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EVALUATION OF THE IMPACT OF THE MC&A REFORM AMENDMENTS ON A REPROCESSING FACILITY

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ABSTRACT

An assessment was completed on the potential for large reprocessing plants to meet the requirements of the Nuclear Regulatory Commission's proposed Category I Material Control and Accounting (MC&A) Reform Amendment. The requirements on which this assessment was based are given in the working draft revision to the rule dated December 30, 1982. The Barnwell Nuclear Fuel Plant (BNFP) was chosen as a reference design for the assessment, but most considerations would be relevant to any large Purex reprocessing facility. Spent light water reactor (LWR) fuels containing 1% Pu were the presumed feed to the plant; the design feed rate is 5 MTU/d.

The approach taken for the assessment was to characterize the process equipment and the nuclear material distribution throughout the plant, to identify quantities of material that must be removed consistent with loss-detection goals, and to determine if any MC&A techniques could detect the removal. Most of the proposed MC&A techniques had previously been tested, and stated loss-detection capabilities were based on these test results. No attempt was made to construct detailed removal scenarios or integrated MC&A systems throughout the plant.

The assessment addressed three general types of material removals or losses:

1. single space, single time (abrupt),
2. multiple space, single time (abrupt with collaboration), and
3. single space, multiple time (recurring).

With few exceptions, the abrupt loss-detection requirements of the Reform Amendment will be achievable with existing or slightly improved capabilities. Some equipment designs and/or measurement technology improvements will be needed. Recurring loss-detection capabilities will be somewhat poorer than capabilities for abrupt loss detection.

1. EXECUTIVE SUMMARY

This report addresses the question of whether a nuclear fuels reprocessing plant could be designed, constructed, and operated to meet the requirements of the proposed Material Control and Accounting (MC&A) Reform Amendment of the Nuclear Regulatory Commission (NRC). This study uses the Barnwell Nuclear Fuel Plant (BNFP) as a reference design. Consideration is also given to the current design effort at the Oak Ridge National Laboratory (ORNL) for the Breeder Reprocessing Engineering Test (BRET) facility.

The Reform Amendment offers improvements over the current MC&A regulations. Under the current regulations MC&A tests are required on two- to six-month intervals, and test sensitivity requirements are tied to throughput. At issue are the timeliness and sensitivity of the required tests. The Reform Amendment would upgrade the required timeliness of detection of unauthorized removals to correspond to the time period associated with conversion of the particular material to an explosive use. Detection sensitivities would be established based on quantities required for explosive device production rather than plant throughput. Indeed, the Reform Amendment would require detection of losses involving 5 formula kilograms (Fkg) of more sensitive nuclear material (which translates to 2 kg of plutonium), within three working days to seven calendar days of removal depending on the form of the material.

The Reform Amendment allows for a wide range of solutions to the problems of achieving sensitivity and timeliness in a reprocessing plant. The facility can be subdivided into small subunits, each with loss-detection tests and sensitivities to achieve the desired goals. However, the proposed rule also considers tests on a broader scale, requiring tests for simultaneous removals from multiple areas and recurring losses of small quantities over longer time periods.

This report details the facilities and equipment associated with a modern large-scale reprocessing facility using the BNFP as the primary example. It first describes in detail each step of the plant process and characterizes the material being handled. It then details the proposed tests to meet the goal for detection of an abrupt removal of 2 kg of plutonium. "Abrupt" in this sense means removal of the material over a period of <4 h and detection of this removal within the prescribed 3- to 7-d period. It then describes tests proposed to detect abrupt removals of smaller quantities from several test areas that total the goal quantity of 5 Fkg (2 kg of plutonium). These are referred to as multiple-space, single-time removals. The report also discusses tests for recurring losses (removals) of small quantities of material. Here, the rule allows for an as-low-as-reasonably-achievable estimate of loss-detection capabilities, and the report assesses the capabilities.

The major subareas of a reprocessing plant that are of concern are (1) the fuel receiving and storage area, (2) shearing and dissolution, (3) separations plant, and (4) plutonium nitrate storage. The separations area can be further divided into a feed preparation area,

codecontamination and partition area, and plutonium purification. There are other areas that provide ancillary functions, but the above areas contain the majority of material subject to safeguards consideration.

A major concern in the design and application of safeguards tests is the form of the goal material. In fuel receiving and storage areas of a reprocessing plant, the material is handled as fuel assemblies. Safeguards can be accomplished by a simple program of item count and periodic inventory verification.

In the dissolver area, assemblies are sheared into short pieces, and the material is dissolved in nitric acid to provide the feed solutions for the solvent extraction process. The goal quantities involve ~20% of a normal dissolver batch, and the plutonium is in solution at 1 to 3 g/L of plutonium in association with uranium at 200 to 300 g/L and the fission products. Very simple volume monitoring techniques can be applied in the dissolver area to achieve the safeguards goal. Removal of hull pieces and the residual uranium and plutonium (a few grams per batch) is not a credible diversion path. Safeguards throughout these areas does not present a problem.

The separations area includes all levels of concentration and radioactive active contamination. At the input accountability and feed adjustment step, the goal quantity of material is contained in 1000 to 2000 L of solution weighing 1400 to 2800 kg. The material remains in solution with uranium and fission products. At the codecontamination step, fission products are removed, but concentrations of plutonium drop below 1 g/L, and uranium still constitutes about 99% of the heavy metal content.

The partition step of solvent extraction finally separates uranium and plutonium. Depending on the details of the solvent extraction design, plutonium concentrations of 10 to 80 g/L are realized in this area. The quantity of significance to safeguards involves 25 to 100 g/L of solution. However, throughout the codecontamination and partition cycles of a 5 metric tons of uranium (MTU) per day reprocessing plant, the plutonium process flow rate is about 2 kg Pu/h. Removal of the goal quantity in 1 h requires removal of the entire stream for an hour. To achieve the same removal within 4 h requires removal of 25% of the process stream for that time. This flow rate consideration is a major factor in design of safeguards tests.

The plutonium purification portion of solvent extraction removes final traces of contamination. The purified plutonium solutions are finally concentrated to product specifications of >250 g/L. Process solutions range in concentrations from 10 to 80 g/L of plutonium. Thus, the goal quantity of material may be removed from solvent extraction with as little as 8 L of product solution but could also require as much as hundreds of liters of the process solution. This area poses the greatest concern for safeguards tests.

Any modern reprocessing facility will also contain a plutonium nitrate storage area for surge capacity and storage between the separations facility and the plutonium oxide conversion facility. This area will likely consist of manifolded slab tanks and have capacity for several hundred kilograms of plutonium. Solutions will likely contain >250 g/L of plutonium. The goal quantity of material will be contained in less than 8 L of solution. Again, very sensitive safeguards tests are required, but the static nature of storage tanks makes these tests easier to apply than those performed under the dynamic conditions of the plutonium purification area.

The report first details tests to detect the abrupt removal of 5 Fkg of material (2 kg of plutonium). An abrupt removal is considered to be removal of the goal quantity from a single location over a period of <4 h. The tests must detect the removal within three working days for category 1A material, which includes product material, or within seven calendar days for category 1B, which includes most other process solutions.

When design-basis, short-cooled fuel is processed, material throughout the head-end of the facility from the fuel receiving area to the codecontamination cycle qualifies for a total exemption from safeguards requirements of the Reform Amendment based on radiation levels. However, it is conceivable that mostly long-cooled fuel will be processed when a reprocessing plant becomes operational, and the radiation exemption may not be appropriate. For this reason, and since some proposed tests for removals of the more sensitive material involve measurements in the input accountability tanks, tests are developed for material throughout the facility.

Simple piece-count and inventory-verification tests provide near 100% probability of detection for removals of goal quantities in the fuel receiving and storage area. With an inventory of 500 fuel assemblies, verification of the presence of 25 assemblies per day would satisfy safeguards requirements. A combination of mass balances for individual fuel lots around the dissolution area, proposed isotopic correlation techniques, and routine surveillance techniques will provide safeguards sensitivities to removals from the dissolution area of the plant.

To achieve desired sensitivities, the separations facility is subdivided into several control units. The first area includes tankage for input accountability, feed preparation, and solvent extraction feed. Material moves through the area in discrete batches; batch movements are made on the order of once per 8 h. The safeguards tests used in this area monitors static tanks and checks tank-to-tank transfer measurements. The test relies solely on volume measurements. Sensitivities of a few tenths of a percent of tank volume can be achieved for static tank monitoring. This corresponds to a few tens of grams of plutonium. Where transfers are made between static tanks, tank-to-tank transfer monitoring is sensitive to removals of only a few percent. The goal quantity involves removal of 20% of a normal batch. These tests should provide a near 100% probability of detection of the goal quantity removal with a near zero unresolved alarm rate.

The most difficult safeguards challenge for this area involves tank monitoring while a transfer is being made from the feed adjustment tank to the solvent extraction feed tank. The feed tank experiences simultaneous addition and removal of material. A volume monitoring program can be implemented that uses tank volume measurements and feed flow measurements. Based on tests at the BNFP, sensitivities on the order of 300 to 400 L, containing less than a kilogram of plutonium, can be achieved for this transfer. Again, detection of a removal of 5 Fkg (2 kg of plutonium) should be near 100% with a near zero unresolved alarm rate.

Throughout the codecontamination and partition cycles, the solvent extraction process is a continuous operation. In the reference 5 MTU/d reprocessing facility, the plutonium flows are ~2 kg/h. Safeguards tests applied to this area monitor process flows to detect removals. This requires measurement of process stream flow rates and some on-line concentration estimates.

Throughout the codecontamination cycle, uranium and plutonium are mixed, and the total heavy metal mass flows are monitored. Material undergoes transition between aqueous and organic phases. A mass-flow balance is monitored from the solvent extraction aqueous feed to the loaded organic stream that leaves the cycle. Removal of the goal quantity involves removal of 100% of the stream for an hour, or 25% for 4 h. Tests at the BNFP indicate mass-flow balances through this area should be accurate to 15 to 20%.

The partition step selectively strips plutonium back from the organic phase into an aqueous solution. Plutonium must exit the partition step in the aqueous stream or remain with the uranium in the organic phase. An on-line alpha monitor detects any plutonium contained in the uranium stream. Thus a check to ensure that the aqueous stream flow entering the partition cycle matches the flow leaving the cycle ensures plutonium has not been removed. This is accomplished by a simple volume flow balance, and the reference facility can easily be instrumented to make these measurements. Again, the goal quantity represents 100% of stream flow, and BNFP tests suggest accuracies of 15 to 20% can be achieved.

The sensitivities of these tests rely on the capabilities of the various on-line measurements that are available. These are generally process control type measurements. Tests at the BNFP suggest these measurements are typically precisely inaccurate. This means they are subject to sizable systematic errors, or biases. The key to sensitivities of these flow comparison tests is to recognize and remove these systematic effects. The BNFP tests show these effects can be removed, but the methods used make calculation of sensitivities and alarm rates difficult. Furthermore, spurious signals and process noise are likely to contribute more to alarm rates than pure statistical probabilities. Thus the ability to resolve alarms is a major factor in false alarm rates and contributes to the difficulty of calculating sensitivities and false alarm probabilities. This leads to the concept of an unresolved alarm rate rather than the purely statistical derived false alarm rate.

The sensitivities projected for the codecontamination and partition cycle tests as well as other safeguards tests described in this report are based on evaluations done as part of the test program at the BNFP during 1978 through 1983. While these tests used natural uranium solutions, they represent the only available detailed evaluation of installed measurement capabilities in an operating environment and should represent capabilities for an operating plant.

The plutonium purification portion of the plant is the remaining area of solvent extraction that is of concern to safeguards. The material contained in this area is the most attractive for unauthorized removal, and the most difficult to safeguard. The recommended safeguards approach subdivides this area and uses a combination of techniques.

Like the codecontamination and partition cycles, the plutonium purification system process flow is ~2 kg/h of plutonium. Mass-flow comparisons are used for loss detection. Separate mass-flow comparisons are made (1) around the 1BP surge tank, (2) across the 2A column, (3) across the combination of the 2B and 3A columns, and (4) across the 3A column. These mass-flow comparisons were the tests most studied during the BNFP demonstration. They make use of available process control measurements available in the reference facility. During test periods, mass flow balance measurements were routinely made to ± 100 to 200 g/h with a nominal 6 kg/h flowsheet during the tests.

The goal quantity represents 100% of the nominal flow over an hour during normal plant operation. The proposed tests can be sensitive to removal of a few hundred grams per hour. If these tests are made frequently (hourly) and sequences of tests are reviewed periodically (perhaps daily), the tests should be sensitive to detect removals of the goal quantities.

Process equipment for product concentration and measurement is the only area within solvent extraction to pose potential problems in meeting the abrupt removal detection goals of the Reform Amendment. Plutonium is concentrated to >250 g/L, and the goal quantity is contained in less than 8 L. The proposed tests involve material balances using mass-flow measurements as solutions entering the concentrator from the 3B column and batch measurements of product solutions removed from this area. The BNFP tests show sensitivities for this test to be near or slightly >2 kg of plutonium.

The BNFP tests relied only on process control measurements. There is some possibility that accountability level measurements could be available in a timely manner to achieve timeliness of detection. This could significantly improve sensitivity to meet the 2 kg of plutonium detection goal. Likewise, the plutonium concentrator in the BNFP design is a continuous process thermosyphon evaporator, which makes inventory measurements difficult. Batch-type concentrators with the ability to transfer the inventory to measurable locations, or improved inventory modeling of these continuous evaporators also offer hope for improvement.

Safeguards tests for the interim product storage tanks rely on static tank volume monitoring and tank-to-tank transfer monitoring. The interim product storage tanks in the BNFP were carefully studied for measurement sensitivities during tests in 1980 and 1981. Removals of as little as 250 mL were readily detected in static tanks. This corresponds to <100 g of plutonium in product solution concentrations.

The same tests are applied to tanks in the plutonium nitrate storage area. Similar results for static tank monitor tests are achievable. Based on BNFP tests in both the interim product storage and plutonium nitrate storage areas, the probability of detection for the abrupt removal of 2 kg of plutonium is near 100% with a near zero false alarm rate.

For both areas the sensitivity to removals during transfers is somewhat less than for static tanks. Tests at the BNFP have shown that transfer measurement comparisons are sensitive at the level of 1 to 2 L. However, with these comparisons, the variations in piping holdup can play a major role in transfer comparisons. This is particularly true with transfers to the nitrate storage area. Here, long pipe runs and extensive valve manifolds are involved. Holdups of up to 6 L were experienced during tests. Clearly, if material is held in lines, it will eventually reach the destination tanks. However, false alarm rates will clearly depend on the ability to resolve these alarms due to piping effects.

In summary, for abrupt removal detection it can be said that the 2 kg of plutonium detection goal is probably achievable for all areas of the design basis reprocessing plant, with the possible exception of the area around the plutonium product concentrator. The goal is possibly achievable in this area with some refinement of measurement capabilities. Throughout the reprocessing plant the probability of detection for abrupt removal of a goal quantity will likely exceed the 90% level. However, false alarm rates will be very dependent on the ability to resolve alarms due to spurious signals and process noise inherent in

the process control data used for the safeguards tests. The second focus of attention for the Reform Amendment and for this report is detection of an unauthorized abrupt removal of 5 Fkg (2 kg of plutonium) by the simultaneous removal of <5 Fkg from each of several control units within the plant. The concept of administratively controlled areas can be used. This means the plant can be subdivided into groups for unit processes to which access is controlled. To meet the goals of the Reform Amendment where multiple, administratively controlled areas are defined, the areas must be isolated to preclude personnel from having access to multiple areas.

Three areas can be defined for a reprocessing facility. Mechanical processing activities from fuel receipt to shearing and dissolution are included in the first administrative area. Chemical processing activities from receipt of dissolver solutions to the measurement of product solutions are in the second area. The plutonium nitrate storage area is the third area.

These are logical divisions based on the ability to control access. Further operations personnel will likely be licensed by a regulatory agency, similar to reactor operators. Separate licenses will be issued for mechanical process operations and chemical operators. Thus, personnel responsibilities and activities will be isolated to one of the administratively controlled areas, mechanical or chemical.

The plutonium nitrate storage area is considered separate from the rest of the chemical process area. While the same operating personnel will have responsibilities in this area, the area can be isolated by an access control system that limits access to approved personnel at approved times. Transfers of plutonium solutions to this area are limited to about once per week, and a computerized access control system was demonstrated at the BNFP to establish this area as an administratively controlled area.

Tests required to protect the head-end area from the abrupt removal of 5 Fkg (2 kg of plutonium) by a multiple area removal are trivial and indeed may not be required under the 100-rem/h exemption. The plutonium is in combination with uranium and fission products throughout. Removal of material in fuel assemblies or subassemblies requires massive shielded containers and transport vehicles to effect. While there is no direct way to quantify capabilities for security measures and area radiation monitors to detect unauthorized removals, the probability of detection is near 100% with a near-zero probability of false alarms.

Even during shear and dissolution, disruption of dissolver operations to a side pocket and removal of significant material in hulls or by another route are not credible scenarios. Since the chemical operators control dissolution and the head-end operators are responsible to charge and discharge dissolvers, a diversion would require a cooperative effort. The goal quantity of 5 Fkg (2 kg of plutonium) is roughly 10% of a nominal dissolver batch in a 5 MTU/d reprocessing facility. This quantity would be associated with 170 kg of uranium. The hull pieces for this amount of fuel would occupy better than 25 ft^3 and have the high inherent radiation levels that preclude easy transport. Area radiation monitors and routine security measures are sufficient, taking these considerations into account.

Combined removals of less than goal quantities from these areas would be equally detectable. The tests involved are the simple piece-count and item-identification methods and practical application of routine security and health and safety monitoring programs.

The multiple-space, single-time tests recommended involve timely material balance tests across conventional material balance boundaries in addition to the individual abrupt removal tests already discussed. The concept of near-real-time accounting has been developing over several years. It involves a computer-based program to maintain the current book inventory that should be in the control area based only on input and output transfers. It is a nontrivial matter to maintain records and update book inventories as transfers (and adjustments to previous transfers) are made. However, the real challenge to the near-real-time accounting application is to measure the in-process inventory for comparison to the book inventory to generate the inventory difference (ID) statistic for safeguards evaluation.

The in-process inventory measurement has been the subject of investigations under the TASTEX program as a cooperative effort between the United States, Japan, and International Atomic Energy Authority (IAEA). This study focused on the Tokai plant, a 200 MTU/year facility in Japan. Throughput and IAEA inspection constraints led to an effort to provide inventories on a weekly basis and to time the inventories to correspond to favorable process conditions.

In tests at BNFP, the focus was to make the inventory measurements on an hourly basis. The inventory-taking process was automatic and completely transparent to operations, requiring no special operating conditions. Tests involved the use of natural uranium. There may be some questions about extrapolating results obtained in the BNFP tests to an operating facility with uranium and plutonium. However, careful attention was paid to use methods and procedures applicable to routine plant operations.

During 1978 and 1979, BNFP tests involved full operations of the entire separations process. In periods of steady-state operation, inventory measurement capabilities of 2 to 3% of the nominal inventory of 12 MTU were demonstrated. Tests during 1980 and 1981 concentrated on activities in the plutonium purification section of the plant only. These tests showed inventory measurement capabilities in the range 3 to 4% of the nominal inventory in the plutonium cycles. The inventory measurement capability for both series of tests suggest an inventory measurement of uncertainty of 4% may be achievable. With a nominal inventory of about 100 kg of plutonium for the operating plant, this translates to an uncertainty of ~4 kg of plutonium.

It is proposed to perform material balance tests at frequencies approaching hourly for an operating large-scale facility. The material balance involves input, output, and inventory measurements. During a 24-h period, three input batches, a product batch and perhaps one to two waste batches will be measured. Thus, with 24 material balances during the day, a maximum of six will involve input/output transfers.

For a balance with no transfers, where two inventory measurements are made, each with an uncertainty of ± 4 kg of plutonium, the material balance sensitivity is ± 5 to 6 kg of plutonium. If timely measurements for input or product are assumed to be available with an uncertainty of ± 1 %, a balance period including one of these transfers will have an uncertainty of ± 5.8 kg of plutonium. Thus detection sensitivities with these tests should also be 5 to 6 kg of plutonium.

There are many considerations that complicate calculation of actual sensitivity to multiple-space, single-time removals. The same considerations apply involving volumes of

solution and radioactivity of various solution throughout the process. There is literally no access to process solutions within the cells. Process lines that penetrate cell walls offer the only access. Can, or will, removals from several points spread throughout the facility be made, undetected by routine surveillance or area radiation monitors? Can this be factored into estimates of detection sensitivities? These are questions to be addressed. However, with projected measurement sensitivities alone, it appears that a detection sensitivity of 5 to 6 kg of plutonium may be achievable for the multiple-space, single-time removal, and this does not meet the goals of the Reform Amendment.

The final consideration involves recurring small losses over time. The proposed rule requires periodic review of data from control units and administratively controlled areas at specific frequencies. It leaves the goal quantity for detection to be established as low as reasonably achievable but with a 90% power of detection.

For the design-basis, large-scale reprocessing facility, the best prospect for recurring loss detection is to submit the frequent, near-real-time material balance closures to the sequential balance tests that are available. These tests range from cumulative effects tests like CUSUM to the recursive predictive techniques like kalman filtering.

Tests at the BNFP have focused attention on the nature and characteristics of the various systematic errors that affect material balance data. Often, these systematic effects manifest themselves as recurring losses. Thus, the problem of detection of recurring losses within sequential material balance data becomes one of interpreting and understanding systematic effect and changes in systematic effects as differentiated from actual losses.

There is a small base of work on which to make judgments concerning recurring loss-detection capabilities. Based on the limited test experience at the BNFP, this sensitivity should be in the range 5 to 10 kg of plutonium. Again, this is dependent on development of methods to isolate losses in the presence of systematic effects and spurious signals inherent to these data.

In summary, it can be said the detection of abrupt removals of 5 Fkg (2 kg of plutonium) from single process units in a modern reprocessing facility should be detectable. The only questionable area is around the plutonium product concentrator, but this should also be achievable. The sensitivity for detection of the multiple-space, single-time removal of the goal quantity probably cannot meet the goals of the Reform Amendment. Sensitivities are likely to be in the 5- to 6-kg range. Recurring loss test sensitivities depend on understanding and developing techniques for handling systematic effects. Projections on sensitivities for these tests are in the 5- to 10-kg range.

2. APPLICATION OF THE REFORM AMENDMENT REQUIREMENTS TO REPROCESSING PLANTS

In order to eliminate a number of concerns regarding existing MC&A systems, the NRC initiated a rulemaking effort to improve its MC&A regulations. The September 10, 1981, version of the proposed Category I MC&A Reform Amendment that appeared in Vol. 46, No. 175 of the *Federal Register* was written primarily with the NRC's existing licensees in mind. These existing licensees did not include a nuclear fuel reprocessing plant and, in fact, fuel reprocessing plants were specifically exempted from the requirements of this version of the Reform Amendment. However, the Advanced Notice of Proposed Rulemaking (ANPRM) solicited public comment on the possible extension of the rulemaking effort to reprocessing. After reviewing public comment from the ANPRM, a decision was made by the NRC staff to extend the application of the Reform Amendment to include reprocessing plants.

The fundamental issue to be resolved by this project is whether or not a large reprocessing plant could be designed and constructed to meet the requirements of the proposed Category I MC&A Reform Amendment. The requirements on which this assessment were based are given in the working draft revision to the rule dated December 30, 1982. This working draft contains much of the substance of options 3 and 4 of the ANPRM but has been totally rewritten to remove unnecessarily prescriptive requirements, to reduce the number of plans and programs required, and to improve clarity.

Although a specific reference design for a reprocessing facility has been chosen, the assessments in this report are intended to be relevant to any large Purex reprocessing design for light water reactor (LWR) fuels. The reference reprocessing facility for the purposes of this study is the BNFP located at Barnwell, South Carolina, which was designed to reprocess 1500 metric tons of heavy metal (MTHM) per year. The BNFP design was chosen for two reasons. First, it is the only large LWR fuel reprocessing facility in this country likely to operate in the next 10 years. Second, significant safeguards information has been gathered from operation of the plant with natural uranium. The BNFP, built in the 1970s by Allied-General Nuclear Services, was designed to recover 15 metric tons of plutonium per year from LWR fuels.

The other reprocessing facility with potential within the foreseeable future is the BRET facility currently under design to be included in the Fuel Material Engineering Facility (FMEF) located on the Hanford reservation at Richland, Washington. This facility is being designed to process fuel from the Fast Flux Test Facility (FFTF) and potentially from future breeder reactors. If this facility is completed, it will likely include

demonstrations of national and international safeguards techniques. The design basis of this facility is 100 kg of heavy metal (20 kg of plutonium) per day. The BRET process equipment and quantities of plutonium processed are considerably smaller than in the BNFP, so the safeguards techniques developed and demonstrated for the BNFP are sufficient to provide safeguards capabilities for the BRET facility if it comes to production. This report will concentrate on the BNFP design.

The BNFP would contain substantial quantities of special nuclear material in the form of uranium- and plutonium-nitrate solutions. However, greater safeguards significance is attributed to the plutonium because (1) less plutonium is required to manufacture an explosive device, and (2) substantial effort is required to separate the fissile ^{235}U from the more abundant ^{238}U. In the BNFP the uranium product will be a nitrate solution containing 350 g/L of uranium, of which <1% would be ^{235}U. Assuming the enrichment capacity were available, it would take over 1400 L of uranium product to accumulate 5 Fkg. This represents 20 to 25% of a normal product batch. Volumetric losses of this size over a 3- to 4-h period are readily detected using simple tank-monitoring techniques. On the other hand, only 8 L of plutonium product is required to accumulate 5 Fkg (2 kg of plutonium). Consequently, this safeguards assessment must concentrate on those portions of the BNFP that will routinely contain plutonium.

The BNFP design throughput is 5 MTU/d with a design-basis plutonium content of 1%. This translates to 50 kg of plutonium per day or approximately 2 kg/h. Thus, plutonium process streams are generally ~2 kg/h. When safeguards tests are applied hourly, or even on a 4-h basis, a 5-Fkg (2 kg of plutonium) removal requires diversion of 100% of a process stream (or 25% on the 4-h basis). Very simple techniques of monitoring mass flows and balances through the purification systems would be sensitive to these quantities.

More safeguards attention is directed towards the various surge vessels where sizable quantities of plutonium can accumulate. These surge vessels are usually designed to handle 8- to 16-h intercycle capacity and usually contain 16 to 32 kg of plutonium. More sensitive techniques are required in these areas to maximize diversion detection capabilities. This report will deal with techniques to monitor the process streams and methods to detect removals from these surge points.

Some informal guidelines have been established to focus the scope of the project on specific aspects of reprocessing plant safeguards. The project was primarily designed to address the performance of MC&A techniques. Physical security protection against external adversaries will not be directly considered in this project. However, where physical security-related techniques, such as access control and penetration monitoring, are proposed, the goal of these techniques will be clearly identified, and the applicable tamper-indicating features will be described.

Assumptions about the potential diverters will be avoided. To the extent possible, the applicability of candidate safeguards techniques will be evaluated, and their performance quantified without making any assumptions.

Quantification of safeguards system performance will be based on normal operating conditions. The performance of the various techniques during process upsets is extremely difficult to determine because of the lack of operating data. This is not to say that safeguards techniques are ineffective during process upsets, startups, or shutdowns. Indeed, the

goal is to be able to track material during these periods. Much effort has been devoted to this task during test runs at the BNFP. The susceptibility of the various techniques to degradation from normal process variation will be addressed.

Safeguards systems are designed in part to minimize the probability and consequences of acts of sabotage. Although sabotage is an important and sensitive issue, it is usually addressed as part of the physical security program. It is not considered germane in assessments of material control and accounting capabilities. It will not be addressed as part of this project.

For the purposes of this report, material that has been codecontaminated will be considered to be inherently more attractive than spent fuel or dissolver solution because the highly radioactive fission products have been removed. These solutions no longer qualify for the >100 rem/h exemption. Plutonium that has completed the partitioning cycle will be considered more attractive than material that has only been decontaminated because the plutonium has been separated from the uranium. Likewise, concentrated product solutions are more attractive than dilute process solutions. The more attractive material forms receive higher levels of protection with a graded safeguards system. The concept of graded safeguards has received wide acceptance by the safeguards community, and this report supports the use of systems based on this concept.

One final generic comment is in order. Reprocessing is a dynamic chemical process. Many of the techniques proposed by the report require the use of data from routine off-the-shelf process control instruments. While these instruments are understood and accepted in the process control application, their use in detailed safeguards analyses is a broad, new approach. It requires a new understanding of instrument outputs.

Performance of these instruments for safeguards applications is best described as "precisely inaccurate." This implies that in a given application, the instrument may exhibit a large bias (systematic error), which is relatively constant over time, with an output signal that is relatively precise around the apparent bias. The process control application considers the "accuracy" of the instrument to be a combination of the precision of the output as well as the possible wide range of potential biases. Thus, where a manufacturer states performance of an instrument at 5 to 10%*, in reality, the precision of the instrument is probably 0.5 to 1.0% in any given application, and the bias may range from 5 to 10%. For the safeguards application, the performance capabilities are 0.5 to 1.0% if the potential of the biases (systematic errors) are accepted and statistical techniques are responsive to the precision within the potential noise of the biases (systematic errors). This report will also attempt to elaborate on this concept and propose the techniques to be used and/or developed.

*Meaning ±5 to 10% at the 95% confidence level on the linear instrument output from 0% to 100%.

3. INTRODUCTION

A structured approach has been identified to resolve the fundamental issues of this project. It is generally accepted (indeed, it is the reason for the Reform Amendment) that conventional material balance with shutdowns and flushout physical inventories cannot meet desired sensitivity goals and timely detection of loss or unauthorized removal of materials from modern reprocessing facilities. Also, where losses have been indicated, there has historically been significant difficulty in resolving the indicated problems. Thus, the Reform Amendment allows for more timely and sensitive safeguards techniques such as near-real-time accounting and process monitoring to achieve the goals. The report addresses the following questions:

1. Unit Process Loss-Detection Capability—Can the plant be subdivided into control units such that a single unauthorized removal of 5 Fkg from any single unit would be detected? What loss-detection techniques should be applied to these units?
2. Administratively Controlled Area Loss-Detection Capability—Can administrative or physical controls be applied to groups of units such that simultaneous small removals from multiple units totaling 5 Fkg would be detected?

   The previous losses are defined as abrupt removals of significant quantities over a relatively short period of time. There is also a question concerning recurring losses.
3. Recurring Loss-Detection Capability—Can control units be established and techniques applied to detect unauthorized repeated removals of small quantities over longer periods of time?
4. Application of the Reform Amendment to a Reprocessing Plant—Are there requirements in the Reform Amendment that cannot be achieved in a reprocessing plant under any practical circumstance, and are those requirements essential for an effective safeguards system?

The report deals with each of these questions in order. Each area of the plant is identified and discussed. Only those areas where problems in conformance to the Reform Amendment are identified are given further discussion. Areas where detection sensitivities can be met or the Reform Amendment is not applicable are identified and dropped from additional discussion.

3.1 UNIT PROCESS LOSS-DETECTION CAPABILITY

The unit process loss detection requirements of the Reform Amendment were put in place to ensure that a loss of material exceeding 5 Fkg (2 kg of plutonium) would be

detected with a high degree of confidence. The amendment specifies that a facility safeguards system must be designed to detect 99% of all losses exceeding 5 Fkg from individual unit processes within 3 d for category 1A material or 7 d for other material. While unit processes may possibly be defined so that loss detection goals can be achieved, this requirement will very likely result in a large number of alarm indications due to normal statistical variation and anomalies that are inevitable in measured parameters. Hence, alarm resolution will play an important role in the loss detection program and will also be included in the discussion.

This section first discusses each proposed unit process and characterizes materials and flows. It identifies techniques to be applied to each area and attempts to quantify sensitivity capabilities.

3.2 PLUTONIUM-BEARING PLANT AREAS

The plutonium-bearing portions of the BNFP can be subdivided as follows:

1. pool storage;
2. shearing and dissolution;
3. accountability, feed preparation, codecontamination, and partitioning;
4. plutonium purification; and
5. long-term product storage.

Each of these subdivisions will be discussed in detail in the following sections. Proposed methods for loss detection will be presented for each subdivision. Several areas present minimal difficulty in meeting the Reform Amendment, and methods are briefly discussed. Those areas that present somewhat greater difficulty are discussed, and safeguards concepts to achieve compliance with the Reform Amendment are identified. These concepts are presented in detail in later sections.

3.2.1 Pool Storage

The spent-fuel pool at the BNFP was designed to accommodate 360 MTU of fuel; 75% of that capacity will be pressurized water reactor (PWR) assemblies and the remaining 25% boiling water reactor (BWR) assemblies. Assuming the pool is maintained at ~75% of its capacity, ~800 assemblies would be stored in the pool. Assuming normal operation of 5 MTU/d, ~11 PWR assemblies or 27 BWR assemblies could be expected to be removed from the pool per day.

Approximately 1% of the heavy metal content of LWR fuel assemblies reprocessed at the BNFP would be plutonium. A PWR assembly would contain ~4.5 kg of plutonium and a BWR assembly would contain ~2 kg of plutonium. A single 5 Fkg (2 kg of plutonium) of interest in regard to the Reform Amendment is available in either type of fuel assembly.

Fuel assemblies recently removed from the reactor would emit radiations >100 rem/h and thereby would qualify for the self-protecting exemption under the Reform Amendment. However, there is an increasing inventory of low-burnup and/or long-cooled spent fuel for which radiation levels may become lower than 100 rem/h at 3 ft. These cooled-fuel assemblies may not qualify for an exemption, and some safeguards provisions may be necessary.

Diversion of a significant quantity of material can conceivably be accomplished by either disassembly and removal of individual pins or by diversion of an entire assembly.

Removal of pins (individual rods) from a commercial fuel assembly is not considered a credible diversion scenario from a domestic safeguards perspective. First, dose rates from a spent assembly are normally sufficient to necessitate remote handling. The radiological protection consideration and the remote handling and disassembly equipment that would be needed are not routinely available in the pool area, and getting them into this area would substantially complicate this type diversion. While such equipment has been designed and demonstrated at the BNFP, introduction and use of this equipment is not routine since mechanical activity involving disassembly of a fuel assembly is not a routine activity. The operations and equipment involved in such a diversion scenario would be readily observed by even modest scrutiny in a pool area. This area could easily be monitored by closed-circuit television, if desired. The time necessary to complete such a diversion compared to the time necessary to remove a complete assembly would be significantly longer. These considerations eliminate disassembly as a diversion consideration.

In order to satisfy the Reform Amendment for long-cooled fuel, the safeguards system must be able to detect the loss of one complete fuel assembly, the only credible removal scenario. The spent-fuel pool area in a reprocessing plant will be a controlled-access area isolated from other material access areas. According to requirements of the Reform Amendment, the safeguards system must detect the loss of a fuel assembly within two months after the loss. If the operator would verify the presence of 25 different assemblies per day from the 800 assemblies in the pool inventory, the safeguards system should be able to detect the loss of an assembly in two months.

An Item Control and Accounting System (ICAS) partially developed at the BNFP, patterned after control programs developed at other facilities such as Hanford Engineering Development Laboratory (HEDL), Los Alamos National Laboratory (LANL), and ORNL would increase the effectiveness of the safeguards applied to the head-end. This system would maintain a computer data base of the assemblies entering, leaving, and stored in the pool. The data base used in the ICAS would greatly facilitate the verification procedure described above.

This system alone should be capable of satisfying the requirements of the Reform Amendment. It can be concluded that the fuel storage area does not present a safeguards problem in the context of the amendment. This area will not be considered further in this report.

3.2.2 Shearing and Dissolution

Fuel shearing and dissolution are performed in the remote process cell of the BNFP. All operations and maintenance activities within this cell are designed to be performed

remotely. The fuel-transfer conveyor transports the fuel assembly from the fuel transfer pool (adjacent to the fuel storage pool) to the remote process cell. The conveyor cart that holds the fuel assembly is pulled up a guide track into a horizontal unloading position. After the cart cover is raised, the fuel assembly is pushed from the cart onto a fuel transfer table and into the shear feed magazine. Both the end fittings and the sheared rods fall by gravity through the diverter, which channels the sheared pieces into the dissolver basket. Approximately 3.5 h of shearing are required to load a dissolver basket containing ~1.7 MTU of fuel (17 kg of plutonium).

The feed mechanism of the shear will not operate unless a control-room signal indicates downstream conditions are suitable for shearing. This control-room indicator ensures that the dissolver cycle status is correct for receiving chopped fuel. The 4-h dissolver cycle includes a dissolution step, leach step, and rinse step (shear and dissolution combined represent an 8-h cycle). When dissolution is complete, a crane is used to remove the dissolver basket containing the hulls from the dissolver and transfers it to the hull monitor. This monitor analyzes the activity of the hulls to determine if they contain undissolved special nuclear material (SNM). These monitors are expected to achieve an accuracy of ±100% on the material contained. This material should be <0.1% of the total uranium or plutonium in the dissolver batch, which means that losses much smaller than 2 kg could be readily detected.

The changing of both the physical and chemical form of the SNM in the remote process cell makes it difficult to safeguard this portion of the plant using dynamic material accounting techniques. Item accounting techniques could be used up to the point where the assembly enters the shear. Once the assembly is sheared, item accounting techniques are no longer useful. At this point additional safeguards techniques must be applied.

The maximum plutonium concentration of solutions in the remote process cell will be 2 to 3 g/L. Plutonium remains mixed with low-enriched/depleted uranium and the high-activity fission products. Diversion of 5 Fkg (2 kg of plutonium) will require accumulation of 700 to 1000 L (i.e., four to five 55-gal drums, each with radiation levels of hundreds of rems per hour.

Alternatively, considering the hull pieces, the nominal residual uranium is assumed to be 0.1% as a generally accepted criteria and is based on limited experience at the BNFP during processing of LWR fuel. The 5-Fkg (2 kg of plutonium) detection goal represents the total residual of more than 100 dissolver batches of hull pieces, all exhibiting the characteristically high radiation levels of fuel pieces. Even considering the possibility of incomplete dissolution, removal of hulls does not represent a credible diversion path.

Although material in this area is usually exempt from the power-of-detection requirements identified in 70.83(b) and (c) of the Reform Amendment, some applicable safeguards functions will be described. In the BNFP design, solutions from the dissolvers are accumulated in the feed surge tank and batchwise transferred to the input accountability tank for measurement as the primary plant input. A control area is established from the shear input to the accountability tank. Area mass balances will be constructed using reactor data for input measurements for the fuel assemblies, input accountability tank measurement as the output for the area, with hull piece SNM residual measurements also considered. The basic goal is to establish S-R differences for site SNM receipt documentation and potential adjustments to reactor burnup codes.

In the safeguards consideration, tank transfer monitoring should be capable of the 5-Fkg loss detection. The abrupt removal of solution containing 2 kg of plutonium represents the loss of 10 to 20% of a dissolution batch. This is readily detected by monitoring transfers between and volumes within the dissolver feed surge tank and the input accountability tank.

Actual material balance calculations will be less sensitive to abrupt losses from this area than tank monitoring. Dissolver operations and the use of the feed surge tank result in blending of solutions from various dissolver batches. Tracking the dissolution of individual assemblies to the input tank for individual assembly measurement comparison is not possible under normal operations. Normal activity for the BNFP design is to flush this head-end area after each customer fuel lot (~1 to 2 weeks). At this time, the balance will be closed, and comparisons of measured quantities to reactor-calculated quantities (shipper's values) will be made.

Considering the typical fuel-lot time of a week, throughput will be 350 kg of plutonium measured in ~20 batches. Assuming an accuracy of ±0.5% (relative uncertainty on total measured plutonium at the 95% confidence level) can be achieved, the limits of error as defined in the regulations are <0.5 kg for the cumulative total measured through the accountability tank. This is the output measurement for the area. However, the input measurement is from reactor calculations. The history of LWR processing at the BNFP suggests that these data are subject to systematic error of several percent (up to 5% relative error on the calculated plutonium content). Thus, balance capabilities are dominated by the accuracy of the predictor codes. As the computational tools are improved, capabilities to achieve the detection goals by mass balance method in the time frame established in the regulations for these highly radioactive solutions could be achieved.

The techniques of routine monitoring and potential for material balance analysis indicate that the requirements of the Reform Amendment most likely can be met in the shear and dissolution area of the reprocessing plant. This area will not be considered further in the analyses of this report.

3.2.3 Accountability, Feed Preparation, Codecontamination, and Partitioning

This area encompasses equipment from the input accountability tank to the point at which the plutonium and uranium streams enter the final purification cycles. At the front end of the BNFP design, after input accountability measurements are made, solutions are transferred batchwise to one of two feed adjustment tanks. Transfers are by steam jet at a frequency of about once every 8 h. In the feed adjustment tank, the acid concentration of the feed material is adjusted to ~2.5 *M*. After adjustment, these batches are transferred to the HA feed tank through a feed clarification centrifuge. This steam jet transfer takes ~4 h to complete. During this time, material is continually added to the HA feed tank while the tank feeds the codecontamination equipment. This dynamic situation makes accurate measurements of both the feed adjustment tank and the feed tank contents more difficult.

Two other process tanks play a role in this area in the BNFP design. A dissolver flush accumulator tank is used to receive dilute flush batches. These batches come through

the accountability tank after head-end turnaround following each change in customer fuel or type. These batches occur every one to two weeks and are gradually blended with feed, whether as adjustments to normal batches or blends in the HA feed tank. A sump collection tank is also provided. While the name implies sump material recycle, it actually serves as a general recycle tank for process solutions and is not expected to routinely contain significant quantities of material.

Fuel solutions bearing uranium, plutonium, and fission products enter the codecontamination cycle. A simplified equipment diagram is provided in Fig. 3.1. A multistage centrifugal contactor is used to achieve initial separation of the uranium and plutonium from the fission products. The organic phase extracts the uranium and plutonium, leaving 95 to 98% of the fission products in the aqueous raffinate. At this point in the process, the dose rate of the organic stream bearing the uranium and plutonium product drops below the 100 rem/h Reform Amendment action limit.

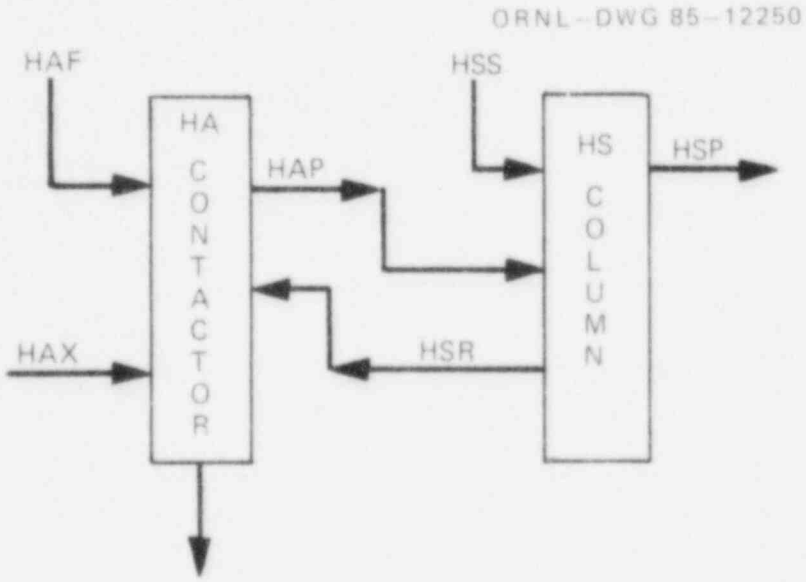

Fig. 3.1. Codecontamination cycle.

Trace quantities of plutonium remain with the aqueous waste stream (HAW). High activity of the associated fission products, with the very low concentrations of plutonium make this waste stream of reduced concern to safeguards. This waste stream undergoes concentration prior to accountability measurement and disposal.

In the BNFP design, the organic product stream from the centrifugal contactor passes through a pulsed scrub column (HS) where a low-acid scrub stream removes most of the residual fission products. The design permits use of this column for decontamination in the event of failures in the centrifugal contactor.

Through this point, while radiation levels fall off, plutonium concentrations are typically 1 g/L or less in the process streams. Removal of 5-Fkg (2 kg of plutonium) quantities requires unauthorized transfers of thousands of liters of solution and diversion of large fractions of process flows over several hours (i.e., 25% over 4 h).

Organic solutions from the HS column (the HSP) are combined with the organic waste streams recycled from the plutonium purification cycle at this point. The recycle stream is typically far less than gram-per-liter concentrations of plutonium and typically less than grams per hour in plutonium mass flow. The combined organic streams pass into the partition cycle in which the plutonium is separated from the uranium. A simplified process diagram is shown in Fig. 3.2. The first step is the 1B electro-pulse column. Although specific details of this column design are proprietary, its operation involves the reduction of the tetravalent plutonium to the trivalent state by electrochemically generated uranium (IV). The electro-pulse column operates in conjunction with a more conventional pulsed scrub column (1BX). The bulk of the plutonium is reduced and stripped to the aqueous phase of the electro-pulse column. The organic stream carries uranium and traces of plutonium to the 1BX scrub column.

Organic uranium product from the 1BX column goes to the 1C column for stripping and on to final purification. The aqueous stream from the 1BX column, after picking up the residual plutonium, recycles back to the electro-pulse column to provide the aqueous phase to strip the plutonium. It passes through the 1BX column and on to the 1BP tank and plutonium purification.

From the electro-pulse column on to plutonium purification, plutonium flows remain at ~2 kg/h while concentrations are now 10 to 20 g/L. Concern about safeguards begins to increase since total volume to remove the relevant quantity of concern is 100 to 200 L

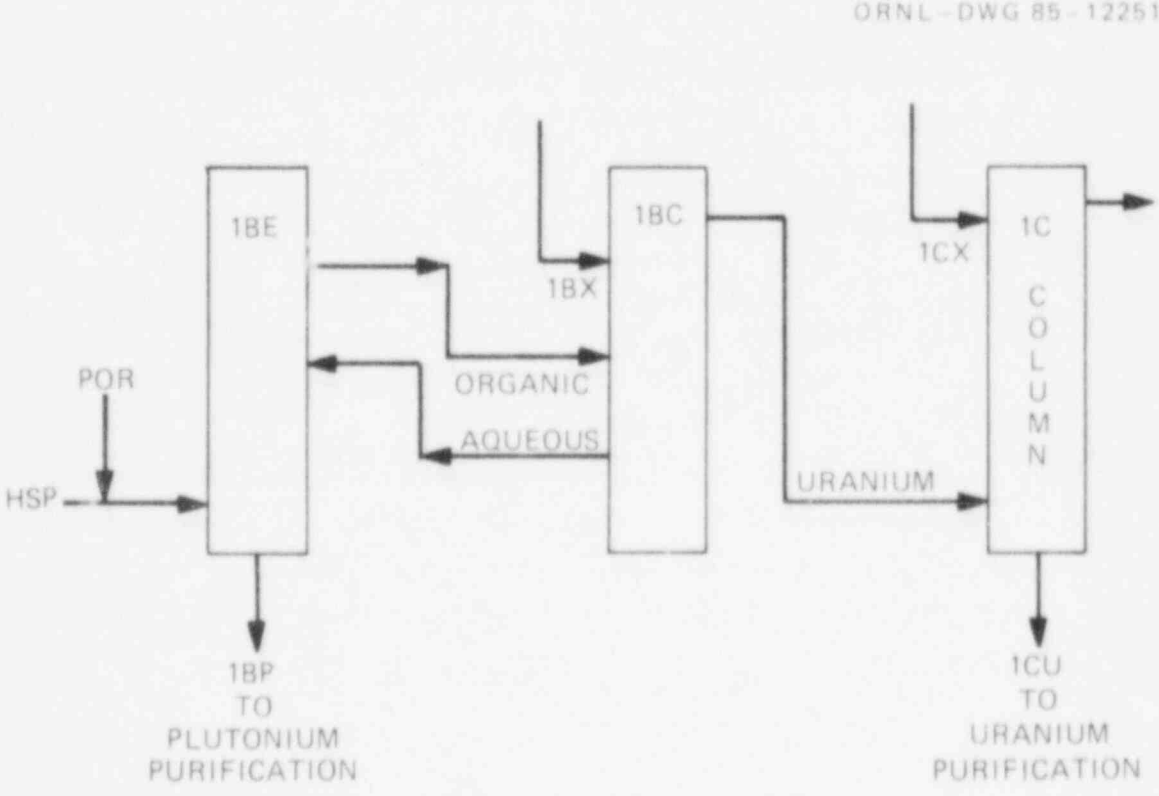

Fig. 3.2. Partition cycle.

(or a single 55-gal drum). Radiation levels are no longer prohibitive. This area of the plant presents a challenge in meeting the objectives of the Reform Amendment.

While the specifics of recommended techniques will be discussed in later chapters, it is proposed to subdivide this area and use a combination of mass/material balance analysis and comparative monitoring of several flow measurements. While the material in this area is still rather unattractive for diversion potential, the material loses its exemption based on radiation levels and must be considered in the safeguards design. The provisions of the Reform Amendment can be met with little additional expense to the operator. It requires safeguards tests that are consistent with modern approaches to process monitoring. Achieving the desired sensitivity requires a thorough understanding of measurements and measurement errors as well as statistical techniques that are sensitive under specific, inherent measurement conditions. The specifics will be discussed in later chapters.

3.2.4 Plutonium Purification

The plutonium purification portion of the BNFP design includes equipment and activities from the 1BP tank, which receives the separated plutonium stream from the partition cycle, to the plutonium product tanks. Plutonium-bearing solutions enter the area at 10 to 20 g/L concentrations with residual traces of fission product activity. They leave as the highly purified product solutions at 250 g/L or more. These solutions, particularly those beyond the product concentrator, are highly sensitive in terms of diversion potential. The dynamic nature of process operations and the sensitive material contained make this area of primary concern for safeguards design.

Physically, the entire plutonium purification cycle, with the exception of the 1BP tank, is contained within the heavily shielded plutonium purification cell (PPC). The 1BP tank is in the adjacent process cell, but interconnecting piping does not penetrate personnel access areas. The PPC is sealed with a massive concrete plug at the top and a shielding door at the lowest operating level. A pump niche is provided just inside the shielding door with access to the actual cell through an airlock door from the pump niche. This design allows access to the product transfer pumps without access to the process cell. However, pump access still requires opening the shielding door, which is not routine.

The plutonium purification process is shown in Fig. 3.3. The description of the process starts with the 1BP tank. It is a 1700-L, Raschig-ring–filled vessel designed to provide surge capacity between the partition cycle and plutonium purification. The vessel will routinely contain ~50% of capacity, which represents a routine inventory of 8 to 16 kg of plutonium.

As noted above, plutonium process rates are ~2 kg/h, and removal of quantities of concern require diversion of most of a flowing process stream. Surge points, on the other hand, usually contain large inventories. In the case of the 1BP, a 5-Fkg removal in the abrupt sense involves from 12 to 25% of the tank volume. The 1BP tank also has a cold chemical add-line to allow continuous acid adjustment prior to feed to the purification cycles. This complicates safeguards tests and must also be considered.

The front end of the purification cycle also includes the plutonium rework tank. This also is a 1700-L, Raschig-ring–filled tank. It provides a catchall for most plutonium purification equipment. Most equipment overflows to this vessel, and it provides capacity

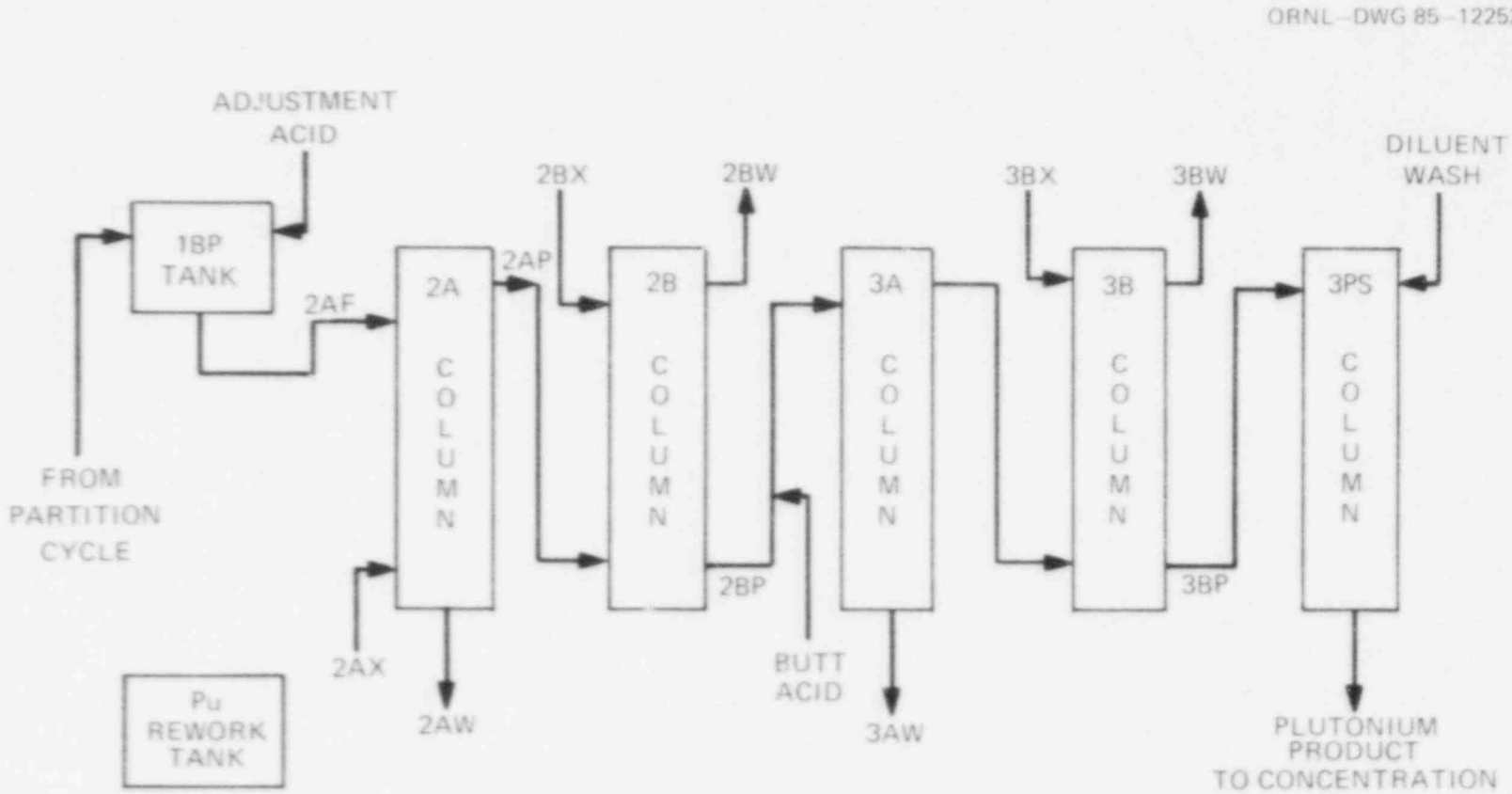

Fig. 3.3. Plutonium purification cycles.

and capabilities for recycle of off-specification plutonium product solution. While this tank is not routinely expected to contain material, solutions collected will normally be blended with solutions from the 1BP tank.

The 1BP tank feeds the plutonium purification cycles. As noted above, feed concentrations are 10 to 20 g/L of plutonium. Two cycles of solvent extraction provide the final purification steps. Throughout these cycles product streams range from 40 to 80 g/L. Column waste streams are generally expected to be considerably lower than gram-per-liter quantities.

The 2A column is a multistage pulse column that is operated with a bottom interface (organic continuous). It is equipped with liquid-level, density, and interface control instrumentation and is vented to the plutonium off-gas (POG) system. Aqueous feed containing the plutonium enters the center portion of the column from the 1BP tank. Two aqueous scrub streams (2AS and 2AIS) formed by in-line blending of recovered acid and recycle water enter the upper portion of the column. The column receives organic extractant (2AX) from the no. 1 solvent system. The column is pulsed through the extractant inlet line. A sample from the aqueous waste stream (2AW) flows through a continuous monitor that may be analyzed for plutonium content. The organic product stream (2AP) flows to the 2B column.

The 2B column completes the first cycle of purification. It is a multistage pulse column that is operated with a top interface (aqueous continuous). It is equipped with liquid-level, density, and interface control instrumentation and is vented to the POG system. The column receives organic feed solution from the 2A column (2AP) and is pulsed through the 2AP inlet line. It receives aqueous stripping solution (2BX) formed by in-line blending of recovered acid and recycled water. The organic waste stream (2BW) is continuously sampled. This sample stream is passed through a monitor that can provide continuous analysis of plutonium content. The aqueous product stream (2BP) is transferred to the 3A column via the 2BP heat exchanger. The 2BP stream can also be sampled.

The 3A column starts the second cycle. It is a multistage pulse column that is operated with a bottom interface (organic continuous). It is equipped with liquid-level, density, temperature, and interface control instrumentation and is vented to the POG system. The aqueous feed stream (3AF) enters the center of the column. The 3AF stream is made up of the 2BP stream and a nitric acid butt stream mixed in-line. Two aqueous scrub streams (3AS and 3AIS) enter the upper portion of the column. The 3AS stream comes from the 3-*M* cold-acid system, and the 3AIS stream is formed by in-line blending of recovered acid and recycled water. The column receives organic extractant (3AX) from the no. 1 solvent system and is pulsed through the extractant inlet line. The aqueous waste stream (3AW) is transferred to the 1SF tank. A sample from the 3AW stream is continuously passed through a monitor that can analyze plutonium content of the stream. The organic product stream (3AP) is transferred to the 3B column.

The 3B column is a multistage pulse column that is operated with a top interface (aqueous continuous). It is also equipped with liquid-level, density, and interface control instrumentation and is vented to the POG system. The organic feed stream from the 3A column enters at the center of the column. The aqueous extractant stream (3BX) enters at the top of the column. The 3BX is made up of 3-*M* cold acid and hydroxylamine nitrate

blended in-line. Samples of the organic waste stream (3BW) streams pass through monitors that can continuously analyze for plutonium content. The aqueous product stream (3BP) may be sampled and is continuously monitored for fission product activity. Normal flow is to the 3PS diluent wash column. If activity levels are high, the stream may be rerouted back to the 1BP tank for recycle or to the plutonium rework tank.

The 3PS diluent scrub column is a packed column filled with stainless steel Pall rings and run with a bottom interface (organic continuous). It is equipped with liquid-level, density, and interface control instrumentation and is vented to the POG system. It receives aqueous feed solution (3BP) from the 3B column. The organic stream is a diluent-only scrub supplied by the diluent feed system. The 3SW organic waste stream, which is essentially pure diluent, flows to the 3SW head pot where it is combined with the 3AP stream. The aqueous product is transferred to the 3P concentrator.

The organic waste streams (2BW and 3BW) are combined and recycled back to the electro-pulse column. Flow should be 200 to 300 L/h with concentrations considerably below gram-per-liter levels. Aqueous waste streams (2AW and 3AW) are combined with the plutonium concentrator overheads, (discussed later in this section) cycled to the 1S waste recovery system. Combined flow of this 1SF stream should be 500 to 600 L/h with plutonium concentrations well below gram-per-liter levels.

To reemphasize a point, mass flows throughout this purification process, are ~2 kg of plutonium per hour. Removal of 5 Fkg (2 kg of plutonium) requires removal of 100% of the stream for an hour (25% for 4 h). While this presents a challenge for safeguards, several monitoring techniques that will be described below are available and can be applied with minimum impact on the plant operator. To this point the only exception is the area around the 1BP tank. This presents somewhat of a larger problem because of the larger inventory and dynamic nature.

The question of pulse-column, in-process inventories should also be addressed at this point. Pulse-column, in-process inventories are dynamic and difficult to measure. The ability to measure these holdups has an influence on the overall sensitivity of safeguards tests. The dynamics of pulse-column operation and characterization of concentration profiles that dictate inventories have been the goals of extensive R&D activities. Beyerlin (Clemson), Burkhart (Iowa State University), Cermak (BNFP), and others, particularly at BNFP, have thoroughly investigated the theoretical models. The BNFP test runs during 1980 and 1981 included several tests to verify inventory predictions. Although these tests were performed at flowsheets of 6 kg of heavy metal per hour, the results demonstrate "ballpark" estimates for inventory in the BNFP plutonium purification columns. The results as reported in BNFP internal correspondence were

2A column: ~20 kg	3A column: ~12 kg
2B column: ~5 kg	3B column: ~5 kg

Again these are tests under operating conditions somewhat different than in normal flowsheets but show general magnitudes for expected inventory.

The 3P concentrator is a thermosyphon concentrator consisting of a simple vertical cylinder, 7 in. diam and 10-ft 10-in. high, and is constructed of titanium. It is equipped

with liquid-level, density, temperature, and pressure instrumentation. A tantalum mist eliminator pad is located in the vapor outlet line. A cold-chemical flush line is provided for the mist eliminator pad. The concentrator receives the aqueous stream from the 3PS column (3PSP). The vapor flows to the 3P condenser. The bottoms solution recirculates through the reboiler to the concentrator. A continuous bottoms stream flows to the plutonium product catch tank. The product line is vented to the POG system above the concentrator liquid level.

The plutonium catch tank is a vertical slab, 3 ft 6 in. long by 5 ft 10 in. high by 2.25 in. wide, with a capacity of 26 gal. The tank has a sloped bottom for drainage and a 20-mil-thick cadmium sheet on the cell side face for neutron isolation. The tank is equipped with liquid-level, density, and temperature measurement instrumentation. An air sparger is provided, and the tank is vented to the POG system. It overflows to the plutonium rework tank. No sampler is installed. The tank receives the concentrated aqueous plutonium product solution (3PCP) from the 3P concentrator. Solution in the tank is transferred batchwise via the plutonium catch tank pump to the plutonium product sample tank. The plutonium catch tank has a 5-gpm centrifugal pump located in the pump niche within the PPC.

The plutonium product sample tank is a vertical slab, 7 ft 6 in. high by 6 ft long by 2.25 in. wide, with a capacity of 56 gal. The tank has a sloped bottom for drainage and a 20-mil cadmium sheet on the cell side for neutron isolation. The tank is equipped with density, liquid-level, and temperature instrumentation. It has an air sparger, is vented to the POG system, and overflows to the plutonium product catch tank. It is equipped with a sampler. Normally, a single batch of product solution consists of two batches from the catch tank. Solutions from this tank may be transferred to the plutonium rework tank or on to the interim plutonium product storage tanks.

The three interim plutonium product storage tanks are vertical slabs, 11 ft 4 in. long by 7 ft 6 in. high by 2.125 in. wide, with a capacity of 110 gal each. Each tank has a sloped bottom for drainage and a 20-mil cadmium sheet on the cell side for neutron isolation. Each tank is equipped with liquid-level, density, and temperature instruments, and has an air sparger and a sampler. One tank overflows to another; that tank overflows to the third; and the third overflows to the plutonium rework tank. The tanks receive solution from the plutonium sample tank. Solution in the tanks may be transferred to the plutonium rework tank, to either of the other two tanks, or to the plutonium product 100-L measuring tank via the plutonium product pumps. The plutonium product pumps are 5-gpm centrifugal pumps, one associated with each storage tank, located in the PPC pump niche.

The plutonium product 100-L measuring tank is a vertical slab, 4 ft 9 in. long by 5 ft high by 2.25 in. wide, with a capacity of 28 gal. It has a sloped bottom for drainage and a 20-mil cadmium sheet on the cell side for neutron isolation. It is equipped with liquid-level and density instrumentation, a sampler, and is vented to the POG system; it has an addition line from the no. 2 multipurpose cold-chemical system. The tank receives solution from the plutonium product storage tanks. Solution in the tank free drains to the plutonium nitrate storage system.

Plutonium purification equipment from the concentrator through the interim storage tanks contains the most sensitive materials. Product solutions are concentrated and highly

purified. Throughout this area, the 5-Fkg (2 kg of plutonium) quantity of concern requires only 8 L of solution (slightly over 2 gal). Static monitoring of process tanks has been demonstrated to be sensitive to this level of removal during tests at the BNFP. Indeed, removals of a few hundred milliliters have been detected during these tests on the sensitive product storage tanks. However, the tanks are not always static. The catch tank continually receives solutions from the concentrator. Batchwise transfer to the product tank is expected approximately every 8 h and will take ~0.4 h per transfer. Thus, on a 16-h basis, transfers are expected from the product tank to the interim storage tanks. The interim storage tanks will be transferred to the long-term storage tank on a weekly basis. During these transfers, intense safeguards activities will be required to monitor tank-to-tank transfers.

The entire plutonium purification area represents the largest challenge for the safeguards design to meet the requirements of the Reform Amendment. While it presents the biggest challenge, it is the most studied and well understood area of reprocessing operations as a result of the minirun demonstrations at the BNFP during 1980–81. A number of safeguards techniques were proposed and tested during those runs that simulated plutonium processing by substituting natural uranium during operation of the plutonium purification system. These test runs were limited in number and duration but provided valuable information on instrument performance and potential safeguards detection capabilities.

These test runs indicate that detection goals of the Reform Amendment can be approached by subdividing the area into several subunits. Mass balance monitoring routines for comparison of related process parameters and monitoring of static tanks are some of the advanced techniques that can be combined to approach the detection goals. The specifics of these techniques and their applications will be discussed in a later chapter.

3.2.5 Long-Term Product Storage (Pu Nitrate Storage Area)

The plutonium nitrate storage area contains vessels and piping required for extended storage of nitrate product. The area consists of 48 geometrically favorable slab tanks contained in two shielded cells. Nonprocess penetrations into the vessels, such as pneumatic instrument probes and dilution air supply, enter at the top of the cells from an occupied area. Process piping penetrations, such as tank inlet and outlet lines and associated valving, are contained in shielded glove boxes.

Each cell is divided into four modules containing six tanks each. Moderator slabs are installed between tanks. The six tanks in each module are interconnected with a manifold to a common pump and manifolded add lines. Each tank is equipped with level, density, and temperature measurement instruments. Air sparge lines are not provided, and mixing is performed by recirculation through the manifolds and common pump.

Each tank has an internal volume of ~800 L. The working volume is reduced to ~670 L to provide a 14-in. air space above the liquid to allow for an air sweep to remove hydrogen generated from radiolysis. The nominal plutonium product concentration is 250 g/L, making the nominal storage capacity for each tank close to 170 kg.

Routine operating procedures have not been demonstrated for the BNFP design. However, it is anticipated that the contents from all three nitrate interim storage tanks will be

transferred to the storage area at one time. Thus, material additions to the nitrate storage area will occur approximately once per week and will require ~8 h for sampling measurements and transfers for each addition.

This area also presents a significant challenge to the safeguards design to meet the Reform Amendment. The material contained is highly attractive from a diversion standpoint with concentrations of 250 g/L or more. The storage tanks are accurately calibrated. Evaluation of calibration data and measurement capabilities show volume measurements can be made to ±0.2 L.* However, representative sampling can only be accomplished after mixing the entire module to homogeneity. Thus, a single sample (or replicates) will be representative of the entire module. At best the analytical methods may achieve ±0.5%* for concentration (relative accuracy on 250-g/L plutonium content). The entire module may contain up to 1000 kg of plutonium.

While extremely accurate volume measurements can be made, the overall uncertainty of a single inventory measurement for a module will far exceed the detection goals of the Reform Amendment. Replicate samples and redundant measurements can improve performance; however, they are costly, result in relatively large quantities of material being removed to the laboratory, are not responsive to detection times of a few hours, and are still not likely to meet the detection goals.

This entire problem is complicated further by physical changes of the solutions from radiolysis and evaporation. Tests at the BNFP have shown that clean-acid solutions in these tanks undergo measurable evaporation over periods of several days.

However, this latter characteristic presents the possible solution to the safeguards problem. Accurate volumetric monitoring coupled to tank transfer monitoring during additions can be very sensitive to removals. The goals of the Reform Amendment may be achievable using these methods. The details for these proposed methods will be discussed below.

3.2.6 Additional Plant Areas

The previous sections have described the BNFP systems that contain significant quantities of plutonium. Obviously, there are other areas of the plant that will have some traces of plutonium, but concentrations will be very low. These are not of much concern to the safeguards design to meet provisions of the proposed rule but are mentioned for completeness.

The 1S system is included in the BNFP design to maximize the recovery of plutonium. This system receives the aqueous waste streams from the plutonium purification system (2AW, 3AW) in combination with the plutonium product concentrator overheads (3PD) and the aqueous waste stream from the uranium purification cycle (2EW). These streams pass though a decanter to remove any carryover organic. The aqueous stream enters the 1SF feed tank, which continuously feeds the 1S pulse column. The feed stream

*Except where noted, through the remainder of this report, uncertainties expressed in absolute or percent units or in percent of measured value (relative errors) are estimates of the 95% confidence limits.

will normally carry a few grams per liter concentration of uranium with very low concentrations of plutonium. Contents of the aqueous feed stream are extracted to the organic and recycled back to the electro-pulse column. The safeguards significance of this system is its potential contribution to the material balance calculations around the partition cycle. Quantities are not expected to be significant with plutonium mass-flow rates of a few grams per hour.

The HAW system provides concentration of aqueous wastes from the codecontamination cycle. The HAW stream, potentially combined with bottoms from other waste concentrations, is continually fed to the HAW concentrator. Bottoms from this concentration are continually drawn off to a catch tank with batchwise transfers to the HAW sample tank for final accountability measurements prior to disposal. The significance of this area is in the potential plutonium content from the HAW stream. This is normally expected to contain a few tenths of one percent of the feed quantities of the codecontamination cycle. Again, this has a small effect on material balance considerations around the decontamination cycle.

There are two solvent cleanup systems in the BNFP design. The no. 1 solvent system receives the organic waste stream from the 1C column. Recovered organic from this system satisfies the needs of the HA contactor, 1S column, 2A column, and 3A column as well as several other small organic streams. The no. 2 solvent system is dedicated to the uranium purification cycle, receiving the waste stream from the 2E column and delivering the extractant stream to the 2D column. Neither system should receive anything above trace quantities of plutonium.

The LAW-acid recovery system receives overheads from the HAW, aqueous waste from the 1S system, overheads from the intercycle and uranium product concentrators, and several other condensate sources. The general-purpose concentrator system receives general-process liquids and waste streams from solvent cleanup. The LAW concentrator bottoms transfer to the HAW system while the general-purpose concentrator bottoms are generally measured for accountability and transferred to disposal. Both of these systems contain only trace quantities of plutonium. With the exception of accountability measurements of general purpose concentrator bottoms for "conventional accounting" considerations, these systems pose no concern under the Reform Amendment.

A service concentrator system handles building drain water, with the bottoms transferred to the general-purpose system. The dissolver off-gas system includes NO_2 absorption and iodine scrub. Vessel off-gas undergoes iodine scrub. Aqueous discharges from the off-gas systems will not include measurable plutonium.

The above systems are not given further consideration in this report. They are presented for completeness of the discussion of the BNFP design and are not a factor of concern for meeting the objectives of the Reform Amendment. For the most part, significant quantities of safeguard-sensitive material cannot reach these systems, and periodic (8 h) samples should detect any upset conditions.

4. GENERAL DISCUSSION OF TECHNIQUES

There continues to be disagreement about the definitions of the various techniques (accountability and process control) that use plant measurement data to make safeguards assessments. While this is not an attempt to standardize the definitions, the following discussions are meant to provide an understanding of how the terms are used in the context of this report for a reprocessing plant.

4.1 NEAR-REAL-TIME ACCOUNTING

Material balance accounting is a traditional safeguards and nuclear material control technique. Very simply, (1) an inventory period is defined, (2) beginning inventory is measured, (3) all measured inputs are added, (4) all measured removals are subtracted, (5) a book inventory is maintained, (6) an ending inventory (physical inventory) is measured, and (7) the material balance closure is made resulting in the calculations of an inventory difference (ID), which is subsequently evaluated as the ID for safeguards considerations.

More appropriately material balance accounting is calculation of the book inventory (beginning inventory plus inputs minus outputs) and measurement of the physical inventory (ending inventory in the traditional definition). Thus, all material balance accounting may be more simply defined as comparison of book inventory to physical inventory, and ID may be defined as the difference between the two.

The term "near-real-time accounting" has been applied to a broad range of activities throughout the industry. For the most part, it has referred to attempts to maintain a near-real-time book inventory and make this book inventory available on demand for reconciliation to some physical verification. For most facilities, this involves reconciliation of item locations and identifications. A reprocessing facility is very different.

Maintenance of the near-real-time book inventory can be achieved with near-real-time accounting techniques for the separations portion of a reprocessing plant. This is a non-trivial problem of maintaining accounts for input and output transfers. However, the large dynamic inventory of the operating facility makes measurement and reconciliation of physical inventory to the book very difficult. The different methods of reconciliation give rise to different subsets of the near-real-time accounting technique. For purposes of this report, three techniques will be considered and terminology developed to distinguish these techniques.

4.1.1 Conventional Accounting

"Conventional accounting" is the term used to describe the method of material balance closure using shutdown and flushout physical inventory. This method requires the shutdown of operations activities, flushout of process equipment, and the accumulation of residual materials in static measurable locations. Obviously, the flushout activity is time consuming and costly, usually requiring two weeks in a plant like the BNFP. Current regulations require this activity on a six-month basis. However, six-month closures are not timely relative to the detection goals of the proposed regulations. The high-throughput quantities during a six-month period also limit the sensitivity of the closure to detect loss or unauthorized removal. This technique does minimize the effects of uncertainties in measurement of plant holdup and provides a baseline to begin the more timely and sensitive safeguards monitoring techniques. While its usefulness in terms of the Reform Amendment is limited, these flushout inventories will still be necessary, perhaps on an annual basis to reset the more timely detection techniques.

4.1.2 Near-Real-Time Accounting

There continues to be considerable discussion throughout the industry of the definition of near-real-time accounting. In many applications, the definition is limited to the activities associated with maintenance of the book inventory, which is then available in near real time for a physical reconciliation to current inventory, usually containers. For the reprocessing plant application, maintenance of this near-real-time book inventory is only part of the near-real-time accounting. The large dynamic inventory within the operating plant requires development of an on-line inventory measurement technique for physical reconciliation to the near-real-time book. Some attention has been focused on providing these in-process inventories at frequencies of a week or a few days (notably during the TASTEX experiments at the Tokai Facility). Tests at the BNFP during 1978–1982 were aimed at hourly inventories with the additional constraint of having no prerequisites involving specific operating conditions. The goal has been to make the inventories frequent and totally transparent to operations.

This near-real-time accounting approach may be applied to the entire facility, thus taking advantage of the accurate accountability level input and output measurements. While this approach has the advantage of accurate throughput measurements, the uncertainties in measurement of the large dynamic inventory is the limiting factor for sensitivity. Thus, the overall facility can be subdivided into smaller units (control units, unit processes, etc.) with near-real-time accounting applied across these smaller units. In this application, the absolute magnitude of the measured inventory, and consequently the absolute uncertainty of the measurement, is reduced. However, there is a trade-off in the ability to make accurate throughput (i.e., input/output) measurements for these smaller units.

While there is little difference in actual technique for the reprocessing plant application, near-real-time material balance accounting can be considered as those accounting activities using the traditional input and output batch measurements. Likewise, near-real-time control unit accounting can be considered as those accounting activities across plant

subunits using available process control measurements (usually dynamic flow and concentration measurements integrated over time) as the input and output measurements. Both near-real-time strategies (i.e., material balances and control unit) require dynamic measurement of the in-process inventory.

4.2 MASS-FLOW COMPARISONS

In many areas of a plant like the BNFP, removal of 5 Fkg of material over a period of 1 to 4 h requires diverting at least 25%/h of the process stream over the 4 h or 100% over an hour. The simple technique of comparison of heavy metal mass flows into and out of an area can be sensitive to these removals. While similar to unit process accounting this technique does not address inventories, and no inventory measurements are needed. While it can be argued that this technique is unit process accounting or near-real-time accounting with an assumed constant inventory for the closure, the terminology of mass-flow comparisons is used to describe this technique for this report.

This technique requires on-line measurement of concentration and measurement of flow. The tests performed at the BNFP have usually involved integration of these measurements on a 15-min basis. Most of this work was done during the 1980–81 miniruns and centered on the plutonium purification cycle. During these tests mass-flow balances around the various columns were made to within ~100 to 200 g/h during operations under a 5- to 6-kg/h flowsheet. Some limited test runs during 1982 indicate similar relative precisions can be obtained around the codecontamination and partition cycles.

4.3 STATIC TANK MONITORING

In the confusing safeguards terminology, the technique of static tank monitoring has been considered a process monitoring technique by some. Others insist it is simply unit-process accounting around a single tank with the assumption of no change in inventory. However the technique is classed, it provides a very sensitive tool for detection of loss or unauthorized removal from static storage tanks.

The technique uses process control instrumentation for level and density measurement. This information is sufficient to calculate tank volumes. The sensitivity of the technique is specific to each tank and dependent on the observed process noise. During tests at the BNFP, routine noise in the interim plutonium product storage tanks was at the level of ±100 mL. Actual removals of as little as 250 mL were routinely detected under tests performed at the BNFP during the miniruns of 1980–81.

4.4 TANK-TO-TANK TRANSFER MONITORING

While tank monitoring is sensitive to removals during static conditions, it cannot detect problems during additions or removals from tanks. This requires a program of tank-to-tank transfer monitoring. Again, this can be considered process monitoring or unit process accounting. However, for this report it is considered separately as one of the necessary safeguards techniques.

Several approaches to this concept have been tried. A simple volume balance after the transfer is complete is probably the most timely. Where transfers are made on a batchwise basis with samples and analytical results for concentration, a mass balance can be calculated.

A third approach is to measure and calculate the rate of tank depletion for comparison to the corresponding tank rate of increase.

All of these variations of tank-to-tank transfer monitoring have applications in the various parts of the BNFP design. The specifics of each application will be discussed in following sections.

4.5 COMPARATIVE PARAMETER MONITORING

There are locations in the BNFP design where a particular parameter is remeasured at a separate location. Comparison of these measurements can be sensitive to removals. For instance, there are several measurements of the organic flow throughout the codecontamination cycles. These measurements should compare. Since removal of 5 Fkg of material requires removal of a high percentage of process flows, this comparison should be sensitive.

Again, in the confusion of safeguards terminology, it can be argued that this is a variation of unit process accounting, or it is simply process monitoring. For this report, comparative parameter monitoring refers to the technique of direct comparison of measured parameters.

4.6 COMPUTERIZED AUTOMATIC TRANSMITTER CALIBRATION (AUTO-CAL)

Computerized automatic transmitter calibration, or "Auto-Cal" as it has become known, is a technique applied at the BNFP to significantly improve the accuracy of inexpensive process control, differential pressure transmitters. These devices provide the majority of measurement data from the reprocessing separations facility. While Auto-Cal is not specifically a safeguards technique, it is necessary to provide safeguards quality data from process control instruments and will be discussed here.

As part of the BNFP test program over the years, a number of commercially available differential pressure measurement devices were tested and used under operating conditions. These ranged from expensive, highly accurate devices like electromanometers to the off-the-shelf process control devices. While accuracies of the expensive devices were on the order of 0.1%, the latter devices were found to exhibit accuracies of ± 5 to 10% (absolute uncertainty of the linear output). More detailed investigations revealed this poor accuracy was due to two major characteristics of these instruments.

The first problem was in the assumptions concerning transmitter output. They are usually analog output devices driving a dc current loop from 4 to 20 mA corresponding to 0% of output to 100% of output. The assumption is that the 0 to 100% output signal, 4 to 20 mA output, is linear over the range and proportional to a linear input signal. In reality, the output is not linear. Over a given linear input signal, the output signal (expressed as percent of scale) may be biased low by 3% at the upper range and high by 5% at the lower range as an example.

The second problem affecting transmitter performance is field calibration. Installed, the lower limit of the output scale (0% or 4 mA) is set to correspond to a lower limit differential pressure (such as 5 in. of water). The upper limit (100% or 20 mA) is set to an upper limit (such as 20 in. of water). The ability of the technician to set these end points exactly is referred to as calibration uncertainty and also limits the accuracy of the transmitter output. Random noise associated with instrument electronics and variations within the pneumatic system itself are also included.

Testing at the BNFP showed the nonlinearity of the transmitters is specific to individual instruments. Rather than assuming linearity, the actual output polynominal curve can be described after some laboratory testing. This characteristic nonlinear output persists although the end points (calibration set points) change due to recalibration, drift, or sudden shifts. However, tests showed the end points stay relatively constant over periods of time (on the order of weeks) with significant shifts (several percent) from changes in instrument-environment temperature (tens of degrees).

It was observed that over periods of weeks, when set point and nonlinear effects were removed (systematic effects corrected), the remaining random error was on the order of 0.5 to 1.0% (absolute error in linear, 0 to 100% output). Thus, these process control devices should be capable of 0.5 to 1.0% performance.

At the BNFP, a computerized calibration check system was installed. Each process instrument was interfaced to the computer system. A high-accuracy, differential-pressure gauge was also interfaced as the standard. Two sets of computer-controlled solenoids were installed with each process measurement instrument. The first set allowed isolation of the instrument from the process measurement lines. Lines to the second set of valves connected to a manifold on the high-accuracy standard device. Activation of these valves placed the standard in parallel to the process device.

The calibration of each device was checked on regular frequencies (usually 4 to 6 h). This was accomplished in one of two ways. Either the high-accuracy devices read the actual process signal in parallel to the process device, or both instruments were isolated from the process signal and a known or standard pressure introduced and read by both instruments. In either case, differences were calculated and used to locate the actual current calibration of the instrument.

The computer contained the actual nonlinear transmitter output relationship (as opposed to the assumed linear output). It also had information about the current calibration and setpoints from the calibration checks. Together these data were used to correct the on-line readings from the process devices. This system of calibration checks and computed output signals improves the performance of routine process control instruments by a factor of ten.

Implementation of such a system is important to the safeguards program. This report deals throughout with extraction of safeguards information from process control information. In most cases, this improved accuracy is necessary to meet the safeguards objectives. The alternatives are to install expensive instruments in parallel to existing instruments to provide the accuracies necessary. The Auto-Cal program is a cost effective way to achieve nearly the same results.

5. SINGLE-SPACE, SINGLE-TIME, ABRUPT-LOSS DETECTION

The fuel storage pool area and the shearing and dissolution area both contain significant quantities of plutonium during routine operation but do not require further discussion for reasons described in the previous section. This section will discuss safeguards techniques that are suggested for each of the other areas to meet the goals of the Reform Amendment.

The first part of this chapter will be devoted to a general discussion of demonstrated capabilities for the safeguards techniques that have been tried by various groups at the BNFP. Then specific recommendations of techniques most appropriate for each control area will be made.

Those control areas described in Sect. 3 of this report as presenting challenges to the safeguards design will be discussed in great detail. While recommended techniques may involve division of these areas into subareas, those original control area designations will be maintained. This chapter will focus on techniques to detect abrupt removals of 5 Fkg. The assumption is made that the removal occurs over a period of <4 h. Tests must respond to these losses within 3 d for Class 1A material. These are the so-called single-space, single-time removals. Later chapters deal with detection capabilities for multiple-space, single-time loss and the protracted (trickle) loss

5.1 ACCOUNTABILITY, FEED PREPARATION, CODECONTAMINATION, AND PARTITIONING

This section deals with the specific tests to be applied for detection of abrupt removals from the front end of the separations process.

This area of the reprocessing plant covers activities and equipment from the input accountability tank to the point where the separated uranium and plutonium streams enter their respective purification cycles. Details of process equipment and stream compositions are presented in Sect. 3.2.

The recommended safeguards program for this area begins with a breakdown of the area into two basic subareas. The first includes surge tankage from the input accountability tank to the HA feed tank. The second covers the codecontamination and partition cycle equipment.

5.1.1 Accountability and Feed Preparation Area Tests

Safeguards to detect the abrupt removal of 5 Fkg (2 kg of plutonium) from the first area can be easily achieved with application of static tank monitoring and tank-to-tank

transfer monitoring techniques. The most difficult applications for the area are detection of removals from the HA feed tank and from the feed adjustment tank during transfers through the feed clarifier to the HA feed tank.

Maximum concentrations of plutonium throughout this first area are 1 to 3 g/L. All transfers are batchwise by steam jet. The nominal batch size is 6000 to 7000 L. Thus, abrupt removal of 2 kg of plutonium requires removal of >10 to 20% of a nominal batch of feed solution. Likewise, since the plutonium cannot be selectively diverted, safeguarding of the uranium or total heavy metal content accomplishes plutonium safeguards. This is an important point since heavy metal content can be accurately predicted ±1% for concentrations >100 g/L from acid and density measurements. This was demonstrated during experimental work at the BNFP using natural uranium. Plutonium and fission product content during actual operations should not seriously degrade this capability.

Solutions are accurately measured in the input accountability tank. Volume measurements can be made to 0.1 to 0.2% relative uncertainty. Accountability quality concentration analyses are likely to be on the order of 0.5%. Thus individual batch measurement accuracies will be 0.5 to 0.6% (relative uncertainty as the 95% confidence level on total-batch plutonium content).

It should be noted that the accountability quality concentration analyses may not be available from analytical laboratories for hours or days after batch measurements and transfers. Thus for abrupt removals, safeguards evaluations that are based on material content should use process control measurements of heavy metal content. The accuracy of a batch measurement of total heavy metal content using process control measurements is not likely to be better than ±1.1%. Plutonium content can be based on Pu:U ratio measurements. Capabilities of these measurements have not been demonstrated under actual operating conditions, assuming ±5% combined accuracy is achievable for the Pu:U ratio, similar to reactor predictions. This capability will depend on development of on-line nondestructive assay (NDA) techniques for these measurements.

Tank instrumentation includes pneumatic dip-tube measurement systems for level and density measurement with differential pressure readout by process control and accountability instrumentation. Volume measurements are accurate to ±0.1% under the best controlled measurement conditions. Degradation of this capability will result from process noise such as air sparging. It is likely that safeguards judgments will have to be made with a random noise of ±0.5% (relative uncertainty of total volume).

It is likely that a future reprocessing plant will be equipped with computer-based measurement and analysis capabilities with interface to process measurement devices. The tank monitoring concept will use this measurement and analysis system to enable data evaluations on a frequent basis, perhaps every 15 min to 1 h. The abrupt removal detection goal involves ~20% of the tank volume. With measurement sensitivities at <1% an unauthorized removal would have a near-100% probability of detection and near-zero false-alarm probability.

The question of alarm resolution must be addressed. The monitoring program must operate continuously in an automatic mode within the computer system, and removal detection is based on detecting abrupt level changes. This monitor application is complicated by the fact that abrupt level changes can be indicated as a result of initiating a routine transfer or as a result of spurious signals from recording devices. These spurious

signals may be electronic in origin or may be the result of process activities such as pressure spikes introduced to clear plugged instrument lines. Restrictions or plugs of these probes occur occasionally because of crystallization of heavy metal solutions at the probe tips due to the dry-purge air bubbles. Clearly, the monitor program must be "smart" to recognize these routine transfers and spurious signals and not interpret them as alarms.

Static tank monitoring is very sensitive to unauthorized removals. From a safeguards standpoint, solutions in the head-end are more vulnerable during transfers between tanks. The accountability tank is routinely (once per 8 h) transferred to one of the two feed adjustment tanks in the BNFP design. Once every week or two, during a head-end turnaround, a batch of dilute flush solution will be transferred to the dissolver flush accumulator. These are steam jet transfers, and volumetric increases of 3 to 7% will be realized during the transfer operation. The transfer operation itself takes 30 to 40 min.

To achieve the goals of the Reform Amendment for abrupt removals, tank-to-tank transfer comparisons of volume will be required. Potential removals of 20% of the tank volumes must be recognized within the "noise" of steam jet dilutions and measurement uncertainties.

In the BNFP design, the feed adjustment tanks are considered backup accountability tanks. Each transfer from the accountability tank is measured and sampled. Comparisons of volumes and quantities received are routinely made to cross-check accountability input measurements. The routine volume measurement instruments, while not capable of accuracies at the level of the accountability tank, are capable of $\pm 0.5\%$ (relative volume).

Transfers from the input accountability tank to the feed adjustment tank are by steam jet. Condensate from the jet adds 3 to 7% to the volume delivered during this transfer. Thus, when a 6000-L batch is transferred, the delivered volume will be between 6180 and 6420 L.

Methods are being investigated to recognize removal of 1200 L (20%) of the tank contents to achieve the 5-Fkg removal. Clearly, this magnitude of removal is detectable within the variations associated with the measurements and transfer process. Probability of detection is nearly 100%. Alarm indications may occur, but actual mass balances based upon remeasurement and sample results in the feed adjustment tank will quickly resolve these alarms. There should be a near-zero unresolved alarm rate.

The next step in a plant using the Purex process is adjustment of feed solution acid content to solvent extraction flowsheet requirements, usually $\sim$2 to 3 M, accomplished in the feed adjustment tank by addition of recovered acid.

During test runs at the BNFP, a computer-based blend program was used to calculate acid addition requirements. The program was interactive with plant measurements and analytical laboratory results to accumulate the data needed for the calculation. It returned exact solution quantities required for the adjustment including final chart readings in units to allow operations personnel to make the precise adjustments based on available process control instruments. During BNFP miniruns, operations personnel consistently prepared feed solutions to $\pm 5\%$. Prior to implementation of the computer-based program feed preparation was usually $\pm 20\%$ of the desired final concentration.

While the blend program is primarily a process control tool, there is a significant safeguards importance as well. A case can be made for the possibility of a diversion of

material during the feed adjustment step with acid substitution to mask the removal. Densities of feed solutions are usually on the order of 1.4 mg/mL. Concentrated nitric acid can approach this density. A volumetric substitution for 20% of the tank contents (5 Fkg) can conceivably be made during the acid addition process and not be apparent on a pure volume monitor program. However, the blend program accurately predicts final acid density and concentration parameters. Each adjusted feed batch is sampled for final acid concentration as a verification. This usually takes <30 min after the acid addition. It is apparent that substitution of 20% of the tank contents with 14 to 16 *M* nitric acid would drive the batch-acid concentration far beyond the desired flowsheet concentration and readily trigger an alarm based on the final sample results. Thus the blend program with final verification is sufficient to detect diversion by substitution at near-100% probability of detection with near-zero unresolved alarm rate.

As noted above, once every one to two weeks, a batch of head-end flush material is received through the accountability tank to the dissolver flush accumulator. This material is likely to be of high-acid concentration and low SNM content. It will likely be blended with the feed solutions, probably in this acid adjustment step. The computer-based program will also use this information in the calculations. The safeguards sensitivities to removal by substitution are valid through this step.

Adjusted feed solution is batchwise transferred to the process feed tank (HA feed tank) as the next process step. In the BNFP design, this involves transfer through a feed clarification centrifuge. Steam jet transfers are made from the appropriate feed adjustment tank through the feed clarifier to the HA feed tank. Typical transfer rates into the HA feed tank are 1400 L/h. Thus, a typical transfer of feed lasts ~4 h. During this period, the typical feed rate to the codecontamination cycle from the HA feed tank is 1000 L/h. Solutions from the feed tank are transferred by an airlift through a metering headpot where the flow rate can be measured. The safeguards technique to be applied to this section uses a batchwise volume balance during the period when feed transfers are in progress. The safeguards test is applied to the balance calculated at the conclusion of the transfer.

There are a number of factors that dictate the sensitivity of this test to the abrupt removal. These factors are specific to the equipment involved. There is limited experience with the equipment installed at the BNFP, most of which was gained during a 9-d shakedown run during 1982. This test was in preparation for an extended run of two to three months that was never executed. Results of this test were never formally documented but provided some insight to potential safeguards applications.

The volume balance equation that describes this system is as follows:

$$\begin{aligned}(\text{Volume difference}) = {} & (\text{feed adjustment tank delivered volume}) \\ & + (\text{steam jet dilution}) - (\text{HA feed tank increase}) \\ & - (\text{volume fed to system during transfer}) .\end{aligned}$$

The transfer test is shown in Fig. 5.1.

The sensitivity of the test depends on the ability to make the various process control measurements involved. To estimate the sensitivity, accuracies of the various measurements are used based on estimates observed during the test runs at the BNFP. All estimates are made as the 95% confidence level.

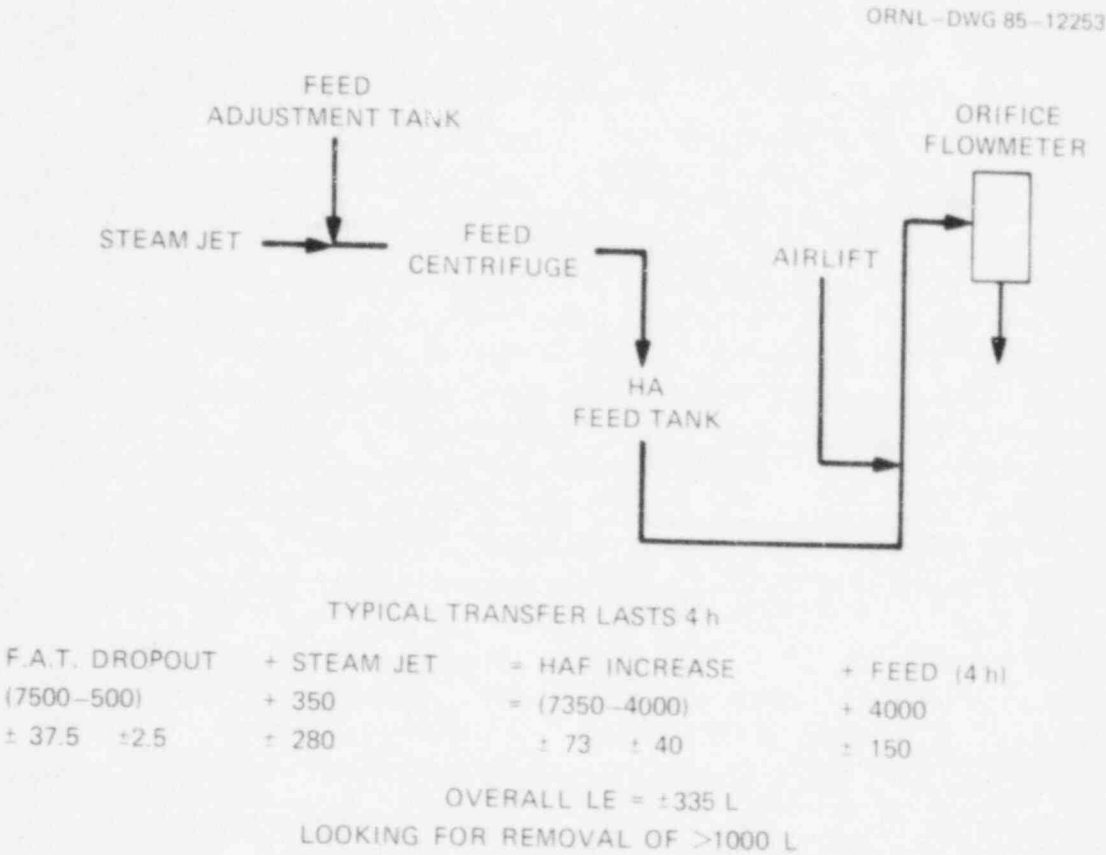

Fig. 5.1. HAF tank volume transfer monitor problem.

At the BNFP, volume measurement instruments on the feed adjustment tank were subjected to the automatic calibration program.

The tank is assumed to be adequately mixed and static before to the start of the transfer. Instrument accuracies and volume calibration results suggest that the feed adjustment tank volume measurements have an accuracy of ±0.5% for the full tank and heel measurements associated with the transfer. Through the use of the automatic calibration program systematic effects are minimized.

The HA feed tank instruments are also subject to the automatic calibration program. However, the tank will likely be continuously sparged introducing additional process noise. It is likely that volume measurement accuracies of ±1% will be realized for this tank on measurements before and after the transfer.

The steam jet transfer between the tanks introduces condensate to the delivered volumes. Experience has demonstrated that the steam jet transfer will introduce a volumetric increase of 3 to 7% over the total volume transferred. For sensitivity calculations, assume that this volumetric increase averages 5% and varies over the range 3 to 7% with a random distribution.

Flow rates for volumes delivered from the HA feed tank to the codecontamination system are controlled and measured by a two-stage airlift to a metering headpot. The analysis is based on an instantaneous flow rate measured every 15 min. The measured flow

is assumed valid and constant over the 15-min period and is integrated with time to calculate the total volume of feed. Based on results during BNFP tests, this flow is estimated to have a precision of ±15%. This estimate is considered to be free of systematic effects and purely random. The assumed absence of systematic error might be questioned, but later discussion suggests this is not unreasonable.

The normal transfer lasts ~4 h. For an example calculation, the initial volume in the feed adjustment tank will be 7500 L. The uncertainty of this measurement should be ±37.5 L. The heel measurement for this tank would be 500 L ±2.5 L. The steam jet should introduce a volume of 350 L ± 280. Prior to the start of the transfer, the HA feed tank volume is assumed to be 4000 L with an uncertainty of ± 40 L under the preceding measurement assumptions. The final HA feed tank volume after transfer would be 7350 L with an uncertainty of ±73 L. Feed flow measurements from the HA feed tank are made every every 15 min during the transfer. Each has an uncertainty of ±15%. The total feed is the sum of these measurements, and simple propagation of errors over this sum results in a total flow of 4000 L ± 150. Here, errors are expressed at the 95% confidence level.

Simple propagation of errors for the preceding measurements and calculations results in a limit of errors for the calculated volume difference of ± 335 L. The goal quantity for the test involves 1000 to 2000 L. Again, this calculation is based on all random errors. The automatic transmitter calibration program is applied to the feed adjustment tank and HA feed tank measurement devices. This limits potential systematic effects on these measurements. If there is to be a problem with resulting false alarms, it will most likely result from systematic error effects on the flow measurement. This problem is minimized by comparative parameter monitoring techniques introduced in Sect. 5.1.2. A very real problem with application of this test is to determine with an on-line monitoring program the exact time interval over which the transfer lasts to perform the flow integration.

5.1.2 Codecontamination and Partition Cycle Tests

Safeguards tests for the codecontamination cycle and partition cycle are next considered here. Note that separation of uranium and plutonium occur after codecontamination. However, the decontamination step removes the bulk of the fission product activity, and the solutions fall below the 100 rem/h exemption criteria. Throughout these areas removal of the 5 Fkg (2 kg of plutonium) goal quantity still requires removal of 100% of the process stream for 1 h down to 25% for 4 h. Two factors remain important. Removal of 2 kg of plutonium will involve 1000 to 2000 L of solution. Also, where uranium and plutonium are not separated, safeguarding of the uranium ensures plutonium safeguards.

Two complementary safeguards techniques are applied to achieve safeguards objectives in the codecontamination step. As noted in Sect. 3.1.3, codecontamination involves the HA contactor and the HS column in the BNFP design. Uranium and plutonium in the HAF are extracted to the organic, leaving fission product wastes in the HAW stream. The organic HAP flows to the HS column. The aqueous scrub stream, HSS, combines with any aqueous carryover and forms the HSR back to the contactor. This stream is treated as an internal recycle in the safeguards analysis. Figure 5.2 shows the system and available measurements.

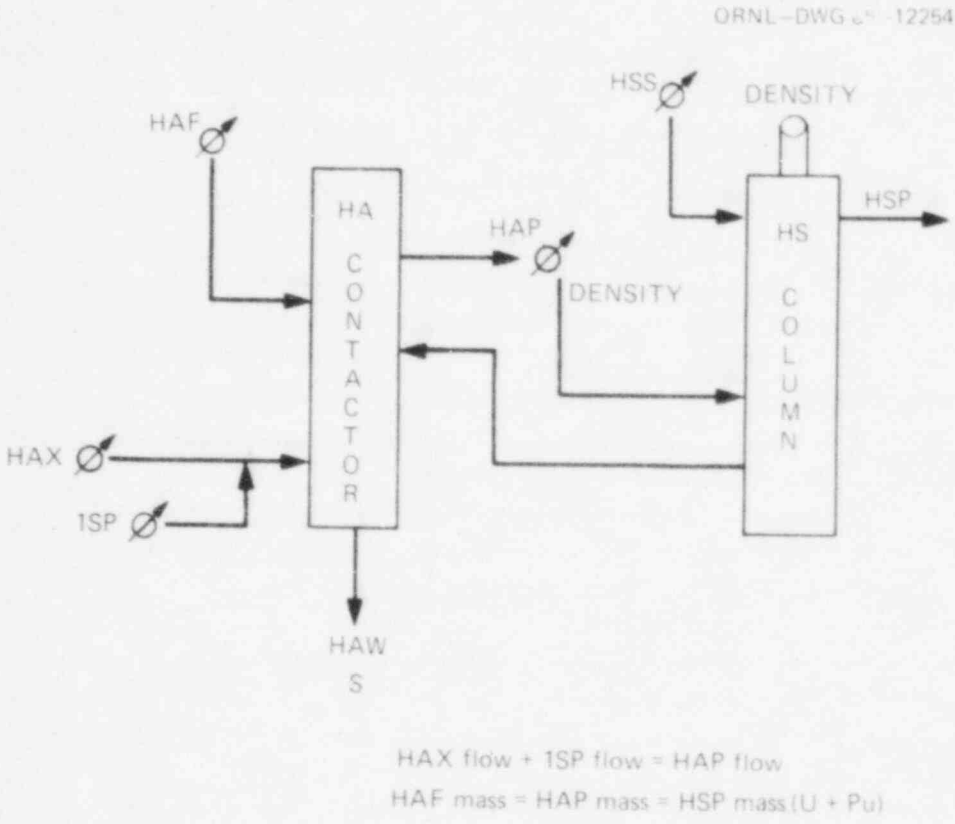

Fig. 5.2. Abrupt loss detection for codecontamination cycle.

Removal of material, avoiding the fission product exposure, requires diverting the HAP or later streams. Comparative parameter monitoring is sensitive to removals in this area.

The HAX stream is the clean organic feed. It is combined with the 1SP stream, which is recycle from the 1S cleanup system (containing very small concentrations of uranium and plutonium). The HAX flow is measured directly. The 1SP flow is measured upstream of the 1S column, as is the 1SX stream, and this measurement is assumed valid as the 1SP flow. Combined they represent the organic feed to the HA contactor. The combined nominal flow is ~2600 L/h.

The organic extracts the uranium and plutonium in the contactor and leaves the contactor as the HAP. Flow of the HAP to the HS column is measured. This measured flow should match the combined HAX and 1SP-measured flow with a slight (~ 4%) adjustment from volumetric increases associated with heavy metal content.

The combined HAX and 1SP flow should match the measured HAP flow. These measurements exhibit the typical difficulties of flow measurements. A continuous program of on-line calibration during steady-state conditions was required to remove systematic effects. These measurements can be made with an uncertainty of ±15%.

Complementary to this volumetric test, calculation and comparison of actual mass-flow rates is used. This involves the flow measurement as well as an estimation of concentration. The HAF flow is measured by a metering headpot as well as by dropout

from the HA feed tank. The uranium concentration of this feed material can be determined from a calculated acid concentration (based on feed adjustment tank measurements) and a measured tank density. With the two independent flow measurements it is estimated that an accuracy of ±15% can be achieved. The concentration estimate should be accurate to ±3% on the 150- to 250-g/L feed solution.

The HAP flow is also measured. This organic stream passes through the HS scrub column to become the HSP stream. Thus, the HSP flow is assumed to be the same as the HAP measured flow. The uranium concentration of the HAP and HSP can be determined from the on-line density measurements. The on-line HSP result is backed up by periodic samples from the HSP stream, which can be used as a calibration check for the on-line estimate. The uncertainty of these measurements is estimated to be ±15% on 2680 L/h for the flow and ±5% on 90 g/L of uranium for the on-line concentrations.

For an actual mass-balance calculation, the HAW (high-level aqueous waste) could also be considered. However, for this test where the quantities concerned require diversion of 25 to 100% of the flow, the HAW calculation is not needed. Upsets that result in high HAW losses should be detected and resolved by HAW samples.

There is very little actual data to support the estimates of measurement uncertainties for this area of the plant. The only BNFP tests involving these measurements was the 9-d preparation run during February and March 1983. Table 5.1 shows codecontamination cycle instrument data recorded during that test. The data illustrate the problems as well as potential of these measurements.

A period covering operations on March 2–3 has been selected. This was a shakedown run and several problems were evident. The data shown include measurements and calculations of the mass-flow rates and cumulative quantities for the feed stream (denoted as HCF on the data) and the HSP stream. Measurements of the combined HAX and 1SX flows are also shown for the flow comparisons.

Of particular significance are the continuous differences between the combined HAX and 1SX flow and the measured HAP. As noted, this was a shakedown run, and there was a considerable bias in the HAX flow measurement. Whether this was a calculational problem or an instrument bias was not determined. However, it points to the kinds of systematic problems that are evident in flow measurements. These are the effects that can be removed with a program of on-line calibration during steady-state operations.

The on-line density measurement for the HA feed tank was not available. The on-line concentration estimate based on this measurement could not be made. The data shown use the results obtained from samples drawn periodically from a temporary sampler installed for the tests.

The HSP concentrations shown were derived from the on-line measurement. While it is not shown in the data, these concentrations were cross checked to a few samples drawn during the test. Agreement was good. In this sense,"good" means there were only two to three samples and the agreement was within a few grams per liter, not sufficient to draw definitive statistical conclusions.

The data shown include calculation of the instantaneous mass-flow rate (expressed as MTU/d) as well as an integrated calculation of cumulative mass flow (started at the beginning of the test). Comparison of mass-flow rates calculated for the HAF (HCF on the table) and the HSP show a consistent bias. Of particular interest is the period around

Table 5.1. Codecontamination cycle instrument data recorded at BNFP, February and March 1983

	DATE	HCF FR-241	[illegible] HCF	MTU/DA HCF	CUMU HCF	HAP FR-242	CALC HSP	MTU/DA HSP	CUMU HSP	HA[illegible] FR-[illegible]544 TO COMPARE
02-Mar-83										
267	12:04 AM	867.29	233.50	4.9	21.8	3071.53	61.97	4.6	25.1	2309.66
268	12:36 AM	865.54	233.50	4.9	21.9	2971.65	64.56	4.6	25.2	2347.56
269	01:08 AM	860.76	233.50	4.8	22.0	3064.42	61.86	4.5	25.3	2215.71
270	01:40 AM	857.15	233.50	4.8	22.1	3002.63	58.32	4.2	25.4	2077.01
271	02:12 AM	856.41	233.50	4.8	22.2	2914.28	56.09	3.9	25.5	2023.57
272	02:44 AM	843.15	233.50	4.7	22.3	2995.98	61.41	4.4	25.6	2272.50
273	03:16 AM	848.06	233.50	4.8	22.4	3019.52	66.07	4.8	25.7	2239.86
274	03:48 AM	865.83	233.50	4.9	22.5	3079.65	61.55	4.5	25.8	2285.02
275	04:20 AM	841.14	233.50	4.7	22.6	3004.6[illegible]	61.17	4.4	25.9	2443.99
276	04:52 AM	847.27	233.50	4.7	22.7	3067.83	66.36	4.9	26.0	2303.91
277	05:24 AM	852.19	233.50	4.8	22.8	2998.55	63.00	4.5	26.1	2549.64
278	05:56 AM	885.51	233.50	5.0	22.9	3056.28	66.83	4.9	26.2	2218.95
279	06:28 AM	0.00	233.50	0.0	22.9	929.14	71.76	1.6	26.3	859.74
280	07:00 AM	0.00	238.30	0.0	22.9	809.21	73.50	1.4	26.3	1289.03
281	07:32 AM	0.00	238.30	0.0	22.9	1012.64	68.34	1.7	26.3	897.36
282	08:04 AM	0.00	238.30	0.0	22.9	2583.17	72.99	4.5	26.4	1971.15
283	08:36 AM	0.00	238.30	0.0	22.9	2245.95	35.23	1.9	26.5	1801.55
284	09:08 AM	0.00	253.00	0.0	22.9	897.18	25.82	0.6	26.5	833.93
285	09:40 AM	0.00	253.00	0.0	22.9	881.33	23.65	0.5	26.5	759.02
286	10:12 AM	0.00	253.00	0.0	22.9	2464.69	30.42	1.8	26.6	1773.00
287	10:44 AM	169.49	253.00	1.0	23.0	3057.91	29.14	2.1	26.6	2484.90
288	11:16 AM	0.00	253.00	0.0	23.0	2944.96	28.34	2.2	26.7	1706.96
289	11:48 AM	0.00	253.00	0.0	23.0	2432.22	42.87	2.5	26.7	1277.72
290	12:20 PM	0.00	253.00	0.0	23.0	2422.14	34.28	2.0	26.8	1377.38
291	12:52 PM	0.00	253.00	0.0	23.0	2227.68	28.87	1.5	26.8	1857.20
292	01:24 PM	0.00	253.00	0.0	23.0	2304.99	19.27	1.1	26.8	1526.32
293	01:56 PM	0.00	253.00	0.0	23.0	2457.49	23.25	1.4	26.8	1540.56
294	02:28 PM	0.00	253.00	0.0	23.0	2641.05	25.20	1.6	26.9	1445.79
295	03:00 PM	0.00	253.00	0.0	23.0	2604.01	26.68	1.7	26.9	1344.59
296	03:32 PM	0.00	253.00	0.0	23.0	2731.62	26.23	1.7	27.0	2177.85
297	04:04 PM	365.84	253.00	2.2	23.0	3050.48	29.22	2.1	27.0	1913.27
298	04:36 PM	812.14	253.00	4.9	23.1	2963.36	50.19	3.6	27.1	1890.99
299	05:08 PM	864.61	253.00	5.3	23.2	3078.33	64.81	4.8	27.2	1895.57
300	05:40 PM	896.4[illegible]	254.00	5.5	23.4	3193.25	72.38	5.5	27.3	2105.49
301	06:12 PM	919.47	254.00	5.6	23.5	3112.49	69.15	5.2	27.4	1906.05
302	06:44 PM	915.11	254.00	5.6	23.6	2991.86	73.19	5.2	27.5	2141.58
303	07:16 PM	920.97	254.00	5.6	23.7	3033.40	78.09	5.8	27.7	1901.34
304	07:48 PM	921.91	254.00	5.7	23.9	3212.68	79.09	6.0	27.8	2192.79
305	08:20 PM	927.41	254.00	5.7	24.0	3170.44	72.71	5.5	27.9	2395.29
306	08:52 PM	955.55	254.00	5.8	24.1	3159.47	72.92	5.5	28.1	1998.66
307	09:24 PM	954.52	254.00	5.8	24.3	3173.47	71.28	5.1	28.2	1845.41
308	09:56 PM	969.33	254.00	5.9	24.4	3181.88	82.49	6.3	28.3	1474.99
309	10:28 PM	963.27	254.00	5.9	24.5	3231.03	79.83	6.2	28.4	1553.15
310	11:00 PM	995.19	254.00	6.1	24.6	3251.20	77.13	6.0	28.6	[illegible]
311	11:32 PM	943.16	254.00	5.7	24.8	3195.80	81.83	6.3	28.7	1408.16
03-Mar-83										
312	12:04 AM	940.79	254.00	5.7	24.9	3138.63	82.11	6.2	28.9	1494.94
313	12:36 AM	741.74	254.00	4.5	25.0	2955.26	80.93	5.7	29.0	759.89
314	01:08 AM	706.68	254.00	4.3	25.1	2934.62	91.36	6.4	29.1	1433.82
315	01:40 AM	675.49	254.00	4.1	25.2	3046.76	86.87	6.4	29.3	1574.94
316	02:12 AM	667.73	254.00	4.1	25.3	2749.34	80.09	5.3	29.4	1395.29
317	02:44 AM	673.59	254.00	4.1	25.4	2833.99	79.78	5.4	29.5	1805.96
318	03:16 AM	682.08	254.00	4.2	25.5	2279.63	75.41	4.1	29.6	1416.97
319	03:48 AM	684.[illegible]	254.00	4.2	25.6	3121.32	94.87	6.4	29.7	2045.46
320	04:20 AM	665.55	254.00	4.1	25.7	2954.43	70.90	5.0	29.9	1596.17
321	04:52 AM	672.23	254.00	4.1	25.7	3069.42	74.27	5.5	30.0	1937.11
322	05:24 AM	649.70	254.00	4.0	25.9	3081.48	71.35	5.3	30.1	[illegible]
323	05:56 AM	640.93	254.00	3.9	25.9	3058.01	75.20	5.5	30.2	1776.04
324	06:28 AM	647.94	254.00	3.9	26.0	2645.75	77.33	4.6	30.3	1470.78
325	07:00 AM	756.57	247.40	4.9	26.1	2909.65	77.99	5.6	30.4	1551.53
326	07:32 AM	801.31	247.40	5.1	26.2	3151.30	69.15	6.1	30.6	1871.58
327	08:04 AM	794.76	247.40	5.1	26.3	3127.88	71.17	4.8	30.7	1892.79
328	08:36 AM	859.91	[illegible]	5.2	26.5	2990.65	72.97	5.2	30.8	2011.44
329	09:08 AM	791.43	247.40	5.1	26.6	3025.78	76.29	5.4	30.9	2335.73
330	09:40 AM	765.71	240.80	4.5	26.7	2771.51	82.76	5.7	31.0	[illegible]
331	10:12 AM	844.74	240.80	4.9	26.8	3125.57	75.56	5.7	31.2	1949.43
332	10:44 AM	[illegible]	240.80	5.0	26.9	3167.73	73.31	5.6	31.3	2209.61
333	11:16 AM	871.47	240.80	5.1	27.0	3150.21	73.54	5.6	31.4	[illegible]
334	11:48 AM	945.39	240.80	5.5	27.1	3097.63	74.97	5.8	31.6	1979.19
335	12:20 PM	955.41	240.80	5.5	27.2	3167.06	75.93	6.0	31.7	2131.54
336	12:52 PM	404.57	240.80	2.3	27.3	3146.45	84.41	6.4	31.9	2319.44
337	01:24 PM	0.00	240.80	0.0	27.3	2973.15	54.64	3.0	31.9	1873.19
338	01:56 PM	0.00	240.80	0.0	27.3	3049.58	35.75	1.9	31.9	2149.31
339	02:28 PM	212.35	240.80	1.2	27.3	3071.99	25.90	1.5	32.0	2006.43
340	03:00 PM	664.76	240.80	3.8	27.4	3014.22	39.19	2.9	32.0	2176.95
341	03:32 PM	747.86	240.80	4.3	27.5	3082.44	64.81	4.8	32.2	2204.23
342	04:12 PM	766.90	240.80	4.4	27.6	2965.13	68.65	4.9	32.3	2274.56
343	04:44 PM	784.21	240.80	4.5	27.7	3115.37	72.84	5.4	32.4	2207.47
344	05:16 PM	791.00	240.80	4.6	27.9	3142.04	78.47	5.9	32.5	2220.49

1 p.m. on March 3, 1983, when the feed was shut off. The HSP rates show a corresponding change with a minimum lag. Indeed understanding the lag periods associated with transients like this is a key to the sensitivity of the safeguards techniques.

While these data are not sufficient to support definitive conclusions about the sensitivity of the measurements and statistical tests for safeguards, they point to potentials of the application. It appears the projected uncertainties of these measurements as presented above are attainable. In this sense the abrupt removal, which involves 25 to 100% removal of the stream, should be detectable with a near-100% probability and near-zero false-alarm rate.

Safeguards around the partition cycle begin to be more difficult. At this point, the plutonium is separated from the uranium and the volumes associated with 5 Fkg (2 kg of plutonium) become much smaller. Concentrations of 10 to 20 g of plutonium are expected; 5-Fkg quantities will fit into a 55-gal drum. Figure 5.3 shows equipment and available measurements for the partition cycle.

The detection goals still represent 100% of design flow over 1 h or 25% over 4 h. The partition cycle is continuous with the codecontamination cycle with no surge capacity between. The HSP stream, which is monitored as part of the previous test, carries the plutonium associated with the uranium. The only flows out of the partition cycle are the 1CU, 1CW, and 1BP. The latter stream normally carries the plutonium content. The 1CU stream has an installed alpha monitor to detect any plutonium content. The monitor is backed up by periodic samples. Thus plutonium must exit through the 1BP stream, and any unauthorized removals must involve aqueous solutions bearing plutonium. Another

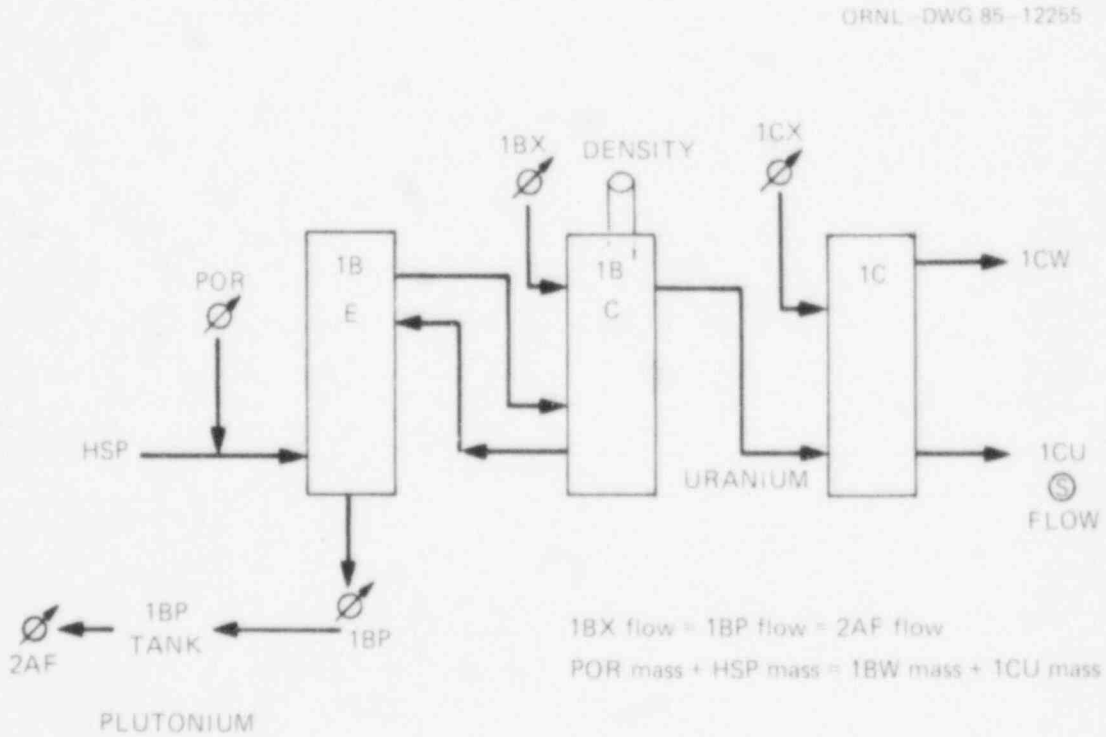

Fig. 5.3. Abrupt loss detection for partition cycle.

removal scenario is to drive the entire uranium and plutonium content through to the 1CW and remove this stream, but conductivity monitors and density measurements would reflect this.

Thus monitoring the 1BX flow with comparison to the 1BP flow measurement ensures the aqueous streams are not removed, considering the goal quantity still requires 25 to 100% removal. The 1BX flow is also measured. The plutonium-laden 1BP stream flow is likewise measured as it exits the partition cycle. The 1BP stream flows into the 1BP surge tank, which provides the surge capacity before the final purification cycles. The feed rate to the final purification cycle, solution from the 1BP tank is designated as the 2AF and is also measured. Both the 1BP and 2AF stream-flow determinations were measured with orifice head pots in the BNFP plant.

The safeguards test compares the 1BX flow to the measured 1BP flow. Both of these flows can be compared to the measured plutonium cycle feed rate, 2AF, after adjustments for level changes in the 1BP tank and any acid butt additions that might be required.

Again, it is very difficult to assess the actual sensitivity of this test. Lag effects from the 1BX to 1BP measurements must certainly be considered. There is not enough data to draw definitive conclusions for this question with respect to overall uncertainty. During the 9-d test run at the BNFP, the 1BP flow measurement was very precise showing variations of plus or minus only a few liters per hour on measured flows of ~300 L/h. This is purely observed variation over time with no particular statistical treatment of the data. Based on these observations, it is estimated that the precision of the measurement is better than 10% and probably on the order of 5%. Similar performance was observed for the 2AF measurement.

The problem of systematic errors persists with these measurements. Under steady-state conditions during this test a difference of ~10% was observed between the 1BP and 2AF measurements. Indeed, during the minirun tests, which were each one week in duration with seven runs performed over a two-year period, average observed biases were 5 to 10% of the measured flow. One exception occurred during a single run when the observed bias was ~40%, which remained constant over the week's run. These biases were observed by detailed comparison of the 2AF flow to a depletion rate observed in the 1BP tank as part of the test. The tank was operated as an isolated feed tank in these tests rather than in the surge mode as originally designed.

Precisions of the 1BX, 1BP, and 2AF measurements observed during BNFP tests will allow comparisons to detect the abrupt removal of 25 to 100% of the stream flow. The systematic effects that may be observed must be considered. However, on-line comparisons to tank-depletion rates should control systematic effects. Techniques to estimate and control systematic effects are very important. Experiences with these techniques gained during the BNFP miniruns are discussed in later sections of this report.

Together, the sensitivities of the measurements and techniques to control systematic effects should make detection of removals of goal quantities from the partition cycle achievable at the required 99% probability of detection. Some false alarms will occur from transient effects of flow adjustments and lag-time effects. The false-alarm rate cannot be calculated or estimated, considering the lack of operational experience with these types of measurements in the remote-reprocessing-plant applications.

5.1.3 Test Sensitivity Summary

In summary, it appears that safeguards of solutions throughout the accountability and feed preparation areas, codecontamination, and partition cycles can be achieved. It appears the required 99% probability of detection can be achieved for losses of 5 Fkg (2 kg of plutonium) over of 4 h or less. Detection would occur within a period of <3 d and is based on the frequency that review of safeguards tests is made. Detection requires a combination of techniques. Static tank monitoring and tank-to-tank transfer monitoring are the safeguards tests applied in the accountability and feed preparation areas. Mass and volume balances, a form of control unit accounting, satisfy requirements around the feed and codecontamination cycle equipment. The plutonium-bearing stream through the partition cycle is well instrumented in the BNFP design and comparison of the several related measurements made on this stream provides the abrupt removal detection capabilities for this system. Similar capabilities should be achievable for a smaller plant such as the proposed BRET facility.

Throughout this area process activities involving adjustments, transients, and spurious signals will result in a number of alarms for each of these tests. The ability to resolve these alarms will be very important. The continuity of processes and the overlapping tests proposed will provide the opportunity to resolve most alarms. It remains to be demonstrated what the mechanism will be to officially respond to and resolve alarms. Additional experience, perhaps with the ORNL facility, and/or the ability to further analyze BNFP data will help satisfy these deficiencies.

A careful safeguards analysis must also recognize the attractiveness, or lack of it, of the material involved. Throughout most of this area, the plutonium is in solution with uranium. In the LWR reprocessing plant like BNFP, plutonium is on the order of 1% of the total heavy metal content. For a breeder fuel plant, this may increase to 20 to 30%, but the overall flows will be smaller. It is not until the partition step that plutonium is separated, and even then concentrations are still small. The goal quantity requires several drums of solution and rather extensive equipment to remove it from plant equipment.

5.2 PLUTONIUM PURIFICATION

The next plant area is the plutonium purification. It contains two cycles of solvent extraction for final purification as well as product concentration. The system is fed with 10 to 20 g/L of plutonium solution. Final product concentrations should be >250 g/L.

The obvious safeguards test is to construct a control unit material balance across the area, using flow and concentration estimates integrated over time for the 1BP input stream and the various waste streams. Product batch measurements would be used as the output. The key to this application is the ability to make in-process inventory measurements. Test performed at the BNFP during 1980 and 1981, the so-called miniruns, suggest that this approach will achieve a sensitivity of 5 to 10 kg of plutonium. This will not satisfy the abrupt removal detection goals of the proposed rule.

To achieve the desired sensitivity this area will have to be subdivided further. The BNFP tests during 1980 and 1981 looked at these subdivisions and developed techniques to improve measurement capabilities to achieve the desired sensitivities.

During the minirun tests at the BNFP, the plutonium purification portion of the plant was subdivided into the following subunits:

1BP tank (using 1BP flow and 2AF flow)
2A column
2B and 3A column
3B column (including diluent wash)
Product concentration and collection

Results and capabilities for these specific subunits will be discussed. In the BNFP tests, several temporary samplers were used that would not be available during process operations without significant facility modifications. The methods used are valid, but a slightly different area subdivision might be required if the BNFP were operated. Sensitivities to removal should be similar to those achieved during the tests, for an operating BNFP or similar large-scale facility. A facility like BRET, if it were built, would require similar safeguards tests to achieve the goal sensitivities.

5.2.1 1BP Surge Tank

The first control unit centers on the 1BP tank. As described in the previous section, this tank continuously receives material from the codecontamination cycle while it feeds the plutonium purification cycle. The BNFP design also permits acid addition for on-line acid adjustment in this tank. The tank normally contains an inventory of 12 to 16 kg of plutonium. The 5 Fkg (2 kg of plutonium) goal quantity represents 12 to 16% of the normal tank inventory.

The proposed safeguards detection scheme involves comparative parameter monitoring and volume balance. For comparative parameter monitoring, the program must reach back to the 1BX flow measurement that is the original cold acid stream that eventually reaches the 1BP tank. This flow must compare to the actual 1BP flow, which is measured as it leaves the partition cycle and enters the 1BP tank. Both of these measurements should compare to measurement of feed to the plutonium cycle, the 2AF measurement. The comparative parameter monitoring program looks at all three measurements (1BX, 1BP, 2AF). If there are significant differences, it looks for corresponding level changes in the 1BP tank and any acid addition in progress.

The sensitivity to abrupt removal of the goal quantities depends on the ability to measure the flow. Tests at the BNFP have demonstrated that precisions of ± 3 to 5% can be realized particularly at the flow levels found in the plutonium system. However, the accuracy may be $\pm 40\%$ due to systematic effects. Thus data analysis requires a history of comparisons, and alarms are based on significant changes.

A parallel safeguards test involves actually calculating the volume balances. This requires integration of measurements over time for the flowing streams and volume calculations in the 1BP tank. The actual volume balance and a volume inventory difference are calculated. This method serves as the backup to the flow comparison method.

It must be remembered that the goal is to detect an abrupt removal of 5 Fkg (2 kg of plutonium) from this area. This amounts to removal of 25% of a flowing stream over 4 h (100% over 1 h) or 12 to 16% of the normal 1BP tank contents. The proposed test uses

hourly volume balances around this area. The series of balances is then analyzed for detection of potential unauthorized removals.

In calculating these balances, the 1BP tank averages an inventory of ~800 L. Volume measurements use process control level and density measurements. Considering process instrument performance and the covariances between beginning and ending inventory measurements, an uncertainty of ±8 L is reasonable for the balance.

Tests at the BNFP have shown that flow measurements at the levels found in this area can be made to ~±5%. However, potential systematic errors, typical of flow measurements, must also be considered.

The systematic effects may be up to 40% for flows. However, they are relatively constant over time, particularly considering the 1- to 4-h period of concern for this discussion. Thus, any particular volume inventory difference calculation will likely not balance, but the difference will be constant over periods of time. A series of calculations should show similar inventory differences and be sensitive to removals of 70 to 100 L of 1BP solution.

5.2.2 2A Column Balance

The second subarea selected for the plutonium purification section involves the 2A column. The safeguards technique selected for abrupt removal detection uses a mass-flow balance equation around the column, selected since the input stream mass flow can be well-characterized using on-line concentration measurements in the 1BP tank and the 2AF flow. Flow measurements are available. The 1BP tank has an installed sampler, and on-line monitors were provided for concentration measurements during BNFP test runs. The 2AP concentration can be determined based on the 2AP density measurement. This measurement is available conveniently from the density measured at the top of the column. The aqueous waste stream also factors into the balance equation. The equipment involved and measurements available are shown in Fig. 5.4.

This particular test was investigated extensively during the BNFP miniruns. Results show that the key to the test sensitivity is an ability to provide on-line calibration of the various measurements. Again, this amounts to development of techniques to remove systematic effects.

The 2AF flow is measured through a metering headpot. During the miniruns, the 1BP tank was operated on a batch basis. Thus, while the tank was being drawn down to feed the system, an accurate dropout rate could be calculated. This dropout rate was compared to the measured feed rate to correct the on-line measurement. During these runs, the adjustment required was usually 5 to 10% of the measured flow (300 L/h). On one occasion an adjustment of 40% was required. This isolated case was attributed to a "piece of crud" in the orifice plate of the flowmeter. With proper corrections, the precision of the flow, based on observed variation of the flows under steady state, was usually on the order of ±10 L/h.

This 2AF flow is a critical measurement. During the BNFP tests, the dropout rate was available due to the batch mode of operation of the 1BP tank. For actual BNFP operations, this tank would be a true surge vessel with continuous additions and removal. The dropout would not be available for calibrations in the original BNFP design. Several proposals were made to provide capabilities for on-line calibration. The most promising

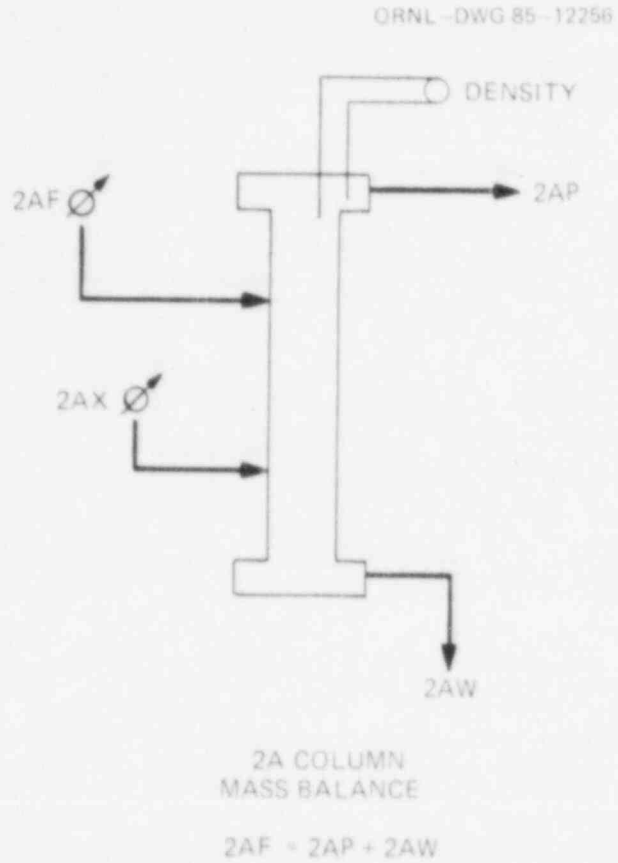

Fig. 5.4. Abrupt loss detection for 2A column.

involved an additional piece of equipment that could be isolated, and the fill rate could be measured periodically. If the BNFP were to operate, some modification like this would be needed. A new facility like BRET should consider equipment to provide the on-line calibration capabilities for flows like the 2AF.

As noted above, the 1BP tank concentration is available by on-line concentration measurement. Several NDA techniques have been proposed for plutonium concentrations in this range. They have yet to be proven under operating conditions. However, during the BNFP tests an X-ray fluoresence and L-edge densitometer were both installed using existing sample equipment. This constitutes a proof of principle for the on-line NDA technique. The frequency of sampling is limited by the count times required at the various concentrations. The devices were interfaced directly to the measurement computer system, and true on-line concentrations were available.

The 2A column product (2AP) solution concentration is also readily available. A very accurate relationship that predicted uranium concentration in organic solutions based on density was developed at the BNFP. The density at the top of the 2A column was available from an on-line instrument. This measurement was used to estimate the 2AP concentration.

Again, on-line calibration of the density measurement is required to achieve desired accuracy. During the BNFP tests, periodic samples of the 2AP solution were drawn and

analyzed for density and concentration. These sample results were used to calibrate the on-line measurement. Usually, corrections of 2 to 5% were required for the on-line density measurements. With proper corrections, the concentration estimates were usually within 3 to 5 g/L. This suggests uncertainties of ±5% on concentrations for organic solutions in this concentration range observed by this technique.

The 2AP flow is not directly measured in the BNFP design. The source of the flow is the organic extractant flow, 2AX. This flow is measured. For the tests, true plug flow was assumed. This ignores the possibility of lag effects from flow changes. The 2AP flow was considered to be 2AX flow with a slight adjustment for volumetric increases due to concentration.

The aqueous waste flow in the balance equation (2AW) is assumed to be the same as the measured 2AF flow, again assuming plug-flow conditions exist. The waste concentrations were based on periodic (8 h) samples during the tests. During operations, this information would be available from an on-line alpha monitor. The waste stream quantities involved are not usually significant to the balance equation under steady-state operations.

Notice that there is no way to calibrate the 2AX flow. It cannot be related to a drop-out. Thus the calibration is made by forcing the mass-flow equation to balance during steady state. With the other parameters calibrated (2AF concentration and flow, 2AP concentration) the 2AP flow correction is adjusted to force the balance.

Considerable effort was devoted to these balance equations for the BNFP minirun tests of 1980 and 1981. With proper cross check and measurement control activities, the balance equations could routinely be closed to within 100 g/h during steady-state operations. During these runs, the equations were closed on a 15- to 16-min basis. Removal of goal quantities of material from this area requires removal of 25% of the stream contents over 4 h (500 g/h) or 100% of the stream for an hour. The balance equation and test should be sensitive to this removal.

The problems associated with calculation of the absolute sensitivity and false-alarm probability are obvious. Accuracies and precision for most of the measurements can be observed. However, the calibration by forcing the balance introduces an interesting covariance effect. This makes it difficult to estimate the sensitivity for the test and presents an interesting challenge to implementation. Some engineering judgment about steady state must be made.

5.2.3 2B and 3A Column Balance

The 2B column performs the strip function for the first cycle of plutonium purification while the 3A column performs the extraction for the second cycle. Concentration predictors for organic solutions worked particularly well during the BNFP test runs. They require the pneumatic dip-tube–measured density only and are particularly well-suited to the "on-line" application. For these reasons, the balance area from the organic 2AP measured stream to the organic 3AP stream (including the 2B and 3A columns) is selected as the next control area. Again, the balance equation without in-process inventory estimates for the columns is used with the hope that demonstration of accurate inventory estimation techniques will improve capabilities during transient conditions.

Figure 5.5 shows equipment and measurements available. Closure of this balance uses the 2AP measurements as discussed above. The 3AP measurement, as the output term of the closure, is a time integration of the 3AP concentration and flow. The concentration is derived from the 3A top-column density measurement. The flow is based on the clean 3AX organic flow measurement with an adjustment for the volumetric increase due to the heavy metal content. This is similar to the 2AX measurement described above.

The balance calculation also includes the 2BW and 3AW. The flow of the 2BW organic waste stream is the same as the measured 2AX. Flow of the 3AW aqueous waste stream is the combination of the 2BX aqueous strip stream, any 3AF acid butt flow and the 3AS scrub stream, all of which are measured. Continuous on-line monitoring capabilities exist for both waste streams. Concentration measurements will be available for calculations for these waste streams in the material balance.

Inclusion of two columns in this balance increases the surge capacity and more process variation will be observed in the balance equation over time. However, during tests at the BNFP with natural uranium, balances to within ±200 g/h were maintained during steady-state operations. These were also obtained without the benefit of on-line concentration measurements for the waste streams. Waste stream flows were estimated based on the above flows and periodic (8-h) laboratory samples and analyses. Again, this technique with capabilities for waste concentration measurements should be sufficient to detect abrupt removals of goal quantities over periods of 1 to 4 h.

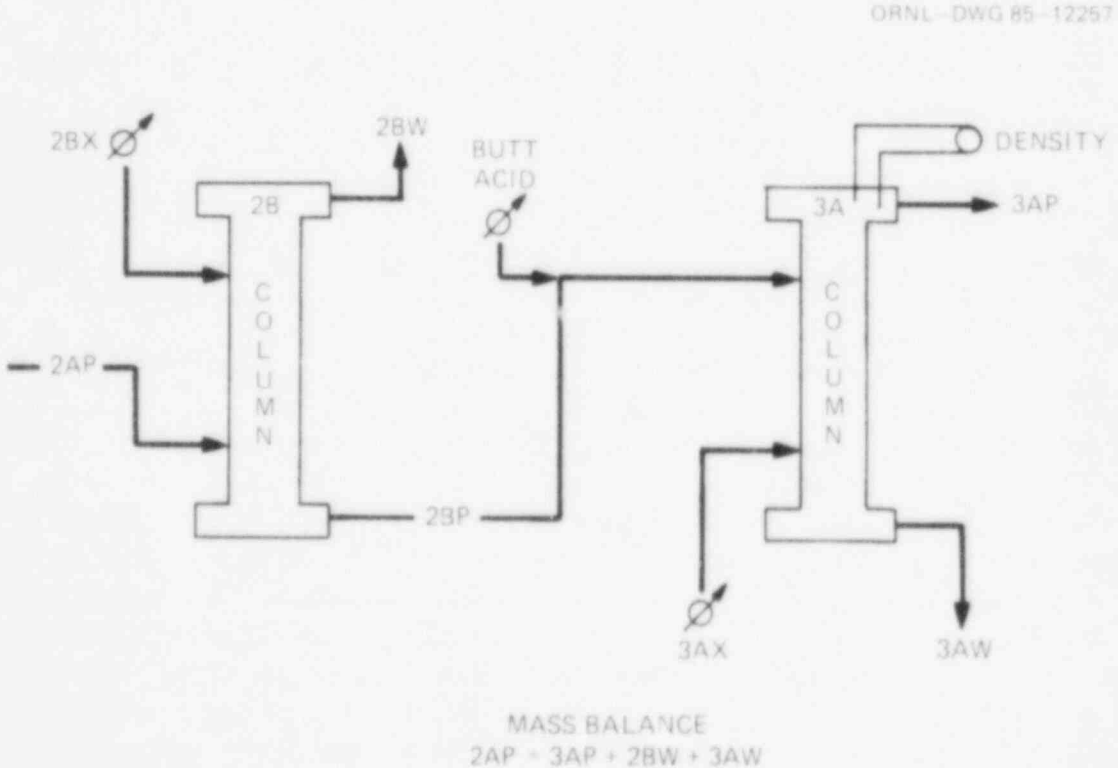

Fig. 5.5. Abrupt loss detection for 2B/3A columns.

Sensitivities and false-alarm probabilities become more difficult to calculate for this area. As discussed above, the 2AP flow measurement (2AX) must be calibrated by forcing a balance during steady-state operations. The 2AP flow is a factor in this equation. Likewise, the 3AX flow, which becomes the 3AP flow, must also be calibrated by forcing the 2B/3A equation to balance. The abrupt removal should be detected based on the observed ability to close the balance to within a 200-g/h flow. Calculation of the actual sensitivities is difficult. Like most other tests, the number of unresolved alarm depends more on the ability to resolve alarms rather than the statistics of the test.

5.2.4 3B Column Balance

A balance area is also established from the 3AP, the organic product on the 3A column, to the 3BP, the aqueous product of the 3B column. This balance uses the 3AP calculation as described above. The 3BP stream flow is a combination of the 3BX clean acid strip flow and the 3BS aqueous scrub. Both of these streams are measured.

The 3BP stream can be continuously monitored for concentration. A gamma monitor was present in the initial design. Any of the proposed techniques for plutonium concentrations in aqueous solutions can be applied. During the minirun demonstrations at the BNFP, where natural uranium was substituted for plutonium, two separate methods were used. In the first, the LANL L-edge densitometer was applied. The on-line application of this instrument in the operating plant environment rather than analysis of process samples was demonstrated.

The second technique used the method of concentration estimate based on density and acid measurements. For this application, acid concentration plays a significant role (as opposed to the minor role of acid concentrations in the organic predictor equations). The BNFP design includes conductivity monitors that measure acid concentration of the 3BX stream ("cold" acid addition to the 3B column). It becomes the 3BP stream after "stripping" the product material. This was adequate for 3BP acid measurement based on the test-run results.

Two methods of density measurement were tried during the BNFP experiments. By the first, density measurements were made with the pneumatic dip-tube system. While the 3B column is not equipped for this measurement, the 3BP stream flows through a 3PS diluent wash column. This column was operated to keep the interface probes submerged in the aqueous 3BP solution. Thus, the interface measurement was used as a direct 3BP density measurement. In the second approach, the 3BP sample line was tapped and a portion of the solution routed through a Parr-Mettler densitometer, which provided a laboratory-grade density measurement on-line for use in the concentration prediction equation.

The above techniques all provided encouraging results for concentration determination of the 3BP stream during the BNFP test runs. Comparisons of on-line concentrations were made to periodic laboratory sample results. A modified Davies-Grey method adapted for process control was used in the laboratory. On-line concentrations showed better accuracy and precision than the process control values. The L-edge densitometer and the on-line laboratory-grade density with the predictor equation both showed accuracies of ± 1 to 2 g/L. The method using the pneumatic dip-tube–measured density produced results of ± 3

to 7 g/L. Process control laboratory results are generally in the range ± 5 to 10 g/L for these concentrations.

Flow of the 3BP stream is equivalent to the combined flow of the aqueous strip stream (3BX) and the scrub stream (3BS). The 3BX and 3BS streams are cold chemical streams and easily measured. The 3BP stream contribution to the balance equation is calculated by integration of the flow and concentration measurement over time.

The final component of this balance equation is the 3BW. Again, this stream can be measured by on-line instrumentation. The source of the stream is the 3AXX, a cold chemical stream flow easily measured. For the BNFP tests, periodic sample results were used (8 h). For operating plants, on-line NDA devices will provide timely concentration information for closures.

Like the other column balance equipment, the 3B column balance could be closed to within 100 to 200 g/h during the BNFP test runs. These closures were made every 16 min. The test-run flowsheet was 6 kg of heavy metal (uranium) per hour. Similar results are expected for the 2-kg/h standard plutonium flowsheet.

Probability of detection and false-alarm rates are again difficult to calculate. The 3BX flow must be calibrated by forcing this balance. These force-fit calibration effects now trace back through the 2AX, 2BX, and 3AX flow measurements. However, the tests must be sensitive to 25 to 100% of the stream removal over 1 to 4 h. In the limited BNFP test-run experience, the balances were observed to be within 100 to 200 g/h (measurements made every 16 min). Variations in the mass balances are a combination of measurement effects and process variation, but there is an indication of achievable sensitivity. In this sense, it appears that detection of abrupt removal of stream contents containing goal quantities can be achieved for this area and the other column balance areas of the plutonium purification cycle.

5.2.5 Plutonium Product Concentration and Measurement

The final subarea of the plutonium purification system covers product concentration and measurement. The 3BP stream is concentrated to product specifications. A material balance across this area involves concentrated, purified, product solution. The nominal inventory for the area is 50 to 80 kg of plutonium. This large inventory of purified plutonium in dynamic process vessels makes the safeguards tasks for this area particularly difficult. Measurement of the 3BP stream is very important to the safeguards objective since it represents the dynamic input measurement for the balance calculation. The importance in the safeguards tests is the reason several methods for on-line concentration estimation were tried during the BNFP tests.

The balance equation for this final section of the plutonium purification area uses transfer of product solutions from the plutonium product sample tank as the output measurement. These measurements occur only once per day in the operating plant and are highly accurate accountability measurements.

The BNFP tests concentrated on closing the product area balance frequently (16 min) with on-line measurement of the inventory quantity. Inventory measurements are required for the 3P concentrator, the plutonium product catch tank, and the plutonium product sample tank. Inventory in the 3PS column is negligible and was not included. On-line

column instrumentation provides this assurance. Likewise, the condensate from the 3P concentrator cannot contain measurable material and was also ignored in the balance calculation during the tests.

The density/acid equation was used for the concentration component of inventory measurements for the various tanks in the area during the tests. In-tank density measurements are available for each of the three major vessels. The latest laboratory acid concentration measured for the product tank was assumed valid for the concentrator and catch tank, since concentrations do not change much during steady state. The assumed acid concentration and measured densities were used in the high-concentration predictor equation. On-line dip-tube level and density measurements were used for volume determinations. The acid concentration assumptions present a potential problem during startup, shutdown, or during operational upsets. Additional tests and modeling should resolve those problems.

Nominal inventory quantities for the various equipment are as follows: 3P column, 1 kg; 3P concentrator, 16 kg; plutonium catch tank, 0 to 20 kg; and plutonium sample, 0 to 40 kg.

This particular material balance exercise was studied extensively during the seventh minirun at the BNFP during August 1981. Material balances were closed and inventory differences calculated every 16 min. Figure 5.6 shows these closures over an 18-h period during the run.

As noted above, the balance uses integration of 3BP flow and concentration as the input and product-tank transfers as the output. The process control measurements of product transfers are used rather than the accountability measurements, which are generally not available for perhaps a day. The figure shows input, output, and the cumulative in-process inventory (book inventory). The measured in-process inventory is used to close the balance, and the calculated inventory difference is shown. The cumulative holdup and the calculated ID are plotted.

As shown in the table, the inventory of this area ranges from 30 to 90 kg as the product tank fills and is emptied. For the goal of 5 Fkg (2 kg of plutonium) removal detection, it is observed from the data that the calculated IDs are larger. The magnitude of the calculated ID is not so important since there will be a sizable systematic error in the input measurement due primarily to the flow measurement. This can be treated as systematic error and compensated for in the analysis. However, the large changes in the magnitude of the calculated ID, individual shifts, between periods is of concern for the sensitivity to abrupt removal detection. There are several examples in the data where a change indicating a 2-kg removal is observed.

This area of the plant offers the most significant challenge to safeguards removal detection. It will require improvement over demonstrated capabilities to meet the detection goal for abrupt removals. Figure 5.6 demonstrates the problem of detection sensitivity at the 2 kg of plutonium level. The data were collected during a limited test run at the BNFP duing 1981. The data show the fundamental problems facing safeguards applications in this area and suggest areas for improvement to provide capabilities to meet the safeguards removal objectives.

A large discontinuity within the data is observed corresponding to the product tank transfer at 05:21 p.m. As noted above, the product tank transfer measurement is based on process-control information. The data used to generate these plots during the test were the

ORNL DWG. 85-116049

THIS IS A MINI IPI AROUND THE 1B COLUMN TO THE PU PRODUCT SAMPLE TANK
THE DATA ARE FROM MINI RUN NO.
FROM NO. 750 AT 07:14 AM ON 24-Aug-81
TO NO. 850 AT 10:10 AM ON 25-Aug-81

THE CUMULATIVE HOLDUP CALCULATION IS REPRESENTED BY A (H)
THE IPI QUANTITY IS REPRESENTED BY A (I)

	KGS COLUMN INPUT	KGS PROD TK OUTPUT	KGS CUMUL HDP	KGS IPI-ID KGS	FOR H FOR I	-30	-20	-10	0	+10	+20	+30
24-Aug-81							80		160		240	
750 07:14AM	.8	0	36.8	-.2								
751 07:30AM	1.5	0	38.3	-.3								
752 07:46AM	1.6	0	39.8	-4.4								
753 08:02AM	1.5	0	41.3	-4.2								
754 08:34AM	3.1	0	44.4	-3.9								
755 08:50AM	1.5	0	46	-3.5								
756 09:06AM	1.6	0	47.5	-3.6								
757 09:22AM	1.6	0	49.1	-3.6								
758 09:38AM	1.6	0	50.7	-3.5								
759 09:54AM	1.5	0	52.2	-3.5								
760 10:10AM	1.5	0	53.7	-3.4								
761 10:26AM	1.5	0	55.1	-3								
762 10:42AM	1.5	0	56.6	-2.8								
763 10:58AM	1.5	0	58.1	-3.6								
764 11:15AM	1.6	0	59.8	-3.2								
765 11:30AM	1.5	0	61.2	-2.7								
766 11:45AM	1.5	0	62.7	-2.4								
767 12:02PM	1.7	0	64.3	-2								
768 12:18PM	1.6	0	65.9	-2.3								
769 12:34PM	1.6	0	67.5	1								
770 12:50PM	1.6	0	69.1	-2.3								
771 01:06PM	1.6	0	70.6	-1.9								
772 01:21PM	1.5	0	72.1	-2.5								
773 01:38PM	1.7	0	73.8	-2.2								
774 01:54PM	1.6	0	75.4	-1								
775 02:11PM	1.7	0	77.1	-.5								
776 02:26PM	1.5	0	78.6	-.7								
777 02:42PM	1.6	0	80.2	-.9								
778 02:58PM	1.6	0	81.8	2.3								
779 03:14PM	1.6	0	83.4	-.4								
780 03:30PM	1.6	0	85	.5								
781 03:46PM	1.6	0	86.6	-.6								
782 04:02PM	1.6	0	88.2	-.1								
783 04:18PM	1.6	0	89.8	-1.4								
784 04:34PM	1.6	0	91.4	-.6								
785 04:50PM	1.6	0	93	.6								
786 05:06PM	1.6	0	94.5	0								
787 05:21PM	1.5	55.2	40.8	-.1								
788 05:38PM	1.7	0	42.5	.2								
789 05:54PM	1.6	0	44	-.3								
790 06:09PM	1.5	0	45.5	-6.2								
791 06:26PM	1.6	0	47.1	-5.8								
792 06:42PM	1.5	0	48.6	-6								
793 06:58PM	1.5	0	50.1	-6								
794 07:14PM	1.5	0	51.5	-5.2								
795 07:30PM	1.5	0	53	-4.8								
796 07:45PM	1.4	0	54.4	-2.3								
797 08:02PM	1.6	0	56	-4.6								
798 08:18PM	1.5	0	57.5	-4.6								
799 08:34PM	1.5	0	59	-4.9								
800 08:50PM	1.5	0	60.5	-4.8								
801 09:06PM	1.6	0	62.1	-4.8								
802 09:22PM	1.6	0	63.7	-4.6								
803 09:38PM	1.6	0	65.3	-5								
804 09:54PM	1.6	0	66.8	-4.3								
805 10:10PM	1.6	0	68.4	-4.1								
806 10:25PM	1.5	0	69.9	-3.1								
807 10:41PM	1.6	0	71.5	-3.8								
808 10:58PM	1.7	0	73.2	.7								
809 11:13PM	1.5	0	74.8	-2.9								
810 11:30PM	1.7	0	76.5	-2.4								
811 11:45PM	1.5	0	78	-3								
25-Aug-81												
812 12:02AM	1.7	0	79.6	-3								
813 12:17AM	1.5	0	81.1	-2.9								
814 12:34AM	1.7	0	82.8	.4								
815 12:50AM	1.5	0	84.3	-3.1								

Fig. 5.6. Material balance closures at BNFP during an 18-h period.

MINI IPI AROUND THE 3B COLUMN TO THE PU PRODUCT SAMPLE TANK (PAGE 2)

	KGS COLUMN INPUT	KGS PROD TK OUTPUT	KGS CUMUL HDP	KGS IPI-ID KGS	FOR H FOR I -30	-20	-10	80 0	+10	160 +20	+30	240
25-Aug-81												
816 01:06AM	1.5	0	85.8	-4								
817 01:22AM	1.5	0	87.3	-5								
818 01:38AM	1.5	0	88.8	-4.6								
819 01:54AM	1.5	0	90.3	-1.7								
820 02:10AM	1.5	0	91.7	-3.3								
821 02:26AM	1.5	0	93.2	-4								
822 02:42AM	1.5	60.5	34.2	-4.2								
823 02:58AM	1.5	0	35.7	-7.6								
824 03:14AM	1.5	0	37.2	-7.6								
825 03:30AM	1.5	0	38.7	-7								
826 03:45AM	1.4	0	40.1	-7.8								
827 04:02AM	1.6	0	41.7	-1.7								
828 04:18AM	1.5	0	43.2	-1								
829 04:34AM	1.5	0	44.8	-6.9								
830 04:50AM	1.5	0	46.3	-6.4								
831 05:06AM	1.6	0	47.9	-6.8								
832 05:21AM	1.5	0	49.4	-7.1								
833 05:37AM	1.5	0	50.9	-6.9								
834 05:54AM	1.6	0	52.5	-6.1								
835 06:10AM	1.5	0	53.9	-5.6								
836 06:25AM	1.4	0	55.3	-6								
837 06:41AM	1.4	0	56.7	-5.4								
838 06:58AM	1.5	0	58.2	-5.2								
839 07:14AM	1.4	0	59.6	-4.5								
840 07:30AM	1.4	0	61	-4.1								
841 07:46AM	1.4	0	62.5	-.8								
842 08:02AM	1.5	0	63.9	-1.7								
843 08:18AM	1.5	0	65.4	-2.6								
844 08:34AM	1.4	0	66.8	-3.9								
845 08:51AM	1.5	0	68.3	-5.4								
846 09:06AM	1.3	0	69.6	-5.1								
847 09:23AM	1.4	0	71	-4.8								
848 09:38AM	1.3	0	72.3	-4								
849 09:53AM	1.3	0	73.6	-4.1								
850 10:10AM	1.4	0	75	-4.2								

Fig. 5.6. Continued.

best instantaneous data available. There was no attempt to correct old data when information such as analytical results became available. While accountability level measurements would eliminate this discontinuity, that type of data is generally delayed by a minimum of several hours. Some timeliness of safeguards detectability is lost if analysis is delayed to incorporate this better information. Obviously, improvements over BNFP test results could be achieved with the better analysis. With a goal of detection within 3 d, this may be a possibility.

The density/acid equations work well for concentration predictions. Density measurement from the various tanks are adequate for this application. However, significant improvement in applications for this area could be made if timely acid concentrations were available. On-line conductivity probes were successfully used during test runs. If these could be adapted for measurements in the concentrator and catch tank, improvements would be realized.

In summary, the BNFP tests suggest that sensitivities to abrupt removals in this area can be on the order of 2 to 5 kg. The lower limit can be achieved if acid concentration determinations can be obtained on-line for the plutonium product tanks. During the tests, this parameter had to be determined from off-line laboratory analyses. Perhaps additional improvement to sensitivities below 2 kg could be achieved by using accountability level analytical data without the timeliness of on-line or process control data.

5.2.6 Interim Product Storage Tanks

The BNFP design includes three interim product storage tanks. These tanks receive transfers from the plutonium product tank, usually on a daily basis. Solutions are accumulated in the tanks for a weekly transfer to the plutonium nitrate storage area.

Safeguards tests for these tanks involve static tank monitoring with tank-to-tank transfer comparisons when transfers are made. Considerable experience was gained during the BNFP tests using these techniques.

The static tank monitoring program simply monitors tank levels while the tank is in a static condition. With only about one transfer per day, the tanks are static most of the time. During the BNFP tests, the computer-based monitor program recorded measurements every 16 min. A check was made to detect any changes in observed tank levels not associated with transfers.

A number of abrupt removals were made from various tanks during the tests in order to demonstrate the sensitivity of the monitor system. These ranged from several tens of liters down to 0.25 L. For the interim product storage tanks involved in this area, abrupt removals of 0.25 L could be detected. This corresponds to <100 g of product material.

At this level, however, there are frequent (several per day) false alarms. These are characterized by an apparent removal followed by an increase. The cause was not obvious but probably was attributable to off-gas or instrument air fluctuation. A more realistic alarm limit for this test was at the 0.5- to 1-L level, which is still far below the goal quantity for the test. There is certainly no problem with detection of abrupt removals from static tanks in this area.

The potential removal of solution during the actual transfer is a more difficult challenge. Transfers between the plutonium product tank and the interim storage tanks were

treated as accountability transfers during the tests. Precise measurement instruments were applied and used to measure quantities transferred and quantities received. The total weight of solution transferred and received was compared. This comparison could be made within an hour of the transfer based on measurements and preliminary analytical results. This gives timeliness to the abrupt removal test. Actual plutonium (or uranium) comparison must await final accountability concentration analysis, which may be delayed by days. However, this comparison serves as confirmation.

During BNFP tests, the nominal difference between the transferred and received quantities was <3 kg of solution. Weight of solution was calculated from volume and density measurements. Some 250 transfers between these tanks were made during the 1980–81 tests. At this level there was an observed alarm rate of ~20%. Most of these alarms are followed by an offsetting quantity in the other direction, indicative of a piping-holdup problem.

Throughout the BNFP tests, the problem of piping holdup with pump transfers was apparent. The actual procedure used by an operator involving the sequence of valve operation can vary transfer comparison results. Thus consistency of activities between operators can influence false-alarm rates. Evidence from BNRP tests indicates that comparative transfer measurements provide the capability to detect removal of material during transfers from the product tank to the interim storage tanks. However, continuous evaluations of techniques and cross checks of measurements are required to limit the number of alarms.

Transfers from the interim storage tanks to the plutonium nitrate storage area were also tried during tests. Fewer test transfers were made, but the piping holdup problem seemed more significant than with the product tank transfers. This is to be expected considering the complexity of piping and valving operations to accomplish these transfers. Measurement capabilities exist and were demonstrated to do comparisons of quantities transferred versus those received for total solution weight (based on volume and density measurements) and to detect removals of the goal quantity. If the BNFP or another large facility were to operate, there would have to be an effort to standardize transfer procedures. It may be a necessity to reconsider traditional valve and piping arrangements to minimize variations in piping holdup.

In summary, there does not appear to be a problem to achieve safeguards sensitivity to an abrupt removal of 5 Fkg (2 kg of plutonium) from the interim product storage area. The technique involves static tank monitoring that is sensitive to removals of <1 L of solution, which is <100 g of plutonium at product concentrations. Comparisons of weights of solution transferred versus those received provide the safeguards test for removals during transfer. They are sensitive to removals of a few kilograms of solution, <1 kg of plutonium.

5.3 PLUTONIUM NITRATE STORAGE

A plutonium nitrate storage area is a requirement for reprocessing facilities to provide a buffer between the separations facility and the plutonium oxide conversion facility. Regulations prohibiting shipment of plutonium nitrate solutions necessitate the close-couple of separations and oxide conversion. Considerations for nitrate storage are inherent to a generic facility to provide surge capacity. The BNFP design evolved as these transport

regulations were being implemented. Thus, the plant was equipped for nitrate loadout as well as excessive storage capacity. This excessive capacity presents a significant challenge to the safeguards effort due to the large quantities of plutonium potentially contained. The safeguard problem with the BNFP design is typical of problems associated with storage of concentrated plutonium nitrate product solutions. While the capacity for the BNFP storage area magnifies the problem, a generic plant will have to address the problem in a similar way.

The BNFP plutonium nitrate storage and loadout area (PNSL) consists of a series of 48 geometrically favorable slab tanks contained within two shielded cells. Nonprocess penetrations into the cells, such as pneumatic instrument probes and dilution air supply, enter the top of the cells from an occupied area. Process piping penetrations, such as tank inlet and outlet lines and associated valving are contained in shielded glove boxes.

Each PNSL tank has a working volume of 667 L. At a plutonium concentration of 250 g/L of plutonium, each tank will contain ~167 kg of plutonium. Groups of six tanks referred to as modules are served by common inlet and outlet manifolds. One pump serves each outlet manifold. There are eight modules in the PNSL. The 48 tanks have the potential to hold a total of >8 metric tons of concentrated plutonium product.

The inventory uncertainty for eight, six-tank modules full of plutonium nitrate using the best available techniques for volume and concentration measurements greatly exceeds the 2 kg of plutonium goal quantity of the Reform Amendment. Therefore, periodic material balances of these tanks cannot meet the loss-detection goals. The recommendation is to treat the six-tank modules as "tamper-safed items." This presents two different problems. The first is to provide a method of monitoring the module. The second is to provide safeguards measurements during additions to or removals from the modules.

The monitoring application is complicated by several factors. There is an evaporative effect of the air bubbles introduced through the pneumatic-bubbler measurement system. There is also an air sweep across the volume surface at the top of the tank to remove hydrogen buildup from radiolysis that adds an additional evaporative effect. Also, there is a direct effect due to radiolysis. The combination of effects results in a gradual reduction in volume. Further, there is a continuous change in concentration from plutonium decay. Sample and analysis with material balances will not be effective. Therefore, volume monitoring is recommended.

When a six-tank module is filled, the plutonium nitrate solution is mixed throughout the module. After final samples and measurement the module is "tamper-safed." At the BNFP, an area of the nitrate storage area was equipped and tested with a closed-loop control system designed and implemented with the help of Sandia Laboratories. This system monitored and controlled valves and glove-box ports to control access to the modules in the "tamper-safed" condition.

Additionally, a computer-based volume monitor system was applied to tank modules and tested as part of the BNFP program. The sensitivity of the computer-based system was demonstrated to be well below the 2-kg limit. The precision of the volume measurement was demonstrated to conform to tank requirements. In a purely additive model over the six tanks of a module, this leads to a sensitivity of 1.8 L over the module. This represents 0.45 kg of plutonium at 250 g/L concentration.

On an individual module basis, each module is easily sensitive to the 5 Fkg (2 kg plutonium) abrupt removal goal during static operating conditions. The only requirement is a computer-based volume monitor program. Again, the abrupt removal is defined to be a period of less than a few hours and scan rates for change over several (perhaps 15) minutes. For tests over longer periods, the evaporative effects discussed previously become important. The sensitivities for removal detection under these conditions will be discussed under the section of recurring losses in Sect. 6.

The above analysis considers the abrupt removal from a single module. Obviously, the question of removal of <0.5 kg from each of the six modules must be addressed. As noted previously, it can be assumed that a system similar to the closed-loop control system will be implemented limiting access to each module. Simultaneous removals from several modules will have to defeat the monitor system as well as the closed loop control systems. While it is difficult to calculate contributions to the probability of detection for these security systems, the combination of monitoring and closed-loop control clearly make detection of the abrupt removal of 2 kg of plutonium likely.

The second part of the safeguards problem is to monitor transfers into and out of the modules. It is proposed to use volume- or solution-weight measurements transferred as the parameters of interest. This does not address the problem of substitute material. However, while the chances of detecting substitute material in a transfer are small, the chances of being able to add the exact amount and proper density of the substitute material is even smaller.

We reduce the problem to an analysis of whether all the solution that was sent was received. Transfers to the nitrate storage area are from the three intermediate product storage tanks in the separations area. Prior to transfer, accountability-grade measurements of the solution to be transferred will be available. Receiving tank volume measurements of similar accuracy will also be made.

Tests at the BNFP during 1978–79 included more than 200 transfers of solution from the uranium product accountability tank back to the input accountability tank. Instrumentation for measurements in these vessels was similar to that expected to be used for measurements of transfers to the nitrate storage area. Transferred versus received quantity comparisons were made to demonstrate measurement capabilities. During the 1979 tests, the differences showed a calculated standard deviation of <0.1% of the total solution quantity (weight) transferred. Very similar capabilities should be available on transfers to the plutonium nitrate storage area.

Limited testing of water transfers to the nitrate storage area did not match this performance. Sizable differences in transferred versus received measured quantities persisted. Often the differences were several (six or greater) liters. It was concluded that variable piping holdup and some valve leakthroughs were the causes.

Transfers from the product tanks to the nitrate storage area are made through a 100-L measuring tank that is free-draining to the selected nitrate storage area tank module. Product flows to a common header. Flow to a chosen tank is controlled by opening the valve to the particular tank. Meanwhile, the outlet lines for the tanks of a module are combined into a discharge header connected to a single transfer pump that services the module. Problems arise when isolation valves on the inlet or outlet headers leak through during a transfer. This allows measured product solution to reach a tank other than that selected for the transfer and complicates any transfer versus received comparison.

The BNFP staff proposed to replace the existing valves with remotely actuated ball valves. Ball valves historically exhibit fewer leak problems, and this could eliminate the leak problem.

The second problem is that different amounts of solution can be held up in the piping depending on the module selected for receipt of product solution. This was observed during transfer tests at the BNFP. A closer look at the piping arrangement will explain the problem. Again, this is specific to the BNFP but generic in the engineering problem of delivering product solution across a distance to a series of slab storage tanks.

The process line of interest is a 1-in. schedule 40, type 304L stainless steel pipe connecting the 100-L measuring tank in the PPC to all the modules in the plutonium nitrate cells. The line is sloped so that solution free-drains from the 100-L measuring tank to the nitrate storage area. This is a typical pipe holdup problem, common to chemical plant design and is of particular significance to safeguarding of the concentrated plutonium product solutions.

The volume of the pipe as installed in the BNFP can be calculated. The pipe length from the valve at the 100-L measuring tank to the storage area, including the header and short sections that drop to the block valves for each module, is 193 ft long. The inside diameter of this pipe is 1.049 in. Total contained volume when the pipe is full is 32.1 L of solution. As product, this is more than 8 kg of plutonium.

There is an obvious wetting of the pipe during transfer. Assuming a 1-mm film of solution on the inside of the entire pipe, the wetting holdup would be 4.8 L, or better than a kilogram of plutonium product.

An associated problem with the transfer route as installed at BNFP concerns the down legs to the block valves at each module. The line is designed to free-drain to the last module. However, solution will fill the down legs for each module upstream of the selected module during any particular transfer. Once filled, the down legs remain full until the block valves are open (or if they leak). Thus, the piping holdups may change considerably from transfer to transfer and the potential for product-solution mixing in the pipes exists.

This is a problem specific to the as-built condition of the BNFP. However, it is generic to piping and transfer systems for the plutonium nitrate storage area of any reprocessing plant particularly if geometrically safe, slab storage tank modules are selected in the design.

The solution is to redesign the transfer system or the procedures to ensure a constant known holdup. An administrative solution to the BNFP problem is to control transfers by using the block valves at the modules, leaving a measured amount in the 100-L tank. This ensures that the entire transfer line is full and the volumetric holdup is known. In this way very accurate determinations of volume transferred versus that received can be made. In practice, tests at the BNFP have quantified holdups and leaky valves at 100-mL levels indicating the sensitivities of measurement capabilities.

This solution still leaves a problem with quantitative measurements of plutonium, which represents a bigger overall problem. Very little can be done to make quantitative measurements of plutonium product in the solutions of the the storage area. Radiolysis and evaporation change solution volumes and concentrations, which make samples valid over short periods. More frequent sampling presents an operating challenge with respect to adequate mixing of the tanks and modules. It also results in large quantities of material in the

laboratory as samples. There is a hope that on-line concentration NDA capabilities can be applied, or perhaps conductivity monitors with density measurements can be used to supplement volumetric measurement techniques to provide the required safeguards capabilities.

In summary, there are a lot of potential problems associated with tests to detect the abrupt removal of 5 Fkg (2 kg of plutonium) from this area. Static tank monitoring and transfer quantity comparison are sensitive tests. Measurement capabilities suggest they are sensitive to removals of solutions containing only a few hundred grams of material. The problem will be with alarm resolutions. There are many administrative problems and a number of mechanical problems such as leaking valves or misvalving that will be encountered. The frequencies of occurrence and associated resolution capabilities for such problems are not yet quantified.

However, the sensitivity of the monitoring techniques to detect problems on the order of milliliters suggest that the abrupt removal of 2 kg of plutonium at a 99% power of detection or better, corresponding to ~8-L solution, is achievable. This high sensitivity implies a narrow null distribution and hence a small false-alarm rate. Alarm rates depend more on the ability to control transfer procedures. Alarm resolution capabilities rely on the ability to see holdup and observe changes in the holdup during subsequent transfers. Alarm resolution capability will dictate ultimate unresolved alarm rates.

5.4 ABRUPT LOSS-DETECTION SUMMARY

The modern large-scale reprocessing plant should be able to meet the single-space, single-time, abrupt loss-detection goal of the proposed rule. Several areas of the plant pose little concern with respect to meeting the goals. These include fuel receipt and storage and shearing and dissolution. Solutions in the feed preparation area and the codecontamination cycle pose little concern to safeguards because of the high radiation levels and low plutonium concentrations among high uranium concentrations. These are considered in safeguards tests because the solvent extraction process from input to product recovery is a single dynamic chemical operation, and some downstream tests rely on tests in the codecontamination cycle.

Process flow rates in a large reprocessing facility such as the BNFP approach 2 kg/h of plutonium. To achieve abrupt loss-detection sensitivities of 5 Fkg (2 kg of plutonium) tests must be applied on frequencies of 1 to 4 h. Evaluations of these tests on frequencies of 3 to 7 d provide timeliness. This frequency dictates a prerequisite that safeguards tests be implemented using computer-based systems interfaced directly to process instruments and use process control measurements.

The actual safeguards tests applied to the solvent extraction and product storage areas involve subdividing the process into several units. Special tests tailored to specific process conditions within these units are then applied.

Safeguards tests for the accountability and feed preparation areas use static tank monitoring and tank-to-tank transfer comparisons to achieve abrupt loss-detection sensitivity. Static tank monitoring is sensitive to a few liters of solution. In the head-end area, inventories are usually <2 kg of plutonium per tank. Tank-to-tank transfer monitoring tests can detect abrupt removals in the range 50 to 60 L during transfers between the

accountability and feed adjustment tanks. Abrupt removal of 300 to 500 L can be detected during transfers between the feed adjustment tanks and the HA feed tank. These provide loss-detection sensitivities of <1 kg of plutonium. Additionally, plutonium has not yet been separated from the uranium and highly radioactive fission products in these areas.

In the codecontamination and partition cycles the safeguards tests involve comparative parameter monitoring. Specifically, the tests use the principles of volume or mass balances. The tests take advantage of mass or volume flow rate measurements on streams that are independently remeasured downstream. In these areas, abrupt removal of a goal quantity requires the removal of 25% of the process flow over 4 h or 100% of the stream over 1 h. When the comparative monitor tests are applied at hourly or higher frequencies, they are sensitive to these removals.

It is difficult to assess the sensitivity of these tests and calculate false-alarm rates for two reasons. The first is a lack of extensive operating experience and safeguards evaluations in reprocessing facilities. The second factor is that remote, in-cell flow measurements are required. These measurements are characteristically precisely inaccurate. They are subject to sizable systematic errors. These systematic errors drift with time, and operating experience has not been sufficient to characterize these measurements in a reprocessing environment. Safeguards tests must be applied, and the goal quantity removals must be recognized within this dynamic measurement error structure.

In the final analysis, evidence indicates that safeguards detection of abrupt removals of goal quantities from the codecontamination and partition cycles should be detectable. At this point, the probability of detection should be at least 99%. However, characteristics of the particular measurements and the error structures are not sufficiently understood to determine false alarm rates for given probabilities of detection.

The mechanism for resolution of alarms as they may occur in the partition cycle tests is not well defined. Clearly, false alarms are going to result in the most part from significant system transients. The mechanisms for alarm resolution will center on identification that a transient did indeed occur. Resolution will depend on the lag-time effects on systems downstream as evidence of the transients to return to steady state.

Through most of the plutonium purification portion of the plant, abrupt removals of goal quantities are readily detectable. This is accomplished by further subdividing the plutonium purification portion of the plant into subareas. Process flow rates are still on the order of 2 kg/h of plutonium, and the abrupt removal over 1 to 4 h requires 100 to 25% stream removal. The actual sensitivity for tests in this area depends on the ability to understand and characterize flow measurements like those required for the codecontamination and partition cycles.

The BNFP tests concentrated on these measurements. Specific techniques to provide on-line calibration of these flow measurements were developed, implemented, tested, and refined over seven 1-week runs spread out over two years of testing. Mass-flow balance calculations, which involve flow and on-line concentration measurements, were computerized. Calculations were made on 16-min frequencies. Mass balances during steady-state operations were routinely obtained to ± 200 g/h on a 6-kg/h-of-uranium flowsheet. Assuming this performance can be achieved on plutonium flow rates of 2 kg/h, the abrupt removal detection goals of 5 Fkg (2 kg of plutonium) can be achieved.

The only subarea that presents a potential problem to meet the goal for abrupt removal detection is the area that includes the plutonium product concentrator, catch and sample tanks. The proposed test uses a material balance test around the area. The sizable inventory (40 to 80 kg of plutonium) and the lack of readily available concentration measurements (or capabilities to install on-line NDA instruments) somewhat limits the capabilities. However, capabilities demonstrated at the BNFP showed safeguards tests can approach a 2-kg detection capability for this area.

Tests for the various product storage tanks in the BNFP plant use static tank monitoring and tank-to-tank transfer monitoring. The static tank monitoring routines have been shown to be sensitive to removals of less than a liter of solution. This sensitivity implies a very high probability of detection for the abrupt loss, which involves about 8 L of solution. Piping holdups present the only difficulty with detection of removals during transfers. Transfer measurement capabilities are sensitive to losses of 2 to 3 L, which again suggests a very high probability for detection of abrupt removals of 2 kg of product material. Transfer procedures that contribute to variations in holdup in transfer piping make alarm rates high. However, monitoring sequential transfers provides resolution, and the unresolved alarm rate should be low.

6. MULTIPLE-SPACE, SINGLE-TIME REMOVALS: ADMINISTRATIVE CONTROL AREAS

The proposed upgrade rule specifies no limit to the number of control units into which a facility can be subdivided for abrupt loss detection. Loss-detection sensitivity, false-alarm rate, and loss-localization capability are key factors. Subdivision into many small units leads to a more difficult problem. An abrupt loss of less than goal quantities from each of two or more single locations may result in a total loss >5 Fkg and not cause an alarm in any of the individual areas.

The Reform Amendment includes the option to establish administratively controlled areas to provide a multiple area loss-detection capability. "Administratively controlled areas" as defined in the Reform Amendment are portions of the plant arrived at by subdividing the plant into groups of unit processes. The objective remains the detection of an abrupt removal, which for purposes of this report has been defined as a removal over a period of 1 to 4 h.

To meet the goals of the Reform Amendment where multiple administratively controlled areas are defined, the areas must be isolated to preclude personnel from having access to multiple areas. This presents a significant constraint for the generic reprocessing facility and the BNFP specifically.

The proposed rule requires the licensee to (1) "detect any abrupt loss of SSNM [strategic special nuclear material] accumulated from the unit processes within the plant or within any administratively controlled area. . . ", and (2) if detection within administratively controlled areas is elected, provide administrative or physical measures to protect against diversion of 5 Fkg from being accumulated from two or more administratively controlled areas.

The quantities of material on hand in a large-scale reprocessing facility and the measurements available suggest establishment of administratively controlled areas as the means to achieve the required area-detection capability. To meet the goals of the proposed rule, isolation of the administratively controlled areas can best be achieved by control of personnel access. Routine activities and responsibilities of the various operating personnel must be considered in designation of administratively controlled areas.

6.1 AREA DESIGNATIONS

Responsibilities and activities of the operating group must be considered. Instrument and maintenance personnel as well as administrative (including safeguards and security) personnel are expected to serve all areas. This should not compromise the concepts of

administratively controlled areas since their access should be limited in frequency and duration. This could surely be a point of discussion. However, for this discussion, it is assumed that these persons will not have the routine access to areas and equipment to effect the removals. Area personnel and radiation monitors offer a level of assurance concerning this assumption.

With the given assumptions, three separate administratively controlled areas can be defined. The first area involves mechanical handling from fuel receipt to shearing and dissolver charging, which includes hulls handling as well. The second area encompasses personnel and activities associated with chemical processing from dissolution through product measurement. The third area involves the plutonium nitrate storage area.

This designation is based on an analysis of operational functions. It is safe to assume based on BNFP experience and operating experience at other facilities like Nuclear Fuel Services (NFS) and Department of Energy (DOE) reprocessing plants, the operating group will have separate personnel for head-end and mechanical activities including fuel receipt and storage and mechanical processing prior to dissolution. A separate group usually has responsibility for chemical process activities ranging from dissolution to product measurement, storage, and loadout. The head-end group has the responsibilities to receive fuel and provide feed material. The chemical process group has responsibility to run the chemical plant and produce the product. The groups are usually separate and distinct involving different personnel who do not routinely move between the groups. In fact, a facility operating under NRC rule will require operators to be qualified for an area (from the perspective of performing MC&A functions), limiting the possibility of their transfer between areas.

Separation of mechanical processing and chemical processing activities with the inherent separations of operating staff is a logical basis for establishing them as administratively controlled areas. The only other consideration is subdivision of the chemical process area. The plutonium nitrate storage area deserves special attention. In the BNFP design this area consists of 48 slab tanks, each with a working capacity approaching 700 L. While this area is likely to be the responsibility of the chemical-process operations group, activities in this area are limited and access to the area can be tightly controlled.

During tests at the BNFP facility, the plutonium nitrate storage area was isolated from the rest of the facility. A computer-based access control system was in place to limit and record access to the area. A closed-loop control system was in place to limit and document material handling activities. In general, this area was under separate control from the rest of the chemical process area. These controls on personnel movement and personnel activities qualify this area for designation as a separate administratively controlled area from the rest of the chemical process area. Thus three separate administratively controlled areas are designated for a large reprocessing facility like the BNFP. They are the head-end, chemical process, and plutonium nitrate storage.

6.2 HEAD-END ADMINISTRATIVELY CONTROLLED AREA

The head-end area encompasses fuel receipt and the disassembly and chopping operations. Material control and accounting techniques applied within this area are item control for the most part with NDA for hulls measurements. Some NDA has been proposed for

spent fuel measurements, but these have not been widely applied and may serve better as signature measurements rather than quantitative techniques.

Diversion scenarios proposed are limited to removal of spent fuel assemblies, disassembly and removal of pins, or removal of sheared pieces through the hull-removal routes. All of these require removal of the plutonium in association with the uranium and fission products. High levels of radiation preclude routine handling of the material and make detection by normal area radiation alarms likely. Discussion of the removal detection capabilities is documented in the discussion presented in Sects. 3 and 5 of this report.

Tests required to protect the head-end area from the abrupt removal of 5 Fkg (2 kg of plutonium) by a multiple-area removal are trivial and indeed may not be required under the 100-rem/h exemption. The plutonium is in combination with uranium and fission products throughout. Removal of material in fuel assemblies or subassemblies requires massive shielded containers and transport vehicles to effect. While there is no way to quantify detection capabilities for security measures and area radiation monitors to detect unauthorized removals, the probability of detection is near 100% with a near-zero probability of false alarms.

Even during shear and dissolution, disruption of dissolver operations to "side pocket," and removal of significant material in hulls or by another route are not credible concerns. Since the chemical operators control dissolution and the head-end operators are responsible to charge and discharge dissolvers, removal requires a cooperative effort. The goal quantity of 5 Fkg (2 kg of plutonium) is ~10% of a nominal dissolver batch in a 5-MTU/d reprocessing facility. This quantity would be associated with 170 kg of uranium. The hull pieces for this amount of fuel would occupy >25 ft^3 and have the high inherent radiation levels that preclude easy transport. Area radiation monitors and routine security measures are sufficient for these considerations.

Combined removals of less than goal quantities from these areas are equally as detectable. The tests involved are the simple piece-count and item-identification methods and practical application of routine security and health and safety monitoring programs.

6.3 PLUTONIUM NITRATE STORAGE ADMINISTRATIVELY CONTROLLED AREA

The plutonium nitrate storage administratively controlled area has the same defined boundaries as the control unit established for abrupt removal detection. In the BNFP design and proposal for the generic large-scale plant, which incorporates storage in the design, this area can be physically isolated. Access to this operational area is through a limited number of portals that can be easily monitored. Access to the area is not routinely required, and during routine activities a limited number of individuals require access. Access can be controlled by locks. In BNFP tests, access was granted and logged by a computer system based on a level of previous authorizations of both personnel and activities.

Since this administratively controlled area corresponds to the control unit, the tests for abrupt diversion are the same as described in Sect. 4. The access control and operational control interlocks add to the detection sensitivities. The sensitivities of the material control tests are discussed in the previous section.

6.4 SEPARATIONS PROCESS ADMINISTRATIVELY CONTROLLED AREA

Excluding the head-end area and the plutonium nitrate storage area, the remainder of the separations process is considered as a single administratively controlled area. This encompasses chemical process activities from dissolution to product measurement. The process liquids range from the highly radioactive dissolver product with plutonium concentrations of 1 to 2 g/L to highly concentrated purified product in the 250 g/L and above concentration range.

The dynamic nature of the separations process with the interdependence of the various chemical systems necessitate a single organization with operating responsibilities. It requires continuous communication between operator personnel to keep the interaction of the various systems within operating parameters. Physical location of control and operating equipment precludes isolation of personnel to specific systems within the chemical process area. The entire area must be considered as a single administratively controlled area on the basis of personnel-control capabilities.

Section 3 of this report dealt with specific tests applied to various control units across the separations facility to achieve a 5 Fkg (2 kg of plutonium) abrupt loss-detection sensitivity. Individually, these areas can achieve the desired sensitivity, but many are close to the limits of detection. Adjusting alarm limits to achieve specified alarm rates and reach a sensitivity of 5 Fkg for the combination of tests on an area basis is not possible for the separations area of a large-scale reprocessing facility.

Analysis of tests and sensitivities to the multiple-space, single-time abrupt removal must consider the material forms involved. Tests with overlapping boundaries must be considered. There is a certain reliance on area radiation monitors to be considered. There are also certain practicalities to consider involving removal of aqueous and organic solutions to obtain the goal quantities, or removing a series of solutions with concentrations ranging from 10 to 250 g/L of plutonium. Likewise, consideration should be given to the equipment and manpower required to extract material from a remote cell whose doors cannot be opened. The problems associated with moving that material out of access aisles if and when it is removed from the cells are also important considerations. All of these factors contribute to detection sensitivities but in a very indirect way. It is difficult to include these factors in sensitivity and false-alarm calculations.

The thrust of this discussion will be directed at tests that can be conducted in addition to the abrupt loss tests described in Sect. 4. Based on results from tests at the BNFP, projection of detection sensitivities for these additional tests are made. However, it is not clear how these additional tests combine with abrupt removal detection probabilities and false-alarm estimates. The unquantifiable contributions of physical constraints and area monitors are also not easily included in sensitivity estimates.

6.4.1 The Material Balance Test

While previous discussions have subdivided the separations process to achieve abrupt removal sensitivity, the capabilities of material balance tests across the conventional material balance boundaries should not be ignored. The concept of near-real-time accounting using this entire material balance area should be considered and developed.

Near-real-time accounting, in this context, implies that a book inventory representing the total material that should be in the control area, based only on input and output transfers, is maintained in near-real-time. This means that the current book inventory is always available and continuously updated as transfers into and out of the area are made. The current book inventory reflects the best available measurements for the various transfers. It does not necessarily wait for the best accountability measurements to update book inventories. Best estimates are used. Any book inventory includes a mixture of best estimates and final accountability results. A book inventory requested at a later time may also reflect adjustments made for final accountability measurements.

In a large-scale reprocessing facility, the nature of this current book inventory using a mixture of the best estimates and accountability measurements is important. To achieve timeliness of detection and sensitivities, most tests are conducted at frequencies of 1 to 4 h. Timely analysis of test statistics must be made. Best estimates must be used in many cases since accountability results may be delayed for days. The analysis cannot be delayed to accommodate these results.

The near-real-time accounting test obtains the current book inventory and compares the book to an on-line, in-process inventory. This in-process inventory is necessary to achieve the frequent material balance closures and test statistics required for the removal detection tests. With the frequencies of closure required for a large-scale facility such as the BNFP, the in-process inventory technique must be computer based, automatic, and totally transparent to operations. It cannot be tied to prerequisites that constrain operational activities. It must use available measurement information, including process-control data, and available sample results. It includes calculations and best available estimates of inventory quantities.

Maintenance of a computerized near-real-time book inventory is the lesser problem, although by no means a trivial problem. However, the more difficult aspect of near-real-time accounting is measurement of the in-process inventory. Specifically, the problem is to make this measurement in a timely manner without constraints on operational activity. Some pioneer work was done as a cooperative effort between the United States, Japan, and the IAEA at the Tokai plant, which is a 200-MTU/year facility. Throughput and IAEA inspection constraints led to an effort to provide closures on a weekly basis. Attempts were made to measure in-process inventories at optimum times when process conditions were favorable. It timed inventory measurement to plutonium product concentrator activities and used a series of concurrent samples for inventory determination.

This approach has merits in that it maximizes inventory measurement capabilities. However, it constrains the operating organization as well as safeguards to make the measurements at the proper time. It also provides data only weekly. In a large-scale facility throughput quantities are large, and weekly tests for abrupt removal lose timeliness and sensitivity.

To be effective for a large-scale facility such as the BNFP, inventory measurements and material balance closures should be performed daily or perhaps hourly. To achieve these capabilities, the inventory measurements and material balance closures must be computerized, automatic, and cannot rely on a series of timely samples under optimum conditions. In this analysis, it is assumed that a computerized data-handling system interfaced to process measurement instruments and the laboratory for sample results is in place and available for material balance calculation and data analysis.

6.4.2 Inventory Measurement Capability—The BNFP Tests

Demonstration of in-process inventory measurement capabilities had been the subject of development and tests at the BNFP for several years, starting in 1978. Throughout these tests, natural uranium was used as a surrogate fuel in the plant systems. It presents some difficulty to extrapolate results from these tests to an operating facility with uranium and plutonium. However, much attention was focused during the tests to use methods and procedures applicable to routine operations.

Throughout the tests, the plant systems were operated by introducing an initial charge of nonradioactive feed material. Product materials were accurately measured as if it were true product, but was then recycled back to the input tank to provide additional feed. The net effect was that the initial charge of material remained in the plant systems, reduced only by the small amounts measured and removed in the waste streams. The actual plant inventory was available based on the initial charge reduced by waste removals. This gave an accurate inventory for comparisons with measured in-process inventory quantities.

This presented a unique opportunity to develop in-process inventory techniques and evaluate measurement performance. The measured inventory could be compared to the known on a routine basis to estimate the accuracy and precision of the in-process inventory measurement directly. The first tests were applied during runs involving the entire separations facility during 1978 and 1979. Many of the measurement and calculation techniques for inventory measurement used in later tests had not been developed. This first application did not include methods of pulse-column inventory estimation. Later tests showed the operational characteristics of plant instrumentation. A method of on-line calibration for these devices later improved measurement accuracies from these instruments by a factor of ten. This had not yet been implemented during the 1979 runs. Many of the on-line concentration estimation techniques that proved so accurate and valuable during later tests had also not yet been developed and implemented.

With the methods and instruments available at the time of these initial runs, 62 determinations of in-process inventory were made during the 1979 tests. Comparisons of these measured inventories to the known values based on the initial charge showed a standard deviation of ± 383 kg of uranium on the total of ~ 12 MTU inventory. This translates to an inventory measurement uncertainty of $\pm 6\%$. This is without the benefit of the various measurement improvements developed during later tests.

Most of these refinements that later became available respond to process changes. For instance, column inventory estimators allow for inventory measurements to reflect small changes in quantities as flow conditions are adjusted. These 1979 tests included periods of special tests where operational conditions were altered to test plant and equipment performance limits. These tests resulted in a number of upsets and process transients. The missing refinements in the inventory measurement program were those designed to respond to just these kinds of upsets. Thus conclusions drawn from these data concerning inventory measurement capabilities reflect some process transients as well.

Making the assumption that transients can be followed with the refinements that have been developed, periods of steady-state operations during these tests were examined. There were two such periods during process throughput rate tests where steady-state conditions existed. These periods show normal variations in the typical surge points but unmeasurable

locations such as columns were very steady. During both of these periods the standard deviation of the differences between measured and actual inventories was on the order of 150 kg of uranium on the total inventory of ~12 MTU. This translates to an uncertainty of $\sim \pm 2.5\%$ for the on-line inventory measurement.

These tests were based on uranium only. Every effort was made to use routinely available plant equipment and not rely on special test instruments. There was a serious attempt to use measurements and estimation techniques that are applicable to hot operations in a plant with radioactive mixed solutions of uranium and plutonium. Still, extrapolation of these test results to plutonium measurements across the entire facility during operations is difficult. A gross assumption is that equivalent relative performance is achievable on the plutonium inventory. As discussed later, this may not be all that bad of an assumption.

Estimates of actual plutonium inventory vary considerably for an operating reference facility like the BNFP. Inventory throughout the feed preparation and codecontamination and partition cycles is likely to be 20 to 30 kg. The plutonium purification portion of the plant is likely to have another 30 to 40 kg. The remainder of the inventory will be in the plutonium product concentrator (15 kg), and plutonium product catch and accountability tanks. At any one time, these product tanks will likely contain upwards to 50 kg of concentrated product. An additional quantity of material may reside in interim product storage tanks included in the BNFP design. During normal operations, these quantities will be well-characterized product solutions and not a part of the in-process inventory measurement problem. A total of 100 kg of active inventory is likely for the typical plant.

With the assumption that results of the 1979 tests indicate potential for in-process plutonium inventory measurement, a measurement uncertainty of ± 2.5 kg is expected. This estimate is based on the observations during steady-state operations. It assumes that the advanced techniques developed in years subsequent to the 1979 tests will have the desired effects on measurement capabilities.

Attempts were made to confirm these assumptions during subsequent tests in 1980 and 1981 at the BNFP. Budget constraints precluded operation of the full solvent extraction cycle for test demonstrations. However, slight modifications were made to allow operation of the plutonium purification portion of the plant on a closed-loop cycle. Like the previous full-plant tests the product solutions were collected and recycled, but only to the start of the purification cycle.

Seven such miniruns were conducted. Among other tests, a program to measure the in-process inventory was implemented. Inventory measurements were made on an hourly basis. The test concentrated on making these computer-based measurements totally automated and completely transparent to operational activities.

During these tests, a program to provide on-line calibration of process instruments was implemented. Several on-line concentration measurement methods were tried. Also, detailed studies of pulse-column inventory estimator techniques were conducted.

Inventory measurement performance capabilities were still rated by comparison to the known inventory. For these miniruns an initial charge of ~400 kg of uranium (as a substitute for plutonium) was used. The inventory measurements were compared to the initial charge. One complication with the minirun configuration was in the area of waste measurements. Unlike the previous full-plant runs where waste solutions were measured batchwise prior to transfer from the MBA, waste solutions from the plutonium purification cycle

columns were continually collected and evaporated over the full week of operation. Only at the completion of each run was the concentrator emptied and waste measurements made. This was a minor problem for comparison of inventory measurements to the known. It represents a continuous removal. As the runs progressed, the continuous inventory measurements and various analysis techniques were used to quantify these combined waste streams.

By the conclusion of the minirun tests, the performance of repeated inventories showed a standard deviation on the order of 7 kg. This was based on repeated comparisons of the measured to the known. (This translates to a capability of ±3.5%). This was over an entire one-week run with normal process variance. This is roughly the same magnitude (as a percentage of inventory) as indicated by the earlier tests over brief periods of steady state. Refinements and additional measurement techniques enabled inventory measurements to follow normal process variations.

A final test at the BNFP was to be implementation of the in-process inventory measurement program across the entire plant with all the refinements and improved measurement techniques developed during the miniruns. Unfortunately, funding for this run was not available, and the BNFP was closed before the test run could be accomplished.

Based upon results of the 1979 test, and reinforced by the minirun tests, it is projected that on-line in-process inventory measurement accuracy will be on the order of ± 4% relative to total inventory, with the nominal holdup of 100 kg of plutonium. This translates to ±4 kg.

6.4.3 On-Line Automatic Calibration in the Inventory Measurement

Any program of near-real-time accounting and the associated in-process inventory measurement applied to a dynamic facility like a large reprocessing plant must rely on many process control-type instruments. While highly accurate devices are available, the associated high initial costs limit their use to very special applications. They are also usually sensitive to environmental conditions and temperature, humidity, and vibration in operating galleries, which also limits their application.

One of the more interesting results of test runs at the BNFP was the development of a computer-based system to improve the accuracy of normal process control differential pressure instruments. This automatic calibration system, or autocalibration, was discussed in Sect. 4. However, the importance of this development as it relates to the in-process inventory measurement as part of the near-real-time accounting must be stressed.

On-line calibration of the differential pressure measurement devices provides a significant improvement in inventory measurement capabilities. To put the effect in perspective, consider the problems associated with measurement of solutions in the 12,000-L HA feed tank in the BNFP design. During routine operations this tank may contain anywhere from 400 kg of uranium (4 kg of plutonium) up to 4 MTU (40 kg of plutonium). Routine instrumentation has been shown to exhibit nonlinearity. The net effect may be a positive bias of 5% at the upper end. In this example, simply filling the tank would show an apparent loss of 200 kg of uranium (2 kg of plutonium) in the inventory measurement as the tank emptied.

The method of on-line calibration was demonstrated to eliminate these effects. As part of this program, individual instruments were brought to the testing laboratory. The nonlinearity of the specific instruments were characterized and described by a polynomial before installation. The instrument outputs were interfaced to a computer system. Readout was interpreted with the specific polynomial relationship rather than with the traditionally assumed linear relationship.

In addition to nonlinearity, the on-line calibration program compensated for drift in the instrument. This computer-based program controlled solenoids to switch a highly accurate device in parallel to individual instruments. This located the output curve and eliminated the effects of calibration shift.

The cost of this installation was ~$100 per device on top of an estimated $700- to $900-initial instrument cost. The net effect was to improve the process control devices from instruments capable of 5 to 10% performance to instruments capable of 0.5 to 1.0%.

There was no attempt during the BNFP tests to quantify the effects of such an application on overall in-process inventory measurements. However, Table 6.1 shows the effects as applied to a single device over a period of time.

For the test shown in the table, a high-accuracy measurement was applied in parallel to the subject process control device. The table shows comparative readings every 2.5 h. The process control device (TAY) was read with (CO) and without (UN) the autocalibration corrections. The high-accuracy device used for comparison of the level measurements on the left of the table was a RUSKA electromanometer. These level measurements and comparisons are in centimeters of water. Of particular interest is the sizable bias of the uncorrected readings and that the bias is quite different at the various levels of reading. In the upper ranges, the bias is nearly 5 cm. In the middle ranges, it is 2 to 2.5 cm. At the lower ranges, it is 1.5 to 2 cm. This is the result of the nonlinearity of the raw transmitter output. The comparisons to corrected numbers reflect the improvements to be realized.

Density measurement comparisons are also shown in the table. Again, the comparisons are made to a high-accuracy electromanometer measurement in parallel. Additionally, these densities are used in a relationship to predict uranium concentrations (UCALC). These comparisons are shown on the far right of the table. Often, these concentrations are used for in-process inventory measurements. These comparisons show the levels of effect these measurements can have on inventory measurements.

Autocalibration probably is not necessary on all instruments. For the final tests as planned for 1983, which were never executed, a detailed look was taken at all measurements to be used in the in-process inventory. The specific application of each measurement and associated quantities of material involved were rated. There were ~30 instruments selected that required the level of measurement achievable with this system. Thus this program of autocalibration provides a reasonable alternative to high-priced equipment to provide safeguards level measurements for the near-real-time accounting application.

6.4.4 In-Process Inventory Measurements in the Material Balance Analyses

As previously noted, while in-process inventory plays a major role in near-real-time accounting, the current book inventory is required for material balance closure. In this particular case the balance is across the entire separations area. The goal is to detect abrupt removals from the administratively controlled area defined to include the full separations plant.

The goal during BNFP tests was to achieve capabilities for hourly in-process inventory measurements. Batch quantities, surge capacity, and throughput dictate approximately three input batches per day. A single plutonium product batch per day can be expected. One or two waste solution batches should be expected. Thus, while there will be 24 material balance closures, a maximum of six will have to deal with actual input/output measurements. This certainly has an implication for safeguards detectability since most closures involve only two inventories.

It is interesting to develop the implications of this situation. A material balance period that includes no additions or removals involves a material balance calculation with only two measurements of inventory. If the measurement uncertainty for inventory determination is assumed to be ± 4 kg of plutonium, propagation of errors for the two inventory measurements gives a detection sensitivity for the material balance of $\pm$ 5.6 kg of plutonium.

It is projected that input and product measurements can be made to $\sim \pm$ 0.5%. This requires accountability level measurement capabilities and analytical results to achieve this accuracy. These are usually delayed by several hours or even days. To achieve timely detection, a process control analysis may be used in place of the accountability number. While there is little practical experience reported with this type of analysis, tests at the BNFP indicate $\pm 1.0\%$ may be achievable for timely results. Indeed, the process control method that relates the acid density to concentration developed and tested at the BNFP showed an accuracy of 0.5%. Similar results should be achievable for process control measurements during actual operations, particularly for product solutions.

Assuming the 1% level is achievable for input measurements, this translates to an uncertainty of ± 1.6 kg of plutonium for a nominal input batch. For a material balance closure, which includes an input batch and two inventories, the combined removal detection sensitivity for the period is around 5.8 kg of plutonium. A similar sensitivity would be calculated for a period covering a product transfer even if somewhat better analytical capabilities were assumed.

The sensitivities associated with periods that include waste transfers are similar to inventory-only periods. Waste transfers are likely to contain only a few hundred grams of plutonium and accountability level measurements are made prior to transfer because of economic and contractual obligations to minimize waste quantities.

The point of this discussion is that with the frequent closures, there is not likely to be input product and waste batches all contributing to material balance uncertainties for a single closure. The inventory measurement uncertainties dominate the individual closures. A high percentage of the material balance closures involve only inventory measurements.

When there is a removal or addition, the uncertainty and sensitivity to removal are not much different. With the assumption about inventory measurement capabilities, an abrupt removal detection sensitivity of 5 to 6 kg of plutonium seems achievable for the entire separations process administratively controlled area.

6.4.5 Additional Considerations

The separations facility contains solutions that range from low concentration (1 to 2 g/L of plutonium) highly radioactive dissolver solution to highly concentrated (>250 g/L of plutonium) purified product solution. A 5 Fkg (2 kg of plutonium) removal from the front end of the process requires removal of 1000 L of highly radioactive solution with an associated weight of >3 tons. After fission product removals, the volume and weight of solution required to achieve the goal removal is even greater and still requires separation from the associated uranium. Throughout the remainder of the separations cycle up to the plutonium product concentrator, plutonium concentrations do not exceed 40 to 60 g/L. This still requires removal of 30 to 60 L of solution weighing 60 to 100 lb. Only after product concentration does the concentration exceed 250 g/L where the goal quantity is <8 L. The weight is ~15 lb, and it occupies <0.5 ft^3.

A practical approach to administratively controlled area removal detection sensitivities must consider these physical aspects of the goal quantities as well as a general consideration of the potential removal routes. Process equipment for the chemical separations portion of the BNFP is contained in five process cells. These cells are heavily shielded with access only through shielding doors at the bottom or by removal of shielding plugs at the top. There are no penetrations through the cell boundaries to operating galleries that routinely carry significant quantities of SNM, other than product tank transfer lines. The doors and shielding plugs cannot be opened while the cell ventilation system is operating without extraordinary equipment. Direct access to equipment in the cells is not credible under operating situations. Opening these cells would disrupt operations and alarm cell-pressure measurement devices.

There is a single exception in the BNFP design. The plutonium product transfer pumps are located in a cell niche within the plutonium purification cell. This niche is isolated from the remainder of the cell by a routinely closed door. Access to the niche is through a normally closed cell door. Routine access to the area is not permitted, but periodic maintenance entries may be required.

For the most part, samplers do not represent a potential removal route for abrupt removals. In the BNFP design, samplers deliver solutions at rates in the range of 100 mL/min. Samplers are located in glove boxes or sample cells. Hundreds of sample bottles are required to accomplish the 5-Fkg removal, even with product solution. In the case of on-line monitors where flowing sample streams are accessible, the flow minimizes available quantities. Product streams present the worst case. Where the goal quantity of product solution occupies 8 L, 80 min of sample flow at 100 mL/min are required.

The current BRET design calls for a remote sampler system that performs all sample operations in-cell with no penetration of sample lines outside the cell boundaries. This contributes to the safeguards effort. With this remote vehicle for sample taking, only single sample bottles are available and the sample schedule must be programmed. If this feature is incorporated in plant design, samplers are not a consideration for removal of material.

The BNFP design incorporates five process cells. Accountability feed preparation, codecontamination, and partition take place in the center cells. Plutonium purification equipment is at one end of the plant with uranium product at the other. Thus, equipment for plutonium purification activities are physically separated in a different cell than the front-end activities. Samplers and process lines for the plutonium purification cell are grouped near the cell with samples located in a glove box. Equipment and samplers for the front-end activities are grouped further down the process building with the samplers in a separate sample cell. While the operating aisles are continuous, equipment for the two process areas are separated by ~20 ft corresponding to a cell and equipment associated with intermediate-level waste activities.

This has an implication for the multiple-space, single-time removal scenario. Since process lines are the focus of attention as the only credible abrupt removal routes, and considering the equipment necessary to remove material through process lines to overcome the inherent head pressures, simultaneous removals from the two main areas separated by this distance increase the problems for a potential diverter.

Thus additional tests for the multiple-space, abrupt-removal, use-overlapping control units. Again, it is not clear how an additional overlapping test can be used to calculate probabilities of detection and alarm frequencies, but there is an inherent improvement over the single test that covers the entire separations area.

Section 6.2 discusses tests at the BNFP that indicate on-line inventory measurements can be made at hourly frequencies with accuracies of 3 to 4%. For a test using the full separations plant, propagation of errors shows the balance test should be capable of detecting 5- to 6-kg abrupt removals.

Material balance tests at the BNFP centering on the plutonium purification portion of the plant show similar capabilities. The relative errors observed for throughput and inventory measurements were similar to these observed during full separations plant tests. The plutonium purification portion of the plant, from 1BP to product measurement (excluding interim storage) should contain ~80% of the total inventory. Both full-plant and limited-plutonium-system tests use the same in-process inventory measurements. Subdividing the plant at the 1BP stream requires integrated flow measurements at the 1BP stream as the input to the plutonium purification control unit. These integrated flow measurements will not match the accountability level input batch measurements associated with the full-plant test. However, with hourly material balance closures, the throughput quantity is small. The absolute uncertainty of the input measurement contributes little to the overall uncertainty of the material balance test statistic. An uncertainty of 5 to 6 kg of plutonium should be achievable for this subarea.

A final consideration is given to the interim product storage tanks, also a part of the chemical process administratively controlled area. As discussed in Sect. 4, sensitivities for this area to abrupt removal are on the order of a few hundred grams.

The above three tests can be combined for the administratively controlled area removal detection test. They provide overlapping test comparisons. As with most of the other safeguards considerations for reprocessing facilities, there is little data to support definitive calculations of alarm rates, detection probabilities and alarm resolution techniques that influence false-alarm rates. However, a combination of the full separations plant balance test, the plutonium purification cycle-control unit test and the interim-product-storage-tank test provides maximum sensitivity.

6.5 MULTIPLE-SPACE, SINGLE-TIME, LOSS-DETECTION SUMMARY

In the modern large-scale reprocessing facility such as the BNFP the possibility for removal of <5 Fkg from several areas to achieve a 5-Fkg removal can be minimized by establishing three administratively controlled areas. The fuel-receipt and mechanical-process area is the first, plutonium nitrate storage is the second, and chemical processing is the third. This structure is suggested by the nature of the operations and operator license requirements, which segregate operator groups to these areas.

Safeguards tests to achieve the detection goals within these areas are not difficult for the first two. Simple extensions of the single-space, single-time, abrupt loss-detection tests as discussed in Sect. 4 accomplish this goal. It is not likely that the 5-Fkg detection goal under the multiple-space, single-time consideration can be achieved for the chemical process area, however.

The tests to be applied to the chemical process section involve combined tests with overlapping control units. The actual sensitivity and false-alarm rates cannot be accurately predicted based on demonstrated capabilities. However, based on tests at the BNFP using natural uranium as a surrogate fuel for plutonium, it seems that a sensitivity to removals of 5 to 6 kg of plutonium (compared to the 2-kg detection goal) can be achieved over a control unit established across the entire chemical process area. Similarly, a detection capability of 5 to 6 kg should also be achievable on a control unit from the partition cycle to the plutonium product. These detection capabilities are combined with capabilities to detect removals in the order of a few hundred grams from the interim product tanks. These are overlapping control units.

There is contribution to the overall detection probability associated with the physical aspects of accomplishing these removals from separate locations in the plant given the remote processing operations involved. Also, the varying degrees of attractiveness of the various solutions, considering concentration, purity, and radioactivity, contribute to the low probability of simultaneous removals from several areas.

There is no apparent method to combine these considerations into a single definitive statistical test evaluation. It is apparent that a removal of 5 to 6 kg of plutonium, compared to the 2 kg of plutonium detection goal can be achieved. The practical considerations involving material attractiveness and accessibility, if they could be combined, could easily contribute to meeting the detection goals. Ideally, a sensible approach considering all aspects of detectability, attractiveness, and physical barriers to removal suggests the multiple-space, single-time removals may be detected in the reprocessing plant.

7. RECURRING LOSS DETECTION: SINGLE-SPACE, MULTIPLE-TIME REMOVAL

High-frequency, near-real-time material balance accounting is intended to make rapid assessments for timely detection of abrupt removals. Abrupt, as defined in the proposed rule, means the time interval between sequential performances of material control tests that cover the material in question, or a 4-h period, whichever is longer. For the reprocessing plant that is the subject of this discussion, the period of time is considered to be 4 h, and tests are often performed hourly. The proposed upgrade rule requires detection of this abrupt removal within seven calendar days for most reprocessing plant material. Separated plutonium solutions are considered class 1A and require detection of abrupt losses within three working days of a loss. Throughout this report the goal has been to isolate losses within a 4-h period and make the judgment within 3 d of the time it occurs.

Beyond the question of abrupt removal detection, there is concern about the potential for recurring losses of less than abrupt removal goal quantities. Recurring losses can be postulated to occur under a wide variety of scenarios. This document cannot address all of these various scenarios. In this report, it is assumed that a recurring loss is one that occurs at a relatively constant rate over a period of concern.

The proposed rule requires recurring loss-detection methods to be implemented. For each unit process, at least every seven calendar days, measurement data accumulated since the last cleanout of the unit process must be evaluated. Under area detection capabilities the rule requires tests for the entire plant or for each administratively controlled area. These tests are required at least every 7 d for data accumulated over the most recent 60 d of operation. Each evaluation must be able to detect a recurring loss with 90% power of detection. The proposed rule allows for the goal quantity to be as low as reasonably achievable.

Statistical tests often proposed to detect recurring losses range from cumulative effects tests like CUSUM to the recursive predictive techniques like Kalman filtering. Inferences using these techniques are usually based on the assumption that the expected value of the test statistic is the mean of a normally distributed variable. In the case of a control unit material balance test, this assumes the expected value of the inventory difference is zero. In the case of a recurring removal of material, the series of inventory differences will show an apparent shift from zero. The sequential material balance tests are selected for their sensitivity to detect this shift.

Safeguards applications in large-scale reprocessing facilities such as the BNFP apply these sequential tests across a series of control units to achieve sensitivity to the recurring loss. These are the same control units used for abrupt loss detection as described in the previous sections. These control units are often drawn across dynamic process boundaries. They often rely on process control-type measurements.

7.1 RECURRING LOSS DETECTION AMONG SYSTEMATIC EFFECTS

Despite efforts such as the automatic calibration system, these data are subject to small systematic errors. These systematic effects generally show the same behavior as actual removals if not accounted for in the analysis. Thus, the safeguards effort encounters a problem in recognizing recurring losses in the presence of systematic and other process effects.

The term "systematic error" implies the existence of a bias that persists over some period of time and may change with time. It is very difficult to define these effects well. This question was the focus of considerable attention during the 1980–81 test runs at the BNFP.

Seven test runs were made over the two-year period. Each run lasted about one week. There was an effort to characterize the systematic effects of a number of measurements during these tests. It was found that the systematic effects (or biases) could be characterized during each of the runs and were constant over the one-week run period. However, the net systematic effect (or apparent bias) would be considerably different for the same measurement over different runs. This is certainly not a conclusive test but suggests that some systematic effects are constant over periods of a week but do change over longer periods.

The proposed regulations require weekly recurring loss-detection tests covering data over a much longer period. This means that the safeguards tests must deal with detection of actual recurring losses that may be indistinguishable from systematic errors. This detection must be made among continually changing systematic errors.

The problems of recurring loss detection were evident throughout the BNFP runs during 1980–81. Several recurring loss tests were performed during these runs where material was actually removed from process equipment under various scenarios to test sensitivity of measurements and detection techniques. These protracted removal tests involved removal of ~8 kg of material over periods ranging from 4 to 40 h.

The loss-detection tests usually involved material balances constructed around specific control units within the plutonium purification system. These usually required measurement of flowing streams by integration of flow and concentration over time. Flow measurements are difficult and subject to sizable systematic effects. Balance equations also require measurement of waste streams, which usually contain low concentrations (<1% of throughput).

Data collected during the test runs were submitted to analysis to detect the various test removals. Results indicate that the measurements were sensitive, and virtually every protracted removal was detected. However, almost universally, the tests indicated removals greater than actually made. In general, these differences were attributed to measured waste streams since the on-line waste stream monitors were not effective in measuring the waste stream concentrations. In reality, these overestimates were a combination of waste stream effects and the combined systematic errors.

How sensitive are the tests to actual removals? What characteristics do measurement data exhibit that affect recurring loss-detection capabilities? The remainder of this section is devoted to answering these questions.

7.2 THE 2A COLUMN CONTROL-UNIT BALANCE TEST

During the BNFP tests considerable effort was directed at understanding process measurements associated with control units established within the plutonium purification portion of the plant. The simple problem of closing a mass balance around various control units under steady-state provides answers to questions about safeguards capabilities. One of the control units established for the tests was drawn around the 2A column.

On the surface, the balance around the 2A column control unit appears simple. Input to the control unit is measured. Flow measurement is available from an in-line flowmeter. During the BNFP test, which used natural uranium as a surrogate fuel, concentration was available from a density-acid relationship. Density was measured in the tank and acid concentration was available from an in-line conductivity monitor. The input quantity for the control unit is the integration of flow and concentration over time.

These are all process control measurements. Fortunately, backup measurements are available for each of these. A tank dropout rate for the tank that feeds the system was available at times when there were no other additions to the tank. This is a more accurate measurement of the feed rate, but it is only available for limited periods of time. It was found that this measurement could be used to correct the flowmeter measurement for apparent biases (or systematic errors). During the seven miniruns, this correction was usually in the range 2 to 10% with one exception where it was 40%. For the miniruns lasting approximately one week each, the observed bias was constant over the week but was significantly different between runs.

The acid- and density-based concentration measurement was calibrated by routine process control samples that were drawn on frequencies of ~8 h. These comparisons also resulted in calibration adjustments of 2 to 5% in the density measurements and 0.1 to 0.5 *N* in the on-line acid concentration measurements. Translated to solutions with concentrations in the range 40 to 60 g/L, these systematic (bias) corrections can change the results by almost 100%. Once corrections were applied based on the comparative measurements, concentrations to within ±5 g/L and flows to within ±10 L/h were achieved. As noted before uncertainties are assumed to represent the 95% confidence interval about the measurement.

To establish the output for the control unit, the clean organic stream, 2AX, was measured. Plug flow was assumed, and the organic product flow was taken to be this measurement with an adjustment for volumetric increase due to the heavy-metal product picked up. Concentration of this product stream was available based on the density measured at the top of the 2A column. The on-line density measurement used in the concentration calculation was a process control measurement subject to systematic effects. The measurement can be calibrated to routine process control samples pulled at a frequency of ~8 h during the BNFP tests. Correction factors ranging to ~ 8% were required on the density instruments used for this concentration estimates during the tests. These corrections had 10- to 20-g/L effects on the concentrations.

For this particular exercise, the waste stream concentrations were based on routine (8 h) samples. The sample result was assumed valid over the entire 8-h period. Waste stream flows were assumed to be the same as the measured aqueous feed rate.

Thus, feed flow was measured and calibrated to a dropout. Feed concentration was available on-line and calibrated to periodic samples. Waste flow and concentrations were available. Product concentration was measurable on-line and calibrated to samples. The only significant measurement without backup calibration was product flow, and based on other flow measurements, the systematic effects with this measurement are potentially significant. For the BNFP tests, the balance was forced by adjustments to the measured 2AX flow. Using this procedure, systematic effects can be removed.

To demonstrate the sensitivity of measurements, some data recorded at the start of one of the test runs are shown in Fig. 7.1. The test was to use the mass-flow measurement data recorded during the startup of the 2A column to calculate the total inventory of the column. Figure 7.1 shows the results of this test.

Natural uranium was used in this test. In the figure, H represents total kilograms of material inventory (holdup) and O and I represent the measured mass-flow rates of the column output and input stream respectively. The inventory is calculated from an integration of the mass flows over the time periods indicated. The data were recorded over 16 h during startup. The column was fully depleted at the start with cold chemical streams flowing.

The data clearly show the column loading during startup. As feed is started, the data show the input mass flow with no measured output flow. The holdup increases and after about 2 h some output flow is detected. The integration of mass flows continues as the product mass flow increases. As the measured product flow approaches the input flow, column equilibrium is neared. The calculated column inventory quantity reaches a maximum of ~20 kg as the measured input and output mass flows reach equilibrium.

Tests at the BNFP also measured actual inventory of columns by stopping operations abruptly, draining the column contents and measuring the solutions. Results of these tests compared well with the estimate from this analysis. The important point is that mass flows were accurately measured to obtain the estimate. The methods used to obtain measurements and calibrate the instruments resulted in mass-flow measurements that came to equilibrium and accurately reflected actual column inventory.

Following this analysis through the remainder of the 16 h shows the calculated inventory decreases by 1 to 2 kg. Operations were very steady through this period, and the actual inventory should be relatively constant. It is likely this slight decrease is a reflection of the accumulation of remaining systematic effects.

Throughout the BNFP tests, this technique of on-line calibration of the various measurements was used to generate mass balances for the four columns in the plutonium purification cycle. Similar mass-balance exercises were performed for all the columns. Extended analysis of these data show mass balances could be closed to within 100 to 200 g/h. This is interpreted as an indication that systematic effects could be routinely reduced to this level. However, for the 2A column balance over 12 to 16 h, this systematic effect adds to better than 2 kg of material in a cumulative analysis.

These tests show that a carefully applied measurement control program can provide measurements capable of closing mass balances around dynamic control units to within a few hundred grams per hour. During the BNFP tests, flowsheet conditions were ~6 kg/h. It is assumed that 100 to 200 g/h represents the capability of the mass balance

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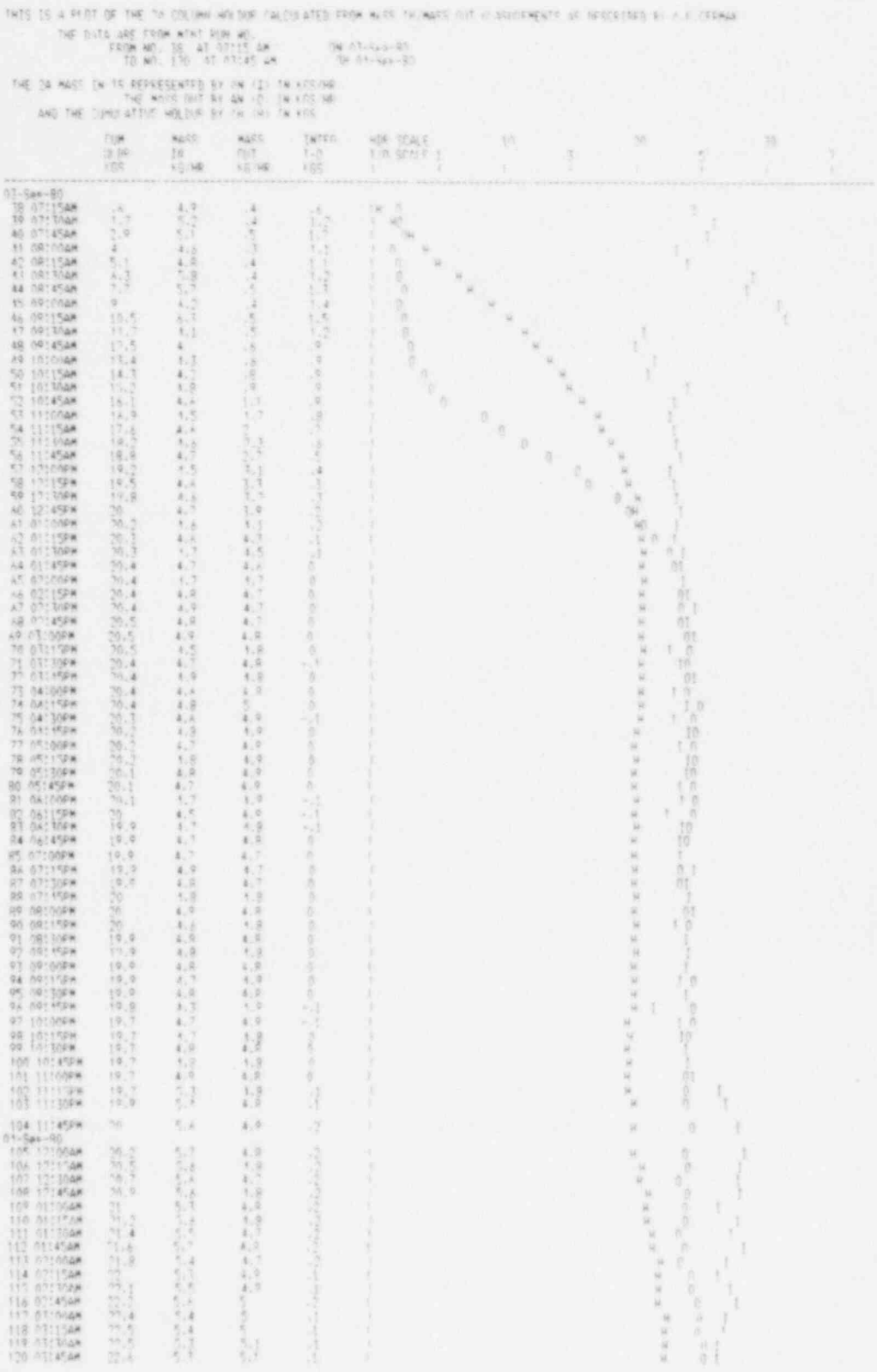

Fig. 7.1. Measurement sensitivity in BNFP tests.

measurement. Statistical analysis of individual measurements can be made. However, the complexity of the on-line measurement control program required to achieve the performance observed makes propagation of errors difficult.

7.3 MEASUREMENT QUALITY IN THE STATISTICAL TESTS

Recurring loss detection requires the use of sequential test methods. These tests are adequate when data are normally distributed and well behaved. There continues to be a need to understand the effects of covariances, systematic errors, and biases on these tests. Systematic effects and the problems of error propagation in view of the complex interaction of the various measurements were discussed above. Another serious question involves the effects of spurious measurements on the analysis techniques.

A major finding of the BNFP tests was the high frequency of data spikes. These result from explainable process activities such as pneumatic dip-tube probe difficulties or other measurement system upsets. Erroneous lab results and on-line instrument problems or simply unexplained electronic spikes in instrument interface loops also produce spurious signals. With the on-line, high-speed data collection and analysis activities necessary to support safeguards tests in the large-scale reprocessing facility, these spurious signals are frequent.

In the safeguards application, the spurious signal produces a residual effect as well as an instantaneous problem. Sequential analysis techniques are designed to detect small cumulative effects within a relatively wide noise signal. In effect, there is a smoothing of the signals to compensate for the noise. Under these circumstances a spurious signal tends to be blended into surrounding data. The net effect is to reduce the size of the instantaneous effect and spread the effect out over time.

This effect was clearly evident during efforts to measure the feed rate to the plutonium purification cycle during tests at the BNFP. The rate was available from a metering headpot, flow measurement device as well as from a calculated dropout rate from a feed tank. The flow measurement device was more accurate but unavailable during periods when the tank was filling. The idea was to use the dropout rate when available to calibrate the flow measurement devices on line within the computer-based information system.

A limited smoothing technique involving a three-point moving average was applied to the tank measurement data. These smoothed data were used to adaptively bias-correct the flowmeter readings using a Kulman filter combination of the dropout rate and recursively adjusted flowmeter reading.

These tests were done on line as part of the computerized data collection. The results showed devastating effects that spurious process measurements can have. The corrected data react quickly to the bad measurement, and the smoothing effects dampen recovery. The bad data effects are minimized in magnitude, but the effects last a long time.

While this isolated application deals with a specific measurement, the techniques used are similar to those proposed for sequential testing of material balance data. The nature of applications to detect recurring losses dictates the use of similar process control type measurements. Similar spurious effects can be expected to affect the material balance data record for these analyses. Indeed, tests at the BNFP show such data. It seems a trivial point to pretreat the data to remove spurious signals. However, the practical application of

this pretreatment to on-line computerized data collection is difficult. This was tried without success for the flow measurement problem encountered at BNFP.

This question remains. It is part of the key to estimating sensitivity and false-alarm rate for the recurring loss-detection tests to be applied to a large-scale reprocessing facility.

7.4 THE ROLE OF OFF-LINE SAMPLE RESULTS

To this point in the discussion, safeguards tests have been constructed with the goal of on-line, real-time data analysis. In this respect, the analysis of safeguards data is made as the data are recorded. This necessitates the use of any and all available information. This usually preclude the use of sample results determined off line in the laboratory. These results are usually delayed for hours, even in the case of process control information.

This on-line data analysis is necessary for the abrupt removal detection goals when frequencies of tests are hourly or on a 4-h basis. However, for the recurring loss-detection tests, where tests are applied weekly, timing is less important, and analysis may be able to wait for laboratory sample results, or even accountability level results.

The practicality and potential for improved sensitivity were not specifically evaluated during BNFP tests. It is apparent that availability of analytical results will only improve sensitivities. These laboratory measurements serve a quality control function for various on-line measurements. For this report, projections are made on sensitivities achievable with on-line techniques based on test results at the BNFP. However, improved capabilities are likely to be achieved when analysis of data for recurring loss is delayed to use analytical results. This may not be the case for the abrupt removal tests where timeliness is still required.

7.5 RECURRING LOSS–DETECTION SENSITIVITY SUMMARY

In summary, it must be said that the sensitivity and false-alarm rate for large-scale reprocessing facilities cannot be clearly projected. The complexity of measurements and the interaction of various processes and measurements make modeling and error propagation difficult, if not impossible. Projections must be based on limited test results from the BNFP.

An on-line, near-real-time inventory capability is required. A current book inventory must be maintained and available. A material balance must be closed frequently with results submitted to sequential data analysis tests to make judgments about potential recurring loss. Based on test results, it appears that individual balances can be closed under these circumstances to ± 5 to 6 kg (assume that this is the 95% confidence level).

These individual closures must be submitted to sequential balance analysis techniques. The sensitivity of these techniques in the presence of residual systematic effects an spurious data signals inherent in process control data will determine the ultimate sensitivity.

The proposed rule makes the goal for recurring loss detection as low as reasonably achievable. Based on test results, this sensitivity should be in the range 5 to 10 kg. Again, this is dependent on the sensitivity of the test methods and the capabilities to perform under the constraints of process operations and with process control data.

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12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

An assessment was completed on the potential for large reprocessing plants to meet the requirements of the Nuclear Regulatory Commission's proposed Category I Material Control and Accounting (MC&A) Reform Amendment. The requirements on which this assessment was based are given in the working draft revision to the rule dated December 30, 1982. The Barnwell Nuclear Fuel Plant (BNFP) was chosen as a reference design for the assessment, but most considerations would be relevant to any large Purex reprocessing facility. Spent light water reactor (LWR) fuels containing 1% Pu were the presumed feed to the plant; the design feed rate is 5 MTU/d.

The approach taken for the assessment was to characterize the process equipment and the nuclear material distribution throughout the plant, to identify quantities of material that must be removed consistent with loss-detection capabilities were based on these test results. No attempt was made to construct detailed removal scenarios or integrated MC&A systems throughout the plant.

The assessment address three general types of material removals or losses:

1. single space, single time (abrupt)
2. multiple space, single time (abrupt with collaboration), and
3. single space, multiple time (recurring).

With few exceptions, the abrupt loss-detection requirements of the Reform Amendment will be achievable with existing or slightly improved capabilities. Some equipment designs and/or measurement technology improvements will be needed. Recurring loss-detection capabilities will be somewhat poorer than capabilities for abrupt loss detection.

14. KEY WORDS AND DOCUMENT ANALYSIS (See instructions)

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