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A DEVELOPMENT AND DEMONSTRATION PROGRAM FOR DYNAMIC NUCLEAR MATERIALS CONTROL*

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ABSTRACT

A significant portion of the Los Alamos Scientific Laboratory Safeguards Program is directed towards the development and demonstration of dynamic nuclear materials control. The building chosen for the demonstration system is the new Plutonium Processing Facility in Los Alamos, which houses such operations as metal-to-oxide conversion, fuel pellet fabrication, and scrap recovery. A DYnamic MAterials Control (DYMAC) system is currently being installed in the facility as an integral part of the processing operation. DYMAC is structured around interlocking unit-process accounting areas. It relies heavily on nondestructive assay measurements made in the process line to draw dynamic material balances in near real time. In conjunction with the nondestructive assay instrumentation, process operators use interactive terminals to transmit additional accounting and process information to a dedicated computer. The computer verifies and organizes the incoming data, immediately updates the inventory records, monitors material in transit using elapsed time, and alerts the Nuclear Materials Officer in the event that material balances exceed the predetermined action limits.

DYMAC is part of the United States safeguards system under control of the facility operator. Because of its advanced features, the system will present a new set of inspection conditions to the IAEA, whose response is the subject of a study being sponsored by the US-IAEA Technical Assistance Program. The central issue is how the IAEA can use the increased capabilities of such a system and still maintain independent verification.

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INTRODUCTION

A number of programs world-wide are examining techniques and technology for the purpose of up-grading nuclear materials accountability systems for safeguards purposes.(1) The Los Alamos Scientific Laboratory (LASL) in the United States has one such program.(2) The program's goals are three-fold: to develop features that improve the effectiveness of a nuclear materials accountability system, to identify the technology necessary to implement such improvements, and to demonstrate that a system built on these principles can function in a real processing environment.

Certain features increase the effectiveness of a nuclear materials accountability system: (a) real-time updating of the inventory records, (b) incorporation of clock-time as part of the information contained in the records, (c) data verification upon entry into the records system, (d) unit-process structuring(3), (e) dynamic materials balancing around the unit-process structure, (f) monitoring of control limits based on these dynamic balances, and (g) incorporation of decision analysis(4) techniques in examining the balances with respect to the control limits.

To incorporate these features into a viable accountability system, we must turn to technology for in-line nondestructive assay instrumentation, interactive terminal data communication, modern computer hardware, and data base management software.

Real time implies that the information generated in the processing area describing the movement or change in form of nuclear material should be incorporated into the computer data base in as timely a fashion as possible. Thus, the "book" inventory is an up-to-date, accurate accounting of the material within the facility, and can be used for material control. Incorporation of clock time as part of each record in the data base permits such features as the monitoring of nuclear material in transit within the facility. For example, when material is sent from the vault to the processing area, the system can monitor the time it is in transit and notify the safeguards office if it fails to arrive in a predetermined time interval. By incorporating time as part of each record, an audit trail can be followed in chronological order. Drawing on the data base, it is possible to follow the movement of material through the facility.

Unit-process structuring consists of dividing the facility into material balance areas, which serve to localize the material within the facility both in space and time. As with any balance area, material is measured as it crosses the boundaries. At certain points in time, material balances are drawn and quantitatively examined for indications of material loss. In a facility based on batch balancing, these points in time are linked to the complete processing of a batch in that particular unit process.

The term "dynamic balancing" implies that a unit-process balance is drawn without stopping the process.(5) Thus the dynamic balance may not necessarily be zero, but contain contributions from material in process, unmeasured scrap and residues, and holdup, as well as the measurement uncertainties. Material control is maintained by comparing this unit-process balance with predetermined control limits. Control limits are set for the individual balances and for the cumulative sum (cusum) of these balances. Processing is allowed to continue as long as the balances and cusum values stay below the limits. When either limit is exceeded, the operator must stop and identify, on a measured basis, the cause of the problem. He can, for example, measure his scrap and residues, clean out the process area, or measure the residual holdup. If, after he takes these steps, the balance is not completely accounted for, then a MUF is declared.

Decision analysis techniques are being developed to analyze dynamic material balance data to provide the maximum sensitivity in detecting material loss, and to give a formal framework in which computer monitoring of the data might take place, eventually leading to a decision as to whether or not material is missing. These techniques, such as Kalman filtering, are described in Ref. 4.

DEMONSTRATION OF DYNAMIC NUCLEAR MATERIALS ACCOUNTING

A demonstration DYMAC system (short for DYnamic MAterials Control) is being installed and operated at the Los Alamos Scientific Laboratory's new Plutonium Processing Facility. It serves not only as the working materials accountability system for the facility, but also incorporates the features mentioned earlier. The new facility houses a variety of processing operations, including metal fabrication, electrorefining, fuel pellet fabrication, nitrate-to-oxide conversion, plutonium oxide powder preparation, and a number of cold scrap recovery operations. As of December 31, 1978, it will contain about 10,000 inventory items. As with any system, DYMAC is being installed in a specific facility and must accommodate itself to the design features of the processing areas. Although some of the system features are specific to the LASL facility, the system contains the generic principles necessary to improve materials accountability as a safeguards tool. Although the facility contains many different operations, with no one operation having a throughput comparable to fuel cycle facilities of the future, modeling and simulation techniques can extrapolate the operating experience obtained there to future facilities.(6)

DYMAC incorporates a number of features for an effective nuclear materials accountability system. As shown in Fig. 1, it has a unit-process structure, with nondestructive assay measurements made at the boundaries of these unit processes; information is communicated from the process area to a central computer system via interactive video terminals located in the process areas; a mini-computer assembles the data, maintaining certain real-time files; and an accountability system structure focusses on unit-process balances so as to provide the material status indicators necessary for control. Figures 2-5 show various features of the DYMAC system: computer, video terminal, electronic balance, and in-line thermal-neutron coincidence counter. Table I summarizes the DYMAC data processing and communications equipment and enumerates the installed NDA instrumentation.

The accountability system focusses its attention on three types of material balance. To begin with, the station balance gives the total quantity of nuclear material contained within the physical walls of the facility, broken down by each type of nuclear material. There are two independent ways to determine the station balance. The first is to take the difference between shipments and receipts of material into the facility. The Nuclear Materials Officer keeps these records in the form of shipping and receiving documents that accompany the items as they enter or leave the building. The second method of calculating the station balance is to add up the individual inventory items within the facility as recorded by the DYMAC accountability system. These two methods produce independently calculated values that should agree exactly. The Nuclear Materials Officer reconciles the two values at the end of each business day.

Coincidentally, a station balance is also available on the international level, in that the IAEA inspector has access to the shipping and receiving documents for each facility that he inspects. Thus, for facility inspection, one check is to add up all its inventory items and compare that value to what the shipping documents predict as the total inventory.

The second kind of material balance area is the formal MBA, which may differ from the national to the international system. In the United States, an MBA is defined as a physically contiguous area within a facility for which all material is measured as it crosses the MBA boundary. At periodic intervals, a closed material balance is drawn around that particular physical area. At the new LASL facility, there are 15 designated MBAs.

Under the DYMAC scheme, material balance areas are further subdivided into unit processes, for the third type of material balance. A unit process coincides with the actual physical process going on within its boundary; often several processes may be combined into a single unit-process area. Material flowing across the physical boundaries of the unit process is measured on a batch basis, and dynamic material balances are drawn for the unit process.

These material balances are not closed, in the sense that the balance can be drawn while there is still material left within the unit process. For example, generated scrap may exist in the unit process and, hence, will be included in the balance. Obviously, the holdup of material within the unit process will also constitute part of this balance. Hakkila et al.(7) have examined how dynamic balancing can work for a continuous process.

The DYMAC approach to materials control works well in a facility, such as the new one at LASL, that processes material on a batch basis. The unit-process balance is drawn only when a batch has completely passed through the unit process. Thus, the balance becomes a primary indicator of material status. The system monitors individual batch balances for each unit process as well as their cumulative sum. Such a cusum plot is shown in Fig. 6 for two unit processes at the new facility. The chart plots the individual points contributing to the cusum as a function of time. It shows a process upset that occurred in the MIPCA unit process for batch 8. Thus we see that the cusum plot not only gives information about the material status, but also about the process operation. This information, which is readily available to the process operator, enables him to run the process efficiently because he can quickly detect problems.

Such detailed information is what process and safeguards people find extremely useful for their own purposes. From the information in the data base, a running time history of material within the facility can be constructed. It is also possible to make use of the unit-process balances by combining them to help close material balances around the MBAs. Problems are quickly identified using dynamic balancing, and are easily traced to their point of origin. Thus, at physical inventory time when the process is closed down, the time spent in closing material balances should be significantly less than under current accountability procedures.(5)

A good example of how the DYMAC system actually works is the pellet fabrication process in the advanced carbide fuels laboratory. Figure 7 shows the flow of material among the six unit processes: oxide blending, briquette press, reduction and sintering, powder grinding, pellet press, and grinding and inspection. Using this unit-process structure, the material is localized to within a single glovebox. Feed material from a storage vault is introduced into the glovebox line in the material management room. The first processing step blends plutonium oxide, uranium oxide, and carbon powder. The powder is pressed into low-density briquettes, which are then sent to a furnace for reduction from oxide to the carbide chemical form. These low-density carbide briquettes are ground into powder, to which binder is added, and this mixture is sent to the pellet press. The low-density pellets are sintered into a high-density form and sent to grinding and final inspection.

The DYMAC system follows the movement of material through each unit process by means of transactions. A transaction is the mechanism for changing inventory information stored in the data base. The process operator enters information at a video terminal keyboard, like the one shown in Fig. 3, which is located in his process area. In answer to successive prompts that appear on the screen, he identifies the process operation he has just completed and the particular batch of material in question. As part of the transaction, he will include a measurement at the unit-process boundary.

DYMAC transactions for the pellet fabrication process begin following the feed material as it leaves the vault. The vault custodian makes a transaction to notify the system that material is on its way to the material management room. The system notes that the material is "in transit" and establishes an expected arrival time. If the material does not arrive within the specified time frame, the system alerts the Nuclear Materials Officer who begins an investigation. When the material arrives at its destination, the receiving operator makes a transaction to notify the system. Part of the transaction verifies that (a) the seal on the container is intact, and (b) the seal number agrees with the number in the data base, which was entered at the time the container was stored in the vault. In addition, the transaction allows for verifying the material by nondestructive assay. In the advanced fuels case, this verification measurement consists of counting material in a thermal-neutron coincidence counter such as the one shown in Fig. 5. The system compares the value obtained from the 17-minute count with the value in the data base. If the two values agree within statistical limits, the original value is kept as the accountability value. The most recent verification value for that material is also entered elsewhere in the data base. If they fail to agree, then the operator must make further measurements. Table II shows the verification results for the first plutonium feed material introduced into the pellet fabrication line. For this case, the verification value agrees with the data base value.

From the material management room, the feed material is sent to the oxide blending unit process via the conveyor system, and the corresponding transactions are written to update the data base. When the plutonium oxide, uranium oxide, and the carbon powder are blended on a weighed basis, this information is entered into the DYMAC system. From this blended lot, sublots of powder are sent to the briquette unit process, each on a weighed basis. The DYMAC system can relate the weight to the amount of nuclear material by means of factors previously determined by chemical analysis. Briquettes are moved out of the pressing unit process on a weighed basis, and at this point it is possible to draw a dynamic balance for that batch of material. The briquettes can be verified using the thermal-neutron coincidence counter located in the glovebox line.

As each sublot of material moves through the pressing unit process, balances are drawn on a batch basis, and a cumulative sum for the successive batches is kept in the data base. This cusum now becomes the material status indicator, which is used for material control. Accountability personnel set limits for the value of the cumulative sum, as well as for each individual batch that goes into that sum. The same procedure holds for the other unit processes in the advanced fuels laboratory. In Fig. 6, the MIPCO chart shows the behavior of material in the powder grinding unit process for the first two months of operation.

To expedite transaction-making, the system displays an option list on the terminal screen from which the operator selects the transaction corresponding to the process step he has just completed. Figure 8 shows the 16 transaction options from which the operator in the advanced fuels laboratory selects. A transaction only requests information necessary for that particular process step. The system checks the operator's entries for validity as he enters them. For example, when he identifies the item he has just processed, the DYMAC system searches the data base to see whether it currently exists on the books; if it is a new item, the system notifies the operator that a new entry has been made for it in the data base.

In addition to making transactions, the operator can recall information from the data base on his video terminal. For example, in Fig. 9, the operator has asked for an MBA level inventory of all the items in the advanced fuels process line, account 711. Note that the display shows which unit process (UP) each item is in. Besides the various items currently being processed, the display shows the items associated with the material balance for each of the unit processes: MIPCO, MIPOB, MIPPP, MIPRS, and MIPSF. To determine how each MIP represents the cumulative sum of the batch balances that have been processed through that unit process (i.e., to determine the individual components of a given MIP) the operator asks for the item's activity internal to the facility, as shown in Fig. 10. The activity report lists all the transactions that have been written for that item in the last 45 days. It is extremely useful in that it enables both process operators and safeguards officers to examine the flow of materials in detail through a given process line.

ROLE OF DYNAMIC NUCLEAR MATERIALS CONTROL IN INTERNATIONAL SAFEGUARDS

LASL and the IAEA are jointly studying the role of a DYMAC-like system in the implementation of IAEA safeguards. The following are a few preliminary thoughts on how an international inspection agency, such as the IAEA, might independently verify an inventory maintained by a DYMAC system.

Basically, the IAEA divides a facility into three MBAs: one at the receiving area where feed material arrives and is stored until it is ready to be processed. The second is a processing MBA, which, in a given facility, might be more than one MBA. The third MBA is the shipping area, where products from the processing area are stored before shipment to other facilities.

Shipping and receiving MBAs are primarily item control areas in which inspection takes the form of ensuring that every item on the inventory listing is indeed present. Some of the items may be verified by portable NDA equipment, for example, and by conventional sample-taking. In these areas, a real-time accountability system can be an asset in that it provides accurate, up-to-date listings of every item. The listings enable the inspector to perform his item check quickly because he has information concerning the location of each item, as well as up-to-date information about its content. Hence, in the shipping and receiving areas, a DYMAC-like system could provide timely records to aid in the inspection process.

The main focus of a DYMAC system, however, is to improve accountability in the processing MBA. The system can localize material by subdividing the MBA into unit processes. It can keep up-to-date, accurate information on the status of the material in each unit process, drawing balances at the appropriate time as material crosses the boundaries.

At the present time, the IAEA inspector has the greatest difficulty taking measurements in the processing MBA, and must limit his inspections primarily to times when the facility is shut down for a physical inventory and cleanout of the material. With material under control of a DYMAC-like system, facilities will tend to have fewer shutdowns and cleanouts. Such a system will enable them to keep track of the material in the facility between physical inventories. At inspection time, the IAEA representative will be able to reconcile the physical inventory quickly without having to resolve errors in the accounting records.

However, fewer facility shutdowns and cleanouts could degrade the IAEA inspection capability unless it can find a method to make use of the computer repository of information. The IAEA may wish to use the unit-process structure, perhaps treating each unit process as an item. When inspecting the processing MBA, the IAEA representative could verify the dynamic balance in a similar fashion to the way he verifies item control areas. He could choose to sample the unit processes and verify the items in one particular process. Even though the number of unit processes is small, it might be possible to consider this a statistical sampling. The crux is to find techniques that enable the inspector to independently verify a particular unit process.

To perform an independent verification, an inspector could use in-line NDA instrumentation in such a fashion that the IAEA could guarantee instrument performance, perhaps by the use of independent standards. The interlocking structure of unit processes and the associated flow of material from one unit process to another can guarantee that a particular unit process is being correctly accounted for, thus enabling the IAEA to verify the process. Inspection would become less burdensome because there is less need to shut down the processing in the facility. In principle, it may be possible to inspect a facility with dynamic nuclear materials control essentially at any time, because the inspections need not coincide with actual plant shutdowns. This gives both the IAEA inspectors and facility operators more flexibility in scheduling inspections.

Should international fuel cycle centers become a reality, the dynamic materials control approach can readily transform a facility safeguards system into an international system. The IAEA would assume control of the facility's material control system, drawing on the accountability information to safeguard the material in the facility.

Throughout the nuclear community, countries are developing accountability systems that exhibit some, or all, of the features I have described in this paper. Once such systems are implemented, we can expect tighter material control both at the facility and national level. These tighter controls will be a distinct asset to international safeguards. As the IAEA continues to gain experience with dynamic material control and assimilates the full implication of improved levels of control, it can develop commensurate inspection techniques.

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(4) SHIPLEY, J. P., "Efficient Analysis of Dynamic Materials Accounting Data," (Proc. 19th Annual Meeting, Cincinnati, 1978), J. INMM VII III (1978).

(5) LOVETT, J. E., "In-Plant Material Controls: an International Perspective," (Proc. 17th Annual Meeting, Seattle, 1976), J. INMM V III (1976).

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(7) HAKKILA, E. A. et al., "Coordinated Safeguards for Materials Management in a Fuel Reprocessing Plant," LASL report LA-6881 (1977).

Figure Captions

Fig. 1. DYMAC system configuration.

Fig. 2. Data General Eclipse C330 computer with system consoles and line printer.

Fig. 3. Teleray video terminal; the system displays messages and prompts on the screen to which the operator responds via the keyboard.

Fig. 4. Digital electronic balance; the weighing unit is located inside the glovebox and the readout unit is installed beneath.

Fig. 5. Thermal-neutron coincidence counter installed on top of the glovebox line. An elevator extends down into the glovebox to convey material up into the counting chamber.

Fig. 6. Cumulative sum charts for dynamic material balances for two unit processes during the period April 17 through June 11, 1978.

Fig. 7. Pellet fabrication process in the advanced carbide fuels laboratory.

Fig. 8. Option list of transactions available to the operator in the advanced carbide fuels laboratory.

Fig. 9. Terminal display of inventory by account.

Fig. 10. Terminal display of the transaction activity for the oxide blending unit process material balance.

TABLE I

DYMAC EQUIPMENT

Equipment	Explanation
Data General Eclipse C330 computer	196,000 16-bit-word memory; two 10-megabyte disks; two 9-track tape units; one line printer; communications interface for 128 lines
27 Teleray video terminals	Cathode ray tube devices with keyboards
6 Texas Instruments hardcopy terminals	
Texas Instruments label printer	
30 Arbor 5.5-kg capacity electronic balances	0.1 g precision; 0.3 g accuracy
5 Arbor 5.5-kg capacity electronic balances	0.01 g precision; 0.03 g accuracy
3 Mettler 15.5-kg capacity electronic balances:	0.1 g precision; 0.2 g accuracy
20 thermal-neutron coincidence counters	
5 solution assay instruments	gamma-ray spectroscopy
2 segmented gamma scanners	gamma-ray spectroscopy
1 random driver	fast coincidence; active interrogation

TABLE II

VERIFICATION MEASUREMENTS OF PuO_2 FEED MATERIAL

Lot	Accountability Value (g)[a]	Verification Value (g)[b]
100	496.2	497 ± 10[c]
200	495.8	488 ± 10[c]
300	496.0	490 ± 10[c]

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[a] Determined by total weight times a chemical factor.

[b] Verified using thermal neutron coincidence counting (500-second count time).

[c] Quoted uncertainties are 2σ values.

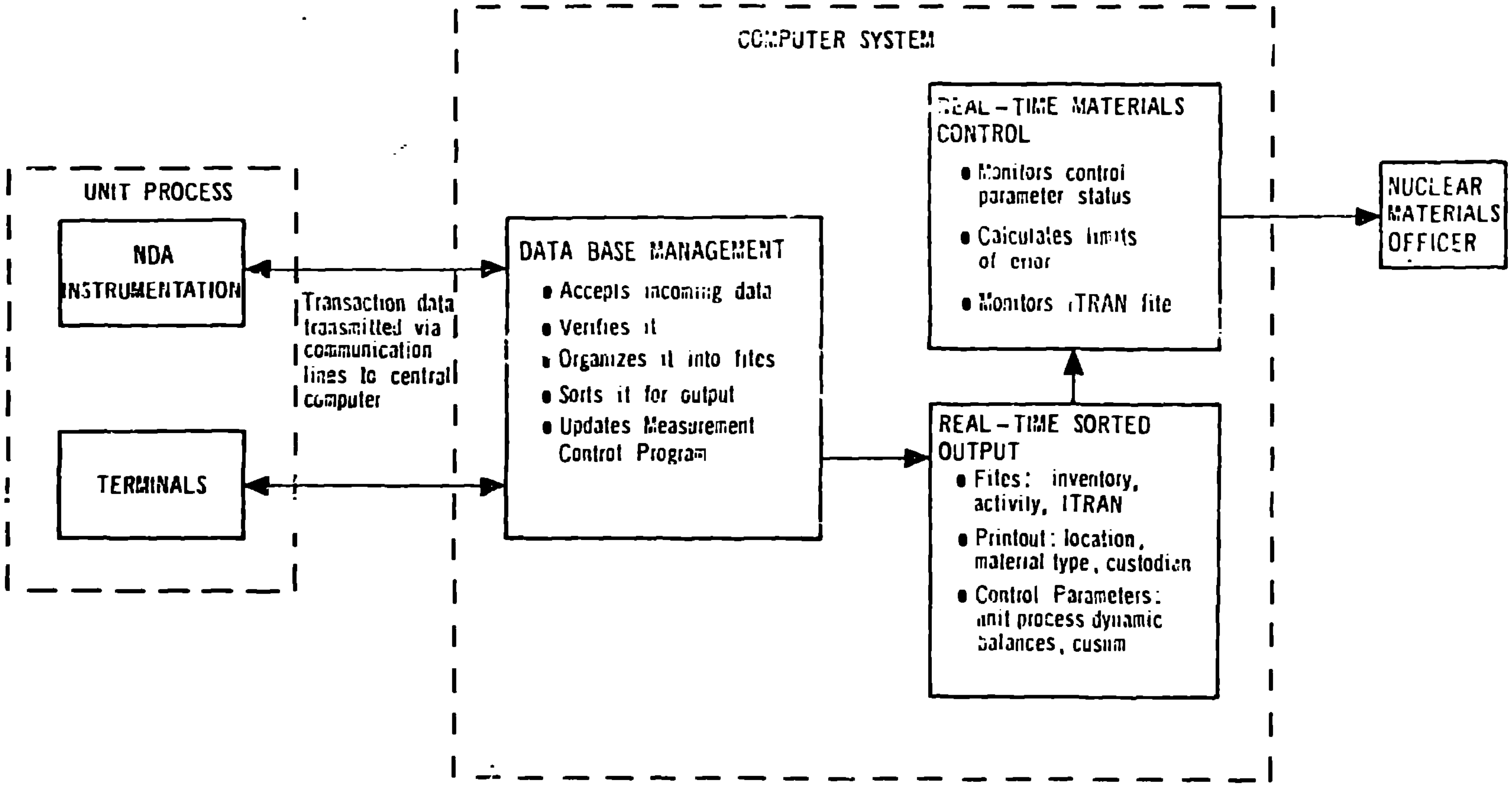


Fig. 1. DYMAC system configuration.

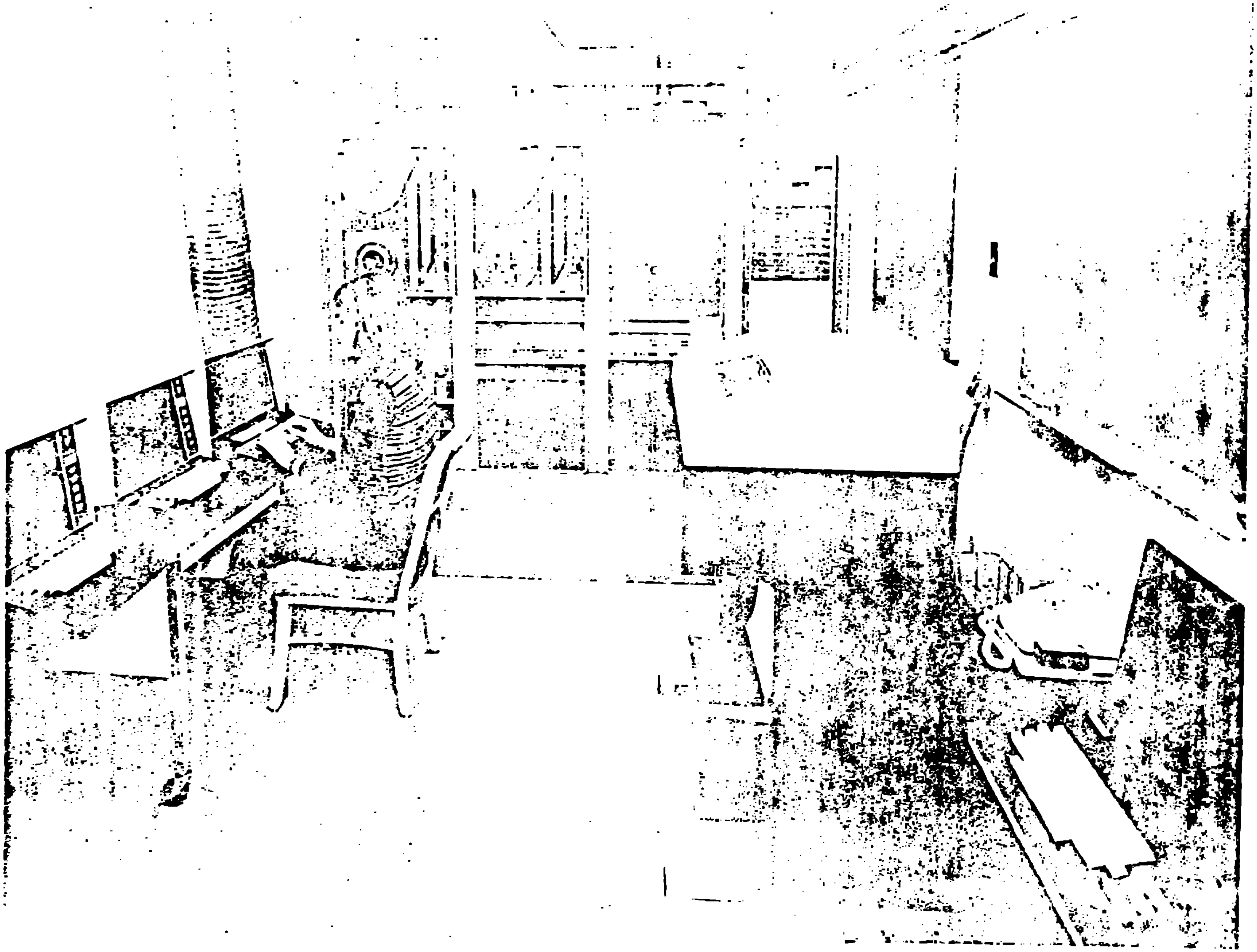


Fig. 2. Data General Eclipse C330 computer with system consoles and line printer.

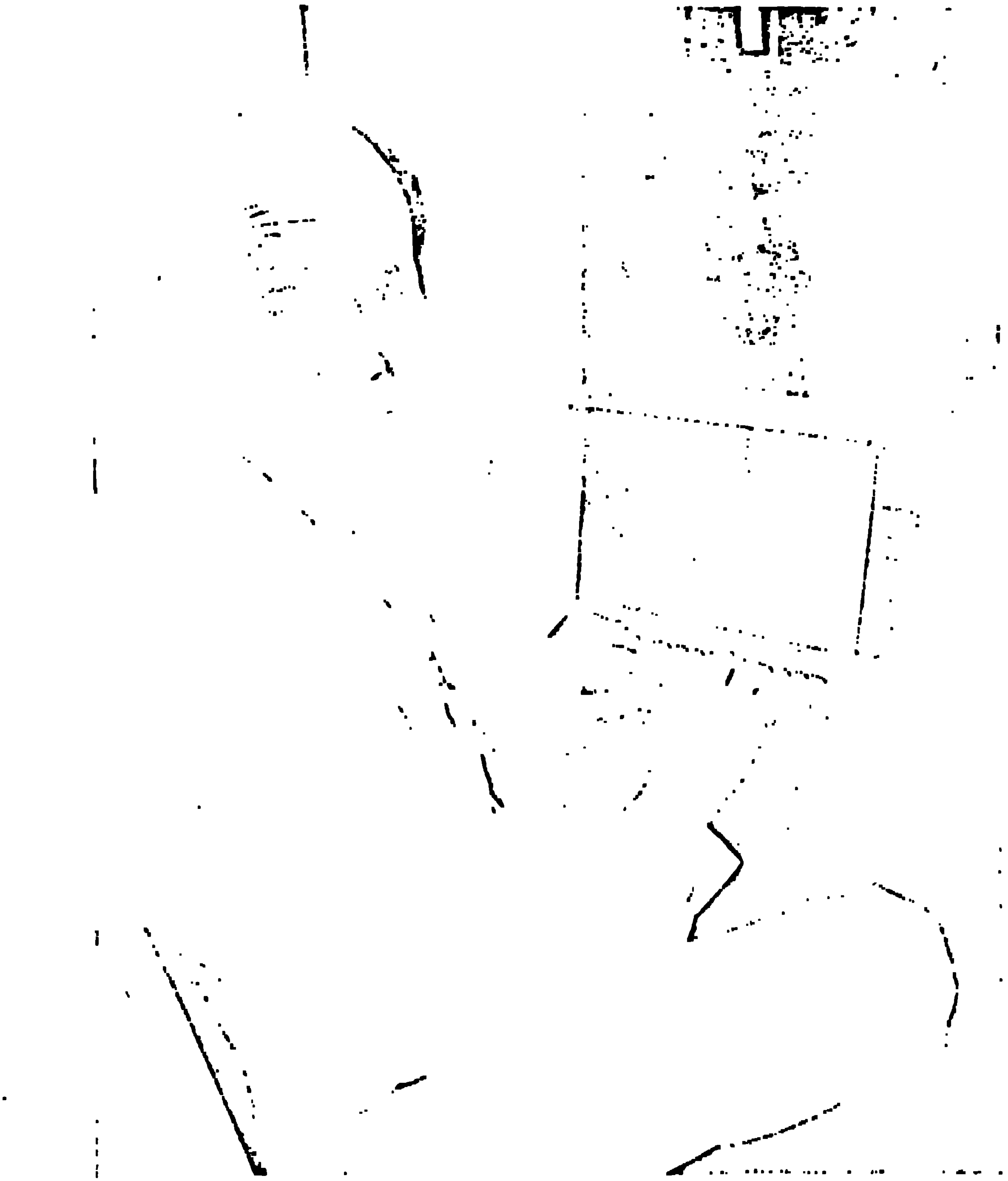


Fig. [illegible]. Teleray video terminal: the system displays messages and prompts on the screen to which the operator responds via the keyboard.

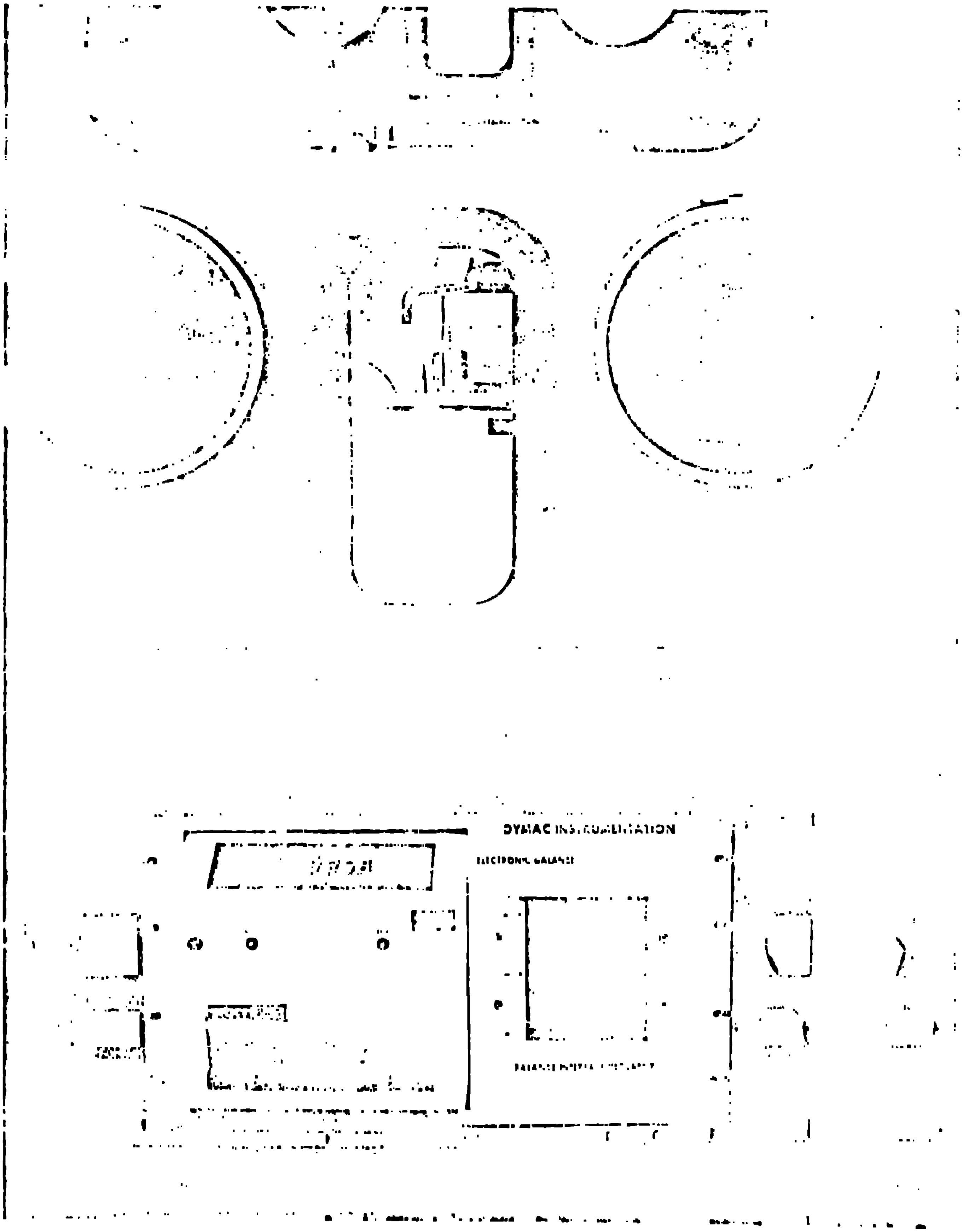


Fig. 4. Digital electronic balance: the weighing unit is located inside the glovebox and the readout unit is installed beneath.

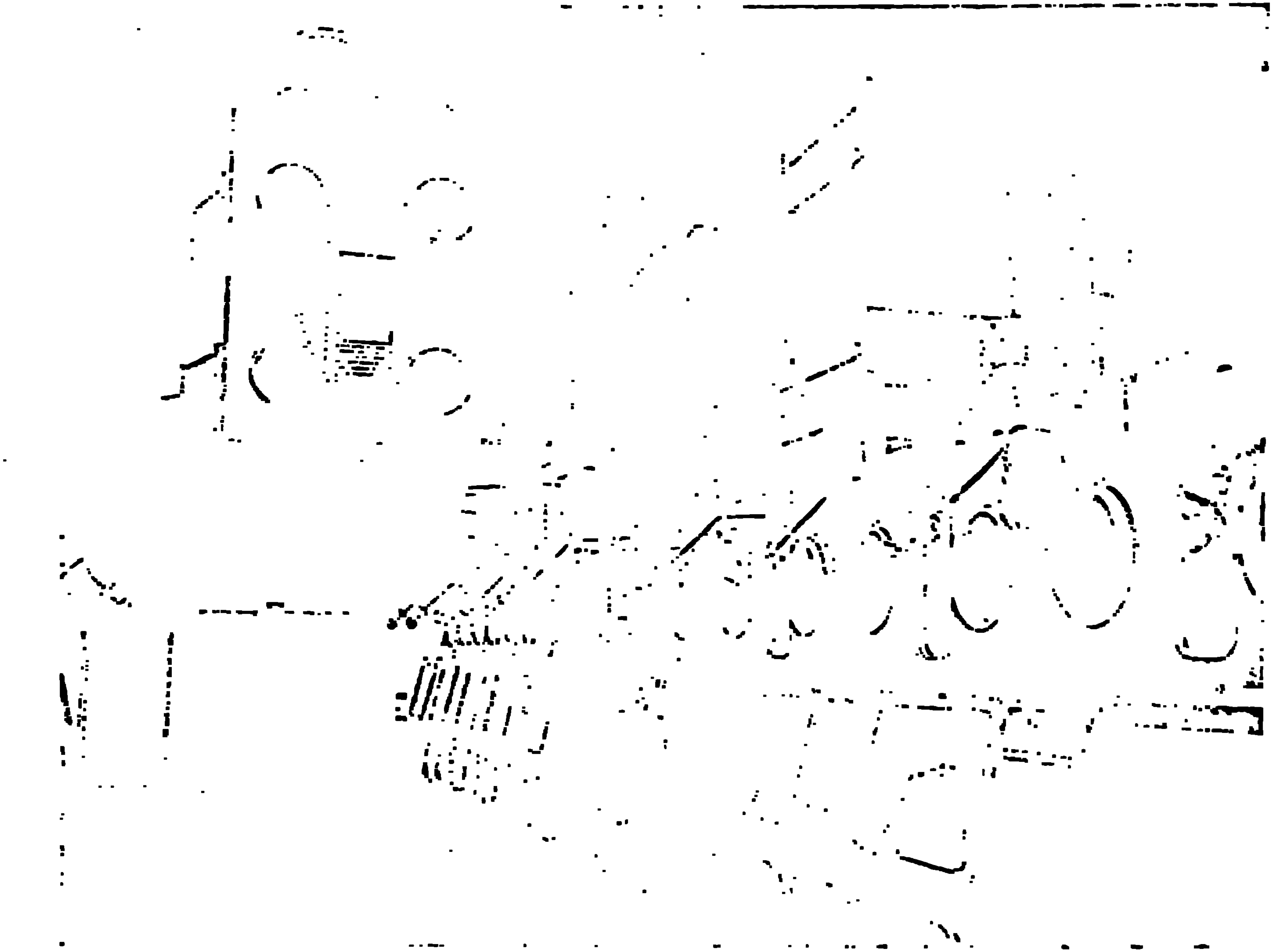


FIG. 5. Thermal-neutron [illegible] extends down into the [illegible]

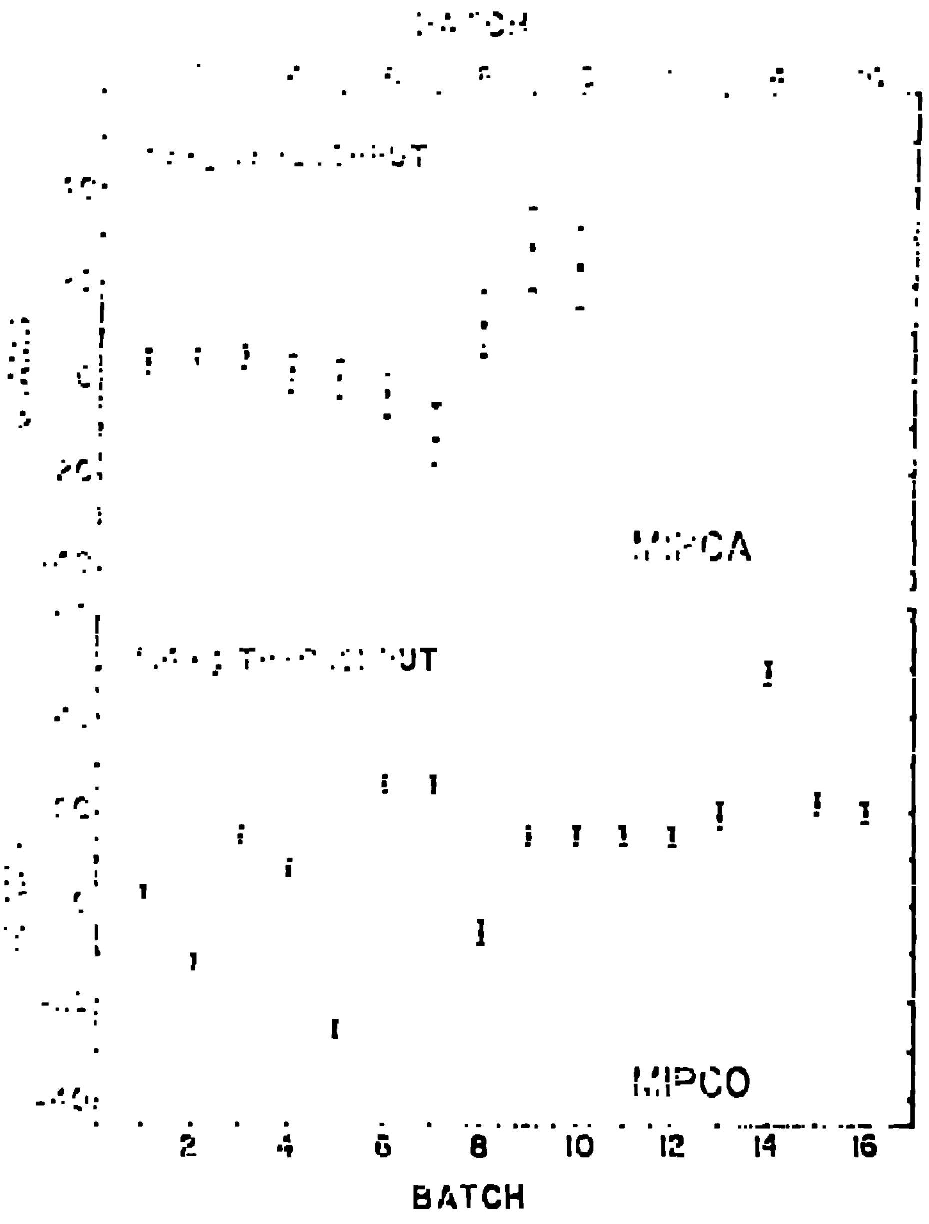


Fig. [illegible] Control time run charts for dynamic material balances for two unit processes during the period April 17 through June 11, 1978.

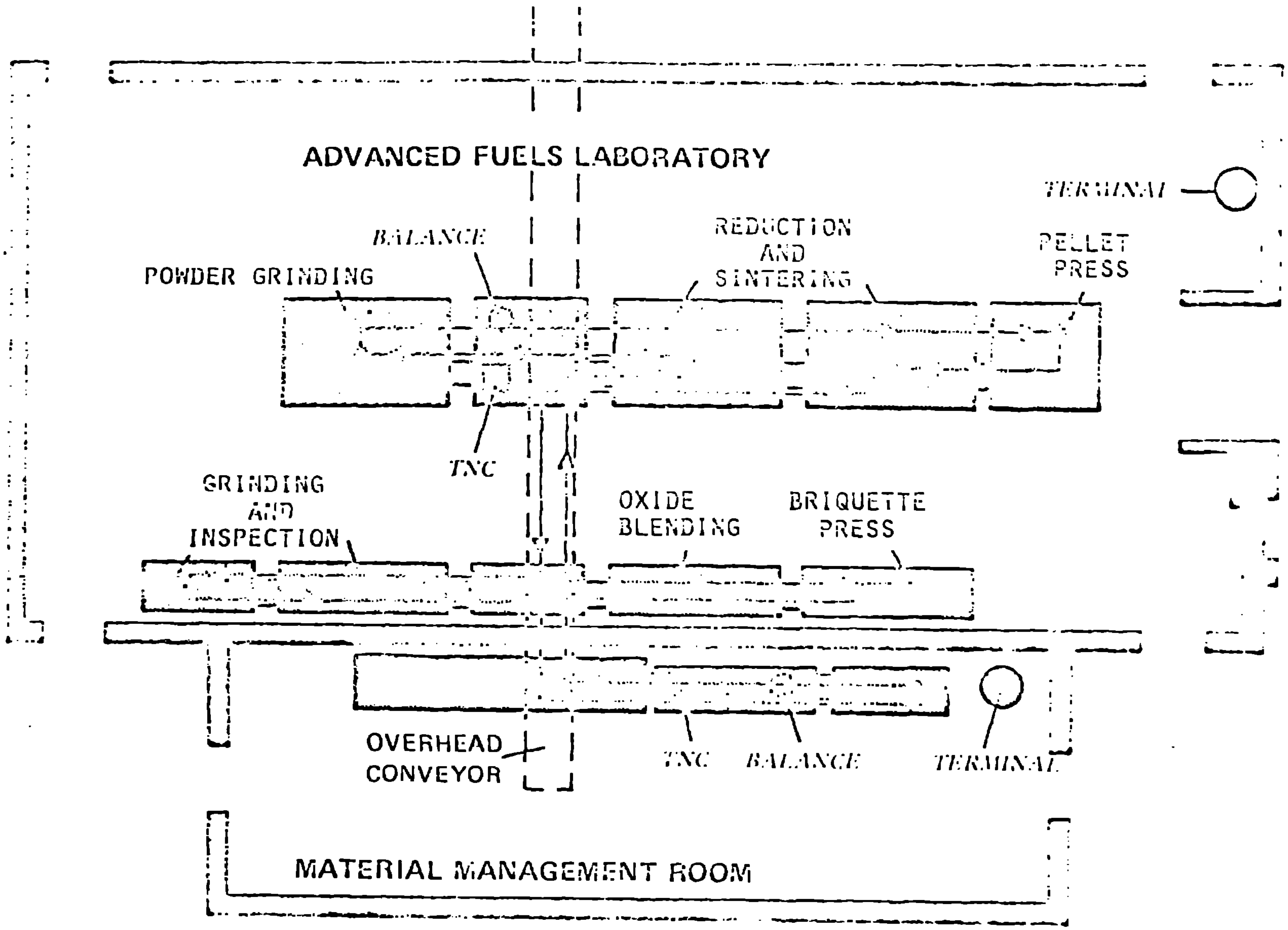
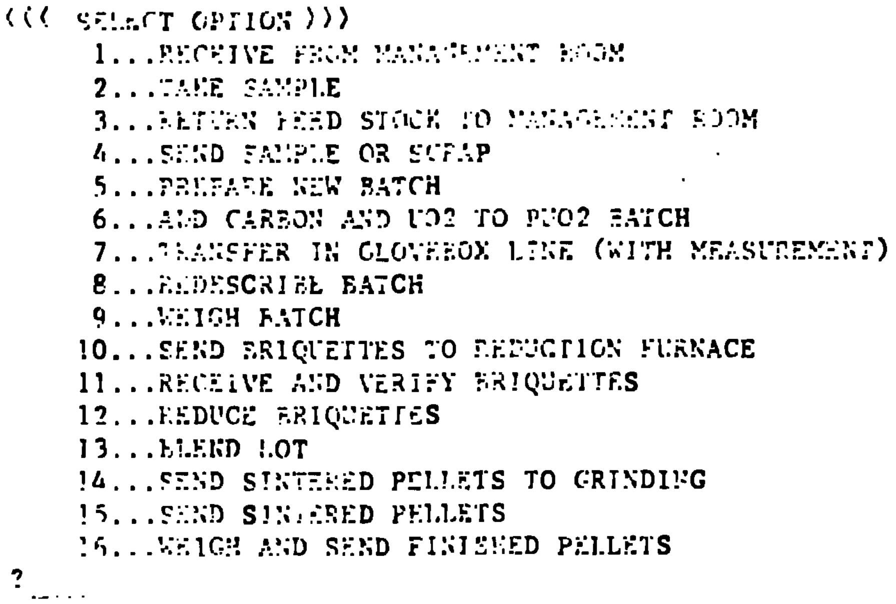


Fig. 7. Pellet fabrication process in the advanced carbide fuels laboratory.



```
((( SELECT OPTION )))
     1...RECEIVE FROM MANAGEMENT ROOM
     2...TAKE SAMPLE
     3...RETURN FEED STOCK TO MANAGEMENT ROOM
     4...SEND SAMPLE OR SCRAP
     5...PREPARE NEW BATCH
     6...ADD CARBON AND UO2 TO PUO2 BATCH
     7...TRANSFER IN GLOVEBOX LINE (WITH MEASUREMENT)
     8...REDESCRIBE BATCH
     9...WEIGH BATCH
    10...SEND BRIQUETTES TO REDUCTION FURNACE
    11...RECEIVE AND VERIFY BRIQUETTES
    12...REDUCE BRIQUETTES
    13...BLEND LOT
    14...SEND SINTERED PELLETS TO GRINDING
    15...SEND SINTERED PELLETS
    16...WEIGH AND SEND FINISHED PELLETS
?_
```

Fig. 8. Option list of transactions available to the operator in the advanced carbide fuels laboratory.

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INVENTORY IN ACCOUNT 711                                         6/12/78,  9:59

LOC    MT      ITEM ID      UP    SNM VALUE    BOOK VALUE    SHLF   DESC    SEAL

G137   1C      3353A01      RS       22. G        23.83 G             CH3
G137   1C      3352A02      RS       57. G        60.00 G             CH3
G137   1C      3353A03      RS       29. G        30.75 G             CH3
G137   1C      3353A04      RS       16. G        17.26 G             CH3
G137   1C      3353B01      RS       44. G        47.00 G             CH3
G133   1C    FS 2770-1      OB     1263. G      1445.58 G             701
G133   1C    FS 2770-2      OB     4092. G      4681.70 G             701
G133   1C    FS 2770-3      OB     2027. G      2319.70 G             701
G133   1C    MIPCO          CO      118. G       126.35 G             CH9
G133   1C    MIPOB          OB       19. G        22.11 G             CJ9
G132   1C    MIPOP          OP        7. G         8.13 G             CJ9
G126   1C    MIPPP          PP        1. G          .59 G             CH9
G136   1C    MIPRS          RS       35. G        38.24 G             CH9
G137   1C    MIPSF          SF       19. G       470.02 G             CH9
G126   1C    SCP    126     PP       25. G        25.80 G             CH9
G132   1C    SCP    132     OP        2. G         2.00 G             CJ9
G133   1C    SCP    133     OB        2. G         1.80 G             CJ9
G136   1C    SCP    136     RS       33. G        34.30 G             CH9
G137   1C    SCP    137     SF      215. G       224.15 G             CJ9
G138   1C    SCP    138     CO      182. G       191.10 G             CH9
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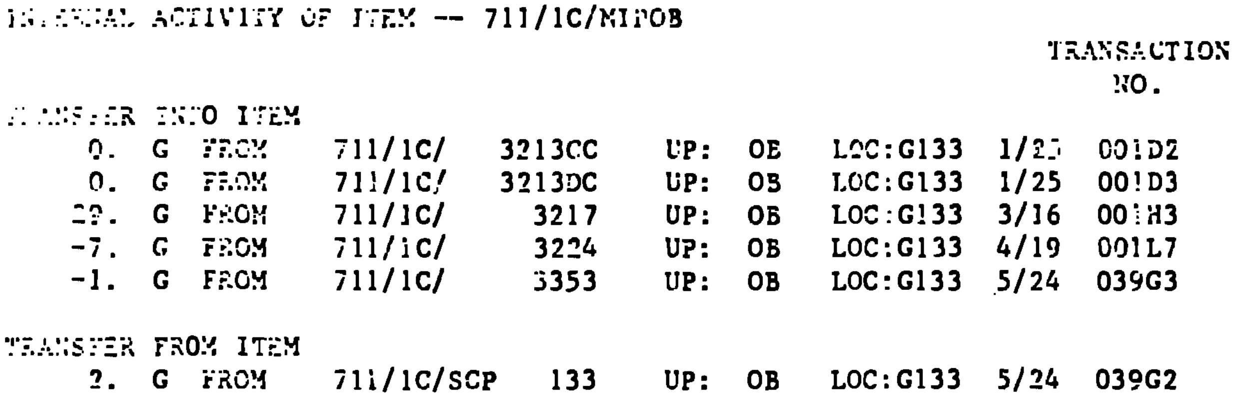
Fig. 9. Terminal display of inventory by account.



```
INTERNAL ACTIVITY OF ITEM -- 711/1C/MIPOB
                                                                  TRANSACTION
                                                                      NO.
TRANSFER INTO ITEM
     0.  G  FROM    711/1C/    3213CC    UP:  OB   LOC:G133  1/25   001D2
     0.  G  FROM    711/1C/    3213DC    UP:  OB   LOC:G133  1/25   001D3
    29.  G  FROM    711/1C/      3217    UP:  OB   LOC:G133  3/16   001H3
    -7.  G  FROM    711/1C/      3224    UP:  OB   LOC:G133  4/19   001L7
    -1.  G  FROM    711/1C/      3353    UP:  OB   LOC:G133  5/24   039G3

TRANSFER FROM ITEM
     2.  G  FROM    711/1C/SCP    133    UP:  OB   LOC:G133  5/24   039G2
```

Fig. 10. Terminal display of the transaction activity for the oxide blending unit process material balance.