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NOTICE



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# NUCLEAR POWER: NEW TECHNIQUE FOR SAFEGUARDING SPECIAL NUCLEAR MATERIAL

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Current awareness of shortages in traditional energy sources, such as oil and natural gas, has placed greater emphasis on alternative fuel sources. With an already developed technological base and cost history, nuclear power is an especially attractive option. However, the public's attitude toward recent terrorism has generated strong demands for improved safeguards measures to deter, detect, and protect against diversion of special nuclear material (SNM). Undoubtedly, a comprehensive safeguards program will include both physical protection, and material control to ensure that physical protection systems are not circumvented. Modern systems techniques and modern technology can provide material control and accountability systems sensitive enough to meet current as well as future needs arising from use of increased quantities of SNM to support the nuclear industry and from political and societal pressures.

Recognition of the need for an improved material control and accountability methodology is reflected in a special safeguards study completed in April 1974 and now known as the Rosenbaum report.(1) One important recommendation made in the Rosenbaum report was that the concept of a periodic measure of material balance around large flows and inventories as expressed in the current concepts of MUF/LEMUF be abandoned as a basis of safeguards. Other current studies (2,3) also have dealt with the limitations of the MUF/LEMUF concept.

To encourage improved safeguards accountability, the Nuclear Regulatory Commission (NRC) has been considering the use of performance oriented regulations to supplement those currently used. In the area of material control and accountability, for instance, one such performance oriented criterion could be the assurance that a given loss of material be detected within a specific time frame. Under the current accountability system it is unlikely that all licensees could meet this type of objective. The present study, sponsored by NRC/Office of Standards Development, evaluated the controllable unit approach (CUA) to meet performance oriented regulations. For purposes of this study the "criterion" is "detection of material loss of two kilograms of SNM with 97.5% confidence." Specifically investigated were the timeliness of detection, the ability to localize material loss, process coverage, cost/benefits, and interface with other safeguards techniques such as DPA and data filtering. This study was undertaken

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as a first step to provide the NRC with the methodology and information to: support development of safeguards regulations that emphasize performance requirements; assess license applications; and inspect processes.

This study describes CUA which, as an alternative to MUF/LEMUF, is a material control and accountability methodology that takes into account the system logic and statistical characteristics of a plant process through the formulation of closure equations. The methodology is adaptable to plant processes of varying degrees of design and operational complexity, exemplary of present and future facilities. Application of the method does not require alteration or modification of an applicant's process. Since base-case calculations are a natural first step in the evaluation scheme, the cost/benefits of refinements in, or changes to, the proposed measurement system for purely safeguards purposes are easily obtained as incremental cost.

Like many successful management systems the CUA methodology iteratively compares the actual situation to the need. In this study, the performance of the proposed or existing measurement system is compared to the material control "criterion." Then additions or refinements to the measurement system or process are iteratively compared to the "criterion" until the "criterion" has been met. This systematic comparison can efficiently ensure that a complicated process measurement system will perform to the level as specified by the need. Furthermore, since the existing or proposed system is mathematically modeled with the CUA method, modifications to the process for any reason can be tested quickly for their effect on material control before implementation.

## CUA METHODOLOGY

A summary flow diagram of the CUA methodology is shown in Figure 1 and described below.

- Model Process. The process as exists or as proposed is carefully modeled especially with respect to factors such as material flow paths, operation modes, physical and chemical forms of the SNM, holdup of SNM, and process interruptions and downtime which can affect control.

- Examine Measurement Information and Formulate Closure Equations. Before any additional measurements are imposed on the process, data associated with the proposed or existing measurement system are evaluated so that the performance of the system can be quantized. The quantization is obtained through formulation of closure equations. A closure equation simply equates the input to the output of a process or subprocess. As shown in Figure 2,

  M(I) = measurement of input system
  M(R) = measurement of recycle stream
  M(O) = measurement of output stream
  M(W) = measurement of waste stream
  ΔH(HOLDUP) = measurement of change in holdup.

CUA METHODOLOGY IS A SYSTEMATIC APPROACH TO MATERIAL CONTROL

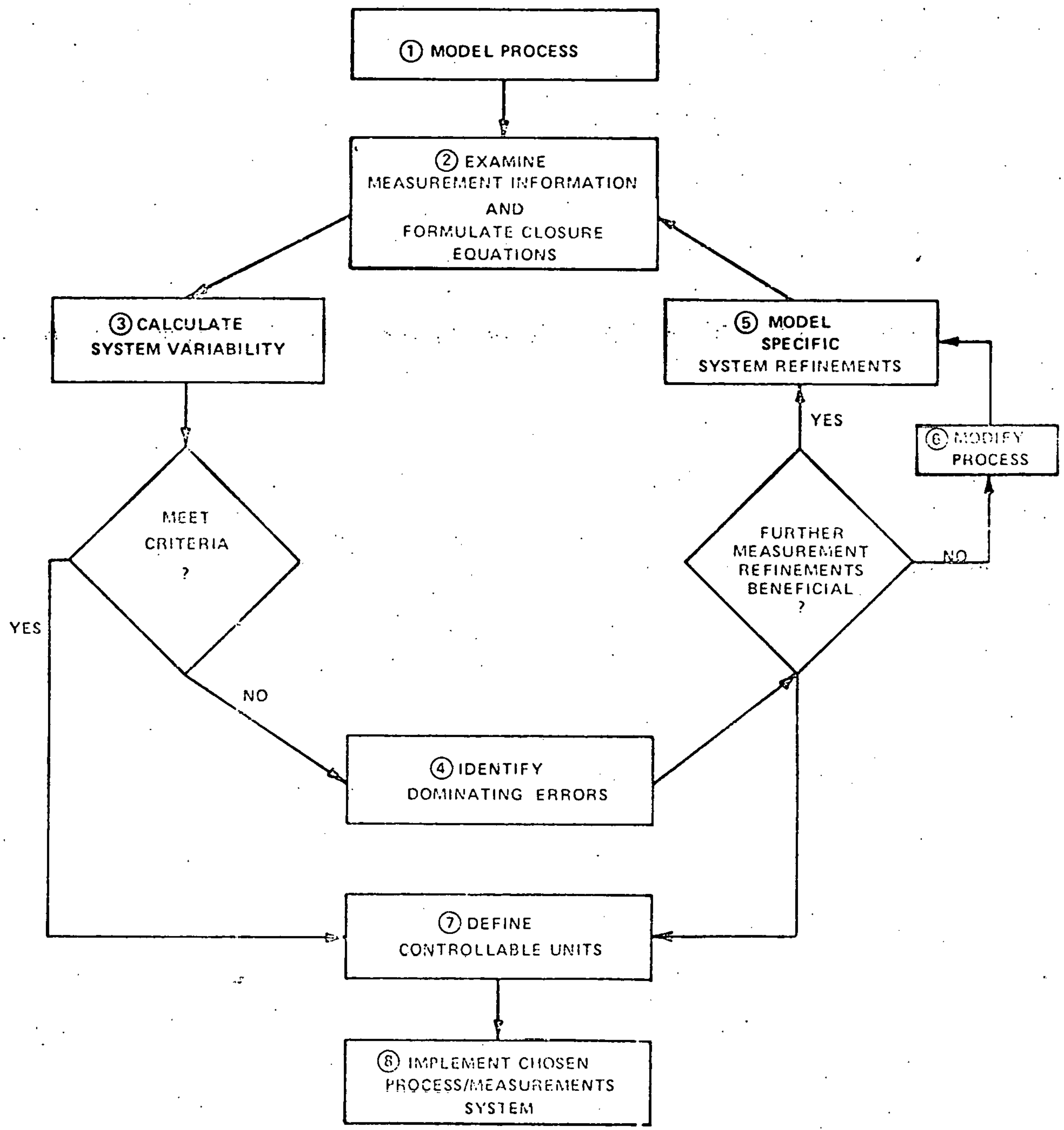


Figure 1

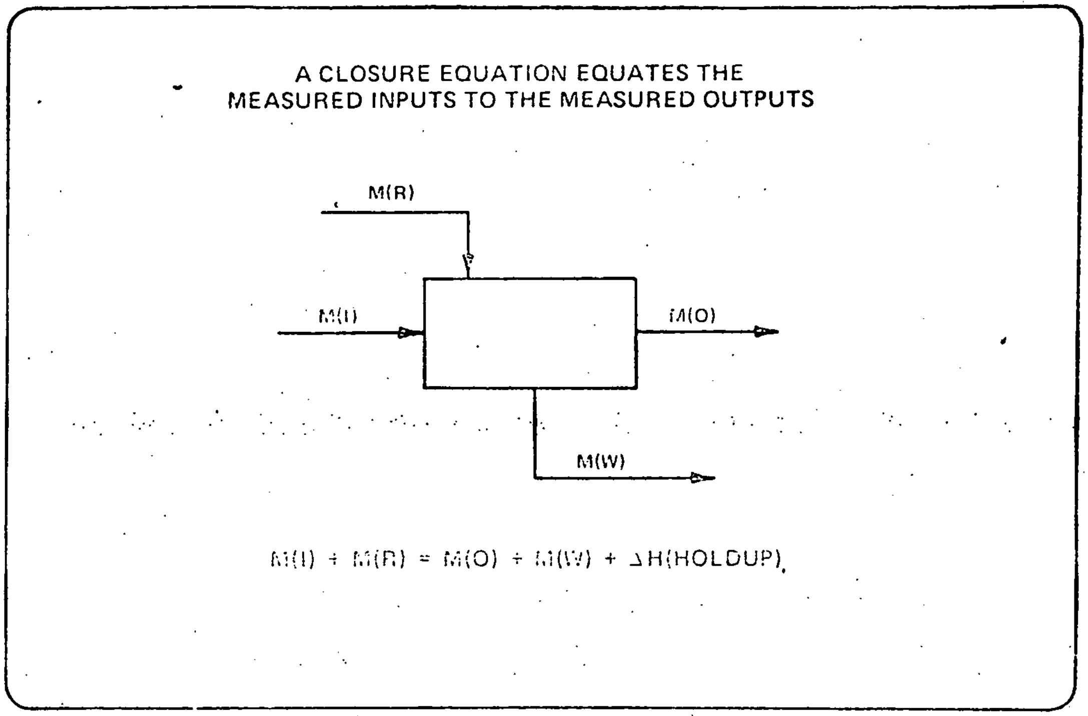
A CLOSURE EQUATION EQUATES THE
MEASURED INPUTS TO THE MEASURED OUTPUTS
M(R)
M(I)
M(O)
M(W)
M(I) + M(R) = M(O) + M(W) + ΔH(HOLDUP)

Figure 2

A closure equation can be considered a logical material balance area (MBA) but since the equation can be formulated between any two measurement nodes it provides greater flexibility and versatility than a traditional MBA. The closure equations can be overlapping, redundant and reinforcing as shown in the closure equation network developed for the mixed oxide process (Figure 3).

- Calculate System Variability. The random, systematic and sampling errors associated with measurements involved in the closure equations can be combined statistically to calculate the limit of error of the closure equation (LECE).

- Meet Criteria? The variability of the closure equations and the timeliness of response of these equations can be compared to the material control need or "criterion" established for the process. Here the question is asked "Does the existing or proposed system meet material control needs?"

- Identifying Controlling Errors. If the system does not meet the "criterion" the specific controlling errors are readily identified through the closure equations. Once the problem area is clearly identified a specific solution can be proposed.

- Further Refinement Beneficial? Here the question is "Are there any measurement system refinements that will reduce the controlling errors or does the system already reflect the present state of scientific development?"

- Modify Process. If further measurement refinements are not practical, modification to the process such as physical separation or parallel production lines can be considered.

- Model Specific System Refinement. Any specific refinement to the measurement system and/or the process is incorporated into the original system and the comparison to the "criterion" is repeated.

- Define Controllable Units. Once the "criterion" has been met the controllable unit or the maximum amount of SNM that can be controlled by the measurement system to meet the "criterion" can be calculated for any part of the process. This effectively defines the boundaries with respect to the material control capacity of the process.

## APPLICATION OF CUA TO A MIXED OXIDE PROCESS

A process model was developed to provide a severe test of controllable unit methodology. The process model was based primarily on a commercial high-throughput (200 MT) mixed-oxide fuel fabrication plant similar to that proposed by Westinghouse (4) and further described by Science Applications. (5) Modeling techniques were developed to include as much realism into the model process as possible. Some of the realistic features of the process model include:

- Three operation modes which may occur simultaneously in the model process.

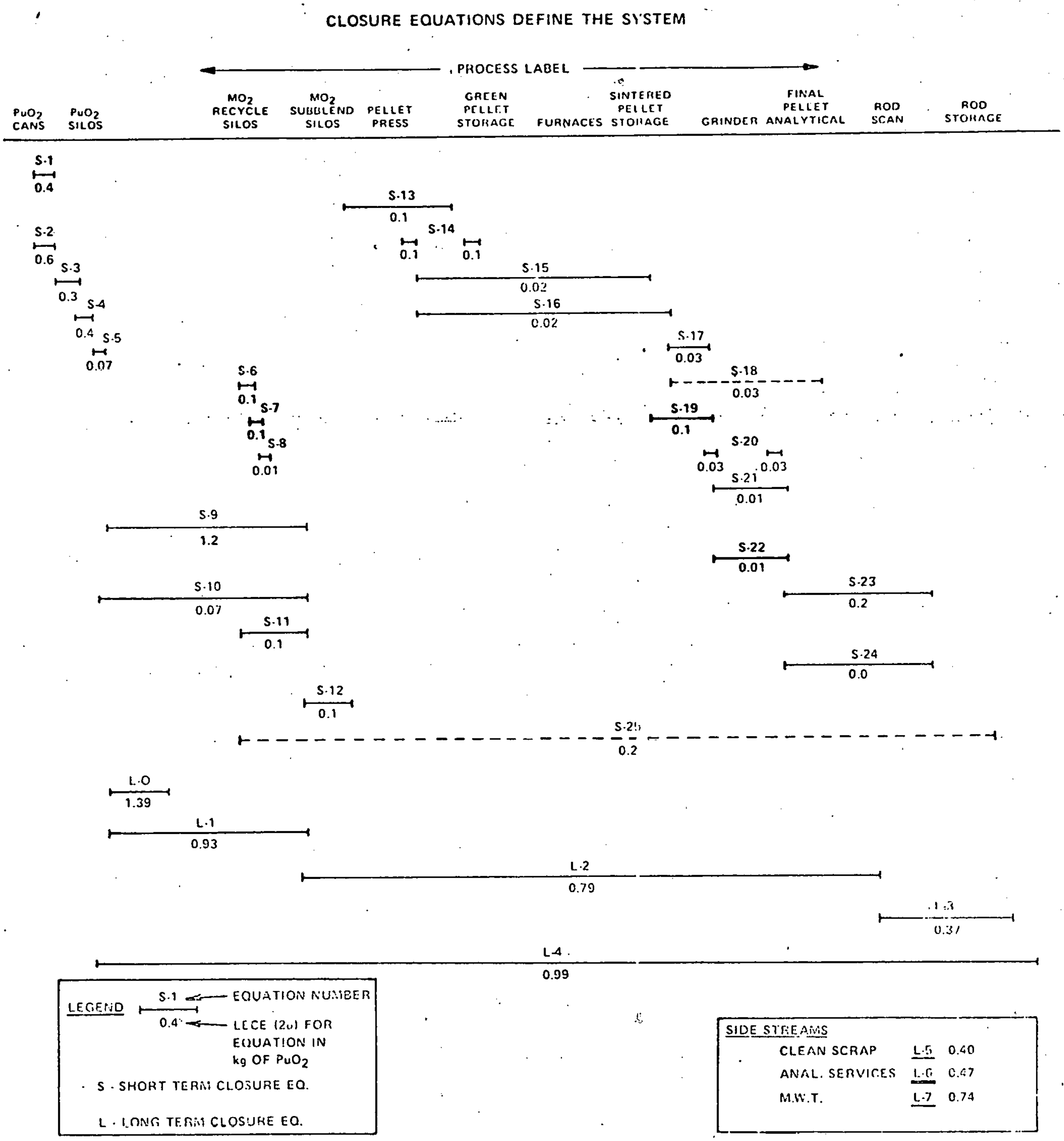
CLOSURE EQUATIONS DEFINE THE SYSTEM
PROCESS LABEL
PuO2 CANS
PuO2 SILOS
MO2 RECYCLE SILOS
MO2 SUBBLEND SILOS
PELLET PRESS
GREEN PELLET STORAGE
FURNACES
SINTERED PELLET STORAGE
GRINDER
FINAL PELLET ANALYTICAL
ROD SCAN
ROD STORAGE
S-1 0.4
S-2 0.6
S-3 0.3
S-4 0.4
S-5 0.07
S-6 0.1
S-7 0.1
S-8 0.01
S-9 1.2
S-10 0.07
S-11 0.1
S-12 0.1
S-13 0.1
S-14 0.1 0.1
S-15 0.02
S-16 0.02
S-17 0.03
S-18 0.03
S-19 0.1
S-20 0.03 0.03
S-21 0.01
S-22 0.01
S-23 0.2
S-24 0.0
S-25 0.2
L-O 1.39
L-1 0.93
L-2 0.79
L-3 0.37
L-4 0.99
LEGEND
S-1 EQUATION NUMBER
0.4 LECE (2σ) FOR EQUATION IN kg OF PuO2
S - SHORT TERM CLOSURE EQ.
L - LONG TERM CLOSURE EQ.
SIDE STREAMS
CLEAN SCRAP L-5 0.40
ANAL. SERVICES L-6 0.47
M.W.T. L-7 0.74

Figure 3

- Process streams which vary randomly.

- Material processed in discrete physical forms with varying chemical impurities.

- Holdup accumulated at 41 locations with flow, time or event dependent functions.

- Equipment malfunctions and bottlenecks resulting in unplanned downtime, entrapped material and alternate operations.

Results for this study were derived from simulated production data based on this process model.

This study substantiates that the Controllable Unit Approach can:

- Identify the areas of minimum detection sensitivity in a process.

- Evaluate schemes for combining process data and accounting data to enhance detection sensitivity without requiring additional measurement points.

- Locate area and approximate time of suspected diversion.

- Define time and sensitivity limits of diversion flags.

- Demonstrate the benefits and limitations of using small area closure equations or material balance areas.

- Define the approximate processing time in which quantities of SNM remain controllable.

- Identify controlling errors for corrective action.

Although conclusions for this study are not yet final, results to date indicate that the methodology will be highly effective in timely detection of SNM material loss and in material control. The principal objectives for this study have been met. Specifically through the CUA methodology, accountability and process data have been used effectively to:

- Demonstrate that the detection capability for material loss of SNM in the mixed-oxide process is 2 kg at a detection probability of 97.5% and a false alarm rate of 3 per year. This applies either to a single event material loss or to random accumulative material losses up to a 2-month period.

- Locate area and approximate time of suspected diversions; generally within a shift.

These results were accomplished without modification of the plant process or operations from the original model. Furthermore, the application of the concept enables estimates of the cost and effectiveness of additional measurements or measurement points anywhere in the process.

Table 1

COMPARISON BETWEEN CUA AND MUF/LEMUF

| | CUA | MUF/LEMUF |
|---|---|---|
| Detection sensitivity to material loss | 2 kg $PuO_2$ | >6 kg $PuO_2$ (6) |
| Timeliness of detection | ≤1 day | ≤2 months |
| Diagnosis of system limitations | List throughput limits and controlling errors | Not usually available |
| Cost/benefit of refinements | Cost directly derivable as incremental costs | Not usually provided |
| Localization of material loss | Specific parts of the process | General plant areas |
| Data falsification | Protection by overlapping, redundant and reinforcing closure equations | Often vulnerable |

Comparative results for CUA and MUF/LEMUF as applied to the mixed-oxide process are given in Table 1. As shown there, CUA provides an improvement factor of >3 for detection sensitivity and a greater improvement for timeliness of detection.

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