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Practicality of Diversion Path Analysis

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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ABSTRACT

One can define the safeguards system for nuclear material as the set of all protective actions taken to prevent or to deter attempts to divert nuclear material to unauthorized use. Maintenance of effective safeguards requires a program for routine assessment of plant safeguards systems in terms of their capabilities to satisfy safeguards aims. Plant internal control systems provide capabilities for detection of unprevented diversion and can provide assurance that diversion has not occurred. A procedure called Diversion Path Analysis (DPA) enables routine assessment of the capabilities of internal control systems in this regard and identification of safeguards problem areas in a plant. A framework for safeguards system design is also provided which will allow flexibility to accommodate individual plant circumstances while maintaining acceptable diversion detection capability. The steps of the procedure are described and the practicality of the analytical method is shown by referring to a demonstration test for a high throughput process where plant personnel were major participants. The boundary conditions for the demonstration case are given, along with some conclusions about the general procedure.

1. PERSPECTIVE

For safeguards, protective actions taken to prevent or to deter attempts to divert nuclear material to unauthorized use may be classed as subsystems by means of which one or more adversary actions may be countered. Thus, the subsystem for prevention of unauthorized access to a facility addresses open attack, surreptitious entry, misrepresentation without concealment of the attempt, etc., on the part of the adversary. The detection of unprevented theft represents yet another subsystem.

Plant internal control systems have inherent capabilities for detecting unprevented diversion, for providing recovery information, and can also assist in providing assurance that diversion has not occurred. However, a procedure is needed for routine assessment of the capabilities of internal control systems for indicating unprevented diversion; for identifying safeguards problem areas within a plant; and for substantiating assurance statements. The procedure should also provide a framework for subsystem design which will allow flexibility in accommodating individual plant circumstances while maintaining acceptable overall diversion indication sensitivity. Such a procedure, named Diversion Path Analysis** (or DPA) has been developed and is nearing completion as an operational tool.

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* Work supported by the U. S. Atomic Energy Commission, Division of Safeguards and Security

** Specialized terms associated with DPA are listed in a glowwary at the end of the paper.

2. APPLICATION OF DPA

2.1 Diversion Path Analysis

Although originally designed for the assessment of internal control procedures, the concepts underlying DPA are also applicable to other safeguards subsystems. The following sequence focuses on the steps employed in the analysis:

- identification of significant parameters for description of diversion possibilities;
- determining the possible ranges of values of the parameters;
- ordering the possibilities by means of the chosen trade-off;
- assessment of a system or a system design in terms of
  - uncovered "holes" (or weak points) revealed through the standard list of possibilities, and
  - extent of coverage within prescribed tolerance.

The procedure may be broadly applied to the facility perimeter system for control of facility access, to the material perimeter system for control of access to material, and the facility perimeter system for control of removal of material from the facility. However, in the present context DPA is discussed as a means for assessing internal control systems to detect covert diversions through systematic examination of paths, proceeding in order of relative path complexity and material attractiveness and in light of all pertinent knowledge about protecting, handling, and storing Special Nuclear Material (SNM) in the area being assessed. The coverage of a particular diversion path is evaluated by assessing the mass, time, and space sensitivities of indication of diversion.

2.2 Purpose

DPA is intended to provide information for management decision; to locate "holes" in systems for detecting unprevented theft; to balance resource allocation on a subsystem scale; and to provide assurance that absence of signal implies that no diversion has occurred within the boundary conditions of the analysis.

Information generated by the DPA allows management to decide whether the internal control system needs to be modified and how this should be done, as well as whether there is cause for alarm. The internal control system may be changed relative to the raw data inputs, data analyses, or internal control procedures. On a continuing basis, management can review experience with abnormal situations; if their frequency is high, perhaps internal controls should be altered to reduce signals arising from innocent causes. However, any decision to modify or upgrade procedures should be supported by a specific statement (which results from DPA) of the diversion possibilities to be covered by the additional abnormal situation test. Should DPA indicate that all diversion path possibilities are covered within prescribed boundary conditions, coverage should be explicitly recognized and "no action" is justified.

When an abnormal situation is observed, DPA generated information specifies those diversion possibilities which could precipitate the abnormal situation and indicates material availability, opportune times for removal and persons having authorized access during the period in question. The DPA also supplies a relatively objective list of possible innocent causes of any abnormal situation under investigation. This permits careful review and examination of other possible causes, generated after the fact under pressure for resolution, to assess their validity.

A key aim of DPA is the location of "holes" in the current system; diversion paths which are not adequately countered within time and mass sensitivity boundary conditions. Through analysis, such paths are highlighted and, oftentimes, easily implemented countermeasures come readily to mind.

The unprevented theft detection subsystem may be balanced, for resource allocation purposes, relative to the different possibilities for removing material. Such balance is achieved through an ordering procedure for generalized diversion paths which is inherent with DPA.

Assurance statements apply to the design, implementation or operation of the system during the preceding time period. DPA supports assurance statements related to design of systems for detection of unprevented theft, providing a specific list of diversion possibilities covered by the system.

2.3 Choices

The DPA procedure requires making a set of choices which influence the resultant characterization of the system with respect to safeguards goals. Some choices pertain to the degree of risk to be tolerated, while others relate to uniformity and consistency if DPA is to be applied to a number of areas within a plant or to a number of plants. Selection of options entails establishment of rationales and, perhaps, alternative characterizations. This was highlighted during a DPA test, particularly when ordering the diversion possibilities to be considered and the decisions of "how far to go" with regard to degree of path complexity for various materials present in the process area. Three fundamental choices apply to the analysis of any area, namely: mass sensitivity, time sensitivity and the relative weights assigned for material attractiveness.

2.3.1 Mass Sensitivity Boundary Value

Mass sensitivity refers to the ability to detect a single diversion of X grams or a series of diversions totaling at least X grams. The limiting value established for X dictates whether available indicators provide adequate coverage for a given diversion path even though other procedures having better mass sensitivity may be available. If the selected level is seen to be attainable by means of some procedure, no further analysis need be applied to that diversion path.

For purposes of analysis, the mass sensitivity value has been selected as 1/10th of the approximate amount of material which might suffice for a crude explosive. Thus, plutonium and U-233 might be assigned a mass sensitivity of 500 grams of contained fissile (Pu-239 + Pu-241). A mass sensitivity of 2.5 kg contained fissile might be chosen for U-235 and U-238 which leads to the mass sensitivity/enrichment relationship shown in

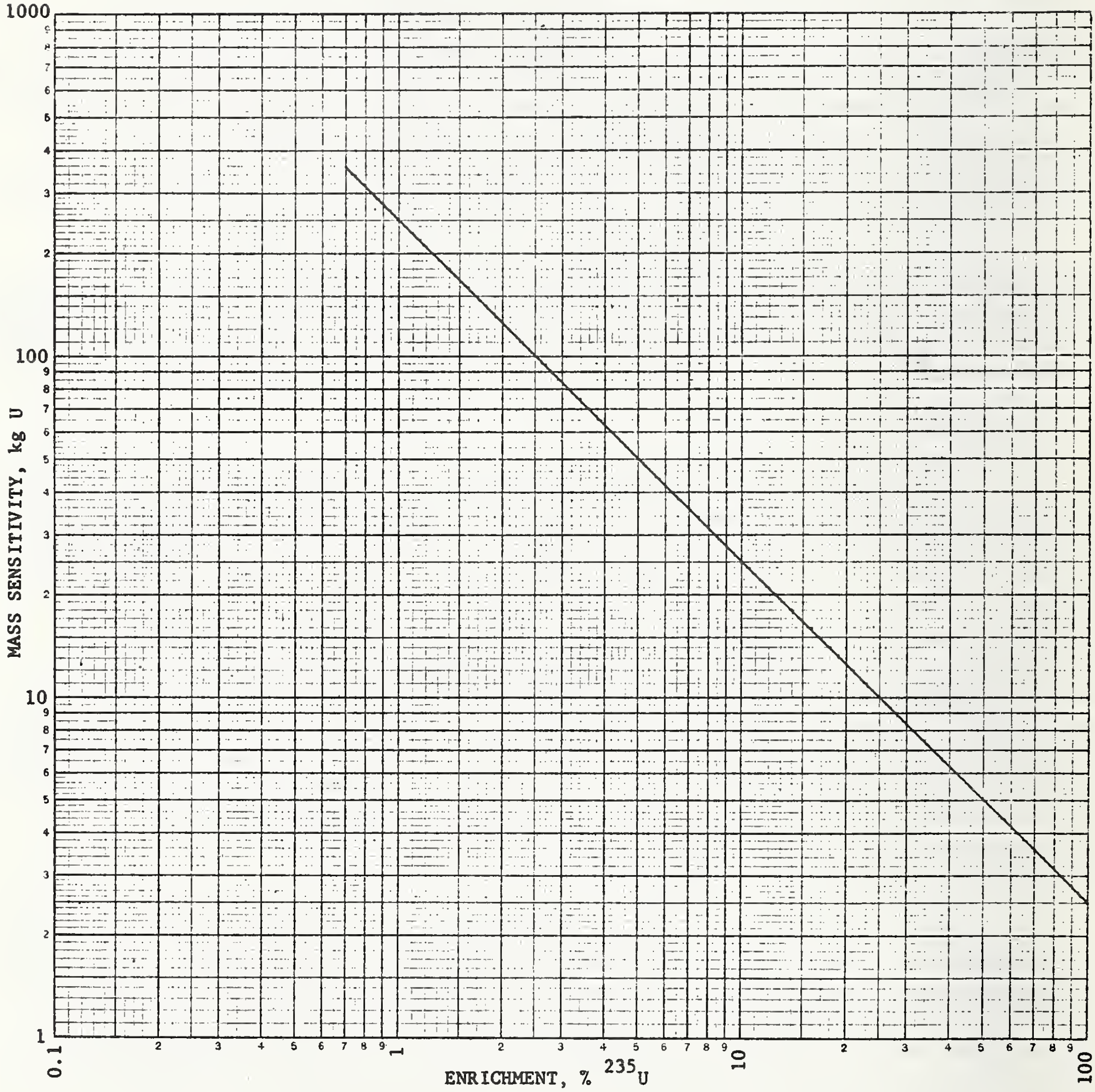

Figure 2.1 Mass Sensitivity as a Function of Enrichment

figure 2.1. For the DPA test, the establishment of 500 grams Pu as the mass sensitivity was further rationalized on the basis of economics of information precision and observed process fluctuation and control.

2.3.2 Time Sensitivity Boundary Value

The choice of time sensitivity was rationalized through the economics of detection, the response time needed for preventing the event, or end-use of the material, and for recovery. In establishing time sensitivity, attractiveness of material must also be considered in light of possible events which might be perpetrated using the particular material type and description.

For the practicality test, indication of diversion within 24 hours for a single removal or within 24 hours of the last removal of a series was chosen as the time sensitivity boundary value for very attractive materials. If some indicator would meet this time sensitivity, a particular path coverage was considered adequate.

2.3.3 Relative Weight Factors for Material Attractiveness

When materials of several types or descriptions are subject to illicit removal from an area, they may vary in desirability by virtue of their relative adaptability to the diverter's intended end-use. Material attractiveness must therefore be viewed in terms of resources, effort and personal risk to the diverter which will be involved in transforming the diverted material into a detonatable form.

2.4 Conduct of DPA

During DPA development, it was estimated that a team of three members of the plant staff could perform the analysis of an area; the area would encompass a Material Balance Area (MBA) or about 10 unit processes, whichever is less. The team would be composed of the area process engineer* and process foreman and a representative of the plant safeguards authority. The process personnel bring to the team first-hand knowledge and can quickly provide complete and detailed descriptions and information about the process and its operation. The plant safeguards authority representative brings knowledge of the DPA procedure and is responsible for performing the analysis. The practicality test verified that this composition is adequate for a DPA team.

Three basic steps are followed, each entailing a number of activities; these are schematically illustrated in figure 2.2. Data gathering refers to establishing the bounds of the analysis and those activities related to gaining thorough understanding of the conduct of the process, its operation and its performance. Information and data gained in this step allows a realistic analysis of the internal control system and provides knowledge of processing situations which would be considered unusual by the operators, process foreman or process engineer.

Analysis of diversion paths is the systematic consideration of possible means of removing nuclear material from the process area and,

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* The process engineer is the professional (or professionals) directly responsible for improvements to the process and for the specification of the internal and process controls to be used in the process area.

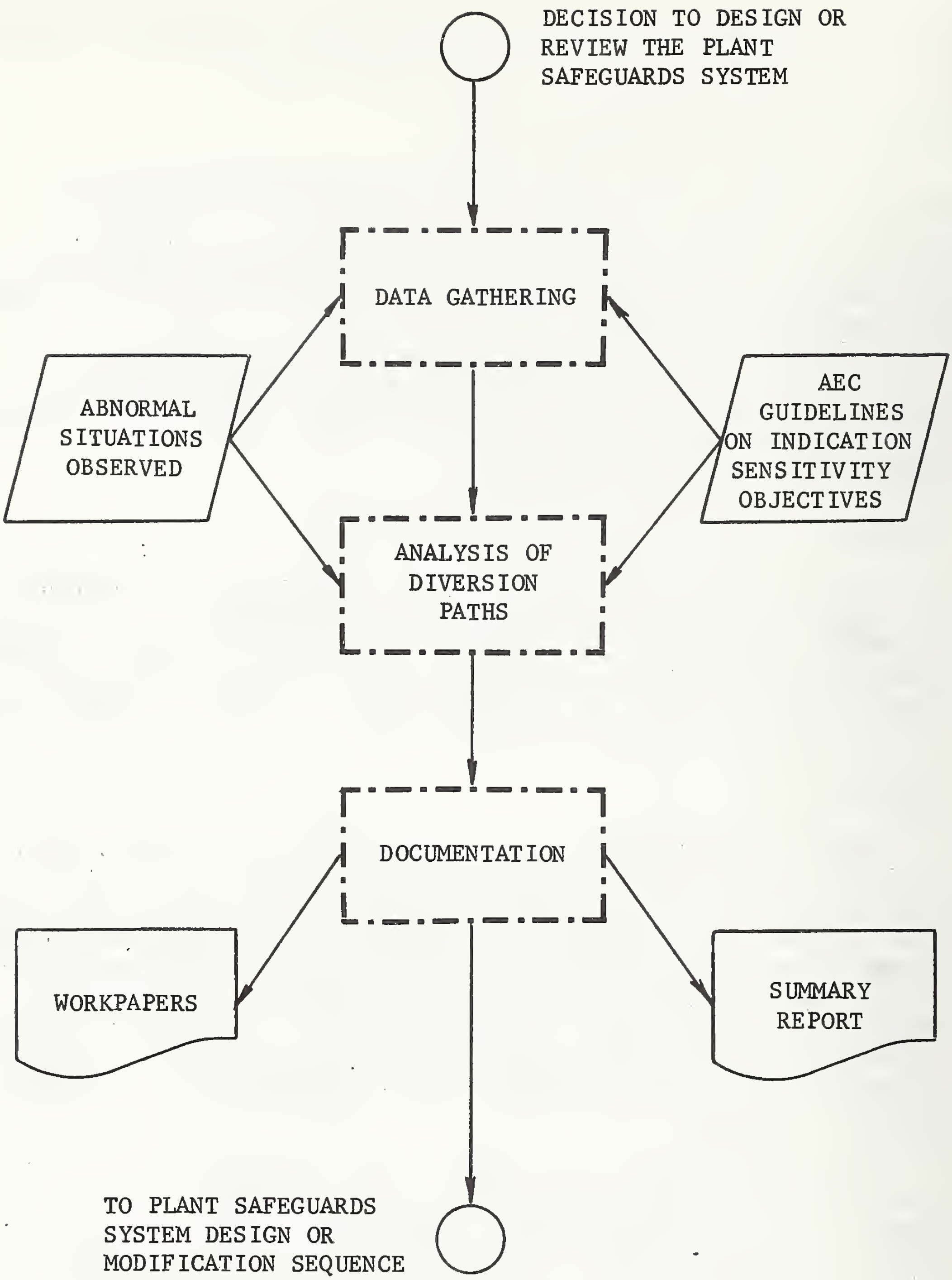

Figure 2.2 Basic Steps of Diversion Path Analysis

if successful, how the removal would be discovered or indicated. Routine documentation of the DPA is accomplished through the workpapers and the summary report. The workpaper document provides a complete permanent record which accurately reflects the analysis performed and serves as the basis for follow-up in the event of safeguards problems and for verification of statements made in the summary report. Completeness of the workpapers is essential to providing assurance about the correctness and adequacy of the design of the internal control system.

The summary document for each DPA pinpoints possible problem areas in the plant safeguards system. Since they are routinely reviewed by management, the content should stand alone providing concise information needed for overall evaluation and management decisions. It is essential that results and conclusions of the summary report be supported by and be traceable to the workpapers.

2.4.1 Data Gathering

There are four facets associated with data gathering each composed of a number of activities as illustrated in figure 2.3

2.4.1.1 Establish the Bounds of the DPA

Explicit agreement must be reached among the team members as to what portion of the facility is to be analyzed. Later, a review is made to ensure that no portion of plant activities has been neglected. There are three types of bounds to the analysis, the first of which is the process bound, an explicit statement of the process activities encompassed by the analysis. Second is the materials accountability bound. Because of the independence of measurements, personnel and geographic localization of currently defined MBA's, an analysis will rarely cross an MBA boundary. However, large or very complex material balance areas may be subdivided for purposes of analysis into groups of about ten unit processes. Third is the personnel bound, that is, which personnel are explicitly to be considered as potential diverters for the area under scrutiny. Those to be included in the class of potential diverters cannot conduct the analysis.

In the practicality test, the process bounds began with acceptance of material coming into an MBA and ended with shipment verifications as the material was transferred to the following MBA. The accountability bounds were the material balance area, and the personnel bounds were all process operators assigned to the area, outside visitors who might be in the area, plant employees assigned to other material balance areas, construction personnel who would not be plant personnel but who have access to the interior of the plant, and persons not authorized to be in the area.

2.4.1.2 Identify the Unit Processes

For purposes of analysis, the overall process stream of a plant is subdivided into many smaller operations, called unit processes, each of which is characterized by a "branch point" in the process stream, that is, where material changes its physical or chemical form or composition, or where by-product, such as recycle or scrap, is generated. Further details of the concept and identification of unit processes have previously been described [1].

DATA GATHE

ESTABLISH THE BOUNDS OF THE DPA

- PROCESS BOUNDS
- ACCOUNTABILITY BOUNDS
- PERSONNEL BOUNDS

IDENTIFY THE UNIT PROCESSES

DETAILED EXAMINATION OF THE UNIT PROCESSES

- STEPS IN THE PROCESS
- IMPORTANT PROCESS VARIABLES
- INCOMING MATERIAL FLOWS
- OUTGOING MATERIAL FLOWS
- RECORDING AND MEASUREMENT ACTIVITIES
- INSTRUCTION FLOWS
- CHECKS AND VERIFICATION FOR PROCESS COMPLETION
- PROCESS CONTROLS
- QUALITY CONTROLS
- MATERIAL ACCOUNTING ACTIVITIES

DIVERSION INQUIRY SESSION

- CHOICE OF DIVERSION INDICATION SENSITIVITY OBJECTIVES
  - MASS
  - TIME
  - SPACE
- MATERIALS LIST AND CHOICE OF RELATIVE MATERIAL ATTRACTIVENESS
- DIVERSION PATH DISCUSSION
  - FOR EACH MATERIAL;
  - IN ORDER OF MATERIAL ATTRACTIVENESS;
  - IN GENERAL ORDER OF PATH COMPLEXITY:
    - IDENTIFICATION OF DIVERSION PATHS
    - ELIMINATION OF IMPOSSIBLE PATHS
    - FOR EACH ABNORMAL SITUATION; THE OBSERVER, MASS SENSITIVITY, TIME SENSITIVITY, INNOCENT CAUSES
    - DETERMINATION OF CURRENT COVER
    - DETERMINATION OF POSSIBLE FUTURE COVER

ABNORMAL SITUATION OBSERVED

- OBSERVER IDENTIFICATION
- MASS SENSITIVITY
- TIME SENSITIVITY
- INNOCENT CAUSES

INDICATION SENSITIVITY OBJECTIVE GUIDELINES

MASS, TIME, SPACE — AS A FUNCTION OF MATERIAL ATTRACTIVENESS

Figure 2.3 Activities Associated with the DPA Data Gathering Step

Each unit process, identified in the previous step, is now examined in depth in order to assure that the points indicated in figure 2.3 under this heading are fully understood by each member of the DPA team. Topics discussed while carrying out this step in the course of the practicality test are listed in table 2.1.

The detailed examination results in an annotated material and information flow diagram for each unit process. Preparation of these diagrams is, however, reserved until the analysis step described below.

2.4.1.4 Diversion Inquiry Session

The diversion inquiry session provides a forum for quickly interchanging raw information among members of the DPA team in order to expose diversion possibilities and their covers. Our experience has been that plant personnel of the caliber composing the team have already given thought to means of removal and can readily make suggestions as to which paths are possible and the status of current cover. Major points to be discussed in the session are set forth in figure 2.3.

- Choice of Diversion Indication Sensitivity Objectives

Sensitivity objectives, possibly in the form of guidelines may be established in the future for purposes of consistency and comparability between DPA's. In the interim, corporate establishment of objectives can contribute toward this goal. Otherwise, the choice of sensitivity objectives falls to the DPA team. The choices of mass and time sensitivities for the practicality test have already been discussed, space sensitivity was automatically restricted to the MBA under scrutiny.

- Materials List; Material Attractiveness

The list of materials, different material types (if more than one is present in the process area) and different material descriptions (chemical and physical forms) will be a direct output of the detailed examination of the unit processes. Relative material attractiveness (pending a uniform choice or more specific guidelines) must then be opted.

- Diversion Path Discussion

The heart of the diversion inquiry session is consideration of all conceivable diversion possibilities. Adequately covered paths can usually be dismissed quickly at this point, leaving the remaining time for discussion of paths not currently covered. In the practicality test, the foreman and process engineer possessed knowledge which allowed rapid dismissal of many diversion paths as meaningless, permitting focus on more meaningful potential paths.

A. CHEMISTRY
   1. CHEMICAL EQUATIONS
      a. REACTIONS
      b. ENERGY RELATIONS
      c. REACTION RATES
   2. RESULTS
      a. EXPECTED (THEORETICAL)
      b. EXPERIMENTAL (CHEM R&D)

B. CHEMICAL ENGINEERING
   1. CHEMICAL ENGINEERING CONSIDERATIONS
   2. PROCESSING PROBLEMS
      a. POSSIBLE CAUSES OF LOW Pu IN SCRAP
      b. POSSIBLE CAUSES OF HIGH Pu IN SCRAP
      c. OTHER PROBLEMS

C. FAMILIARIZATION WITH PROCESS AREA

D. PROCESS PROCEDURES
   1. OPERATION 1
   2. OPERATION 2
   3. OPERATION 3
   4. OPERATION 4
   5. OPERATION 5

   EACH TO INCLUDE
   - OPERATOR ACTIVITIES
   - FORMS COMPLETED
   - ROUTING OF FORMS
   - RECORD MAINTENANCE
   - RECORD ACCESSIBILITY
   - ENGINEERING CALCULATIONS
   - ENGINEERING JUDGMENTS
   - ENGINEERING DECISIONS

E. EXPERIENCE
   1. YIELDS
   2. FREQUENCY AND CAUSES OF BAD YIELDS
   3. OTHER PROCESS PROBLEMS
   4. MISPLACED MATERIAL (RESOLUTION TIME AND EXPLANATIONS)
   5. RESIDENCE TIMES FOR MATERIAL IN VARIOUS PROCESS STEPS
   6. RESIDENCE TIME OF SCRAP IN STORAGE
   7. COMPARISON OF BY-DIFFERENCE SCRAP TAG VALUES AND RECOVERY VALUES
   8. NDA EXPERIENCE WITH SCRAP
   9. PRIOR PERIOD ACCOUNTING ADJUSTMENTS
   10. ACCOUNT MUF VALUES

Table 2.1 Topics Discussed For Detailed Examination of Unit Processes During Practicality Test

Typical questions were: "If you were after such-and-such material, what specifically would you take and how would you do it?" The ensuing discussion led to "How would you know the removal had occurred?" and "How could you determine this type of falsification, substitution or whatever more quickly?". Although the discussion concentrated on more complicated paths, information was also provided about the coverage of less complicated paths, usually expressed as "you wouldn't do that because...".

The sequence of analyzed paths is soon terminated at a point where remaining paths have relative weight values less than the pre-selected boundary conditions (related to credibility as a function of path complexity); another material is then selected for consideration. The procedure ends when each material in the precess area has been considered at all locations where that material may be found.

2.4.2 Analysis

Data gathering and the inquiry session illuminate the safeguards status of the area under scrutiny, and analysis provides assurance of completeness. One is thereby assured that there are no paths which are either uncovered or only marginally covered (that is there are no "holes" in the internal control procedures) within the boundary conditions. The analysis portion of the DPA is illustrated in figure 2.4. Each step is amplified below.

2.4.2.1 Process and Internal Control Understanding

- Generate the Information and Material Flow Diagrams

The data are analyzed to isolate the following information and material flows for each unit process:

- incoming material and information flows;
- information and data generated at this node;
- records maintained at this node;
- records and reports prepared at this node;
- outgoing material and information flows; and
- other characterizations of the node such as material handling activities.

The resulting information is summarized in an annotated diagram, shown for the general case in figure 2.5 and for a particular unit process examined in the course of the practicality test in figure 2.6. Accompanying these diagrams are notes in which the material and information flows are detailed. The notes shown in outline form in tables 2.2 and 2.3 correspond to the diagrams in figures 2.5 and 2.6, respectively. It may be observed that the diagrams and notes are less complex for the actual unit process than for the generalized case since the latter must include all possible flows, many of which may not apply in a particular situation.

- Numerical Analysis of Process Data

The end result of numerical analysis of process data is a characterization of all variables which might reasonably be expected to have safeguards significance by manifesting abnormal fluctuation should

ABNORMAL SITUATION OBSERVED

- OBSERVER IDENTIFICATION
- MASS SENSITIVITY
- TIME SENSITIVITY
- INNOCENT CAUSES

INDICATION SENSITIVITY OBJECTIVE GUIDELINES

- MASS
- TIME
- SPACE

} AS A FUNCTION OF MATERIAL ATTRACTIVENESS

ANALYSIS

PROCESS AND INTERNAL CONTROL UNDERSTANDING

- INFORMATION AND MATERIAL FLOW DIAGRAMS
- EXPLANATORY OUTLINE
- NUMERICAL ANALYSIS OF PROCESS DATA
- TIMING INFORMATION

CONSIDERATION OF EACH GENERALIZED DIVERSION PATH

- ORDERED DIVERSION PATH CHECK LIST
- CONSIDERATION OF EACH PATH IN ORDER OF
  - EACH MATERIAL
  - NO COLLUSION
  - COLLUSION
- DIVERSION PATH NOTES
  - DIVERTER
  - MATERIAL
  - CONCEALMENT SCHEME
  - ABNORMAL SITUATION
  - POSSIBLE INNOCENT CAUSES OF ABNORMAL SITUATION
  - SENSITIVITY AS A FUNCTION OF DISTRIBUTION OF DIVERTED AMOUNTS
- DIVERSION PATH CHECK-OFF DATA

SUMMARIZATION OF DIVERSION PATH DATA

- ABNORMAL SITUATION LIST
- LIST OF DIVERSION PATHS FOR GIVEN ABNORMAL SITUATION
- DIVERSION PATH--ABNORMAL SITUATION CROSS-REFERENCE TABLE
- INTERNAL CONTROL HISTOGRAM CHARACTERIZATION
  - NO COLLUSION
    - FOR EACH MATERIAL
    - FOR ALL MATERIALS
  - COLLUSION
    - FOR EACH MATERIAL
    - FOR ALL MATERIALS
- SINGLE PARAMETER MEASURE

Figure 2.4 Activities Associated with the DPA Analysis Step

General Node Description

Location: PLANT

Decision Maker: PROCESS OPERATOR (UNIT PROCESS)

Information Needs of Decision Maker

List of items or containers received, on-hand or transferred-out
Independent check-weight data for receipts and transfers
Tag value for each container of material in unit process
Production instructions and specifications
Normal process operation (process foreman and/or experience)
S-R distribution information (probably gained from experience)

Characterization of Node

Information flows are illustrated schematically in figure 2.5. Pertinent details of the contents of the node and of the flows are given below (numbered circles are for cross-reference to figure 2.5).

I. INCOMING INFORMATION FLOWS TO THIS NODE
  A. From the process operator of preceding unit process
6   1. Data traveling with material
        a. Tag information
          1) Date and identification of preparer
          2) Identification of batch, item or container
          3) Gross and/or net weight
          4) Physical-chemical form (type-/description-code)
          5) SNM content of material
        b. Other records
          1) Transfer information if first unit process in MBA
          2) Instructions for operational activities
          3) Material use information
9   B. From MBA SNM custodian
      1. List of material transferred into unit process if first unit process in MBA
10 C. From process foreman
      1. Routine information about normal process activities such as results to be expected, information enabling process operator to know that process is operating properly, and factors constituting abnormal situations
      2. Work instructions for unit process activities
      3. Authorization to withdraw material from vault and/or process area storage (may be copy of work instructions)
      4. Solutions to unit process activity problems
      5. Specifications for items
      6. Abnormal situation information
        a. Elapsed time allowed before notifying next echelon (for each type of abnormal situation)
        b. Innocent cause or resolution
        c. Feedback
      7. Safeguards policy from plant management

II. INFORMATION AND DATA GENERATED AT THIS NODE
2   A. Unit process receiving activities
      1. Check of item or container identification
      2. Gross weight measurement (if applicable)
      3. Observation of S-R (if applicable)
      4. Dependent on diversion paths for this unit process
        a. NDA data
        b. Chemical or isotopic analysis of samples
        c. Other appropriate measurements
3   B. Unit process activities
      1. Varies with functional aspects of unit process
4   C. Unit process shipping activities
      1. Check of item or container identification
      2. Observation of material transfer from unit process (tag and transfer data usually generated during [II.B.])
      3. Dependent on diversion paths for this unit process, check-weight or other appropriate measurements just prior to transfer-out
  D. Observations for abnormal situations
  E. Observations of process operations

III. RECORDS MAINTAINED AT THIS NODE
  A. Abnormal situation log
  B. Unit process log
  C. Unit process temporary storage log (provides a record of in-process items transferred into and out of temporary storage in unit process area if such storage is used)

IV. RECORDS AND REPORTS PREPARED AT THIS NODE
15 A. Abnormal situation log
      1. Date and time of discovery
      2. Identification of discoverer (man- or badge-number)
      3. Brief statement of pertinent facts
        a. Material type
        b. Quantity
        c. Location
        d. Initial actions taken
  B. Unit process activity records and reports
      1. Production logs
      2. Status reports
      3. Data sheets
  C. Unit process temporary storage log
  D. Data to travel with material
  E. Notification of material receipt, shipment or item identity change

V. OUTGOING INFORMATION FLOWS FROM THIS NODE
7   A. To process operator of following unit process
      1. Data traveling with material
        a. Tag information [I.A.1.a.]
        b. Other records
          1) Transfer information if last unit process in MBA
          2) Instructions for operations to be performed
          3) Material use information

Table 2.2 Details of Information and Material Handling Flows Associated with Generalized Unit Process

(11) B. To plant data acquisition

For direct transmission of information to the plant data processing system. Use of this flow is optional with the facility and depends on the sophistication of the data processing system employed for maintenance of the safeguards related data base (manual, dedicated mini-, local-, or central-computer), diversion paths associated with the unit process, and types of data analyses to be performed.

If used, information on material movements, item identity change, and production parameters, data and variables would typically be transmitted directly (on-line acquisition) to the plant data processing system.

If not used, production data and accountability information would be sent to the process foreman and later analyzed and/or entered into the data processing system by a decision maker other than the process operator [V.E.1.].

(12) C. To MBA SNM custodian
1. Notification of receipts into first unit process in MBA
2. Notification of shipments from last unit process in MBA
3. Notification of item identity change resulting from unit process activities (possibly copy of production records)
4. Physical inventory at inventory time
5. Verification of receipts from off-site if not performed in receiving area
6. Authorization to remove material from process area storage (possibly copy of work instructions)

D. To vault manager
1. Authorization to remove material from vault (possibly copy of work instructions)

E. To process foreman

(13) 1. Unit process activity reports (at plant option, some may be entered directly into plant data acquisition system [V.B.])
   a. Production logs
      1) Production throughput
      2) Operator identification
      3) Process control and parameter information
      4) Traceback for quality control
   b. Data sheets
   c. Status reports

(14) 2. Abnormal situation information and alerts
   a. Discovery information
   b. Investigative information
   c. Innocent cause information
   d. Resolution information
3. Other information
   a. Observations relating to unit process activities
   b. Problems arising from unit process activities
   c. Assurance information

(16) F. To process foreman and process engineer

A carbon copy of the abnormal situation log entry [IV.A.] is sent to each in order to insure independent two-level reporting, start the elapsed time clock, and provide a record for use during investigative actions. This report is purposely brief so that the process operator is not overburdened with report preparation, which might deter him from filing the report, and also to minimize reporting costs should the abnormal situation be from innocent cause.

(17) G. To process engineer and plant safeguards authority

Periodic review of abnormal situation log when these decision makers verify that the plant safeguards system is correctly designed and properly functioning.

VI. OTHER CHARACTERIZATIONS OF NODE

A. Material handling activities

(1) 1. From preceding unit process
   a. Product from unit process in same or different MBA
   b. Material stored in same or different MBA
   c. Recycle from unit process in same or different MBA
   d. Material received from off-site

(5) 2. To following unit process
   a. Product to unit process in same or different MBA
   b. Material for storage in same or different MBA
   c. Recycle to unit process in same or different MBA
   d. Samples to analytical laboratory
   e. Material to R&D areas
   f. Scrap to recovery
   g. Waste to measured discard
   h. Material to be shipped off-site

B. Unit process operator

(18) 1. Preceding unit process
   a. Operational unit process in same or different MBA (process operator)
   b. Storage unit process in same MBA (MBA SNM custodian)
   c. Storage unit process in different MBA (vault custodian or MBA SNM custodian)
   d. Analytical laboratory (analytical chemist)
   e. R&D area (R&D technologist)
   f. Off-site receiving (shipping dock clerk)

(8) 2. Following unit process
   a. Operational unit process in same or different MBA (process operator)
   b. Storage unit process in same MBA (MBA SNM custodian)
   c. Storage unit process in different MBA (vault custodian or MBA SNM custodian)
   d. Analytical laboratory (analytical chemist)
   e. R&D area (R&D technologist)
   f. Off-site shipping (shipping dock clerk)

Table 2.2 Continued

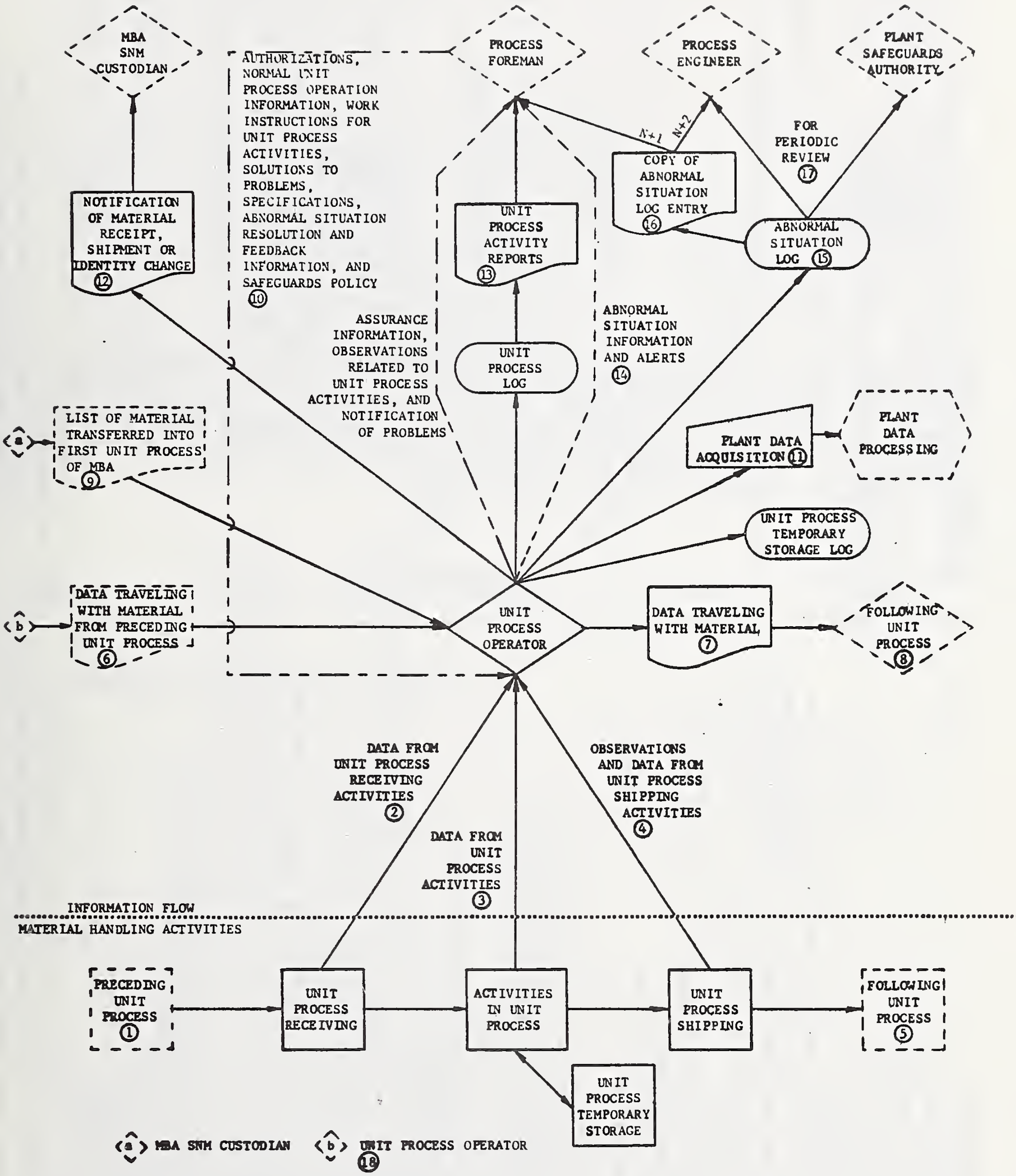

Figure 2.5 Information and Material Handling Flows Associated with Generalized Unit Process

General Node Description

Location: MBA XYZ
Decision Maker: OPERATOR 2

Information Needs of Decision Maker

Work instructions
Material use instructions

Characterization of Node

Information and material handling flows are illustrated schematically in figure 2.6. Pertinent details of the contents of the node and of the flows are given below.

I. INCOMING INFORMATION FLOWS TO THIS NODE

1 A. From operator 1
    1. Pink copy of Form 1 with indication items have been placed in process storage

2 B. From process foreman
    1. General work instructions
        a. Material use
            1) First in -- first out
            2) Quantities
        b. Acceptable tolerances for measurements
        c. Abnormal situation instructions
        d. Instructions for performing operation 2
    2. List of items to be used on daily basis
    3. Solutions to problems

II. INFORMATION AND DATA GENERATED AT THIS NODE

3 A. Material acceptance
    1. Item identification on receipt
    2. Indication on Form 1 that specified items are received
    3. Item weight measurement
    4. Observation for shipper-receiver difference
    5. Completion of "Before Operation 2" portion of Form 2

4 B. Operation 2
    1. Material weight measurement after operation 2 performed
    2. Comparison of weights before and after operation 2
    3. Observation for greater than allowable weight difference
    4. Completion of "After Operation 2" portion of Form 2
    5. Indication of Form 1 that operation 2 completed for item

5 C. Preparation for transfer to operation 3
    1. Tare weight measruement of container
    2. Identification of container
    3. Completion of Form 3
        a. Form 4 number
        b. Tare weight
        c. Net weight

Table 2.3 Details of Information and Material Handling Flows Associated with Operator 2

III. RECORDS MAINTAINED

6 A. Holds pink copy of Form 1 until all items listed have been used (usually 2 to 3 days, may be up to 5 days)

7 B. Holds copy of Form 2 until page is completed (usually about 5 days)

IV. RECORDS AND REPORTS PREPARED AT THIS NODE

8 A. Form 1
    1. Indication of item receipt
    2. Indication shipper-receiver difference in acceptable tolerance
    3. Indication that operation 2 is completed

9 B. Form 2
    1. "Before Operation 2" portion
    2. "After Operation 2" portion

10 C. Form 3
    1. Form 4 number
    2. Tare weight
    3. Net weight

V. OUTGOING INFORMATION FLOWS FROM THIS NODE

A. To operator 3
    1. Data traveling with material (Forms 3 and 4)

B. To process foreman
8   1. Pink copy of Form 1 when all items listed have been used
9   2. Form 2 when page is completed
11   3. Notification of problems and observations
12   4. Abnormal situation information and alerts [VII.]

VI. MATERIAL HANDLING ACTIVITIES

13 A. Material acceptance
    1. Identity verification
        a. Obtain list of items to be used from process foreman
        b. Obtain key to process storage from process foreman
        c. Locate items in process storage
        d. Transfer items to be used into holding area
        e. Check item identification as transfer is made
        f. Indicate on Form 1, as transfer is made, that specified items are transferred into holding area
    2. Weight verification
        a. Transfer one item from holding area to operation 2 work area
        b. Weigh item
        c. Compare value with weight indicated on Form 1
            1) If difference is n grams or less, accept and, indicate on Form 1
            2) If difference greater than n grams, notify process foreman immediately
    3. Complete "Before Operation 2" portion of Form 2

14 B. Operation 2
    1. Perform operation 2 per work instructions
    2. Weigh material after performing operation 2
    3. Compare weights before and after operation 2
        a. If difference greater than m grams, follow

prescribed procedure
   b. If still unresolved after procedure, notify process foreman immediately
4. Complete "After Operation 2" portion of Form 2
5. Indicate completion of operation 2 for item on Form 1

⑮ C. Preparation for transfer to operation 3
1. Measure tare weight of container
2. Place material in container per work instructions
3. Write Norm 4 number on container for identification
4. Complete Form 3
   a. Form 4 number
   b. Tare weight
   c. Net weight
5. Remove container from operation 2 work area
6. Afix Form 4 onto container wrapper
7. Transfer container to operation 3 work area

VII. OBSERVATIONS FOR ABNORMAL SITUATIONS
A. Is item missing from process storage prior to material acceptance?
B. Is there a significant shipper-receiver difference (outside of acceptable tolerance)?
C. Is material missing after operation 2 is performed?

Table 2.3 Continued

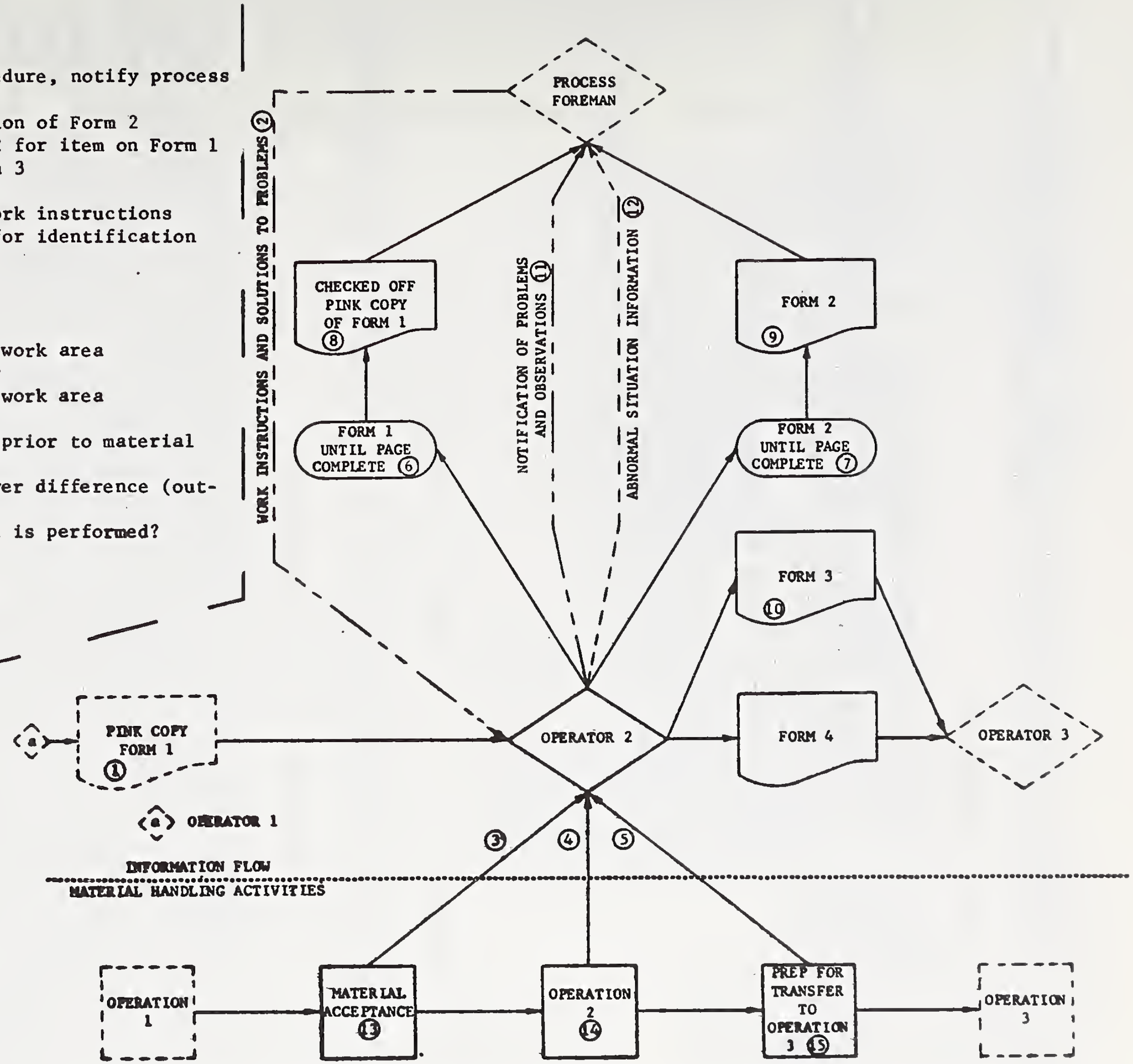

Figure 2.6 Information and Material Handling Flows Associated with Operator 2

material be removed at some point of the process. Possible types of numerical analysis of process data were covered in detail in an earlier paper [1].

- Timing Information

Timing information may come from interview, the opinions of the foreman, etc., or from analysis of process data. Impressions may not be entirely accurate, so timing information gained through interview should be verified, when possible, by process data. The information required for establishing time sensitivity is:

- residence time of all materials at intermediate points;
- time for completion of operations;
- time between measurement and incorporation of the measurement into the safeguards system;
- time between completion and analysis of information on forms;
- time between notice of an abnormal situation and response; and
- inventory frequency.

2.4.2.2 Consideration of each Generalized Diversion Path

Central to diversion path analysis is the systematic consideration of paths or diversion possibilities.

- Ordered Diversion Path Check List

A standard check list of diversion path possibilities is generated based on diversion path parameter combinations, an accepted set of relative weight factors, and a path ordering program. In generating the list, one can use the generic names for material attractiveness or the material descriptions specific to the process under analysis.

The relative weight factors associated with material attractiveness and path complexity, the latter being the remaining parameter values taken collectively, combine to form the relative path weight; they thus enter into safeguards significance in two ways. First, they determine the order in which paths are to be examined and second, they determine which paths lie below the cutoff and are not to be examined in depth. In selecting the cutoff point, one must consider credibility of paths as a function of complexity and of material attractiveness. Paths just below the chosen cutoff should be examined at least cursorily to assure that no credible paths have been neglected, otherwise the cutoff decision must be re-examined.

The diversion path parameters, parameter values, and associated relative weight factors used in the practicality test are shown in generalized form in table 2.4. As discussed in an earlier paper [1], a product of relative weight factors determines a relative path weight and enters the implicit trade-off between material attractiveness and path complexity. The first page of a standard list using generic material descriptions is shown in table 2.5. A forthcoming paper [2] will provide a more complete description of the path ordering program and procedures.

DIVERSION PATH PARAMETERS			RELATIVE WEIGHT FACTOR
1.	MATERIAL ATTRACTIVENESS (M)		
	M1	FEED PRODUCT	1.000000
	M2	RECYCLE	0.500000
	M3	SCRAP	0.200000
	M4	LAB SAMPLES	0.100000
	M5	WASTE	0.010000
2.	RECORDS (F)		
	F1	NO FALSIFICATION	1.000000
	F2	FALSIFY NON MEASUREMENT DATA	0.900000
	F3	FALSIFY GROSS AND/OR NET WT	0.800000
	F4	FALSIFY CONCENTRATION MEASMT	0.500000
	F5	FALSIFY NET/GROS UNCERTAINTY	0.200000
	F6	FALSIFY ISOTOPIC COMPOSITION	0.100000
	F7	FALSIFY CONC/ISOTOPIC UNCERT	0.020000
3.	DISTRIBUTION OF DIVERTED AMOUNTS (D)		
	D1	1	1.000000
	D2	2	0.707107
	D3	3	0.577350
	D4	4	0.500000
	D5	5	0.447214
	D6	6	0.408248
	D7	7	0.377964
	D8	8	0.353553
	D9	9	0.333333
	D10	10	0.316228
	D11	15	0.258199
	D12	20	0.223607
	D13	25	0.200000
	D14	30	0.182574
	D15	35	0.169031
	D16	40	0.158114
	D17	45	0.149071
	D18	50	0.141421
4.	REMOVAL MODE (R)		
	R1	SIMPLE	1.000000
	R2	SUB-INERT	0.700000
	R3	SUB-ISOTOPIC	0.100000
5.	NUMBER OF INDIVIDUALS (I)		
	I1	1	1.000000
	I2	2	0.300000
	I3	3	0.111109
	I4	4	0.037036
	I5	5	0.012345
	I6	6	0.004115
	I7	7	0.001372
	I8	8	0.000457
	I9	9	0.000152
	I10	10	0.000051
6.	TYPE OF INDIVIDUAL (P)		
	P1	INSIDER	1.000000
	P2	OUTSIDE EMP	0.500000
	P3	OUTSIDE VSTR	0.100000
	P4	UNAUTHORIZED	0.100000

Table 2.4 Diversion Path Parameters, Parameter Values and Associated Relative Weight Factors

ORDERING OF DIVERSION PATHS -- PRODUCT
LIST I - OUTPUT PATHS WITH WEIGHT > .1

* * * * * * * * * * * * * * * * * * * FEED PRODUCT * * * * * * * * * * * * * * * * * * *

CURRENTLY COVERED OR NOT POSSIBLE
. FUTURE COVERED
. . NOT COVERED

Coverage	No.	M	F	D	R	I	P	RELATIVE PATH WEIGHT	SEQ.
* * * *	1.	FEED PRODUCT	NO FALSIFICATION	1	SIMPLE	1	INSIDER	1.000000	1
* * * *	2.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	1	SIMPLE	1	INSIDER	0.900000	2
* * * *	3.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	1	SIMPLE	1	INSIDER	0.800000	3
* * * *	4.	FEED PRODUCT	NO FALSIFICATION	2	SIMPLE	1	INSIDER	0.707107	4
* * * *	5.	FEED PRODUCT	NO FALSIFICATION	1	SUB-INERT	1	INSIDER	0.700000	5
* * * *	6.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	2	SIMPLE	1	INSIDER	0.636396	6
* * * *	7.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	1	SUB-INERT	1	INSIDER	0.630000	7
* * * *	8.	FEED PRODUCT	NO FALSIFICATION	3	SIMPLE	1	INSIDER	0.577350	8
* * * *	9.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	2	SIMPLE	1	INSIDER	0.565685	9
* * * *	10.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	1	SUB-INERT	1	INSIDER	0.560000	10
* * * *	11.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	3	SIMPLE	1	INSIDER	0.519615	11
* * * *	12.	FEED PRODUCT	NO FALSIFICATION	4	SIMPLE	1	INSIDER	0.500000	14
* * * *	13.	FEED PRODUCT	NO FALSIFICATION	1	SIMPLE	1	OUTSIDE EMP	0.500000	13
* * * *	14.	FEED PRODUCT	FALSIFY CONCENTRATION MEASMT	1	SIMPLE	1	INSIDER	0.500000	12
* * * *	15.	FEED PRODUCT	NO FALSIFICATION	2	SUB-INERT	1	INSIDER	0.494975	16
* * * *	16.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	3	SIMPLE	1	INSIDER	0.461880	17
* * * *	17.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	4	SIMPLE	1	INSIDER	0.450000	18
* * * *	18.	FEED PRODUCT	NO FALSIFICATION	5	SIMPLE	1	INSIDER	0.447214	20
* * * *	19.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	2	SUB-INERT	1	INSIDER	0.445477	21
* * * *	20.	FEED PRODUCT	NO FALSIFICATION	6	SIMPLE	1	INSIDER	0.408248	22
* * * *	21.	FEED PRODUCT	NO FALSIFICATION	3	SUB-INERT	1	INSIDER	0.404145	23
* * * *	22.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	5	SIMPLE	1	INSIDER	0.402492	24
* * * *	23.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	4	SIMPLE	1	INSIDER	0.400000	25
* * * *	24.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	2	SUB-INERT	1	INSIDER	0.395980	27
* * * *	25.	FEED PRODUCT	NO FALSIFICATION	7	SIMPLE	1	INSIDER	0.377964	28
* * * *	26.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	6	SIMPLE	1	INSIDER	0.367423	29
* * * *	27.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	3	SUB-INERT	1	INSIDER	0.363730	30
* * * *	28.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	5	SIMPLE	1	INSIDER	0.357771	31
* * * *	29.	FEED PRODUCT	NO FALSIFICATION	2	SIMPLE	1	OUTSIDE EMP	0.353553	33
* * * *	30.	FEED PRODUCT	FALSIFY CONCENTRATION MEASMT	2	SIMPLE	1	INSIDER	0.353553	32
* * * *	31.	FEED PRODUCT	NO FALSIFICATION	8	SIMPLE	1	INSIDER	0.353553	35
* * * *	32.	FEED PRODUCT	FALSIFY CONCENTRATION MEASMT	1	SUB-INERT	1	INSIDER	0.350000	38
* * * *	33.	FEED PRODUCT	NO FALSIFICATION	4	SUB-INERT	1	INSIDER	0.350000	37
* * * *	34.	FEED PRODUCT	NO FALSIFICATION	1	SUB-INERT	1	OUTSIDE EMP	0.350000	36
* * * *	35.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	7	SIMPLE	1	INSIDER	0.340168	40
* * * *	36.	FEED PRODUCT	NO FALSIFICATION	9	SIMPLE	1	INSIDER	0.333333	41
* * * *	37.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	6	SIMPLE	1	INSIDER	0.326599	42
* * * *	38.	FEED PRODUCT	FALSIFY GROSS AND/OR NET WT	3	SUB-INERT	1	INSIDER	0.323316	43
* * * *	39.	FEED PRODUCT	FALSIFY NON MEASUREMENT DATA	8	SIMPLE	1	INSIDER	0.318198	45
* * * *	40.	FEED PRODUCT	NO FALSIFICATION	10	SIMPLE	1	INSIDER	0.316228	46

Table 2.5 First Page of a List of Generalized Diversion Paths

It was found useful to separate the generated ordered paths into two groups, the first of which comprised all paths with relative weight 0.1 or greater. The second group consisted of paths with relative weights less than 0.1 to bring the total number of paths to 3000. Remaining paths had relative weights still smaller than those of listed paths. Within the major groups, sub-groups were formed, classifying in turn by material attractiveness and the number of individuals working in collusion. Ordering within sub-groups by relative weight was then carried out. In all, the first group had 192 paths associated with feed-product, 99 with recycle, 14 with scrap, 1 with lab samples and none with waste. The number of paths for a given material attractiveness category, however, depends on the choice of material attractiveness relative weight factors; the sensitivity in choosing parameter values is currently being examined. The effect of the weight factors on system characterization and total coverage is small because the list is used only for ordering the sequence of path examination. In fact, if all paths can be covered, then the weight factors have no effect.

- Consideration of each Path in Order

The path list is then used as a guide to analyze diversion possibilities. For a given material, starting with persons acting alone, the internal control system is checked for possible diversion paths satisfying the generalized path parameters. Any diversion possibilities are recorded, along with possible corresponding indicators of an abnormal situation. Actual diversion paths may not match generalized diversion paths on a one-for-one basis. More actual paths may derive from material in the process or the make-up of potential diverters (from among the process operators, for example). Conversely, a simple diversion path may correspond to several generalized paths, as in the case of different numbers of separate removals in a series to add up to the desired mass sensitivity. Physical constraints of a process may preclude some paths. For example, if all process samples are about 10 grams, 500 grams cannot be obtained with only one removal. The basis for physical exclusion of any paths should be recorded.

- Diversion Path Notes

Diversion path notes in the workpapers are the documentation of the considerations given each diversion path. They should include:

- diverter - the person or persons who are the potential diverters;
- material - the amount, type, chemical form, physical form, and authorized location of the material to be taken;
- concealment rationale - why the diverter chooses a given type of concealment, including the size of the individual diversions in a series, explicitly what information is falsified, how that falsification will conceal the diversion, and the removal mode (see table 2.4);
- abnormal situation - a description of the first observable indication of abnormal situation resulting from the diversion;

- related innocent causes - unusual circumstances which would innocently cause the same abnormal situation (possible causes of false alarms); and
- sensitivity as a function of the distribution of diverted amounts, that is, if the time sensitivity is a function of the number of separate removals in a series (see table 2.4).

• Diversion Path Checkoff Data

The checkoff procedure is used to record the worst time sensitivity for a set of specific paths satisfying a generalized diversion path in the check-off column (table 2.5). If that worst time sensitivity is within the boundary condition, one proceeds to the next generalized path, otherwise, consideration is given to other possible abnormal situations which are not currently observed but which might provide the desired indication.

For example, a second copy might be added to work instructions; by denying the diverter access to that second copy, the foreman's comparison of the completed work form with the second copy would reveal falsification with respect to material used in the process, its identity, or other data on the work forms.

Similarly, a shadow measurement of the canned and tagged final product or material going into storage would uncover substitution of inert material.

Failure to identify a way to cover the diversion path within the time boundary condition is recorded in the third column of the check-off list. Data in the check-off columns form the basis for generation of the characterization histograms.

2.4.2.3 Summarizing Diversion Path Data

• Abnormal Situation List

All abnormal situations which are related to the diversion possibilities considered during the analysis are listed. It is useful to number the abnormal situations notes as well as those for diversion paths for ease of reference.

• List of Diversion Paths For a Given Abnormal Situation

The paths to be investigated following observation of an abnormal situation are listed. A standard operational procedure is followed to determine if the observed situation is due to an innocent cause and, if not, then to initiate investigative action. For example, observation of a bad yield as the abnormal situation should lead to routine inquiry to verify that the stated amount of SNM was in the scrap, recycle or waste streams related to that yield value. If the abnormal situation is not innocently resolved, then it is necessary to start an investigation, and knowledge of potential paths for the given abnormal situation comes into play.

• Diversion Path - Abnormal Situation Cross-Reference Table

The diversion path - abnormal situation cross-reference table is a tabulated summary of information contained in the list of diversion paths considered during the analysis. It displays the diversion paths which have a detection time sensitivity problem; sensitivities as a function of number of removals (where that is applicable); and the abnormal situation for each diversion path. The first page, with certain deletions, of the diversion path - abnormal situation cross-reference table from the practicality test is shown in table 2.6.

• Internal Control Histogram Characterization

The purpose of every aggregation of raw data is to highlight some aspect of results of the analysis. For the internal control histogram, the object is to allow a relatively high level manager to see at a glance which analysis areas have safeguards problems and, in the context of the known boundary conditions, to furnish insight as to what can be achieved by including additional abnormal situation observations in the internal control system.

Figure 2.7 illustrates an internal control histogram generated during the practicality test and the change in system coverage stemming from additional observations for abnormal situations. The bars represent the fraction of the generalized diversion paths falling within each relative path weight range, which are detected as abnormal situations within the indicated time sensitivity ranges. The data for the upper histogram came from the diversion path list in conjunction with a knowledge of the characteristics and time response of the abnormal situations. For the lower (modified coverage) histogram, a new set of data was generated by considering the change in each of the time sensitivities resulting from some additional observations in the internal control system.

• Single Parameter Measure

A further level of aggregation of DPA data has been considered. The weights reflecting the relative usefulness to safeguards recovery response may be combined from histogram information into a single, normalized number through a weighted summing. This becomes an aggregated index of the usefulness of the particular internal control system for safeguards. As for the internal control histogram, it is essential that a safeguards problem be reflected by such a composite index, and that the index not indicate a safeguards problem when, in fact, there is none.

2.4.3 Documentation

2.4.3.1 Workpapers

The workpaper document provides evidence of and basis for conclusions from the analysis, as well as motivation for and justification of recommended modifications to the internal control system. It also provides assurance to plant management of the validity of the safeguards properties of the internal control system, a basis for assurance to the AEC regarding internal control system diversion detection sensitivity, and a basis for investigating an abnormal situation which cannot be immediately ascribed to an innocent cause.

After the analysis step, all information in hand must be reviewed for consistency, completeness and understandibility. Figure 2.8 summarizes items which should appear in the workpapers, including most information and data collected for the study.

DIVERSION PATH (DP)	DISTRIBUTION OF DIVERTED AMOUNTS (D)	CURRENT ABNORMAL SITUATION NUMBER (AS)	CURRENT COVER TIME (DAYS)	FUTURE ABNORMAL SITUATION NUMBER (AS)	FUTURE COVER TIME (DAYS)	MATERIAL ATTRACTIVENESS (M)
1	1-10	1				
2	1-10	2				
3	1-10	3				
3	1-10	4				
4	1-10	4				
5	1-10	5				
5	1-10	5				
6	1	9				
6	2,3	10				
6	4-10	5				
7	1	47				
8	1-10	13				
9	1	16				
9	2-4	17				
9	5-10	18				
10	1	19				
10	2-4	19				
10	5-10	20				
11	1	19				
11	2-4	19				
11	5-10	20				
13	1	16				
13	2	17				
13	3-5	18				
13	6-10	20				
14	1-10	21				
15a	1-10	22				
15b	1-10	5				
15c	1-10	24				
15d	1-10	25 to 1kg				
15d	3-10	5				
15e	1	26				
15e	2-4	27				
15e	5-10	5				
15f	1	26				
15f	2-4	27				
15f	5-10	5				
16	1-10	5				
16	1-10	5				
17	1-10	5				
18a(1)	1,2	17				
18a(1)	3-10	18				
18a(2)	1-10	5				
18b(1)	1	30				
18b(1)	2-5	27				
18b(1)	6-10	5				
18b(2)	1-10	31				
18c	1-10	31				

Table 2.6 Typical Page of a Diversion Path--Abnormal Situation Cross-Reference Table

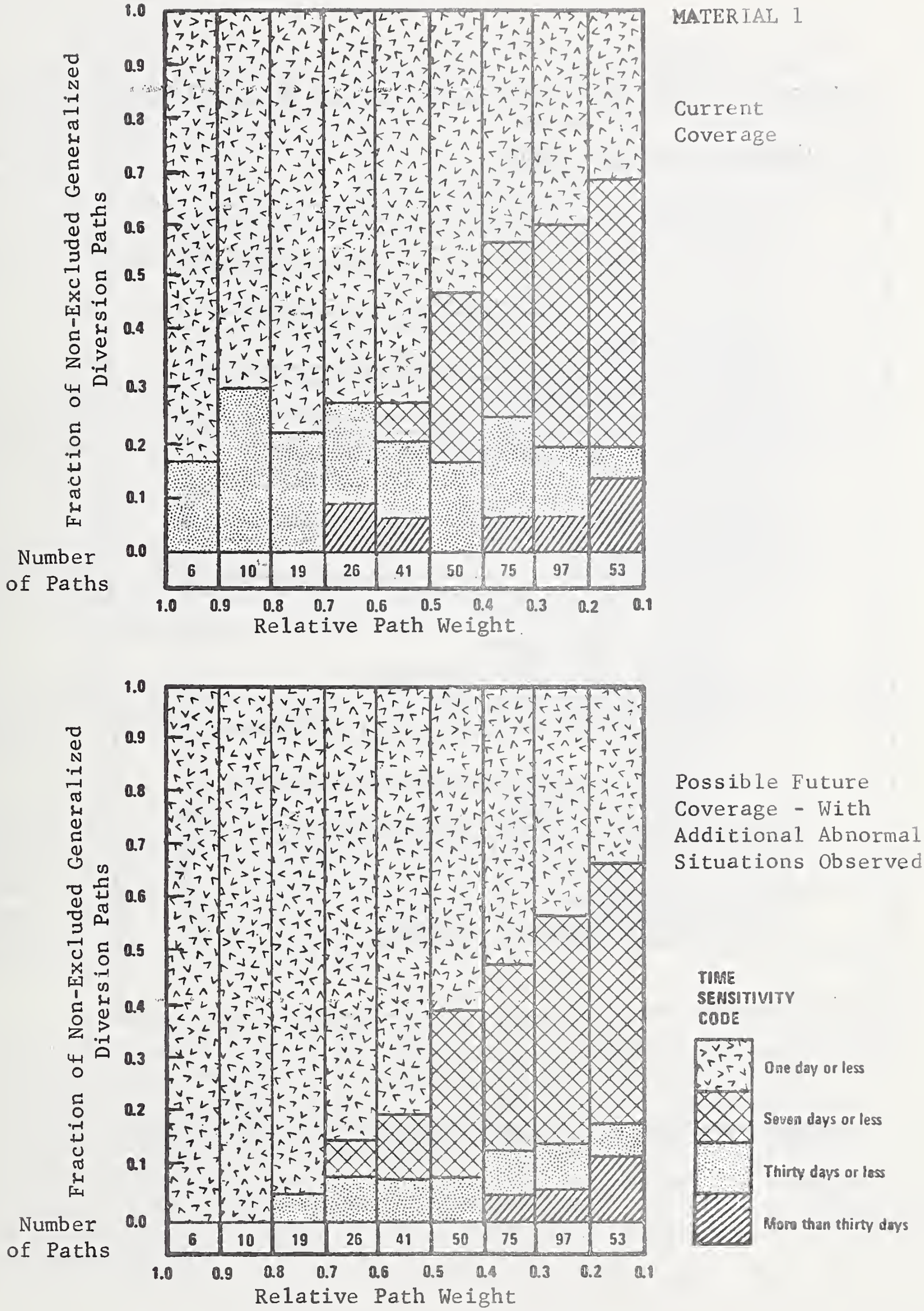

Figure 2.7 Internal Control Histograms

DOCUMENTATION--WORKPAPERS

INQUIRY SESSION NOTES

PROCESS NOTES

PROCESS FORMS

PROCESS DESCRIPTION

INFORMATION AND MATERIAL FLOW DIAGRAMS

NUMERIC SENSITIVITY DATA

NUMERIC ANALYSIS

DIVERSION PATH ANALYSIS

- DIVERSION PATH NOTES
- DIVERSION PATH CHECK-OFF DATA
- ABNORMAL SITUATION LIST
- LIST OF DIVERSION PATHS FOR GIVEN ABNORMAL SITUATION
- DIVERSION PATH--ABNORMAL SITUATION CROSS REFERENCE TABLE

SUMMARY STATEMENT DATA

- FOR HISTOGRAMS
- FOR SINGLE PARAMETER MEASURES

Figure 2.8 DPA Documentation Activities -- Workpapers

2.4.3.2. The Summary Report

The summary report presents highlights for management review of pertinent facts and conclusions contained in the workpapers. It should be sufficiently detailed and complete to allow understanding by a manager who is only generally familiar with the process. The contents, summarized in figure 2.9, state briefly the bounds of the analysis, process description, summary of the numerical analysis, timing information, number of paths analyzed, worst case information under current and future coverage, and characterization of the internal control system relative to safeguards goals.

2.4.4 Results of the Test of the DPA Procedure

A DPA was conducted with plant personnel performing the major role in data gathering and provision of base information on diversion paths through the inquiry session. NBS took the basic data and generated the remaining diversion path information, the workpapers and the summary report. The results are presented in distilled form to protect company proprietary information.

"Holes" are identified in the system through the DPA procedure by highlighting specific actions which might be taken by the diverter. Often, not much imagination is required to specify additional internal control procedures to cover the diversion possibility.

Conclusions from the test were:

- The systematic conduct of a comprehensive DPA is feasible and can be performed without excessive expenditure of time and effort by plant personnel knowledgeable of the process area under consideration;

- DPA can be used to characterize in-plant information, procedures, measurements and controls with respect to safeguards goals using general, straightforward analysis techniques. Validity of the analysis is critically dependent on knowledge of process practices actually employed, in contrast to practice as specified in manuals. Further, DPA provides a means of demonstrating additional coverage of diversion possibilities which might be gained through modification of present plant practice;

- A number of parameters were identified which permitted a choice for value. When made, such choice could be supported by a rationale which was not necessarily amenable to determination by objective analysis. The choices constituted the general boundary conditions for considering and ordering generalized diversion paths as a function of path complexity and material attractiveness. For the DPA, it is essential that the ordered list of generalized diversion paths be complete and present all diversion path parameter value combinations for consideration. Some will be impossible because of process constraints in the specific case; these need be given no further consideration.

DOCUMENTATION--SUMMARY REPORT

DATA

- BOUNDS OF THE ANALYSIS
- PROCEDURE SUMMARY
- PROCESS DESCRIPTION
- NUMERIC SENSITIVITIES
- TIMING INFORMATION

ANALYSIS

- MATERIALS AND MATERIAL ATTRACTIVENESS
- PATH ORDERING PROGRAM
- RESULTS OF SYSTEMATIC CONSIDERATION OF PATHS
- ABNORMAL SITUATIONS OF IMPORTANCE
- DECISION STRUCTURE AND DECISIONS

FINDINGS

- CURRENT COVERAGE
  - INTERNAL CONTROL CHARACTERIZATION HISTOGRAMS
  - WORST CASE INFORMATION
- RECOMMENDED COVERAGE
  - ADDED ABNORMAL SITUATION OBSERVATIONS
  - ADDED PROCEDURES
  - INTERNAL CONTROL CHARACTERIZATION HISTOGRAM
  - REMAINING WORST CASE INFORMATION

Figure 2.9 DPA Documentation Activities -- Summary Report

• The DPA of a specific process area was completed based on the choice of one set of relative weight factors. Additional information is needed, however, of the effect of alternative assignments for relative weight factors, and mass and time sensitivity limits. Also the analysis procedure used in this initial DPA led to a characterization, by means of histograms, of the safeguards effectiveness of the internal control system; alternative means should be explored and tested.

3. SUMMARY

This paper reflects current understanding of the context and steps of a routine diversion path analysis as applied by plant personnel to internal control systems. The basic steps of data gathering, analysis and documentation were discussed. In particular, emphasis was placed on the analyses steps for understanding process and internal control; consideration of diversion paths ordered according to generalized diversion path parameter combinations; and generation of histograms characterizing the safeguards usefulness of internal control systems for safeguards goals.

Conclusions from the most recent test of DPA were presented, demonstrating that it is possible, practical and feasible (without excessive cost) for plant personnel to carry out routine DPA. The foreman and process engineer, together with a representative of the plant safeguards authority group, should form the DPA team. The coverage provided by the internal control system and possible alternatives can be analyzed and results presented to fairly represent safeguards usefulness of the system.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance provided by Rocky Flats personnel in carrying out the practicality test.

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GLOSSARY

ABNORMAL SITUATION
: An occurrence inconsistent with historical experience and/or normal process operation which can be related to possible diversion of SNM.

BOUNDARY CONDITION
: A specific value assigned to a variable for the purpose of delimiting an analysis.

COVERED PATH (COVERED)
: A diversion path for which indication of an abnormal situation would result, within the mass and time sensitivity boundary conditions, if diversion were attempted by means of that path.

DISTRIBUTION OF DIVERTED AMOUNTS
: A diversion path parameter for describing the mass of SNM in, and number of, separate removals included in a diversion path.

DIVERSION
: The illicit removal of SNM from uses permitted by law or treaty (theft, robbery, or unauthorized or illegal acts committed by persons in authority). The authorized transfer of SNM from one use to another in the materials management sense, also called diversion, is not considered a part of these studies.

DIVERSION PATH (PATH)
: The complete and detailed description of a <u>modus operandi</u> and rationale, devised as an independent method, for illicitly removing and concealing the fact of removal of SNM.

DIVERSION PATH ANALYSIS
: A procedure for directing systematic analysis of diversion paths, ordered according to relative path complexity and material attractiveness, in light of all pertinent information about protection, handling and storing of SNM in the area under scrutiny. How well a particular diversion path is now or might in future be covered is evaluated by assessing the mass, time and space sensitivities of indication of attempted diversion.

DIVERSION PATH PARAMETER
: A variable associated with a generalized diversion path description, such as: (1) material attractiveness; (2) falsification of records; (3) distribution of diverted amounts; (4) removal mode; (5) number of individuals; and (6) type of individual.

DIVERSION PATH PARAMETER VALUE
: An attribute of a diversion path parameter.

FALSIFICATION OF RECORDS
: A diversion path parameter for referencing deliberate recording of differences between information or data elements and current reality as a part of the concealment plan of the diverter.

GENERALIZED DIVERSION PATH

A description, in terms of diversion path parameters, of a potential means for illicitly removing and concealing the removal of SNM.

INSIDER

A diversion path parameter value of the parameter for type of individual, indicating an employee who is authorized access to both the plant-site and to the SNM.

INTERNAL CONTROL

The plan of organization and all of the coordinate methods and measures adopted within a business to safeguard its assets, check the accuracy and reliability of its accounting data, promote operational efficiency, and encourage adherence to prescribed managerial policies [3].

MASS SENSITIVITY

An attribute of diversion indication for denoting that in the event of a diversion of a threshold mass of X grams, there is at least a p% probability that a signal in the information, i.e., an abnormal situation, will result which will serve to initiate additional investigation. Also, a boundary condition for specifying the quantity of the threhold mass.

MATERIAL ATTRACTIVENESS

A diversion path parameter for expressing the concept that when several material types or descriptions are subject to illicit removal from an area, some may be more desirable to a diverter than others because of the ready or easy adaptation to intended end-use.

MATERIAL DESCRIPTION

The physical form (solid, liquid or gas) and chemical form (composition, purity, concentration, etc.) of the SNM as distinquished from material type.

MATERIAL TYPE

The nuclear properties of the SNM (depleted-U, enriched-U, Pu-240 content, etc.).

NUMBER OF INDIVIDUALS

A diversion path parameter for indicating the number of persons participating in the diversion. Two or more persons acting in concert are considered to be in collusion and using the same diversion path. When acting independently, even if removing SNM from the same area, they are considered to be using different diversion paths.

OUTSIDE EMPLOYEE

A diversion path parameter value of the parameter for type of individual, indicating an employee who is authorized access to the plant-site but not to the SNM.

OUTSIDE VISITOR
A diversion path parameter value of the parameter for type of individual, indicating a non-employee who is authorized access, under escort, to both the plant-site and to the SNM.

PATH COMPLEXITY
The collective consideration, for a generalized diversion path, of all diversion path parameters except material attractiveness which serves to express the interrelationship of these parameters.

RECYCLE
SNM suitable for use in another unit process without undergoing prior chemical processing.

RELATIVE PATH WEIGHT
The numerical value derived as the product of relative weight factors (one for each diversion path parameter to reflect both material attractiveness and path complexity) as a means of expressing relative order or rank of generalized diversion paths.

RELATIVE WEIGHT FACTOR
The relative numerical value assigned to a particular diversion path parameter value.

REMOVAL MODE
A diversion path parameter for indicating one of three removal mechanisms available to a diverter, namely: (1) removal of SNM without replacement of any kind (simple theft); (2) removal of SNM accompanied by substitution of inert material; and (3) removal of SNM accompanied by substitution of SNM having different isotopic composition.

SCRAP
SNM which must be sent to chemical recovery before further use is possible.

SENSITIVITY
See MASS SENSITIVITY, TIME SENSITIVITY and SPACE SENSITIVITY.

SPACE SENSITIVITY
An attribute of diversion indication for denoting that in the event of diversion, there is at least a p% probability that there will be a signal in the information (i.e., an abnormal situation) pinpointing the area wherein removal occurred and highlighting the personnel having access to the SNM. Also a boundary condition for specifying the area and personnel included in the analysis.

TIME SENSITIVITY
An attribute of diversion indication for denoting that in the event of diversion, there is at least a p% probability that there will be a signal in the information (i.e., an abnormal situation) observed within d days. Also a boundary condition for specifying the time interval within which observation should occur.

TYPE OF INDIVIDUAL

A diversion path parameter for expressing one of four levels of access authorization possessed by a diverter, namely: (1) insider; (2) outside employee; (3) outside visitor; or (4) unauthorized person.

UNAUTHORIZED PERSON

A diversion path parameter value of the parameter for type of individual indicating a non-employee who is not authorized access to either the plant-site or to the SNM.

UNIT PROCESS

The subdivision (for purposes of analysis) of the overall process stream of a plant into many smaller operations (the unit processes), each of which is characterized by a "branch point" in the process stream, where material changes its physical or chemical form or composition, or where by-product, such as recycle or scrap, is generated.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

One can define the safeguards system for nuclear material as the set of all protective actions taken to prevent or to deter attempts to divert nuclear material to unauthorized use. Maintenance of effective safeguards requires a program for routine assessment of plant safeguards systems in terms of their capabilities to satisfy safeguards aims. Plant internal control systems provide capabilities for detection of unprevented diversion and can provide assurance that diversion has not occurred. A procedure called Diversion Path Analysis (DPA) enables routine assessment of the capabilities of internal control systems in this regard and identification of safeguards problem areas in a plant. A framework for safeguards system design is also provided which will allow flexibility to accommodate individual plant circumstances while maintaining acceptable diversion detection capability. The steps of the procedure are described and the practicality of the analytical method is shown by referring to a demonstration test for a high throughput process where plant personnel were major participants. The boundary conditions for the demonstration case are given, along with some conclusions about the general procedure.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Analysis; Diversion of Nuclear Materials; Diversion Path Analysis; Internal Control System Characterization; Nuclear Material Safeguards; Safeguards

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