November 1973

U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 5.13

CONDUCT OF NUCLEAR MATERIAL PHYSICAL INVENTORIES

TABLE OF CONTENTS

CONDUCT OF NUCLEAR MATERIAL PHYSICAL INVENTORIES

A. INTRODUCTION

Part 70 of Title 10 of the Code of Federal Regulations requires licensees authorized to possess more than 350 grams of contained U-235, U-233, or plutonium to conduct a physical inventory of all special nuclear material in his possession at intervals not to exceed 12 months. Licensees authorized to possess more than one effective kilogram of special nuclear material are required to conduct measured physical inventories of their special nuclear materials more frequently than annually depending on the materials. Further, these licensees are required to conduct their nuclear material physical inventories in compliance with specific requirements set forth in Part 70. Licensees possessing material for use in the operation of a nuclear reactor, as sealed sources, or as reactor-irradiated fuels involved in research, development, and evaluation programs in facilities other than irradiated fuel reprocessing plants are exempted from these latter requirements.

This guide describes measured physical inventory procedures which are acceptable to the Regulatory staff with respect to compliance with the physical inventory requirements set forth in 10 CFR Part 70.

B. DISCUSSION

1. Measured Physical Inventory

a. Inventory Measurements. Assurance against undetected loss or diversion of special nuclear material can be achieved only by a measured physical inventory. Various systems of physical protection can be employed to protect against, deter, or detect theft or diversion of special nuclear material. Various systems of material control and accounting can be employed to account for the material. However, a material balance based on a measured physical inventory that provides conclusive evidence of the physical presence of the material is the only means for assuring that the physical protection and material control and accountability systems have been effective and that no significant losses or diversions have gone undetected.

It is only when all significant components of the material balance are measured that the balance has meaning in assuring that material has not been lost or stolen. For a material balance to be a credible indication of the effectiveness of a material control system, the quantities of material on inventory must be measured for the balance or assurance provided that prior measurements remain valid. The components of a material balance involving the movement of material into or out of an area, e.g., receipts, shipments, and discards, should be measured. These components are not within the scope of this guide except as they affect the remaining material balance component, i.e., that material remaining on inventory at the close of an accounting period.

(1) Precision and Accuracy. Constraints are specified in 10 CFR Part 70 for the limits of error of the material balance. The limits of error of the respective components of the material balance combine to produce the total material balance limits of error, or limits of error of material unaccounted for (LEMUF). The precision and accuracy needed for specific inventory measurements can be determined only in the context of a specific plant, process, or material balance relative to the LEMUF limits specified in 10 CFR Part 70. If the inventory limits of error are large in relation to the other component limits of error, their effect on the LEMUF for the total balance will be greater. Consequently, to meet the LEMUF limits specified in 10 CFR Part 70, some of the random and systematic errors associated with the inventory measurements may need to be relatively smaller for inventory quantities which make up relatively large portions of the total. Similarly, the measurement of a portion of the inventory with a relatively small special nuclear material content may be less precise than a portion having a relatively large special nuclear material content. For example, the inventory measurement of the residual material in a piece of cleaned-out equipment can be less precise than the inventory measurement of the material in the same piece of equipment that has not been cleaned out for inventory and still contains a significant quantity of special nuclear material.

The accuracy of inventory measurements may not affect the limits of error of the material balance but can affect the MUF, i.e., whether a balance is achieved. The effect of the accuracy of inventory measurements will depend on the quantity involved and the magnitude of the inaccuracy. To carry this to the extreme, a quantity of material that is not measured and not included in the balance can be considered to be totally inaccurate. If such a quantity of material were large, the MUF thus would be increased significantly and might exceed the LEMUF. If such a quantity were small, for example, the residue in a cleaned-out piece of equipment, the effect on MUF might not be significant.

Static material, i.e., material which has not been processed or remeasured during a material balance interval does not affect the LEMUF of the material balance for that interval. The requirements as stated in

10 CFR Part 70 set limits on the LEMUF only for that material that was "in process"[1] during a material balance interval. Any covariance effects of that "in process" inventory, such as measurement uncertainties of static inventory, would be eliminated from the LEMUF calculations. It is beyond the scope of this guide to deal with covariance. This will be treated in other regulatory guides with respect to inventory as well as to other components of the material balance.

(2) Measurement Control and Quality Assurance. Control of measurements made specifically for inventory purposes is necessary to assure valid measurements and to permit determination of the limits of error associated with such measurements. Many inventory measurements will be so controlled because they will have been made prior to the inventory as routine material accounting measurements. The use of prior measurements is discussed in section B.1.b.

(3) Factors, Nominal Values, and Calculated Values. By their nature, factors such as the special nuclear material content of a process intermediate, nominal values such as the stoichiometric value for a compound or the target isotopic composition of a process material, and calculated values such as by-difference values or values based on mixing calculations depend on steady-state or normal operations. Perturbations such as unknown losses, substitution of materials, or diversion invalidate the use of factors, nominal values, and calculated values as accurate representations of special nuclear material element and isotopic values for purposes of a measured physical inventory.

Measurement precision for factors normally produce limits of error that are somewhat wide so that the use of factors and their associated limits of error may result in exceeding the limits for the material balance as specified in 10 CFR Part 70.

Nominal values are not the result of measurements sufficient to be acceptable as physical inventory measurements. Limits of error for nominal values cannot be determined because of the lack of sufficient measurements.

While calculated values usually result from the combination of one or more measured values, there often is an unmeasured component that invalidates the calculated value. For example, two measured quantities are mixed to provide a batch of material. The calculated special nuclear material values would be the sum of the two mixed quantities provided none of either of the original materials or the final mixture had been lost or diverted. There is no way to determine this by calculation. It can be determined only by measuring the actual mixture on inventory. Conversely, if there is a measured quantity introduced into a process vessel and a measured quantity is removed from the vessel the calculated remainder is the correct value only if there has been no other removal or loss. Again, the absence of other removal or loss cannot be determined by calculation, only by measurement of the remaining material. On the other hand, calculated values derived from a representative sample of a weighed quantity of material negate the possibility that a loss or theft of material has gone undetected.

(4) Scrap and Other Heterogeneous Material. Special nuclear material inventory in scrap or other heterogeneous material not amenable to sampling or other conventional measurement techniques often is a major contribution to an unacceptable LEMUF or MUF for a material balance. This is mostly because scrap and waste measurements normally are less precise and less accurate than other special nuclear material measurements. Keeping the quantities of scrap and waste on inventory small will assist in minimizing the effect of these imprecise measurements. A scrap recovery campaign just prior to the physical inventory is one way to accomplish this. Routine continuous recovery of scrap probably would be better.

b. Acceptability of Previous Measurements. The measured physical inventory will consist of measured values of many types and from many different sources. Previous measurements may be used for special nuclear material inventory values. The source of such data, the controls imposed on the generation of the data, and the controls imposed on the material to which the data apply will determine the integrity of the data as acceptable inventory values.

Integrity of the data means that the data correctly reflects the quantity of special nuclear material involved. A primary means for assuring the integrity of the prior measurement data for a quantity of special nuclear material is tamper-safing. It is defined in 10 CFR Part 70 as:

> "...the use of devices on a container or vault in a manner and at a time that ensures a clear indication of any violation of the integrity of previously made measurements of special nuclear material within the container or vault."

The requirements for tamper-safing in 10 CFR Part 70 are intended to assure against the undetected occurrence of such things as unauthorized or unrecorded removal of portions of material from a container, removal of containers or items containing special nuclear material from a vault, or substitution of items or quantities of different materials which would

[1] As defined in 10 CFR Part 70, Material in Process means any special nuclear material possessed by a licensee except in unopened receipts, sealed sources, and ultimate product maintained under tamper-safing.

cause prior measurement data to be incorrect. Tamper-safing is not intended to prevent such occurrences but to give a clear indication that such an occurrence might have taken place and that a previously measured special nuclear material value may no longer be correct.

Tamper-safing can be used to reduce inventory measurement of in-process intermediates in storage at inventory time when process measurements provide a valid measure of the element and isotopic content of such material. When it is expected that such intermediates will be in storage at the end of a material balance period they can be placed in storage under tamper-safe conditions using the appropriate process measurements and identification.

c. **In-Process Measurements.** The extent to which a process must be shut down, drained down, or cleaned out to measure inventory quantities of special nuclear material will depend on the quantity of special nuclear material in the equipment at any stage of operation, cleanout, shutdown, etc. and the precision and accuracy with which such material can be measured. The critical parameter is the limit of error of the process quantity measurement, in absolute terms, and its effect on the total material balance uncertainty. These absolute limits of error become a significant factor when there are large quantities of special nuclear material in in-process inventory measured with relatively imprecise techniques. They become less significant as the quantities of in-process inventory decrease or the quality of the measurements improve. There are several techniques for measuring in-process inventory which involve various combinations of measurements and inventory quantities.

(1) **Process Draindown and Cleanout.** Process draindown and cleanout are relative terms which indicate degrees of removal of special nuclear material from process equipment. Draindown implies moving the bulk of the special nuclear material to measurable points in the process but not necessarily cleaning out the process equipment. Cleanout implies a more rigorous effort to remove the material from the process equipment so that it may be considered to contain no residual special nuclear material. Whatever the degree of removal, the procedure is essentially the same. The special nuclear material is moved from its normal process location to a location and form in which it can be measured. The location may be a calibrated process vessel or it may be bottles or containers separate from the process.

Residual quantities in equipment under draindown conditions, rather than cleanout conditions, normally will be larger and will require measurement with better precision and accuracy than smaller cleanout residues. While equipment that has been cleaned out could be considered to contain no special nuclear material, there is the danger of inflating the MUF if the absence of a significant amount of special nuclear material in such equipment is not verified.

(2) **Dynamic Inventories.** To eliminate, or minimize, the disruptive effect of shutdown and cleanout or draindown inventory procedures, dynamic inventory techniques could be considered. Such techniques include any inventory procedures which permit the process to continue to run during inventory, i.e., remain in a dynamic state. Some techniques may require changes in processing procedures which will result in reduction of process throughput but not to the extent of cleanout or draindown. Four techniques are described here. Specific application will depend on the facility and process. Other regulatory guides will consider some of the specifics of these techniques.

(a) **Process Blank.** This technique is particularly applicable to batch-type processes where it is feasible to separate batch flow and insert a blank, i.e., a batch containing no SNM (batch blank) or to clean out the equipment stepwise as the process proceeds (cleanout blank). The technique also could be applied to a continuous-flow process, but the introduction of the blank and maintaining segregation of the blank from the normal process flow are more difficult.

The technique involves inventorying all SNM not held under tamper-safing and not in the process line at a given time T_0. This could include raw material awaiting processing, process-generated scrap or recycle, and product. The process is interrupted following the batch in the first step of the process at time T_0 either to clean out the first step of the process or to introduce a batch containing no SNM. In a dry process the technique probably would call for cleanout of the step (cleanout blank). In a liquid process the technique could include introduction of all of the ingredients of the batch except the SNM (batch blank). Separation between the batch blank and the preceding and the following batches is maintained to avoid off-specification product and to permit measuring residual SNM in the equipment after the batch blank.

As the process proceeds, each separable step of the process is treated by cleanout blank or batch blank processing. Raw material previously inventoried at time T_0 can be introduced into the process after equipment in the first process step has been cleaned out or the batch blank has cleared the step. In either case the residual SNM in the equipment is measured, either after cleanout or after the batch blank has passed, to assure that the equipment is clean or to add the SNM quantity to the inventory. As discussed in section B.1.c.(1), such residual quantities of SNM involved will be small in relation to the total balance.

As the blank proceeds through the process, there may be SNM-bearing material generated as scrap or recycle material. Such material generated in front of and during the blank processing and after time T_0 is segregated from such material generated in the process before time T_0 and from such material generated after the blank. The SNM content of these materials generated in front of and during the blank processing and after time T_0 is measured and added to the inventory taken as of time T_0. Measurement of such material could be in the form of a short scrap recovery campaign immediately following the inventory.

As processing proceeds, product is generated until the blank reaches the end of the process and the last step of the process sees the cleanout or batch blank at time T_1. Such product is measured and added to the inventory taken at time T_0. Product, scrap, and recycle generated in front of and during the blank processing from time T_0 to time T_1 is kept segregated from such material inventoried at time T_0 to ensure that no quantity of material is inventoried more than once. Tamper-safing and inventory identification tags can be used to accomplish such segregation if it cannot be done by actual physical segregation.

The inventory at time T_0 thus would consist of:

i. SNM in raw material, scrap, recycle, and product on inventory but not in the process line at time T_0.

ii. SNM in scrap, recycle, and product generated in front of and during the blank processing between time T_0 and time T_1, including the SNM content of the batch blank, if any; and

iii. Residual SNM in each step of the process equipment after the blank has passed and before the following SNM is introduced.

(b) Tracer or Step Function. To avoid the necessity of shutdown and cleanout or even the introduction of a blank, the introduction of a tracer or step function is particularly suitable for liquid continuous processes such as the recovery of SNM from spent reactor fuel or a scrap recovery process. The technique involves displacing the SNM inventory in the process with SNM identifiably and measurably different from that in the process. It may not be the SNM that is different but the solvent or an addition of tracer to the solution. The displaced material can be measured quantitatively in the subsequent output and product from the process along with the displacing material until the inventory has all been displaced as evidenced by the output measurements.

One application of this technique has been tested in a reprocessing plant by displacing the in-process inventory of known minor isotope ratios with another batch of material having different minor isotope ratios. From the minor isotope ratios of the output, calculations show how much of each type of material is present until the output becomes entirely the second type. The inventory that was in the process when the second type was introduced can then be calculated. References 1 and 2 discuss the results of two experiments using minor isotope ratios for in-process inventory in a chemical reprocessing plant.

If the isotopic ratios do not or cannot be varied to provide the step function of two identifiably and measurably different materials, a tracer may be added to the second type of material. The additive will depend on the process and subsequent use of the product. A tracer that would be removed in subsequent treatment or a tracer that would be acceptable in the finished product could be used. For example, a volatile tracer that would be removed in a subsequent calcining step or a tracer that would not precipitate or extract with the SNM could be used.

(c) Counter-Current Inventory. The basic principle of this technique involves movement of the inventory-taking team counter-current to the process flow. As the material moves past the inventory team, or vice versa, the inventory is measured, counted, recorded, etc. This technique is best applied to processes or parts of processes in which the SNM is contained in discrete items, such as fuel pins, pellets, or containers of material such as furnace trays or bottles of process intermediates.

(d) Process Parameter Measures. This type of inventory involves measuring the special nuclear material essentially in situ in the process with little or no interruption of the process. Application of this technique depends on plant and equipment design considerations for equipment calibration, process flow control, and instrumentation for measuring process parameters such as temperature, flow rate, concentration, specific gravity, and those related to various radiometric nondestructive assay techniques. Other regulatory guides will address some of the specifics of such design considerations.

The ultimate for this technique would be a fully instrumented process with a series of in-line instruments and gauges. Readings from such instrumentation would be taken at a given time or over a specified time interval in an appropriate sequence. The inventory at the specified time would then be calculated from the recorded parameters. While the ultimate would be to apply this technique to an entire process, the practical would be to select parts of the process amenable to the technique, especially those most difficult to shut down and start up. While the technique employs more advanced technology and requires design considerations, it could eliminate, or at least reduce, costly plant shutdown or draindown.

Flow measurements through an isolatable step of the process coupled with some measure of concentration such as specific gravity or gamma absorption could provide a measure of the SNM in that step. Cutoff procedures are employed to assure that material in one such part of the process does not flow to the next, which could cause it to be inventoried twice or not be inventoried. Cutoff could be based on mechanical valving or other physical isolation procedures or on a time factor for equilibrium conditions for completion of a given process step.

2. Inventory Organization and Planning

Even though the most accurate and precise methods are used for inventory measurements, the procedures used in the conduct of the inventory can have a significant effect on the results. The techniques and procedures used to obtain inventory data and to process them to obtain inventory values for specific material type balances, material balance areas (MBAs), or total plant balances will determine the validity of the resultant balances.

a. Assignment of Responsibilities. Clearly defined responsibilities, duties, and authorities together with proper orientation of personnel and assurance that each person understands his place in the inventory program will materially assist in more rapid, trouble-free conduct of physical inventories.

b. Cutoff Procedures. A major factor in planning a physical inventory is establishing the timing of and controlling the various cutoffs necessary for accurate inventories. Cutoffs or cutoff procedures are so called because, at the specified time, activities such as movement of material or posting to the records are stopped or cut off. Each physical inventory is the ending inventory for one material balance interval and the beginning inventory for the next material balance interval. The timing of the material and records cutoff is critical to assure definition of the inventory interval for given processes, material types, or material balance areas.

c. Inventory Instructions. Nuclear material physical inventories are complex and involve the interaction of many persons and activities. Not all materials will be inventoried at the same time. Material balance areas may be inventoried in sequence or in parallel. For example, three plutonium MBAs may be inventoried in sequence by one team for a material balance interval of two months while three low-enrichment uranium material balance areas may be inventoried simultaneously using three teams for a material balance interval of six months.

Certain ways of preparing inventory lists may make subsequent data handling easier and more rapid. The inventories may provide for separate sheets to be used for different types of material and inventory categories. Material that is in process as defined in 10 CFR Part 70 could be listed separately from material that has been tamper-safed and considered to have been removed from process. This will facilitate calculations of the separate in-process material balance required by 10 CFR Part 70. Material types such as high-enrichment uranium and low-enrichment uranium could be listed separately, as could plutonium and U-233. This may be automatic because the different materials are in different MBAs, but it is possible, for example, in a mixed oxide fuel fabrication plant, to have plutonium and low-enrichment uranium in the same MBA. Other separations may be desirable, such as sealed sources listed separately from tamper-safed material.

Detailed written inventory instructions provide the means to coordinate the complex activities of the inventory to produce a valid acceptable result.

C. REGULATORY POSITION

It is recognized that a variety of combinations of the techniques and procedures described in this guide can pertain to any given plant or material balance area. Such combinations would need to be evaluated as to their effectiveness in each such situation. Acceptable techniques and procedures are not limited to those described in this guide. It is expected that additional inventory mechanisms will be developed as the nuclear industry progresses. Combinations of the techniques and procedures described in this guide and that conform to the following are generally acceptable to the Regulatory staff for use in the conduct of a measured nuclear material physical inventory.

1. Measured Physical Inventory

a. Inventory Measurements. The requirements for physical inventories in 10 CFR Part 70 specify that the quantity of special nuclear material associated with each item on inventory be a measured value of the special nuclear material.

(1) Precision and Accuracy. Inventory measurements should be made with precision and accuracy appropriate to the significance of the inventory quantities to the material balance.

(2) Measurement Control and Quality Assurance. Inventory measurements should be subject to quality controls as are other special nuclear material measurements. Planning for inventory measurements should include planning for the determination of the quality of such measurements. Measuring devices such as scales and balances, measuring tanks or vessels, and nondestructive analysis (NDA) instruments should be calibrated in accordance with plant quality assurance procedures. Sampling plans and procedures should be supported by data showing that inventory samples are valid and representative of the material. Analytical methods should be those for which quality control data are available for use in determining the quality of the measurements.

(3) **Factors, Nominal Values, and Calculated Values.** Factors should be determined on the basis of measurements, their continued validity monitored through a measurements quality assurance program, and the limits of error of the factor determined through such measurements. Supporting data for such factors should be documented and verified by additional measurements during the inventory in a manner similar to that used to verify prior measurements that have not been protected by tamper-safing. The limits of error of each factor should be included in the calculations of the LEMUF for the material balance.

Nominal values are not acceptable as measured inventory values.

Calculated values in which there are unknown and unmeasured components are not acceptable as inventory values.

(4) **Scrap and Other Heterogeneous Material.** Quantities of special nuclear material in scrap and waste should be kept relatively small. Process and inventory schedules should give consideration to the need for recovery campaigns prior to inventories. Solving the scrap measurement problem, however, should not be left until inventory time. A continuing scrap and waste management and control program should be maintained. Such a program should have the primary objective of reducing the effect of the uncertainty of scrap measurement on the material balance. The objective can be attained by:

(a) Eliminating or reducing to a minimum the amount of special nuclear material on inventory in such scrap or heterogeneous material;

(b) Treating, segregating, compositing, and packaging such material so that the special nuclear material content can be measured with precision and accuracy appropriate to the quantity involved; or

(c) An appropriate combination of (a) and (b) depending on the quantities involved and the measurement capabilities available.

Regulatory Guide 5.11, "Nondestructive Assay of Special Nuclear Material Contained in Scrap and Waste," discusses the use of NDA for material accounting measurements of scrap and waste components of inventory.

b. Acceptability of Previous Measurements. Quantities of special nuclear material on inventory for which there are previous measurement data of acceptable quality need not be remeasured provided the integrity of the previous data can be assured and the data are identified with the material in question.

(1) **Identification.** There should be means of identifying the material with the measurement data for such data to be considered acceptable. Material identification should provide means for tracing lot numbers, sample numbers, and analytical results or tracing lots, containers, or items to nondestructive assay (NDA) log books. Container or item labels should include:

(a) Special nuclear material quantity data, i.e., element and/or isotope;

(b) Lot identification;

(c) Bulk quantity data, i.e., gross, tare, and net weights or volume data; and

(d) Sample identification or NDA log book reference.

If such data are not included on the container or item label, a unique identifying number or symbol should be affixed to each container or item, which number or symbol should be traceable to the appropriate data as listed above. All such quantity and identification data which provides for validation of previously made measurements should be tamper-safed so that there is a clear indication of any changes made to the data or identifying information.

(2) **Tamper-safing.** To be acceptable, tamper-safing must be applied immediately upon completion of the operations which establish the special nuclear material content of an item. Such operations may include the nondestructive analysis of fuel elements or rods that have been sealed and identified or of a series of rods or pellets which are then stored in containers or in a vault under tamper-safing. They also may include sampling, packaging, and weighing a lot of material into a number of containers, each of which is sealed with a tamper-safe seal. Analyses may be performed later but the integrity of the sample also must be protected.

Shipper's data may be used for inventory of unopened receipts provided the shipper's tamper-safe seals are intact, or if any items were sampled, they were immediately tamper-safed, i.e., resealed with a tamper-safe seal or placed in a tamper-safed vault.

Devices to be used for tamper-safing are the subject of a separate regulatory guide.

(3) **Remeasurement.** If tamper-safing is not employed to assure the integrity of prior measurements, 10 CFR Part 70 requires remeasurement of the material. Remeasurement, either in total or of a sample, may include weight or volume, element, and isotope for each item remeasured. It may include use of an NDA method for each item or the selected samples of items. In any case the measurement must be such as to assure the total element and/or isotopic content of the items measured. For example, check-weighing of a series of containers is not considered sufficient verification of prior data without element and/or isotopic analyses. Various statistical sampling plans and statistical tests of hypotheses or tests of significance may be used to assure that prior measurements are valid within limits of error applicable to the original measurements.

The application of such statistical methodology to material control and accounting, including inventory verification, is the subject of separate regulatory guides.

c. **In-Process Measurements.** The combination of the quantity of special nuclear material in process and the quality with which such material can be measured should be considered for each process or material balance in relation to the effect on the LEMUF for the balance. Combinations of in-process inventory techniques and measurement methods should be selected to obtain measurement limits of error as low as practicable. The acceptability of the respective inventory techniques will depend on the procedures employed in using the techniques.

(1) **Process Draindown and Cleanout.** Process equipment from which material has been removed should not be considered "clean." i.e., to contain no special nuclear material, unless measurements are made to verify this. Measurements should either verify that the residual quantity is not great enough to affect significantly the material balance or should result in a material quantity to be included in the inventory. If experience with specific cleanout procedures indicates that, if a specified procedure is followed the equipment will be clean, it may not be necessary to verify the cleanout.

While prior measurements and cleanout procedures are acceptable bases for concluding that a process residue contains no special nuclear material, such is not the case with draindown procedures. Draindown procedures and prior measurements of residues should be used to establish expected quantities, inventory factors, variations in holdup, and limits of error. The residual quantities should be measured for each inventory or measurements made to verify the validity of any factors used. Such measurements of residual quantities may be accomplished using NDA techniques which have been calibrated to the equipment by measurement and cleanout tests at a prior time. Further, the special nuclear material quantity remaining in equipment should not be calculated as the difference between the material put into the equipment and the material taken out (see section 1.a.(3)).

Other regulatory guides deal with minimizing residual material holdup in equipment and with the measurement of such material.

(2) **Dynamic Inventories.** Strict material handling controls and cutoff procedures for material movements and transfers are necessary for dynamic inventories to ensure that: (1) material does not move through the process without being inventoried, (2) material is not recycled during the inventory to cause it to be inventoried more than once, (3) material is not removed from the process after inventory so that it might be inventoried a second time in a storage location, and (4) material which has already been inventoried as a raw material or process intermediate in storage is not introduced into the process.

(a) **Process Blank Inventory.** In using either the batch blank or cleanout blank inventory technique, measurements should be made to assure that there is no significant residue of special nuclear material in the equipment after the blank or, if there is such a residue, to provide a measure of the quantity to be included in the inventory. If experience with specific procedures for a given process has shown that the equipment will be clean, it may not be necessary to verify this fact.

(b) **Tracer or Step Function Inventory.** Any tracer used should be homogeneously distributed in the batch of material and should be in a concentration sufficient to be identifiable and measurable with precision and accuracy appropriate to the quantity of special nuclear material involved. A step function used for inventory should be of sufficient magnitude to be identifiable and measurable with precision and accuracy appropriate to the quantity of special nuclear material involved.

(c) **Counter-Current Inventory.** Caution should be observed in this type of inventory that the inventory teams do not bypass material moving past them or that they do not inventory material more than once. Tagging is not always possible in this type inventory but some procedures should by employed to assure inventory accuracy. Such procedures may involve physical segregation or area tagging rather than item or container tagging.

(d) **Process Parameter Measures.** This technique should be employed only where process equipment and instrumentation have been designed and calibrated for in situ measurement of the special nuclear material. Measurements of this type should be more accurate and precise than those used for residual material measurement because larger quantities of special nuclear material are involved resulting in greater effects on material balance uncertainties. Equipment and instrument calibrations and reliability should be evaluated to provide data for calculating limits of error for inventories of this type.

2. Inventory Organization and Planning

10 CFR Part 70 requires that physical inventories be planned, organized, and conducted according to written inventory instructions prepared for each inventory. The purpose of this requirement is to assure complete and accurate coverage, no duplication, and minimum interference with plant operations.

a. **Assignment of Responsibilities**

(1) **Plant Inventory Supervisor.** One individual who is familiar with the areas to be inventoried and with the principles and procedures of conducting physical inventories of nuclear materials should be assigned primary responsibility for planning, organizing, and conducting the physical inventory.

The responsibilities and authority for the inventory supervisor should be stated in writing to prevent misunderstanding and assist the supervisor in discharging his responsibilities. Specific statements should be included for the inventory supervisor's authority with regard to process shutdown, startup, interruption, and control preceding, during, and following the inventory. The inventory supervisor should not be a member of an inventory team but should be available at all times during the inventory to handle problems that might arise and to assure that the inventory is proceeding satisfactorily.

(2) **Material Balance Area Inventory Supervisor.** One individual in each material balance area should be assigned the responsibility for the inventory in that area. This person should be familiar with the operations and material in the MBA and probably will be the material custodian for the MBA.

The responsibilities and authority of the MBA inventory supervisor should be stated in writing. He should be responsible for all aspects of the inventory within his assigned MBA as directed by the written inventory instructions for the MBA. His authority should extend to any matters relevant to preparation for and conduct of the inventory within his MBA within the framework of the written inventory instructions. He should not have the authority to deviate from the written instructions without approval of the Plant Inventory Supervisor.

(3) **Inventory Teams.** Teams for conducting the inventory, i.e., the actual listing, tagging, measuring, etc., should consist of at least two persons. More people may be required on teams where material handling or nondestructive measurements are to be carried out during the inventory. Alternatively, nondestructive measurement teams or material-handling teams may be established to assist other inventory teams as required and specified in the inventory instructions. Each inventory team should contain one person who is familiar with the areas assigned for inventory and one person from another area or organizational unit to serve as a controller to assure accuracy and compliance with instructions. Inventory team instructions should be in writing and should include all of the specific activities for each team for each assigned area. The inventory teams should have no authority to deviate from specific instructions without approval of the MBA Inventory Supervisor or the Plant Inventory Supervisor.

b. **Cutoff Procedures.** The time of the inventory should be specified for each material balance so that a finite material balance interval can be established. Cutoff procedures should be established to assure that the quantity of material which results from the physical inventory activity accurately represents the material physically present at the specified inventory time and that this quantity is accurately reflected in the records at the same specified time. Material cutoff procedures should be coordinated with records cutoff procedures to assure that the same material balance interval is used for both.

(1) **Receipts, Shipments, and Other Removals.** For the given material type which is to be inventoried, the inventory instructions should specify a time at which material receipts, shipments, and other removals such as waste discards are cut off. No more material of the specified type should be received into or shipped or removed from the plant after that time. The records for receipts, shipments, and other removals also should be cut off after the last receipt and the last shipment or discard prior to the specified cutoff time and the books closed for the material balance interval. The material cutoffs should be controlling, with the records brought up to date to the final receipts and removals. However, if data are not available for a receipt received close to or after the cutoff time, such a receipt should not be included in the inventory and the records.

When it is necessary to make a shipment or take a receipt after the cutoff time and before the inventory is finished, such receipts and shipments should be made with the approval of and under the control of the Plant Inventory Supervisor. He should maintain a log of such items so that they are properly reflected in the records and in the physical inventory data. Any receipt after the cutoff should be identified and segregated so that it will not be included in the physical inventory. Addition of such receipts to the records should be made for the material balance interval following the inventory. If it is necessary to make a shipment after cutoff but before the inventory is completed, such shipments should be inventoried before shipment at the measured shipment value for the material and such quantities included in the physical inventory. The records for the shipment should be shown in the following material balance interval. Material discards should be coordinated with inventory schedules so that all discards have been made and properly recorded before the inventory cutoff time.

(2) **Internal Transfers.** Inventory instructions should specify the cutoff times and procedures for each MBA. All MBAs do not need to be inventoried at the same time, but may be taken in sequence with or counter to the process or merely in sequence of assignment to the inventory team. Material movements between MBAs should be controlled prior to, during, and after the inventory to assure that all material has

been inventoried and that none is inventoried more than once.

Internal transfer cutoff times should be established and stated in the inventory instructions so that material is not transferred between material balance areas during the inventory. MBA records cutoff should be coordinated with the material transfer cutoff so that the records will accurately reflect the inventory of the MBA. Internal transfer cutoff times do not have to be the same for all MBAs. They may progress with the inventory.

When the inventory in an MBA is complete, the transfer cutoff should remain in effect until the entire inventory is complete. To avoid process shutdown or to permit earlier startup, enough material should be moved into the MBA inventory prior to cutoff to keep the process going until the inventory is complete and transfer cutoff is lifted.

If it is necessary to make internal transfers before completion of the inventory, these should be made on an exception basis with the approval of and under the control of the Plant Inventory Supervisor. He should maintain a log of all such transfers to permit the proper adjustments to the inventory.

(3) Process. Process cutoff does not necessarily mean shutdown of the process. The process may continue to operate during inventory. Cutoff controls should be established to assure accuracy of in-process inventory. The various techniques for dynamic inventory require carefully controlled cutoff procedures to provide an accurate in-process inventory. Transfers to or from the process should be handled in a manner similar to MBA internal transfers. Material and records cutoff for the transfers to and from material in process as defined in 10 CFR Part 70 should be carefully controlled to permit establishing the in-process material balance as required by 10 CFR Part 70. Inventory instructions should specify the manner in which the in-process inventory is to be taken and the process cutoff controls to be used. Such controls could include:

(a) No raw material added to the process after a specified time;

(b) No recycle permitted after a specified time;

(c) Transfers to and from intermediate storage cut off at a specified time;

(d) Scrap and waste generated after a specified time or between specified times segregated from all other scrap and waste; and

(e) Product produced after a specified time or between specified times segregated from all other product.

c. Inventory Instructions

(1) General Instructions. Inventory instructions should include a detailed description of the procedures to be followed in taking the inventory to assure that all items and materials are inventoried once and not more than once. Such description should include instructions for listing the inventory and tagging inventoried items and for control of inventory lists and tags. Preprinted serially numbered inventory tags and lists should be used and should be controlled by the Plant Inventory Supervisor.

Inventory teams should be assigned specific blocks of numbered sheets and tags, and all such items should be accounted for by the team to the Plant Inventory Supervisor. The inventory sheets should have a column for the tag number along with other columns for the inventory data sufficient to identify each item, record the associated quantity of SNM element and isotope, and any other data pertinent for the inventory such as sample numbers or NDA test results or log book references. When an item is inventoried it should be tagged and listed. The tag number should appear in the column for tag numbers on the line for the properly identified item. Every tag number assigned to a team should either appear on one of the lists assigned to that team or be returned to the Plant Inventory Supervisor. All inventory sheets should be returned whether used or not. When a sheet is full, it should be initialed by both team members and any auditors or other observer, as appropriate. Completed sheets should be collected by the Plant Inventory Supervisor at frequent intervals during listing. Sheets that are voided for some reason should not be destroyed but should be marked void, initialed by the team, and returned to the Inventory Supervisor. Any changes made on the sheets before they are returned to the Inventory Supervisor should be initialed by the team members and any auditors or observer as appropriate. Multiple copy listing can be used to provide the Plant Inventory Supervisor with an original control copy of the lists to check against tag numbers and list numbers and subsequently to maintain control of any changes made to the sheets during reconciliation.

The inventory instructions should make provision for anomalies and discrepancies such as the discovery that a tamper-proof seal has been opened. The inventory teams should have no discretion to deviate from the written instructions; therefore, the instructions should provide that the MBA or Plant Inventory Supervisor be called to resolve any problems.

(2) MBA Inventory Schedules. Inventory instructions should include a schedule for MBA inventories which specify starting times for the inventory team assignments and cutoff procedures necessary for each MBA to be inventoried. All MBAs in a plant need not be inventoried at the same time nor during the same material balance interval. Inventory instructions should identify which MBAs are to be inventoried and the specific timing of such inventories.

(3) MBA Instructions. Inventory instructions should be prepared for each MBA to specify in detail how the inventory is to be conducted in each MBA.

(a) The type of inventory should be specified, i.e., shutdown, dynamic, counter-current, etc.

(b) The extent of shutdown and cleanout should be specified with appropriate cutoff for processing and material transfers. When only a portion of the MBA or process is to be shut down, instructions should be given as to the equipment to remain operative, that to be shut down, and how the interface between the static and dynamic portion of the area is to be controlled.

(c) For equipment that is shut down, instructions for cleanout, flushout, dismantling, etc., should be given. These instructions should include the treatment, handling, and measurement of material removed from such equipment.

(d) For areas of the process not shut down, specific operating instructions should be included as to how the process will be operated to permit inventorying the material. Cutoff procedures should be included to provide for the interface between inventoried and not-inventoried material associated with the operating process. Procedures for measuring the SNM content of the operating process should be specified. Such procedures could include processing to an intermediate stage and sampling for analysis or a nondestructive analysis technique coupled with volume or flow measurements.

(e) Where item control, either sealed sources such as fuel pins or containers or possibly vaults containing SNM, is used in an MBA, instructions should be included for identifying and locating all such items in relation to the records for the items. The inventory team could prepare a list of items as they locate, identify, and tag them. This list then could be checked against the identity and location records for the items as required in 10 CFR Part 70. Conversely, the inventory team could use a copy of the record and check each item as it is located, identified, and tagged. The team should assure that all items physically present are tagged and checked against the list and that all items on the list are located, identified, and tagged.

(f) Where item control includes tamper-safing of containers or vaults, inventory instructions should include procedures for verifying the integrity of the tamper-safing devices. The instructions should describe the tamper-safing devices and how the inventory team can tell whether the device has been compromised. Instructions should include procedures for the team to follow if they find a tamper-safing device that has been compromised. The first thing to do in such a case should be to notify the MBA and Plant Inventory Supervisors.

(g) When tamper-safing has been used and for uniquely identified sealed sources (i.e., the SNM is sealed in a tube, jacket, capsule, or other such mechanism which makes the SNM inaccessible), previous measurements of the SNM content may be used for inventory purposes. Inventory instructions should identify the measurement data that are to be used. These should be the data resulting from measurements performed closest to the time of the sealing or tamper-safing that are sufficient to establish the SNM quantities and associated limits of error consistent with required LEMUF limits for the material balance.

(h) When tamper-safing has not been used or has been compromised, when SNM has not yet been sealed, e.g., trays of fuel pellets, or when sealed items are not uniquely identified, e.g., unnumbered fuel rods or pins, the validity of previous measurements should be verified or the SNM content of the items remeasured. Inventory instructions should specify the extent of such verification or remeasurement. Remeasurement should be performed at a level of confidence equivalent to the original or normal measurement for the type of material in question. This may involve lot blending and sampling or pellet lot sampling equivalent to the original sampling plans. Where tamper-safing has been compromised, the original lot integrity and homogeneity may also have been compromised or altered so that remeasurement should be made at a higher intensity or level of confidence than the original measurements. Inventory instructions should include the sampling plans, remeasurement, sampling, and analytical procedures, or NDA techniques to be used to verify prior measurements. Such verification and remeasurement procedures should include assignment of responsibility for the sampling and measurement to the appropriate plant personnel. The analytical laboratory should be made aware of the expected sample load so that proper capability and capacity can be scheduled for prompt analytical service.

d. Preliminary Inspection and Review. Prior to the conduct of a physical inventory the Plant Inventory Supervisor along with each MBA Inventory Supervisor should conduct a preliminary inspection of the plant areas to be inventoried and review inventory instructions and procedures with the responsible personnel. Such inspections and reviews should be made sufficiently in advance to allow time for corrective action, if needed.

(1) Process Conditions. The Plant and MBA Inventory Supervisors should review process conditions and status with operating supervision of each MBA or process to be inventoried. Inventory instructions should be reviewed in relation to production schedules to assure that they are compatible and that any areas to be shut down are properly scheduled for shutdown.

(2) MBA Preparations. Preparation in each MBA for inventory should be reviewed with MBA custodians and MBA inventory supervisors to assure that each understands his instructions, duties, and responsibilities during the inventory. The areas should be inspected to assure that material is measured and tamper-safed, packaged, labeled, stored, or otherwise prepared for the inventory. Arrangements should be

made for the measurement and tamper-safing of any unmeasured material in the MBA that will be present during the inventory.

(3) Records. Plant and MBA records should be reviewed to assure that they are current and that record clerks and accountants understand the records cutoff procedures and times applicable to each set of records.

(4) Measurements. Sampling and measurement procedures to be used during the inventory should be reviewed with the responsible persons to assure that they understand their instructions, duties, and responsibilities. Any equipment to be used in such procedures should be inspected and calibrated or calibration records checked to assure that the instrumentation is ready for accurate inventory measurements. The analytical sample schedule should be reviewed with the laboratory supervision to assure prompt analytical results

(5) Inventory Teams. Inventory instructions should be reviewed with each inventory team in detail for each area it is to inventory to assure that each team member understands his duties and responsibilities. A tour of the areas in which each team will work should be used to orient the inventory teams.

3. Conduct of Inventory

The inventory should proceed according to instructions and plans. If proper planning, inspection, and personnel orientation have been carried out, there will be a minimum of problems. Nevertheless, the Plant Inventory Supervisor should not be assigned to any specific activities, such as being team member, so that he can be available at any time to take care of anomalies and to approve deviations from planned procedures. During the inventory it may be useful for the Plant Inventory Supervisor to move from area to area to maintain cognizance of the progress of the inventory. When touring the areas, he should keep in touch so that he is available for problems and to maintain control of tags and inventory lists.

4. Post-Inventory Activities

a. List and Tag Accuracy Check. Upon completion of the inventory in each area, before the area is released from cutoff, the Plant Inventory Supervisor should inspect the area with the MBA Inventory Supervisor for the area to assure that all material in the area has been tagged with current inventory tags. A random sample of the items in each area should be checked against the inventory lists, and a random sample of the items on the lists should be checked against the items in the area to assure that items have been tagged and have been recorded accurately on the inventory sheets. It is neither practical nor necessary that these verification checks be 100%. A valid statistical sampling plan should be used for the two populations, i.e., the population of tagged items and the population of listed items. If these tests of the inventory accuracy do not show a high level of confidence, in the order of 95% or better, additional checks should be made or the area reinventoried. In addition to the list and tag accuracy checks for an area, the tags and lists assigned to the area team also should be accounted for. Upon completion of the entire inventory all tags and inventory lists should be accounted for by the Plant Inventory Supervisor.

b. Cutoff Verification. Upon completion of each MBA inventory and of the entire plant inventory, the plant and MBA cutoff procedures should be verified to assure that all internal transfers were recorded in the proper MBA records and none were recorded in more than one area; that material was inventoried in the proper area; and that all receipts and shipments were recorded properly with respect to the cutoff times for the respective material movements. All transfers into or out of each MBA should be checked for a short period (perhaps a day) prior to and after the cutoff time to assure that the transfers were recorded in the records of the MBA in which the material was inventoried. Documentation of receipts and shipments should be checked in a similar manner to assure that only those receipts included in the material balance interval ended by the inventory just taken are included in the plant records for that interval and that all shipments made before the cutoff time have been removed from the records. Documentation of measured discards also should be checked in a similar manner.

c. Inventory Summary and Reconciliation. The raw data from the inventory lists should be summarized as soon as possible after listings are completed. Some MBA summaries may be prepared before the total plant inventory is completed. It also may be that completed summaries will have to wait on analytical data to provide element and/or isotopic extension for some line items on the inventory sheets. Analytical scheduling should be planned to make this delay as short as possible. The original inventory lists and their summaries should be maintained under the control of the Plant Inventory Supervisor. Copies of inventory lists and summaries should not be provided to an MBA until the Plant Inventory Supervisor's summary for the MBA has been prepared and reconciled to the MBA records. Such reconciliation should be done under the control of the Plant Inventory Supervisor. The MBA inventories should be summarized under the control of the Plant Inventory Supervisor to provide the total plant inventory.

Inventory summaries must include a summary of the material in process as defined in 10 CFR Part 70 for each material type for the total plant inventory to permit calculation of the MUF and LEMUF for each such material type in accordance with requirements of 10 CFR Part 70. Material in-process balances may be calculated for each MBA as an aid to management in localizing the major MUF and LEMUF contributions. The total plant inventory for each material type must be prepared to provide data to comply with the records and reports requirements of 10 CFR Part 70.

Inventory reconciliation involves comparing the results of the physical inventory to the inventory as stated in the records and resolving any differences to the extent possible by correction of errors in either set of data. A record should be made of all adjustments made during reconciliation to either the physical inventory data or to the records. Such adjustments to the inventory data should be approved by the Plant Inventory Supervisor. Adjustments to the records should be approved according to established plant control procedures for such adjustments. The final adjustment should be the material unaccounted for (MUF) which will bring the records for the respective MBAs and the total plant into agreement with the physical inventory. This MUF adjustment should be documented and approved for each MBA and for the total plant according to the established plant procedures for recording MUF.

Using the physical inventory data, other plant record data, analytical data, and quality assurance data, the limits of error of the MUF (LEMUF) must be calculated as required by 10 CFR Part 70 for the in-process material balances. The statistical techniques and methodology for this calculation are beyond the scope of this guide and are the subjects of other regulatory guides.

d. **Final Report.** The final report of the inventory should document the inventory summaries, the respective material balances and the MUFs and LEMUFs to permit facility management and the AEC, if appropriate, to evaluate the results. If MUF and LEMUF for any balances are in excess of the applicable limits specified pursuant to 10 CFR Part 70 or plant-imposed limits, additional reporting according to 10 CFR Part 70 requirements and possibly plant management requirements would be necessary.

REFERENCES

1. "Evaluation of Minor Isotope Safeguard Techniques (MIST) in Reactor Fuel Processing," USAEC Report WASH-1154, Office of Safeguards and Materials Management, February 20, 1970.

2. "Process Inventory Determination by Isotopic Techniques," R. A. Ewing, Battelle Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, prepared for presentation to the IAEA Panel on the use of Isotopic Composition Data in Safeguards, Vienna, Austria, April 10-14, 1972.