is in increased timeliness and sensitivity. Preliminary tests involving the BNFP and ORNL test facilities show that process monitoring applications can be sensitive to removal of as little as a few grams of plutonium in certain application. Timeliness is a function only of the frequency of inspector data collection and analysis.

The disadvantages of process monitoring from the point of view of IAEA involve the potentially large output of data that could overwhelm the IAEA inspector. Condensation is necessary, but it implies a loss of information. Thus, an important function of the IAEA safeguards analyst is to condense this information into a concise, meaningful summary. Of equal importance is that the detailed information be made available on call to the safeguards inspector.

A thorough review of a process flow sheet by the agency is necessary to adapt process monitoring to the facility. A continuing exchange of information on subsequent process changes is necessary for updating process monitoring software. This effort will require a technical expertise within the agency regarding plant processing technology.

The major advantage of process monitoring is its ability to collect and analyze the large amount of process data that may be derived from existing instrumentation and procedures. With this information, the inspector is able to understand virtually every aspect of process operation for the purpose of detecting unauthorized use of material. While these analyses could be available on line, a realistic application involves inspector collection of data on electronic media, transmittal to agency headquarters, and analysis by staff specialists. Thus, timeliness is, in effect, dictated by inspection frequencies or by the potential of on-site resident inspectors.

The most often expressed concern with applications of process monitoring involves verification of data. We should note that this concern is relevant to any application involving process data, including computer-based applications of NRTA. From the BNFP miniruns, we learned that the same set of data supported both the NRTA and process monitoring efforts. All participants were tapped into the same data base. It was only a difference in the frequency and structure of the tests that separated the functions. It was also learned that the volumes of data used in analysis and the interactions of various tests necessitate an extensive effort from an adversary to falsify information. The very nature of process monitoring tests that use such a broad range of information offers a degree of inherent verification that needs to be explored. Hopefully, later tests at the ORNL facilities can address data falsification as an issue.

An effective process control system should also be an effective safeguards system. Past efforts at BNFP and ORNL have concentrated on applications that do not require special safeguards instruments or measurement systems; but it should be noted that some additional instruments may yet be required. This fact cannot be overlooked in specifying benefits and impacts.

6. SELECTION OF CANDIDATE PROCESS MONITORING APPLICATIONS

This report will concentrate on discussing process monitoring for limited use in IAEA applications. A previous report issued under Task C.59 [ISPO-255 (ORNL/TM-10515)] identified eight elements essential to a complete process monitoring application. These are:

1. Functional objective.
2. Logic structure and test parameters.
3. Data requirements, characteristics, and acquisition.
4. Performance criteria.
5. Alarms, alarm resolution, and response.
6. Hardware: sensors and data.
7. Vulnerabilities, tamper resistance, verification.
8. Resource requirements.

This report will discuss these elements as they apply to safeguards surveillance in a generic sense and with respect to a specific practical application. In so doing, elements for a broader application will become evident should the international community commit to expanded activities.

6.1 BASIS FOR SELECTIONS

Chapter 4.4, *An Advanced Safeguards Approach for a Model 200 T/A Reprocessing Plant* (STR-140), discusses surveillance and process monitoring. This chapter contains a discussion on possible scenarios for material removal and presents the role of process monitoring to detect these covert activities. It rates the product concentration and measurement area as the most attractive for possible removal, but it considers upstream flows as concerns, inversely proportional to concentrations and purity. Flow measurement comparisons are identified as important to safeguards activities in detecting unauthorized removals from these areas.

As noted in STR-140, material for potential removal cannot be invented. It must be in the process area. The material must enter the process area and progress through the purification cycle to the point of removal. To avoid detection by the accountancy system, one scenario suggests the by-pass of the input accountancy tank with dissolver solutions containing the quantity of material to be later covertly removed prior to product measurement. Effective monitoring for potential bypass activities remains a concern for international safeguards activities.

6.2 CANDIDATE APPLICATIONS

Two process monitoring applications are proposed for implementation and demonstration in the IET facility at ORNL. These focus on the concerns identified in the IAEA/STR documents. The first involves monitoring of input accountability and feed preparation tankage in an event-logging role. The second involves comparison of solvent extraction mass flow measurements. These data in the second application can be integrated for mass flow measurements. The measurements in both applications can support certain NRTA applications or indicate process activities that attempt to circumvent accountability measurements or sidepocket material for covert recovery. These applications can be used to verify accountancy flow measurements and predict downstream concentrations.

7. FUNCTIONAL OBJECTIVES

The functional objectives of any process monitoring activity must be clearly defined as a first step in the application. In developing these objectives, consideration must be given to the fundamental differences in the applications for domestic safeguards versus international safeguards. For domestic applications, the monitoring activity may be active (i.e., with potential for intervention in process operations). Responsibility for implementation and maintenance rests with the operating organization. In international applications, only passive functions are currently acceptable. It represents a significant change in the scope of international safeguards to obtain data directly from a facility. Functional objectives considered here limit the applications to monitoring activities with limited, direct, on-site involvement by the inspector.

7.1 FUNCTIONAL OBJECTIVES OF AN EVENT-LOGGING APPLICATION

The functional objective of the event-logging application for process monitoring is to detect solution movements that potentially reflect covert additions of material to bypass the accountancy measurement tank. This application focuses on tankage in the feed preparation area of a reprocessing plant, including equipment associated with input accountability, feed adjustment, and feed to the solvent extraction system.

In the international application, this is a passive function, consisting of a monitor system that records information for inspector review. Conceptually, the data are recorded on site and analyzed at mutually agreed intervals by on-site inspectors. An inspector may retrieve selected data sets and submit them for agency review.

The event-logging application monitors measurements to detect any change in tank contents. If a change is observed, contents of adjacent tanks are checked for corresponding change. The application provides the agency with an indication of nonroutine additions or removals that do not correspond to normal transfer of declared input solutions.

Functionally, this application is directed at the concern for detection of undeclared additions to the process that bypass the accountancy tank. In application, it is sensitive for detection of unauthorized removals as well. In addition to the monitoring of routine transfers for consistency checks, this application actually logs accountability batch transfers. In this sense, it also contributes to verification of input quantities reported for material balance purposes.

Event logging is described in this report for application to the feed preparation area of a typical reprocessing plant. The possibility for extension of this logic to the product area of a typical plant is obvious. There has been extensive work in process monitoring applications for product storage tanks, notably associated with the plant at Tokai under TASTEX and its extensions. The application described here and implemented in IET extends previous efforts and deals with such process problems as steam-jet effects and incorporation of process flow measurements in the safeguards decision logic.

7.2 FUNCTIONAL OBJECTIVES OF A FLOW-MONITORING APPLICATION

Monitoring of process flows within the solvent extraction systems of a reprocessing plant represents a second application to be demonstrated in the IET facility at ORNL. The functional objective of this application is to recognize the removal of significant quantities of process streams. In the scenario of processing undeclared input solutions, this application recognizes the removal of such purified product solutions prior to product-handling equipment and measurements. Product area equipment is easily subjected to an event-logging routine such as described in Sect. 7.1. This application addresses flow monitoring in equipment prior to product measurement.

A flow-monitoring program compares material flows at various points throughout the solvent extraction process. In the computer-based process monitoring application, these comparisons are frequent, perhaps on the order of minutes. As such, they provide frequent flow measurements. These data can be used to integrate flow quantities. Thus, a secondary functional objective for this application is to integrate flow quantities in support of I/O measurements required for potential NRTA applications on plant subunits. Again, this application goes beyond currently accepted international safeguards activities. However, if timeliness and sensitivity of detection capabilities are to be improved to meet stated objectives, institutional problems limiting new applications will have to be addressed.

8. LOGIC STRUCTURE AND TEST PARAMETERS

The logic structure of a process monitoring application defines the type of information and analyses required to achieve the functional objectives. It also constructs test parameters that are subjected to analysis. Decision logic of the analysis routines produce indications of potential loss or unauthorized use of material from the facility.

8.1 THE LOGIC STRUCTURE FOR AN EVENT-LOGGING APPLICATION

The logic structure for event logging, in very simple terms, looks for any **significant** change in tank contents and tries to find corresponding changes in adjacent tanks or process measurements. The decision logic, as applied in the IET facility, makes use of all available measurements and indicators. Test parameters include volume and solution weight comparisons.

The test covers all tanks and equipment from the input accountancy tank to the point at which solutions are fed to the solvent extraction system. This includes the acid-and-water addition step which adjusts feed concentrations to flowsheet conditions.

In the IET facility, feed is measured in the accountancy tank. Measured feed is transferred to the feed adjustment tank. Acid and water additions are made, and adjusted feed is transferred to the solvent extraction feed tank, which continuously supplies feed to solvent extraction. Solution transfers are accomplished by steam jet which introduces a volumetric increase (resulting from steam condensate) during the transfer. Recycle acid and water systems supply adjustment solutions. Air-lift mixers or air spargers are used to mix process solutions. Installed logic has the capability to make decisions on movements of process solutions with these effects acting on process measurements.

Static tanks are monitored. In the feed preparation area of the IET facility, positive-indicating binary indicators are provided on the transfer actuators. These are primary indicators of transfers in the decision logic. If tank contents change without transfer indicators, the logic structure signals potential problems.

When transfers are indicated, logic includes algorithms that recognize source and destination tanks, compute rates of transfer for comparison, and make a cumulative comparison on completion of the transfer. For routine transfers, the comparison considers steam-jet dilution effects. In the case of water and acid adds, an integrating flow meter is installed to measure additions. Flow meter measurements are compared to tank measured volume changes. Additionally, volume changes in the recovered acid and water storage tanks are considered. Some of these tanks satisfy several process stream requirements simultaneously; the measurements are only tertiary backup in the safeguards decision process.

For transfers between the feed adjustment tank and the process feed tank, decision logic must recognize the transfer that is in progress and consider comparisons that account for the effects of steam-jet dilution as well as volume changes that result from quantities fed to the solvent extraction system while the transfer is in progress. For this latter consideration, the logic structure uses process control measurements of flows. This structure involves indirect measurement of the feed flow as well as direct flow measurements of cold chemical streams for the solvent extraction system in the IET facility.

While the decision logic may seem somewhat simple on the surface, actual implementations to consider the multiple effects of process activities complicate the application. The decision logic begins to approach an applied "expert system." Multiple indicators of process events and backup comparisons to support primary indicators are required to limit alarm (false) indications. More will be presented on this subject in later sections.

8.2 THE LOGIC STRUCTURE FOR A FLOW-MONITORING APPLICATION

The flow-monitoring application for process monitoring involves process stream flow comparisons. For the IET application, and as appropriate for reprocessing plant applications, the logic structure is concerned with heavy-metal mass-flow measurements. In the solvent extraction process associated with fuel reprocessing, heavy-metal content includes uranium and plutonium. Test parameters relating heavy-metal flows are selected because heavy-metal content in solvent extraction streams is readily estimated from process density and acid concentration measurements. Tests applied in the IET facility and proposed for international safeguards thus can use process measurements and will not have to rely on sophisticated and expensive on-line concentration analyzers.

The logic structure for this application uses process control measurements recorded every 4 min. Calculation routines are included to compute heavy-metal flow quantities for each of several streams in the IET facility solvent extraction cycle. These rates are integrated, over time, to produce a cumulative flow measurement. Comparisons of these cumulative flows become the test parameter submitted for analysis.

9. DATA REQUIREMENTS, CHARACTERISTICS, AND ACQUISITION

A data acquisition system to support a process monitoring activity must recognize the data requirements to support the decision logic. This includes an assessment of the specific measurements required and the frequency of data collection. Characteristics of the typical data set must also be recognized. In this section, we characterize the data requirements for the chosen process monitoring applications for the IET facility.

9.1 DATA REQUIREMENTS FOR AN EVENT-LOGGING APPLICATION

For the event-logging process monitoring activity, as implemented in the IET facility, the basic data requirements are level, density, and temperature measurements for each of the three major tanks involved. These are:

Input accountancy tank.
Feed adjustment tank.
Solvent extraction feed tank.

The IET facility control system allows interrogation of process equipment status. These interrogations are returned as binary (on/off) signals. The event-logging application in the IET facility takes advantage of four of these binary signals that indicate activation of solution transfer mechanisms (steam-jet supply status indicators):

Accountancy to feed adjust transfer.
Accountancy to feed tank transfer.
Feed adjust to feed transfer.
Feed to feed adjust transfer.

In addition to these signals, binary indicators are also available to show mixer status (air-lift and sparge ring) on the accountancy tank.

Additional signals submitted to analysis indicate recovered acid and water use. An integrating flow measurement device is installed on the acid add line and the recycle water add line that serves the feed adjustment tank. Additionally, a level-measurement instrument on the recycle water surge tank gives volume information. Level and density instruments on the recycle acid tank provide similar indications for backup calculation of volume additions for adjustment.

As noted, the decision logic must consider solvent extraction feed rates to make volume comparisons during transfers from the feed adjust tank to the feed tank. Likewise, when this application is used to support NRTA, for example, flow measurements must be integrated, over time. Tank depletion rates are the most accurate calculations for flow. Additional process flow measurements must be in the data base to confirm process feed flow indications and calculate quantities as backup to depletion rates while the feed tank is filling.

Considerable effort was devoted to development of an adequate algorithm for calculation of feed flow in the IET facility. To support this algorithm, the following measurements are included in the data base:

Feed flow (by measuring air-lift supply air flow).
Feed flow (backup direct magnetic flowmeter).
Organic extractant flow (HAX).
Intermediate recycle flows (HSS, HSIS).

The need for these extra measurements to properly monitor feed flow points to the necessity to understand characteristics of the measurements in order to apply an effective process monitoring program for safeguards. As it evolved, the algorithm recognizes potential drift (characteristics) in the instrument "zero" settings. It requires that all flows indicate that the feed stream is on before it calculates the rate from tank depletion. It then recognizes potential transfers that invalidate the depletion calculation and activates backup calculations to compute feed rate.

The flow measurement algorithm also points to considerations of timing. Data collection (scanning) routines must have a frequency that can react to routine process changes. The collection and evaluation schemes must not miss a significant event. The rationale used in development of the IET facility application was that routine tank transfers take an average of 15 min. It was desirable to obtain three data points during a transfer to perform rate calculations. Thus, a data collection frequency of 4 min. was selected. As it turned out, this frequency has worked well for flow integration as well. Individual flow measurements are assumed valid over the 4-min interval, and cumulative quantities are calculated from the flow measurement and the time interval between data collection cycles.

Data characteristics impact performance criteria. Such criteria for the event-logging application will be discussed in the next section. Data characteristics, in terms of accuracy and precision, are key to establishing and attaining performance criteria. It is generally understood that measurement systems have associated statistical qualities. It is not generally understood that the quality of process control data changes over time. This changing quality of process control data has become known as process variation. For the event-logging function that deals with measurements in the feed preparation area of a plant, the IET facility application has attempted to deal with process variation.

Tank mixing is an excellent example of a process function that can change characteristics of process measurements. The IET application uses process measurement accuracies in assessing the occurrence of significant events. In order to compensate for process variation, binary signals for tank mixing have been used in evaluating accountancy tank measurements. In other applications, a moving variance algorithm has been applied to compensate for process variation. These techniques become necessary for conditioning data to limit alarm rates and subsequent investigations to acceptable frequencies.

9.2 DATA REQUIREMENTS FOR A FLOW-MONITORING APPLICATION

Process flow and heavy metal concentrations in solvent extraction process streams are the basis of the flow monitoring application. As applied to the IET facility that contains a single cycle of solvent extraction, three flows are monitored and compared:

HAF (aqueous feed flow to solvent extraction delivered to intercycle surge tank).
HCU (aqueous product from solvent extraction).
Aqueous feed to the product concentrator.

The IET facility is a test facility. The basic process flow diagram is given in Fig. 1. We have attempted to select a stream monitoring application that is representative of a situation in an actual plant. Therefore, we have chosen typical process-control-type measurements. The IET facility processes only depleted uranium solutions. Thus, the heavy-metal content is only uranium. Uranium and heavy metal concentrations are synonymous. Consequently, the IET application is somewhat easier than typical plant applications. However, measurements devices in the IET facility including concentration monitors, have characteristics typical of those devices that would be encountered in an actual facility.

In support of the flow monitoring application, the HAF (solvent extraction feed stream flow) is measured as described for the event-logging application. However, this application also requires uranium concentration (heavy metal). In the IET facility, an in-line, spectrophotometric concentration monitor is installed on the HAF line. This device returns uranium concentration for the feed stream. This measurement is supplemented by a determination of concentration from measured tank density (process control differential pressure measurement) and in tank conductivity measurement. Neither of these concentration methods have proven totally reliable. It is an interesting challenge to the safeguards technician to construct the decision logic to take advantage of the cross-checks available from these redundant measurements. In the IET application, we are attempting to use these multiple measurements, coupled to periodic calibration by sampling and laboratory analysis. Again, this type of data availability and analysis breaks from the tradition of current IAEA safeguards applications but is the basis for any advanced applications to improve timeliness and sensitivity.

Uranium is extracted from the aqueous feed streams into the organic solution, which is supplied as the HAX streams (Fig. 1) in the HA contactor. An intermediate monitoring point can be established by measuring the concentration of the organic phase as it exits the HA contactor. This particular measurement is not conveniently available in the IET facility.

The HCU stream is the aqueous intermediate product from the solvent extraction cycle. This stream leaves the strip column (HC) and is airlifted to an intercycle surge tank (HCU surge) through a separator pot and decanter. Again, this stream measurement is selected as typical of a process application.

In the solvent extraction process (and the IET in particular), uranium (heavy metal) is stripped from the organic stream in the HC column by the aqueous HCX stream. The HCX is an easily measured cold chemical stream (and is always measured for process control). This stream becomes the HCU after it strips the uranium in the contactor device.

ORNL–DWG 87–5387

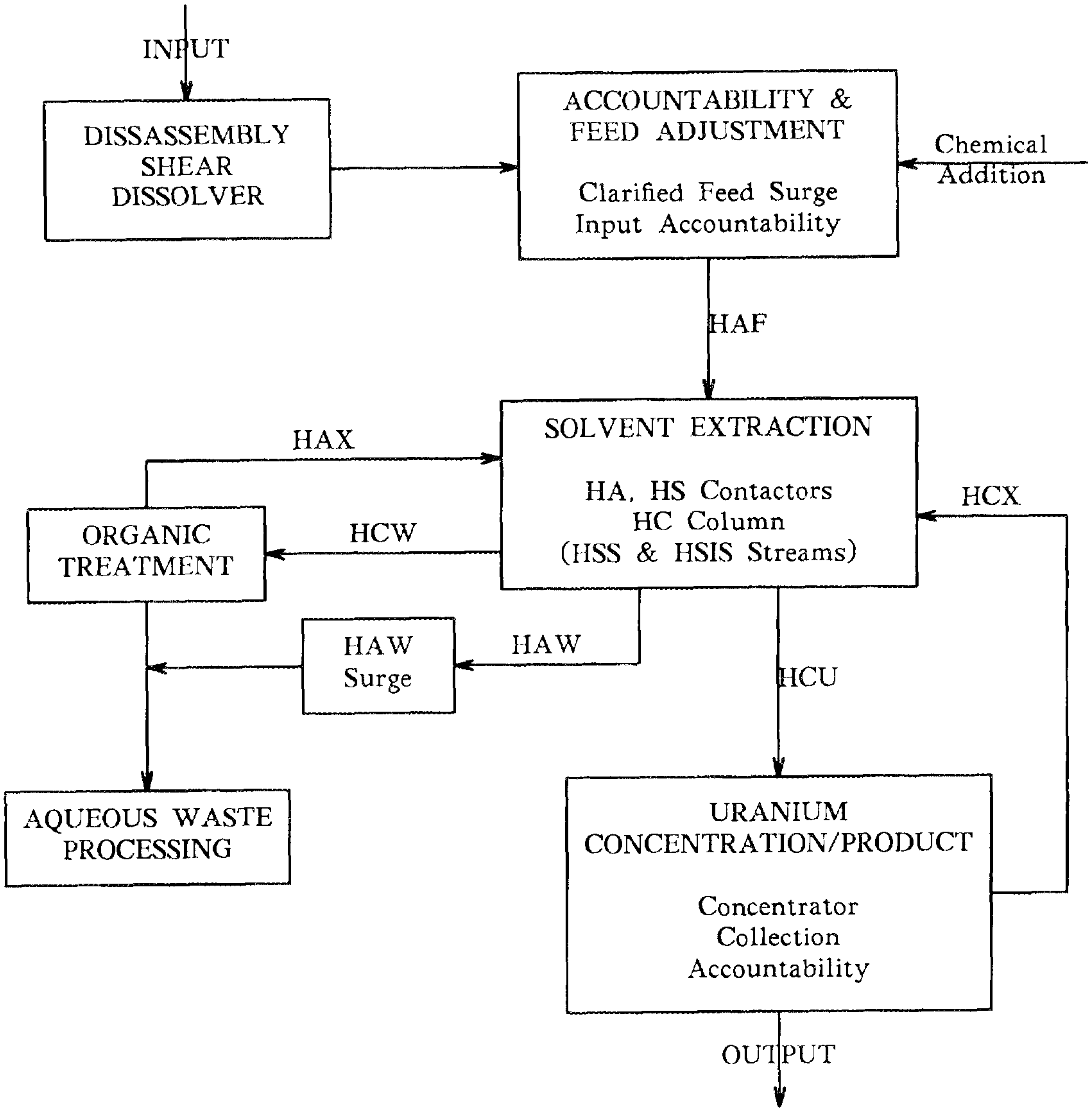

Fig. 1. IET process flow.

Thus, measurement of the HCX stream flow is a valid measure of the HCU stream flow. The organic process stream leaves the HC column as the HCW after uranium is stripped (Fig. 1). A minor correction for trace uranium could be applied for the HCW, but it is not necessary in the IET.

In the IET facility, a density measurement device (differential pressure, dip-tube system) is installed on the HCU decanter. This measurement (with an assumption of acid concentration) is used for heavy-metal concentration estimation.

Concentration and flow are integrated, over time, for cumulative heavy-metal flow determination. Centrifugal contactors in the IET facility solvent extraction system limit system holdup. The most significant holdup variations occur in the HC column. Thus, a fairly direct comparison of the HAF and HCU stream flows can be made.

For the flow comparison process monitoring application, the final stream measurement of the dilute aqueous product delivered to the concentrator. Feed to the concentrator is airlifted from the HCU surge tank to a separator pot, with gravity flow to the concentrator. Air supply to the air-lift is measured and can be related to product delivery rates. However, a magnetic flow meter is installed on the surge tank discharge line, and this provides measurement of the delivery rate for the IET tests. Note that the surge tank continually receives and delivers solution, and dropout rates are not generally available. Concentration of this stream is estimated based on a density measurement in the surge tank and an assumption of acid concentration.

For the flow monitoring test, this heavy-metal stream flow is compared to the other two. However, changes in the surge tank must also be considered in the analysis.

Applications of safeguards tests that use process control data, particularly integration of flow measurements that propagate systematic errors (biases), require continuous evaluation. In the case of flow monitoring, a very important consideration is implementation and maintenance of calibration corrections. In the application discussed here, several such corrections are required:

Density on feed tank.
Density on HCU decanter.
Density on HCU surge.
HCX flow (aqueous strip).
HAF airlift flow calculation.

For the IET facility application, the magnetic flow meters are fairly accurate, and not much attention is given to development and maintenance of calibration corrections for these measurements.

In the current application, these corrections are being applied by manual review of data and direct manipulation of correction factors. Efforts at implementing decision logic for maintenance of these factors are in progress, but more experience is needed before recommendations in this area can be made.

10. PERFORMANCE CRITERIA

Performance criteria for individual tests should be related to the detection of the removal (or addition) of a goal quantity of uranium or plutonium. This goal quantity has been the subject of numerous discussions. In the United States, regulatory requirements are beginning to focus on 2 kg of plutonium for most removal scenarios. The evolution of goals for international safeguards has been described in the IAEA *Safeguards Manual.* Chapter SMO 2 of this document identifies a goal quantity as 8 kg of ^{239}Pu detectable on the order of 1–3 weeks for separated plutonium—like that found in the purification area of a reprocessing plant. Domestic (U.S.) regulations differentiate goal quantities for different removal scenarios (one goal for abrupt and another for protracted). International goals do not include such differentiation.

The specific performance criteria for a particular process monitoring will depend on the functional objectives and the particular test formulation. The criteria must relate directly or indirectly to the goal quantities.

10.1 PERFORMANCE CRITERIA FOR AN EVENT-LOGGING APPLICATION

In the case of the monitor application for the feed preparation area of a typical fast breeder reactor (FBR) reprocessing facility, which is modeled by the IET facility, volume and solution weight are the basis for test parameters. In the IET facility tests, the goal quantity for detection was set at the equivalent of 2 kg of plutonium to correspond to proposed domestic U.S. regulations. The IET facility is a prototype for a breeder fuel reprocessing facility. Feed preparation area process solutions typically have concentrations of 20–40 g/L of plutonium. Thus, the goal quantity of plutonium would be contained in 50–100 L of process solution in this area of a typical operating breeder fuel processing plant. Although the IET facility processes only natural uranium, feed solutions are considered to contain the equivalent flowsheet quantity of plutonium. The performance criteria for the event-logging application is thus established as determination of the loss (or unauthorized addition) of 25 L or 25 kg of solution during any activity. Additionally, the tests are designed to detect the removal (or addition) of 10 L from a static tank in the system.

The performance criteria are established for abrupt removals, or additions over a 4-min period (the typical data scan and evaluation cycle time). An additional test is also applied for abrupt removals or additions of 25 L or a 25 kg of solution over longer periods. Currently, this longer interval is set at 1 h, but the logic can be extended to even longer periods. In this sense, the performance criteria are expanded to detect longer term removals that begin to resemble protracted.

10.2 PERFORMANCE CRITERIA FOR A FLOW-MONITORING APPLICATION

Performance criteria for the flow monitoring application in the IET facility are also the detection of the removal of the equivalent of 2 kg of plutonium. Again, the IET facility processes natural uranium as a surrogate for plutonium. The performance criteria are related to the removal of uranium in the IET process.

The performance criteria must be related to the test parameters. In the case of the flow monitoring application, the test parameters involve total heavy-metal content of the process stream. In the case a typical large scale reprocessing facility, plutonium throughput is on the order of 2 kg/h. Thus, the performance criteria are related to removal of some percentage of the total stream contents.

The goal of the application in the IET facility is to detect the abrupt removal of the goal quantity. In the case of process flow monitoring, *abrupt* is defined as the removal over several hours. As most often stated in the IET applications, the abrupt removal requires removal of 25% of the process stream over 4 h or 100% over 1 h.

In the IET facility, the solvent extraction system simulates the first cycle of the prototype plant. Design flows for most of the tests have been on the order of 2 kg/h of heavy metal. Thus, the performance criteria have been set to detect the removal of about 2 kg of heavy metal.

11. ALARMS, ALARM RESOLUTION, AND RESPONSE

The generation and handling of alarms depends to a great extent on the performance criteria that have been established and the characteristics of the process data. The alarm limits, the resolution techniques appropriate for each alarm, and the response activities associated with the failure to resolve the alarms can then be addressed based on the performance criteria established in a later section.

11.1 ALARM CRITERIA FOR AN EVENT-LOGGING APPLICATION

The event-logging function applied to the feed preparation area of the IET facility is also a prototype for a breeder fuel reprocessing facility. Local alarms are generated when removals (or additions) are detected. The alarm mechanisms are applied in two ways. The IET facility application performs analysis as the data are accumulated. In this sense, alarms are generated, and messages detailing alarm information are produced at a local terminal, presumably for inspector alert. Additionally, the system installed at the IET facility archives the messages and the accumulated data. These data can be replayed for local analysis as well as to generate the alarms and information for later analysis by inspectors.

A series of analysis programs are also available with the installed system at the IET facility to assist in alarm resolution. With the limited operational experience using this application in a test environment at the IET facility, an alarm frequency of 2–3% has been realized on the 4-min data collection and analysis cycle. These tests have included actual removals. However, false alarms have been the significant portion of the observed alarms. Analysis routines consist of detailed transfer analysis routines and trend analyses. Most of the alarms have been resolved as false indications by considering successive tests around an alarm. The alarm indications are usually associated with a spurious signal with recovery in the next successive test. Software fixes may be accomplished by introducing a lag in the analysis. In some cases, this has been successfully implemented However, any application will likely suffer an increase in the alarm frequency because of spurious signals, and analysis routines will be necessary to resolve these alarms.

11.2 ALARM CRITERIA FOR A FLOW-MONITORING APPLICATION

Alarm mechanisms for the flow monitoring are not simple to implement. The test involves monitoring differences between cumulative flows. This comparison is complicated by effects of systematic errors (biases) in the measurements. For the current IET facility application, an alarm is generated when the difference in the cumulative quantities exceeds the 2 kg of heavy metal based on performance criteria established in the previous chapter.

In tests to date, operating time has been limited to several days. Measurement characteristics are evaluated, and test application includes manual adjustment of correction factors (bias adjustments) to remove most of the systematic effects. Comparisons of cumulative quantities are made over limited time windows. Generally, these tests are directed at detecting short term or abrupt removals.

Broader applications must recognize the effects of removals among changing systematic errors in the measurements. Methods of on-line calibration of measurement systems are needed. In many cases, these can be comparison of redundant measurements and periodic calibration efforts. This is the key to improved sensitivity for the longer term or protracted removals.

In the IET facility, the attempt has been made to recognize the change in overall systematic effects as indicative of possible loss or removal. This has been somewhat successful on a limited basis but needs demonstration over longer term test applications.

Resolution of these alarms again involves extensive evaluation programs that perform these calibration checks.

11.3 RESPONSE MECHANISMS FOR PROCESS MONITORING

The response mechanism has been considered in depth at the IET facility and ORNL in general. It remains a problem to work out the interfaces to a regulatory agency for process monitoring tests. To date, the tests have been applied locally and analyzed in depth at the site. To an extent, the regulatory interface has been simulated by the delayed analysis routines that have been implemented. Response mechanisms must be dictated by the alarm rates and resolution schemes that evolve from applications. There needs to be interaction established between the facility operator and the regulatory agency beyond the current level applied to international safeguards. This is a problem faced by applications of process monitoring or NRTA and represents a new level of activity for international safeguards beyond the current approach of verification of state-system data.

12. HARDWARE, SENSORS, AND DATA PROCESSING

A major element of a process monitoring system is the sensors and data acquisition hardware. One of the principles of IAEA safeguards is minimum interference with operation of the facility. Effective and economic application of process monitoring requires that all process sensors used for international process monitoring applications be installed, operated, and maintained by the operator. Specialized instruments may be provided by the inspector and then installed and maintained under inspector observation. Such instruments may be installed in locations that permit verification of the routine process instrumentation.

The data acquisition system must be designed to access measurements from process sensors in a manner that prevents any active capabilities with respect to the process. The hardware and software capabilities of these systems are discussed separately in the following sections.

12.1 HARDWARE CONFIGURATIONS

A basic concept of process monitoring for safeguards is that the on-line process data used by plant operators to control the process can be used also to detect loss or unauthorized use of the material. Current plants usually are well instrumented for this purpose, although frequently the process data are acquired from sensors in which the data presentation is by individual readout or control devices covering an extensive control panel. To be utilized in an effective safeguards program, whether NRTA or process monitoring in scope, these data must be collected and made available to a single safeguards computer. In some plants the sensor and control signals are already multiplexed into a process computer, thus eliminating the individual readout devices. In this case the data can be sent directly to the safeguards computer using conventional communications technology. Although effective, this method leads to complications of the verification process.

If there is no process computer, the safeguards computer may tie into the signals at the readout devices. An analog-to-digital (A/D) converter may be inserted into the readout circuit of each sensor and the digital output fed into a minicomputer, microcomputer, or personal computer. If retrofitting to a plant with pneumatic transmitters, the transmitter signals must be interfaced through a pneumatic multiplexer to an electronic transmitter. Alternatively, electronic transmitters must be installed parallel to the pneumatic devices.

Future reprocessing plants will likely take advantage of recent advances in data processing and communications technology which have greatly reduced the costs of highly instrumented and even automated plants. Such systems will facilitate both the process control and process monitoring functions. These proposed systems typically involve a network of computers, or clusters of computers, arranged in an hierarchical fashion, which exchange information along the interconnecting data highways. The process control and safeguards analysis functions are then distributed among these computers. International safeguards data collection and evaluation are easily interfaced to these systems.

12.2 HARDWARE AND DATA PROCESSING FOR IET APPLICATIONS

The hardware and data acquisition systems of the IET facility are prototypical of those of future reprocessing plants. This system, DDACS, consists of unit process control modules (PCMs) with dedicated measurement, control, and data acquisition functions; communications control modules (CCMs), which coordinate all system communications; a host minicomputer at the plant supervisory level; and a safeguards minicomputer and personal computer workstation.

With few exceptions, process sensors and control actuators are located on the top floor of the facility, two or more stories above the production floor. The electronic signals from the sensor transmitters are routed to the PCMs, which provide A/D conversion of the measurement signals. Each PCM is associated with one or more unit operations of the production process. Based on the sensor values or on command from the plant operator, the PCMs generate control signals that are directed to the control actuators. Thus, the primary functions of the PCMs are to monitor process variables, to provide continuous control of process loops, and to control sequential operation of mechanical devices. Hardware in the PCMs provide four types of I/O: analog input, analog output, digital input, and digital output. A typical PCM has the capability of interfacing to hundreds of external sensors and actuators, giving a system-wide capability of controlling or monitoring thousands of points. The PCMs are interconnected with each other and with the host computer through a high-speed data highway communications system. At the top of the DDACS structure is the host computer, a PDP 11/70. The host is used for software development, microprocessor data-base storage and loading, system monitoring, console display of the process, and alarm message generation.

In the IET facility, safeguards tasks other than those associated with the actual collection of data are resident in a second minicomputer, a PDP-11/44, which communicates with the host computer via a 9,600-baud hard-wired line. The safeguards computer is provided with random access disks for the storage of current information and with magnetic tape drives that are used for the archiving of process data for both safeguards and operations purposes. Interaction with the safeguards computer by safeguards personnel is provided both by terminals and by a DEC PRO/350 personal computer, which, by reason of its PDP-11 structure, can interchange information directly with the PDP-11/44.

12.3 GENERIC SOFTWARE REQUIREMENTS FOR SAFEGUARDS ANALYSES

Sensor data signals must first be collected and converted from raw values into engineering units. In an hierarchical distributed system, these operations are performed by microprocessors that may be grouped in a fashion to serve plant production and support areas and to interchange information with larger microprocessors or minicomputers. The validation of the data and transaction processing is accomplished at this lowest level. Additional data processing occurs at the intermediate level, where data are stored for trend analysis and display and subsequent archiving. This computer maintains overall control of the data base.

Special safeguards analyses are performed at another level of the hierarchical system. Data specific to these analyses are submitted to intensive checking and cross-checking to validate the correctness of the raw and computed values. Process monitoring data may be used to establish inventory files to compute ongoing material balances. Each process variable determination is compared with one or more predictions based on the past preformance of the variable and on the behavior of associated variables.

Binary signals defining pump status, valve settings, and the like are examined to determine the process operations currently in progress. Under normal conditions, these determinations explain the status of the process variables. Changes in process conditions that cannot be resolved in this fashion together with, say, discrepancies in tank-to-tank transfers are designated significant anomalies. Upon termination of the anomalous condition, the balance files may be interrogated to determine whether the system has returned to normal inventory.

12.4 THE IET DATA ACQUISITION SYSTEM

The IET data acquisition system is a typical configuration to handle safeguards data for process monitoring. A data acquisition cycle may be initiated at any time from the safeguards computer. Normally this is done at regular intervals of 4 min, thus facilitating sequential analysis of the incoming data. The actual timing depends on the process and is chosen so that several readings of process data are obtained for every routine process occurrence (e.g., a tank-to-tank transfer.)

Upon receiving the prompt from the safeguards computer, the data collection task in the DDACS computer interrogates the PCMs, retrieving data according to a predefined listing. All data are accumulated before transmission to the safeguards computer, thus minimizing the time-spread between the first and last process variable values. The accumulated data are transmitted with appropriate protocols and with error checking.

Data handling within the safeguards computer provides immediate access to current data by a variety of independent tasks running simultaneously. Incoming data are stored in a memory resident common from where they can be accessed by each task. When all data for the current data acquisition cycle are received, this common is written to a random access disk file, which always contains the data for the previous 8 h of operation. Every 8 h, normally at the conclusion of a shift, the data for that shift are copied onto a disk. Periodically, these disk files are copied onto magnetic tape for archival storage.

13. VULNERABILITIES, TAMPER RESISTANCE, VERIFICATION

A major element of the process monitoring system concerns its vulnerabilities, the possible tamper-resistance methods, and methods of verification of the data. All process monitoring information should be subjected to validity checks before use by the inspector/analyst. Such checks guard against misuse and mishandling of data either deliberately or by mistake. False or spurious data may occur as a result of human error, instrument malfunction, or unexpected process upset. They may also occur as the result of a deliberate attempt to insert or alter data/signals for the purpose of misleading the analyst. This section discusses methods to ensure that the data are valid.

13.1 PROCESS ANOMALIES AND DATA TAMPERING

Because the process monitoring system is intimately connected with the operator's data acquisition system, one of the most significant and obvious vulnerabilities is a situation in which access to process data is interrupted either by deliberate operator actions or by other occurrences. Other events that may be expected during routine plant operation (or may be invoked by the operator) include such occurrences as increases in the noise content of the data or instrument calibration changes, any of which can compromise the process monitoring sensitivity.

Manipulation of the sensor signals, either in the field or in the computer, introduces anomalies in the process data that do not conform to routine plant operations. To detect such events, consistency checks are conducted by comparing incoming information against archived, usually recent, process data. Expected results are compared with the new incoming data using statistical tools that determine whether the observed difference is significant. If so, additional checks are made until the problem is resolved. Frequently, multiple checks facilitate resolution of the anomaly because alteration of a single sensor value often requires that associated sensor values be changed at the same time and by an appropriate amount if detection is to be avoided.

In the IET application being developed, numerous sources of information may be used to verify the incoming process data. For example, binary signal data that show valve and steam-jet status may be used to infer material transfers in progress that must be confirmed by a drop or rise in tank volume. Additional confirmation may be found by checking for a corresponding volume increase in an appropriate tank upstream or downstream.

There is, then, an inherent tamper resistance with process monitoring in that the data used in the monitoring are coupled tightly to other data in a sequential process operation. This coupling permits some consistency checks that will, in essence, substantiate the data quality. This procedure overlaps with the process monitoring concept because there is no well-defined line separating the two approaches.

13.2 VERIFICATION TECHNIQUES

The most important verification concept for the data used in process monitoring is afforded by comparison of process data with sample analysis. Such comparisons provide a means of identifying anomalies that take place over an extended time and are not readily apparent as they occur. For example, the clogging of instrument probes takes place slowly and can not be easily identified. Procedures could be installed that use sample measurements to detect this gradual malfunction and determine a correction for use in subsequent process monitoring calculations.

With the advent of computer control and computer collection of data, human error is minimized. Still, common transcription errors can easily occur when preparing software or when interrupting the program to introduce densities and other similar laboratory results. Incorrect calibration equations can also introduce strange results.

Special circumstances determine when the facility operator offers his process instrumentation and process computer for safeguards purposes. This greatly facilitates the safeguards task in providing the data required for process monitoring and indications of the activities of the process operators. However, the possibility exists that the data transmitted from the process computer were actually recorded at a previous time or that the computer has been used to generate false but believable data.

Ideally, the data from the process sensors would go first to a secure distribution box, which would split the signals from key sensors and from which signals would be sent both to the process computer and, over secured lines, to the safeguards computer. Raw data from the sensors can then be used to check the raw and computed data from the process computer, thus validating the process computer data.

An important verification technique is the limited use of duplicate sensors at specific process key measurement points. Such sensors would be dedicated to the inspectors and would permit continuous comparisons with the process sensors. Unaltered data signals from sealed process instruments would be transmitted over secured lines to a safeguards computer. Methods for protecting these lines are discussed below. Details such as procedures for selecting, testing, calibrating, and replacing this instrumentation should be worked out between the IAEA and facility operator early in the negotiations.

13.3 DATA TRANSMISSION

Data used for safeguards purposes must be transmitted from the process sensors to the safeguards computer, which is often located on-site, but at some distance away. These transmission lines are vulnerable to tampering. Authentication of these process data becomes of great importance to safeguards personnel, who must be confident that no data have been falsified. It is difficult to protect data transmission cables from tampering. Hardening the cable channels to withstand physical attack is an expensive measure that must be incorporated into the original plant design and, frequently, interferes with optimal design of the facility. There was hope that optical fibers would provide a transmission medium that could not be breached: it now appears that such cables can be effectively tapped.

Although absolute security against tampering does not appear feasible, tamper-indicating measures have been demonstrated. Special cables with three concentric conductors permit transmission of an associated signal which monitors against tampering. Other systems consider encryption of the transmitted signal.

Encryption of the transmitted data implies that a hardened device, such as a microcomputer, performs a functional transform on the actual data values (termed the **plaintext**), thereby rendering it into unintelligible ciphertext, which is sent along the transmission line. The safeguards computer then performs the inverse function to render it intelligible again. In its simplest form, the transform and its inverse depend upon a key that is kept secret from the public. However, if the line is tapped and the probable values of the transmitted data can be inferred over a sufficient period, the key can be extracted. To prevent this, the key must be changed at frequent intervals.

Encryption has been incorporated into the process monitoring data collection system for the Arroyito heavy-water plant in Argentina. The encryption application is based on a Foxboro supplied EPROM chip with 64K passwords. A similar system could provide satisfactory encryption of process monitoring data in a reprocessing plant.

13.4 DATA ARCHIVING

Process monitoring applications such as those proposed in this report produce on-line indications of safeguards-related events. Messages related to these events are reviewed by on-site inspectors. Process data relating to safeguards analysis should be recorded and available to the inspector for review as part of his analysis. In addition, the data archival system would likely include other data which may be released to the inspector in resolution of safeguards alarm indications triggered as a result of spurious signals characteristic of process data. Transportable storage media should be considered for data archival to facilitate possible transfer of data to the agency for additional analysis.

The data archival system in the IET facility recorded a safeguards data base as a subset of a facility process control data base. These data support the basic safeguards analysis. As a mechanism for resolution of false alarms, the safeguards data base includes pointers into the process control data base. As previously stated, archival data are currently stored on magnetic tape. However, this form of data storage is bulky and cumbersome in a regulatory environment. For this reason, we propose using an optical disk to archive both raw and computed data. One type of optical disk is particularly appropriate for this purpose. It operates like a magnetic disk except that the information is burned into the disk media with a laser beam. Once written, this type of disk cannot be erased, but it can be repeatedly read. Called the WORM (Write Once, Read Many times) disk, current technology allows 14-in.-diam disks to hold 4 GB of computer data. This would replace about 40 reels of magnetic tape, and, as with conventional magnetic disks, the data are located on the disk in a fraction of a second and accessed at high speed (3 MB/s).

14. RESOURCE REQUIREMENTS

The final major element of a processing monitoring system is the identification of the resource requirements associated with implementing the monitoring system. The description of the resource must be expressed in terms of the equipment, manpower, and associated resource requirements. Consideration must also be given to the distribution of the resource requirements among the facility operator, the state system, and the international inspector and support system.

Computer hardware and the data acquisition devices are primary equipment requirements. The necessary equipment has been discussed in Sect. 12 and may be modified for each facility.

The nature of process monitoring safeguards activities requires the use of a broad range of process-control-type instruments. This differs from more conventional safeguards techniques, which have concentrated on a few measurements and which expend considerable effort to refine these measurements to a high degree of accuracy. A firm commitment to computerization of process data acquisition is required for practical implementation of process monitoring. Fortunately, process monitoring can be successful and cost-effective by the use of process grade instruments. When this is done, safeguards personnel must acquire a broad understanding of the capabilities of these instruments and the characteristics of the data.

The greatest effort in implementing process monitoring occurs at the system startup. Here the instrument characteristics must be established, the analysis programs devised, and the process variabilities examined. Such efforts can be carried out by personnel brought in to implement the system. It is important that process monitoring be implemented by a highly qualified group. The implementation of the data acquisition system requires personnel skilled in real-time computer systems. The software development requires detailed knowledge of the plant operations and the ingenuity to develop effective safeguards analysis programs. These personnel must, in addition, have a detailed understanding of the process operations. Process monitoring applications require large amounts of process data and often lengthy and complex analysis routines. Although certain aspects of safeguards software can be transported from other facilities, significant additional effort is required to adapt the software to a specific plant.

Once the system has been put in place, the technical requirements are reduced, and, after specialized training, inspectors can then proceed with more specialized personnel acting as backup. Most anomalies can be resolved in the field by the inspectors. Where adequate archiving of data has been effected, anomalous events can be referred back to the backup personnel. The resolution of alarms by a highly qualified group is essential to attaining credibility for the system.

14.1 RESOURCES AVAILABLE FOR THE IET FACILITY DEMONSTRATIONS

The elements of the IET facility were designed to be prototypical of future reprocessing equipment. The process control and associated computers represent a similar advancement in plant operations that can be used for safeguards concepts. This equipment and the safeguards software have been described earlier. It is admirably suited for demonstrating the role of process monitoring in safeguards.

The safeguards staff is involved entirely in the development of advanced concepts of safeguards using depleted uranium as a surrogate for fissile materials. Members of the staff bring to the task practical experience in fuel reprocessing and safeguards obtained at several U.S. sites, experience in the development of real-time data acquisition tools and in programming for computerized and near-real-time SNM material accounting, and experience in statistical analysis of process data and the statistical methods of material control.

Safeguards demonstrations are planned by the safeguards staff and carried out in conjunction with the IET Operations staff. This brings to the assistance of the safeguards personnel the help of an instruments and controls staff, equipment engineers, and an analytical chemistry staff, each of whom can call upon their divisions for backup support.

15. CONCLUSIONS

The introduction of large-scale reactor fuel reprocessing plants having capabilities in excess of 1,000 Mt of uranium annually, coupled with an increased concern with nuclear material safeguards, has led to a significant effort to develop new methods and applications to improve safeguards. Current international safeguards practices take advantage of the state's nuclear material accounting systems backed up by inspections of each facility for the purpose of collecting independent data to verify the data supplied by the state. With increased throughput, the current systems may not provide the necessary timeliness in the detection of losses. NRTA has used computers to speed the flow of accounting information and increase the frequency of material balance closures. Reprocessing plants now under construction, and certainly those to be built in the future, will use sensors to speed process information to a central computer for use in operating the facility. Interfacing with this wealth of sensor data would provide safeguard specialists with information that would enable close surveillance of the nuclear material.

Progress in the development of process monitoring systems has lagged behind that of NRTA largely because process monitoring requires an interface to extensive process information. Few present-day facilities have the process sensors and the computer information systems to support process monitoring applications. Development projects carried out at INEL, the ICPP, and at the Tokai plant of PNC have been successful in providing encouraging results toward the acquisition and use of process data. ORNL was the major sponsor for the BNFP miniruns in which solution removals in various amounts and at various locations provided an insight into the removal detection sensitivities. Tests at the IET facility at ORNL have produced further data on the sensitivity and false alarms associated with process monitoring.

The IET facility provides a unique test bed for process monitoring. It is a full-scale test plant for field testing of advanced reprocessing plant equipment and design and uses depleted uranium to simulate actual plant conditions. It incorporates a distributed computer-based system for data acquisition and control. Data of interest to safeguards are transmitted to a separate computer for analysis. Because the facility is devoted entirely to development activities, safeguards demonstrations are more easily accomplished than in other facilities that are actually reprocessing fuel on a production schedule and with the constraints imposed by handling fissile material.

Two processing monitoring demonstrations in the IET facility are proposed. The first involves monitoring of the input accountability and feed preparation tankage in an event-logging role. Bypassing input accountancy will be considered as well. The second involves monitoring of process flow measurements. The hardware and software for the data acquisition phase are completed and have been tested. The specific software for the safeguards analysis has been developed and is undergoing testing. Test runs to investigate the sensitivities and vulnerabilities are under way.

These field tests will also provide further information on the degree to which process monitoring can be integrated into the existing international safeguards program. Demonstrations will attempt to show process monitoring as a regulatory tool directed at specific safeguards concerns. Process monitoring applications can detect activities to bypass the accountancy tanks. In this role, it can provide verification (confirmation) of downstream concentrations based on input concentrations in support of NRTA applications. Process monitoring has a role in detecting data tampering when computer systems are applied for regulatory data collection. The necessity for extensive process information means that existing plants must be retrofitted with expensive process sensors and data acquisition systems, while future plants can be expected to incorporate such systems as a natural extension of the technology. Facility operators will be understandably concerned over the possible interference with plant operations and the possible infringement of proprietary information. Implementation of process monitoring for safeguards will require a cooperative effort between the facility operator and the regulatory agency. With this cooperation, process monitoring can complement and enhance other safeguards activities to provide a comprehensive system to meet the goals and challenges of international safeguards in large processing facilities.

ORNL/TM-10458
ISPO-275
Dist. Category UC-86

INTERNAL DISTRIBUTION

1. D. E. Benker
2. J. O. Blomeke
3–5. W. D. Burch
6. J. E. Dunn, Jr.
7–11. M. H. Ehinger
12. R. D. Ehrlich
13. M. J. Feldman
14. R. W. Glass
15. W. S. Groenier
16–18. T. L. Hebble
19. J. R. Hightower
20. R. T. Jubin
21–23. H. T. Kerr
24. R. K. Kibbe
25. L. J. King
26. E. H. Krieg, Jr.
27. S. A. Meacham
28. D. R. Moser
29. F. L. Peishel
30. C. W. Ricker
31. J. H. Shaffer
32–33. R. W. Sharpe
34. B. H. Singletary
35. G. R. Smolen
36. B. B. Spencer
37. J. G. Stradley
38. V. C. A. Vaughen
39–41. J. W. Wachter
42. P. Welesko
43. R. M. Westfall
44. M. E. Whatley
45–46. T. J. Williams
47. R. G. Wymer
48–49. Laboratory Records
50. Laboratory Records, ORNL-RC
51. ORNL Patent Section
52. Nuclear Safety Information Center
53. Central Research Library
54. ORNL–Y-12 Technical Library Document Reference Section

EXTERNAL DISTRIBUTION

55. D. E. Bailey, Director, Division of Fuels and Reprocessing, Office of Facilities, Fuel Cycle, and Test Programs, U.S. Department of Energy, Washington, DC 20545
56. F. P. Baranowski, 1110 Dapple Grey Court, Great Falls, VA 22066
57. C. Eberhard, U.S. Nuclear Regulatory Commission, GPA/IP, MS EWS-418A, Washington, DC, 20555
58. C. W. Emeigh, U.S. Nuclear Regulatory Commission, MS 881-SS, Washington, DC 20555
59. L. Green, International Safeguards Project Office, Brookhaven National Laboratory, Upton, NY 11973
60. M. J. Ohanian, Associate Dean for Research, College of Engineering, 300 Weil Hall, University of Florida, Gainesville, FL 32611
61. C. N. Smith, U.S. Nuclear Regulatory Commission, MS 881-SS, Washington, DC 20555
62–137. A. Waligura, International Safeguards Project Office, Brookhaven National Laboratory, Upton, NY 11973
138. L. W. Wirfs, U.S. Nuclear Regulatory Commission, MS 881-SS, Washington, DC 20555
139. Office of Assistant Manager for Energy Research and Development, DOE-ORO, Oak Ridge, TN 37831
140–235. Given distribution as shown in TIC-4500 under UC-86T, Consolidated Fuel Reprocessing Category