Work Performed Under Contract DE-AC09-78ET-35900

ALLIED-GENERAL NUCLEAR SERVICES
P.O. BOX 847
BARNWELL, SC 29812

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Available from
National Technical Information Service, U. S. Department of Commerce
5825 Port Royal Road, Springfield, Virginia 22151

Price: Printed Copy $ 4.00 ; Microfiche $3.00

AGNS
Allied-General Nuclear Services

AGNS-35900-CONF-131
CONF-810706--34

Distribution
Category UC-83 Special

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IN-PROCESS INVENTORY ESTIMATION IN A REPROCESSING FACILITY FOR NEAR-REAL-TIME ACCOUNTING

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July 1981

For Presentation at the 22nd Annual Meet INMM
July 13-15, 1981
Sheraton Palace Hotel
San Francisco, California

ALLIED-GENERAL NUCLEAR SERVICES
POST OFFICE BOX 847
BARNWELL, SOUTH CAROLINA 29812

PREPARED FOR THE
DEPARTMENT OF ENERGY
WASTE AND FUEL CYCLE TECHNOLOGY OFFICE
UNDER CONTRACT DE-AC09-78ET35900

IN-PROCESS INVENTORY ESTIMATION IN A REPROCESSING FACILITY FOR NEAR-REAL-TIME ACCOUNTING

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Abstract

A modern large scale reprocessing facility (1500 MTU/yr) presents a unique challenge to meet current safeguards objectives for timely detection of material losses. For material accounting to be responsive at these throughput rates, frequent material balance closures are required. The limiting factors have been physical costs, downtime and operability constraints of inventories for frequent-material balance closures.

An In-Process Inventory Technique (IPI) has been developed and tested at the Barnwell Nuclear Fuel Plant (BNFP) to provide frequent inventories without cost or instrusiveness to plant operability. A computerized measurement system makes available process measurements and process control analytical information. These data are processed to determine the process inventory. The calculation routines use routinely available process control measurements and sample results. The technique requires no shutdown, no special preparations, and no special measurements, or samples. With this technique, hourly inventory frequencies and material balance closures have been achieved during demonstration runs in the 1500 MTU/yr at BNFP. Results show sensitivities of 2 to 5% of the normal process inventory are achievable during normal operations. Recent improvements in data handling routines indicate the technique can be sensitive during transient process conditions as well.

INTRODUCTION

The role of accountancy in nuclear material safeguards in a bulk handling facility is to detect loss or diversion of material balance measurement data. For a spent fuel reprocessing plant, the effectiveness of accountancy in this role has been limited by the necessity to perform a flushout and physical inventory to close the material balance. Economics and plant operability limit the frequency of these inventories to something on the order of twice per year which complies with national regulations but cannot meet international goals for timeliness of detection.

Timeliness goals can be met when material balance intervals can be closed on a more frequent basis. However, this requires an accounting system to provide "near-real-time" accounting reports and a method of measuring plant inventory without the traditional plant shutdown and flushout.

Near-real-time accounting has been accomplished at a number of facilities. At the BNFP, the installed and operable accounting system features computerization of material balance measurement routines and data logging. These routines incorporate direct computer readout of measurement instruments and on-line computer access to analytical laboratory measurement data. The real-time material balance accounting portion has been thoroughly demonstrated.

Development of inventory taking capabilities without shutdown and flushout has been the recent goal at the BNFP to fulfill the timeliness requirements for material balance closures. The technique has become known as "In-Process Inventory."

At the BNFP, the installed computer system includes direct interface to almost 500 process instruments and on-line monitors. Current analytical laboratory measurement data are also available for all process control and accountability sample points. These data are combined for in-process inventory estimation. Demonstrations with the plant operating in a test mode using natural uranium indicate inventory sensitivities in the range of 2 to 5% of normal process hold-up are achievable during routine operations. During test periods process inventory determinations have been conducted as often as once per hour allowing frequent material balance closures for safeguards evaluations.

This has been accomplished under the constraint that only routine process control information is used. There have been no requirements for special inventory preparations, special samples, or special measurements. The procedure is a "snapshot" of current plant activities with no cost or instrusiveness to plant operability.

The In-Process Inventory Procedure

The basic procedure is an adaptation of a process control tool used in the reprocessing industry for many years. In the past, the production control manager usually received an in-process inventory total as part of his daily production report. This total was based upon "best available" measurements on the various surge points throughout the plant. These measurements usually involved current instrument values for volumes and best estimate of concentration based upon a "most recent process control type sample" (which could easily be several hours old) or the operator's judgment. The operations manager could evaluate the inventory data pinpointing problems with waste or product specifications based upon this in-process inventory. His evaluation understood the nature of the data used to generate the inventory. However, he could pinpoint problems based upon inventory quantities generated without complicated inventory preparations and inventory procedures. The key consideration is that the daily inventory technique used process control measurements, process control sample data and operator judgment. There were no special preparations, no special samples, and no special measurements. The technique was transparent to operations with no instrusiveness, downtime, or inherent costs over routine operations.

The in-process inventory technique, as it has evolved at the BNFP, extends this basic approach. With the installed Computerized Nuclear Material Control and Accounting System (CNMCAS), some 500 process instruments are interfaced and available for inventory calculations. All analytical sample results are logged to the Computerized Laboratory Data System and are available to the IPI program. This Laboratory Data System features direct interface to a number of analytical instruments and on-line analyzers for timeliness of data transmission. With timely process measurement data available for computer processing, development of the IPI program began in 1978.

Development

The first efforts were applied during full plant testing operations where the entire solvent extraction cycle was operated. The initial applications concentrated on measuring holdup in major surge locations with the assumption that unmeasurable holdup in additional process equipment was "constant" under steady state operations. In terms of full plant operations, the nominal uranium holdup was approximately 11 MTU. Initial tests showed unmeasurable holdup during routine operations was approximately 1000 kilograms of uranium and the precision of the In-Process Inventory technique was 2 to 3%.

However, the assumption of steady-state operations was essential to these initial applications. When process upsets or feed interruptions occurred, pulsed column and equipment holdup were displaced to surge tanks. The stability of IPI measurements and assumptions of unmeasurable inventory were affected. It became apparent that an effective safeguards program must respond to these transient situations to be a valuable indicator.

Early system studies by Los Alamos National Laboratory considered in-process inventory measurements and their effects on safeguards detection capabilities by near-real-time material balance accounting. They studied column holdup estimation as part of the in-process inventory measurement. The concluded column holdup estimation should be included and further concluded that estimation of column inventories to 10% was adequate for sensitive detection of losses.

As part of the 1980 IPI development activities, a crude technique for estimating holdup in the pulsed columns was developed at AGNS and applied in retrospect to 1979 full plant test run IPI data. The technique used the differential pressure measurement over the length of the column (weight recorder reading), to calculate the average solution density across the entire column and infer holdup. This approach resulted in considerable improvement in IPI results. The precision remained at 2 to 3% but unmeasured holdup fell to ≈500 kilograms. It also gave the first indication that IPI measurement could reflect column loading and unloading during process transient conditions. It showed the potential of the technique as a safeguards tool which was sensitive during the non-routine process situations.

1980 was the turning point in IPI development. The basic data collection and calculation routines for in-process inventory measurement had been developed at AGNS. The statistical techniques for analysis of frequent material balance closures had been the development work of Los Alamos. Under Los Alamos sponsorship, General Atomic Company, Iowa State University, and Clemson University had refined techniques for estimation of column holdup.

Funding limitations at AGNS would no longer allow testing under full plant operation. However, a limited test run plan was implemented to support continued development for all concerned groups. Under this test plan, or "mini-run" plan, as it has become known, the plutonium purification portion of the plant is isolated, and operated as a closed-loop cycle. Development could focus on the plutonium cycles which is the most sensitive to safeguards applications.

The mini-run cycle provided the test bed. The AGNS IPI technique for data collection and data processing was applied to generate in-process inventory measurements at the front end of the safeguards evaluation system. Los Alamos brought the column holdup estimation techniques and applied their sequential material balance analysis package DECANAL. Six test runs have been made to date. Natural uranium is substituted for plutonium in the mini-run cycle. However, the measurement techniques for IPI determinations are similar to those applied during actual operations. With this test loop, a total throughput over 5 MTU has been realized for test and evaluation. The tests have included actual material removals to test sensitivities of the various safeguards analysis techniques.

Results

For recent applications in the mini-run cycle, nine process tanks, and five columns were closely monitored by the In-Process Inventory Program. Inventory data was collected at hourly intervals with data fed to the Los Alamos DECANAL Program. In-process inventory measurement technique continues to show sensitivities of 2% during steady operations. The test results show protracted removals of less than one kilogram per hour from process streams can be detected. With enhanced monitoring of sensitive storage vessels, discrete removals of a few hundred milliliters are detectable.

The in-process inventory techniques have been superimposed on operations activities. The routine process control measurements including sample results are the basis for IPI determinations. During testing activities in the mini-run cycle, over 1200 IPI measurements have been made over approximately six weeks of operating activities with no requirements for shutdown or special preparations.

Certain specific problem areas have been identified and require additional development to improve IPI sensitivities. As an example, certain blending tanks for feed preparations are subject to erroneous measurements during blending operations. Stratification within the tank prior to mixing and after addition of dilution acid results in erroneous concentration predictors and volume measurements. Detection of these anomalies and the logic to overcome them need to be incorporated.

Another problem arises when certain tanks are drained below instrument sensor heels. These instances result in erroneous measurements as well and require complicated logic to recognize and resolve the problems.

The simple solution to these problems is to impose constraints on the operating organization to avoid these situations during IPI measurements. However, by design, the IPI process must be transparent to operations, and include no operating constraints. Thus, the challenge rests with the safeguards application to overcome all foreseeable anomalies and maintain the sensitivity of the technique.

Cost Benefit

As stated above and has been pointed out in a number of recent presentations at safeguards conferences around the world, there is an increasing awareness of the cost and intrusiveness of applications to meet international safeguards objectives with material balance accounting. The Computerized Nuclear Material and Accounting System (CNMCAS) has been retrofit to the BNFP. Original process control measurement devices were in place and included terminal strips for computer application. Scanning hardware, computer hardware and software preparation to effect near-real-time accounting, and in-process inventory measurement have been developed over the last five years. It is estimated that full development such as this for a large scale facility such as the BNFP may cost 6- to 10-million dollars. These costs must be evaluated in terms of cost benefit.

As in-process inventory has developed, the parameters measured have become available for process control applications. The logical extension has been to incorporate these parameters to video graphic displays which show process equipment and associated measurement data. These have been enhanced with alarm limits and displays to signal process anomalies.

Using IPI measurements, mass balances around individual columns have been established to within a few hundred grams of material per hour. Analysis of these data can signal process upsets and trigger sampling to verify out-of-limit conditions and required corrective actions. On-line instruments indicate product stream concentrations and provide an early signal for deviations. Again, these provide early signals of problem areas which may affect product quality to effect corrective action before they result in feed interruption or downtime. At a rate of 0.5 to 2.0 million dollars per day for downtime, early warning for process upsets is a valuable tool.

From the safeguards standpoint, the system provides early warning of measurement anomalies and abnormal losses. These can be signaled in time for corrective action. Not only as a benefit to timely detection, the system satisfies the safeguard inspectors' requirements in a timely manner to avoid downtime for verification in the event of a safeguard problem.

In general, with costs in a modern facility, if the computerized system providing near-real-time accounting and in-process inventory measurements saves only a few days of downtime. The installation and development costs are easily justified.

Conclusion

An effective in-process inventory technique to meet safeguards requirements for material balance accounting can be applied to a modern, large scale reprocessing facility. Routine process control type information is used. There are no special preparations, special samples, or special measurements over those required for routine operations. The technique can be applied to provide inventories as often as hourly with no process downtime or intrusive costs. An inventory sensitivity of 2% can be achieved and analysis techniques are available to detect protracted losses of <1 kg/hour from process streams and discrete removals of a few milliliters from sensitive process vessels.

DISTRIBUTION FOR CONFERENCE PAPER NO. AGNS-CONF-131

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