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Abstract

The accounting system based on filing of data and inquiry processing by the use of an optical mark reader (OMR) has been developed and operated satisfactorily for criticality control and accountancy of nuclear materials in plutonium facilities of PNC. The OMR system has merits, especially compared with an old chit and punch card system, such as low cost, abundance of the data included on a single sheet, universality of use for all kinds of material transfers, easiness of data correction, and large capacity to deal with. The OMR system is applied to the material transfer and also for the physical inventory taking. This system, together with the use of an accurate automatic balance equipped at each glove box, which is generally designated as an accounting unit for the criticality control, generated a MUF of 0.43 % for a fuel fabrication campaign of 119 assemblies for a fast reactor, which can be decreased further.

In correspondence to the recent safeguarding situation and also to fitting to an automatic fuel fabrication process, however, further development of the present system will be needed in the near future. The future system is discussed with reference to criticism against the current accountancy system by Rosenbaum and others, and its possible framework stressing on weighing and reading of numbered items is suggested.

1. Introcuction

A computer was first introduced in 1967 for the accountancy of nuclear materials into the plutonium facilities of Atomic Fuel Corporation which was later reorganized to the present Power Reactor and Nuclear Fuel Development Corporation (PNC). The purpose to introduce a computer was originally for the criticality control of plutonium, which has been made principally by mass control of the nuclear materials in each glove box.

It is indispensable to certify before material transfer that the box receiving some amount of the material together with one already contained will not accomodate more material than the amount given by the criticality control criteria. This certification, though simple, can not be treated manually when number of the material transfer is considerably large. The accounting system of PNC has been improved several times and the present system seems to be satisfactory not only for the criticality control but for the safeguard purpose in its reliability of filing and demonstrating of all the material transfers and inventory listings at a real time basis.

In accordance with recent request from safeguarding of the material, however, a need may be rising to improve the system. This paper describes the present computerized system for accountancy of the nuclear materials and also discusses its path to an automatic material control in an automatic plutonium fuel fabrication facility.

2. Outline of the Present System

2.1 Facilities and Design Bases of the Present System

PNC has two major facilities for plutonium handling. The older facility, now called Plutonium Fuel Development Facility (PFDF), was constructed in 1965 in an attempt to perform R & D work on the plutonium fuel technology concerning fuel fabrication of both pellet and sol-gel vipac type, measurement of the physical and chemical properties of plutonium fuel, evaluation of plutonium fuel behaviour under irradiation and so on. The newer facility, called Plutonium Fuel Fabrication Facility (PFFF), was constructed based on the experience of PFDF in 1971, and started operation in 1972. The PFFF has two fabrication lines, and aims essentially production of the plutonium fuels for heavy water reactor and sodium cooled fast reactor, both of which are two principal reactor projects of PNC.

Since the criticity control is done by mass control in both facilities, although a part of the wet scrap recovery process is controlled geometrically, all the process steps are divided into many accounting units.

Number of the units is nearly 700, whose 79% is occupied by storages. One accounting unit is assigned to a glove box for fuel fabrication, a set of glove boxes for analyses and physical property measurements, or one box or rack in storage, depending on amount of the material handled at one time and the condition of the material, since the safety limit of handling ranges from 220 g (Pu-fissile + U-235) in arbitrary state to 12,600 g for the dry state mixed oxide of a low plutonium content in the PFFF. The value of safety limit is given by the criticality amount multiplied by safety factor 0.43.

The design bases of the computerized accountancy system, therefore, were set up (1) to maintain always the material amount less than the limit, (2) to perform the accountancy of the material at a level to satisfy the safeguard requirements, and (3) to have conformity or exchangeability of the system data with process or quality control data.

2.2 Hardwares Used

The central processing unit is a FACOM 230-45 S digital computer having 320 kilobyte core memory. The attachments for the input and output are four remote terminal typewriters, two characteristic display units of which one is placed at the head office in Tokyo, two optical mark readers (OMR), and common accessories such as card reader and line printer. Memory is generally kept in disc packs and transfered later into magnetic tapes.

The amount of the nuclear material is generally measured with an automatic balance which is installed in each accounting unit except storage. It is note-worthy that the measurement is generally carried out doubly at both accounting units for shipper and receiver. The accuracy of the balance placed in key measuring points and other important measuring point such as blending of PuO_2 and UO_2 powder is in a range from 1/3000 to 1/10000. Measurement of plutonium within the MBA is generally made in the weight basis by blending ratio, but is converted to the weight by the analytical value upon shipping to other facilities.

2.3 Procedures for the Material Transfer

An optical mark reader (OMR) sheet is submitted from a process operator to the accountancy group, when the material is planned to transfer from an accounting unit to another unit. The OMR sheet was adopted instead of an old chit and punch card method because of (1) time saving, (2) direct input,

(3) low cost of computer processing, (4) easiness of data correction, and (5) abundance of the data included on a single sheet. Two kinds of OMR sheets are used for the material transfer, one for fuel pins and the other for the other forms of the material, eg. pellets, powder and solution.

The OMR sheet is marked for informations of more than 100 characters such as shipping and receiving unit, purpose and scheduled time for transfer, shape, weight, Pu content, batch number, etc. of the material transfered, number of fuel pins and pin numbers, if the material is in a fuel pin or an assembly, and so on. The weight may be eliminated at this step, if it has not yet been measured. The OMR sheets are gathered from all the units of the operation side to the accountancy group, marked with sequence number, processed by an OMR attached to the central processing unit twice a day, and then transfer plan sheet with a key code of five characters are printed out for convenience of the transfer procedure. Details of the computer system was published already.[1)]

There are various errors occurred in marking on the OMR sheet. These errors could be treated by a computer program for checking, which might need a big complicated program, so that the manual checking by a personnel responsible for each process step has been done before submission of the sheet together with the use of simple error check lists by the accountancy group. When an error is found, the sheet is rejected, and an error message is printed out. Number of error message lists is about 50, most of which is for logical check of no mark or double marks.

Next step is input of the key code with the determined weight of material if not input yet, using a terminal typewriter set in the operation area just before the transfer. Amount of the material transfered with other data are filed in the disc pack and this transfer file is checked in comparison with the inventory file for the criticality safety of the receiving accounting unit by an inquiry program. Then, a transfer confirmation sheet is printed out on the terminal typewriter with a sign of "yes" or "no" for the criticality limit. When it is yes, a sign of recognition is sent to the CPU to change the inventory file, and the transfer operation is carried out in responsibility of the accountancy group after checking of the confirmation sheet by both shipper and receiver.

2.4 Physical Inventory Taking

The inventory file is revised with every material transfer, and the final inventories together with all the transfer listings are printed out every day. Since the above mentioned system measures only amount of the material transfered in each accounting unit, accumulation of the measurement error by repeated transfers becomes significant with increasing time elapsed after the last physical inventory taking (PIT), which is then carried out quarterly at every accounting unit. The PIT data is gathered also by using similar OMR sheet to one for the transfer. The inventory file in the disc pack is revised to the newly obtained physical inventory data, and the difference of the older and newer inventories are calculated as MUF. Various PIT lists are printed out in categories such as project, shape, chemical form, etc. together with nationality which is necessary for the present safeguard system, and MUF lists for all the accounting units, process batches, etc, are also printed out. Similar inventory lists for an arbitrary period are easily available whenever needed for the verification by inspector.

3. Practical Experience of the Accounting System

3.1 Experience and Discussion

The present accounting system based on filing of the data and inquiry processing using an OMR sheet has been functioned effectively in the plutonium facilities for four years since 1971 without any trouble. In accordance with approaching plutonium utilization in a large scale, and also in correspondence to the recent social situation in the safeguards, however, there still remain some problems to be solved in the near future. The operation experience of the present system are summarized as follows.

(1) The use of an OMR sheet is very pertinent for the plutonium handling R & D facility, since it can be used for a wide range of the materials and for any transfer direction from any accounting unit. This system can treat very large number of transfers with large amount of informations.

(2) Procedures for the transfer using the OMR sheet is a little intricate for the operator and marking mistake occurs in unneglegible probability though less than a punching input from a chit which was used previously. The mistake reached about 10% at the beginning of the system, but decreased by practice and use of the check lists.

(3) The OMR sheet is not available for a future fully automatized fuel fabrication facility, where a new direct input system from the measurement apparatus should be applied, although the latter may not

be used for the present plutonium facilities, where direction of the material transfer from an accounting unit is not definite.

3.2 MUF

The present accounting system generates MUF in PIT every three months for plutonium and uranium. Two kinds of MUF's are generated, one for every accounting unit and the other for the MBA or for the total plutonium facilities. In order to avoid confusion, the former is designated as MUF_{au} here. The MUF_{au} has no direct significance to the safeguards but to the criticality control and the process control, although it is very usefull for the MUF analysis and a future accounting system described later should be related to it.

The physical inventory for the mixed oxide at each accounting unit is obtained from weight of the oxide multiplied by the plutonium or uranium content which is generally calculated from blending ratio of PuO_2 and UO_2 powders whose plutonium or uranium content has been analyzed. The MUF , hence, takes place as a sum of hidden inventories (such as contained in wastes and filters), accumulated error of the repeated weight measurements, input mistakes, change of O/M ratio and adsorbed water content, and errors of the chemical analyses for starting PuO_2 and UO_2 pwders. One example of MUF_{au} for Pu in the pellet fabrication, which account for most of the total MUF in the fuel fabrication process, for the fuel of an experimental faxt reactor "JOYO" is given below.

Weighing	-24.4 %
Blending, granulation & pressing	45.2 %
Sintering	78.4 %
Pellet inspection	8.9 %
Dry recovery process	-8.1 %

Negative MUF_{au} appears at powder weighing glove box and dry recovery glove box, which can be attributed to a minute weight increase by moisture adsorption during staying in the boxes. High MUF_{au} value in sintering process, in spite of small probability of scattering of the material, seems to be caused by the negative MUF_{au} in the preceding process, since the amount of plutonium determined by the above mentioned method coincides well with the result of chemical analysis as discussed below.

Concerning MUF of the total MBA, Fig. 2 shows a relation between MUF and amount of plutonium handled, which is obtained from the integral amount of the material transfered between two accounting units. The figure clearly indicates that the ratio of MUF to amount of plutonium handled decreases and less fluctuates with increasing amount of plutonium handled, or with elapse of time experienced in which some improvement in the accountancy system has been achieved together with progress in the measurement apparatus.

Throughout the fabrication campaign for the "JOYO" fuel of 119 assemblies using 250 kg of plutonium as the feed material, the total MUF was found to be 0.43 % of the total throughput. It has been found from the data of gamma scanning of waste drums stored from the beginning of the Pu facilities that about a half of the plutonium MUF can be attributed to the solid waste. Then, the probable percentage of plutonium in the solid waste generated in the "JOYO" campaign to the plutonium throughput may be estimated from the above to be 0.43%/2 = 0.215%. Then, MUF might be decreased down to 0.22%, if the solid waste had been removed from the MUF.

It should be mentioned that loss of plutonium during storage caused by decaying of Pu-241 to Am-241 can not be neglected even in a plutonium of low burn-up type such as from a gas cooled reactor used for the "JOYO" fuel (Pu-241 = 3.35 % of total plutonium). A rough estimation gives a value of 0.20 % loss of the total plutonium during an average period of 1.17 year from receiving of Pu to analyzing the pellets. The above value for the MUF, 0.43 % is not affected by this fact, because the value was obtained from the weight and the theoretical coefficient for the mixed oxide pellets. Difference between physical inventories of plutonium based on the chemical analyses and on the theoretical content corrected for the Pu-241 decay was found to be only 0.037 % for the plutonium contained in the total 119 fuel assemblies.

3.3 Correlation with Other Data Logging System

The daily inventory data filed is utilized for other purposes such as fabrication process control, quality control, quarterly throughput, quarterly material handled, and radiation exposure control for estimation of radiation doze at specific sites. On the contrary, the data from fabrication process and quality control which are filed separately from those for accountancy, are used for the accountancy of the material in the fuel pins or assemblies, as shown in Fig. 3 & 4, on which amount of the material in fuel pin in an assembly is printed out (Fig. 3), together with a graphic display of pin numbers of the assembly (Fig. 4).

4. Future System

The nuclear material control system for the plutonium fuel fabrication facility is now in a transitional period, when viewed in the request of the safeguarding and also in the fitting to a new automatic fabrication process which is requested from necessity to decrease the external radiation exposure for operators rather than upgrading of productivity.

Special safeguards study reported by D. M. Rosenbaum and others[2] at the request of the USAEC seems to be unique in its acute critics against the current accountancy system as a basis of the safeguards of plutonium. They recommended that "the current concept of MUF and LEMUF be abondoned as a basis of safeguards and that they be replaced by a different type of accounting and measurement system, ...". Reason why they concluded the above is simply the lack of timeliness and sensitivity for the detection of diversion by the current system. They pointed out for the timelines that "the time delay in the inventory system is long enough to allow a skilled diverter to have constructed an explosive device before the system can reach a conclusion that diversion has taken placed", and for the sensitivity that "the measurement of the total inventory can never be known to better than one tenth of one percent". Their recommendation instead of the current system are (1) double contingency in measurement, (2) counting as soon as an identifiable shape is established, (3) comparing the flow of data from all measurements against a working model of the system on a daily basis, (4) effective application of advanced measurement techniques to possible diversion paths, and (5) organizational function.

Examining the recommendation against our system, it should be emphasized first that the sensitivity of the MUF would not be so bad as they insisted and may be possible to reach one tenth of one percent in the near future, if the future system will have such a system that the waste and other possible output of the material is measured, even though how small it is, and also the measurements are cautiously calibrated always to minimize the systematic error, as suggested from the above mentioned experience in the "JOYO" fuel fabrication campaign.

A new system which satisfies five recommendations by Rosenbaum and others may be as follows: As to recommendation (1), we have already been performing double measurements for the weighing in both accounting units of shipper and receiver where careful calibration of balance is generally carried out every day. It seems necessary to apply NDA to some points of the fabrication process, for example, for determination of plutonium content at a point just after the blending of PuO_2 and UO_2 powders, which need to be equipped also for the sake of quality and process control, especially in the case of automatic process. The NDA for plutonium content in a fuel pin has been used in many facilities including our plutonium facilities, and this is undoubtedly one which should be equipped for double checking and also for verification.

With regard to recommendation (2), it may not be essential to count number of the pellets, but instead of the counting, a container including cladding or tray for the pellets should be identified by number and weight linked with the number. The present our system can give the amount of the material included in cladding from the data file by inputting pin number. An automatic number reader has been developed and now under testing.

The present system gives a real time inventory on a daily basis, although it is basically a book inventory. Recommendation (3) can be met with only a little calibration of the coefficient to minimize the MUF_{au}. The real time material control system, however, is essentially to be based on the physical inventory. This will not be satisfied unless with a new facility, in which a new design concept such as consistency or containment of the batch, or minimized hold-up together with its proper estimation in nearly complete flow production, or automatic clean-out system of the process equipment accompanied with the use of in-process storage, which seems to be also useful for adjustment of the process flow and decrease of the external radiation doze during maintenance of the equipments.

Concerned with recommendations (4) and (5), measures are comparatively easy to deal with and not described here. It is better to mention that a future automatic plutonium fuel fabrication facility has much less probability for penetration or diversion of the material, since it has structurally very limited oppotunity for diverter to access the material, and also may have a continuous perfect containment for a series of process.

As seen from the above discussion, the very core of our future system will be composed laying stress on weighing and reading of numbered containers. It seems to be inadequate that NDA plays the leading part of the accountancy in near future, because of difficulty to maintain and to obtain a standard sample, its cost, and accuracy, although it is very useful as a support, if casting is good, and effective use of them must be promoted. The most important thing in the future system is saving cost, and this will be possible by a way that measures for the safeguarding are utilized also for other control purposes such as for criticality, quality, process, or vice versa.

References

1) Akutsu, H., et al., A Real-Time Accountancy and Control System at Plutonium Fuel Facility of PNC, INMM 16th Ann. Meeting, New Orleans, (June, 1975).

2) Rosenbaum, D. M., et al., "Special Safeguards Study", USAEC T201, (Apr. 1974).

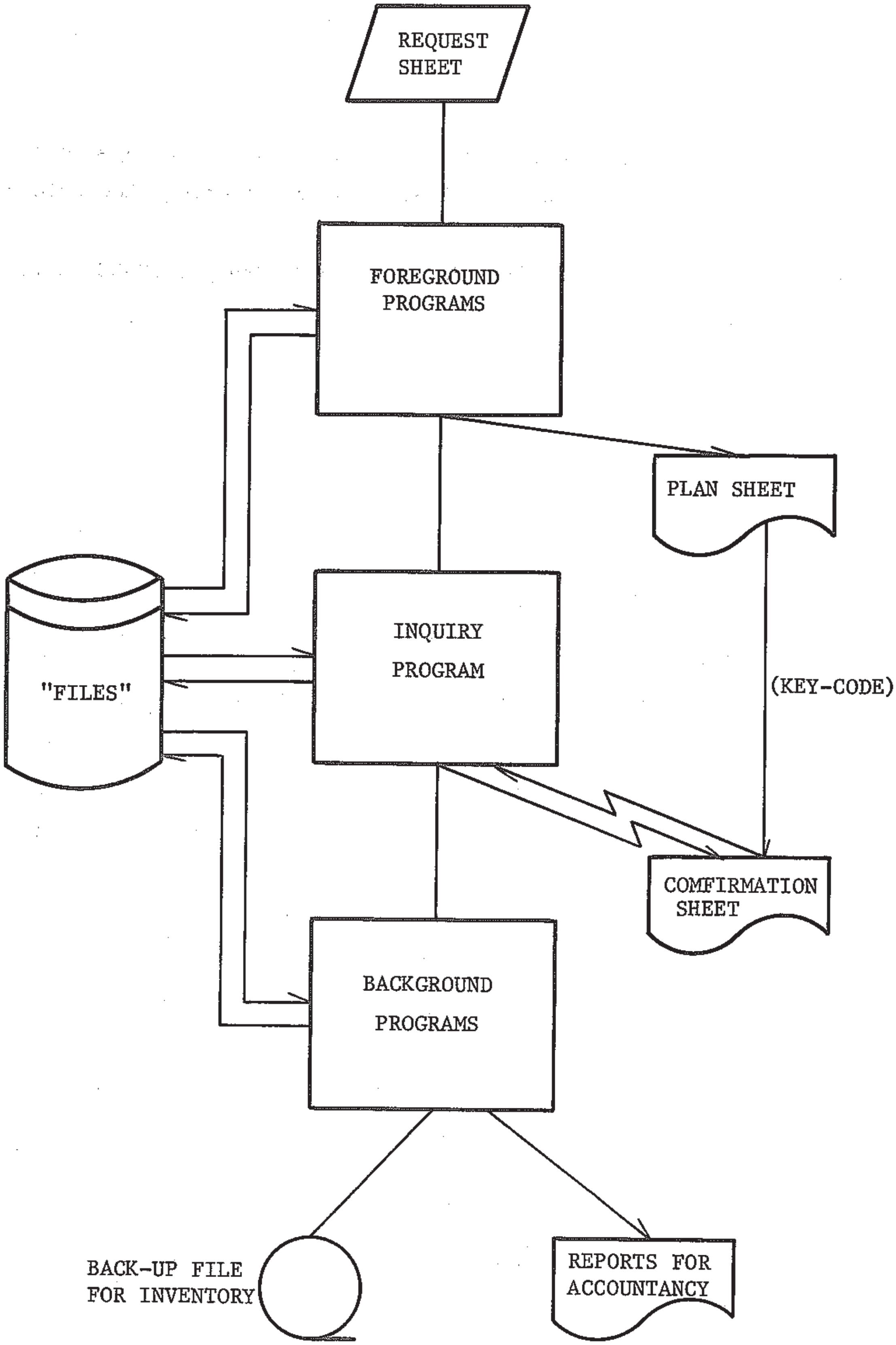

Fig. 1 General Flow of the Material Transfer

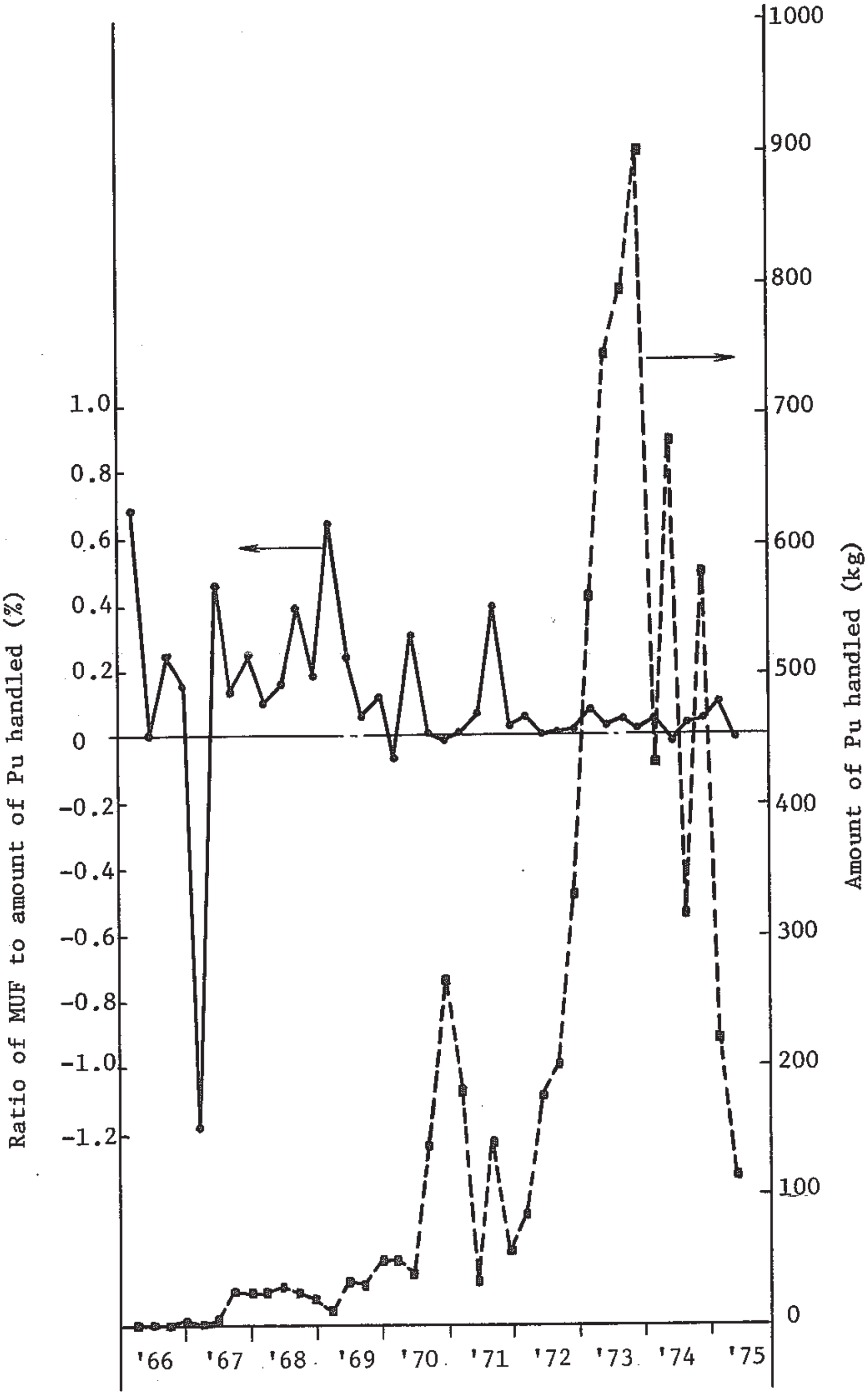

Fig. 2 Relation between MUF and Amount of Pu Handled

```
*******************************
***  PIN  MATERIAL  WEIGHT  ***
*******************************
                      UNIT : G
PIN NO. : 00007

   CORE
      M.O                 141.46
      PU(METAL)            22.08
      PU(FISSILE)          17.66
      EU(METAL)           102.57
      EU(U-235)            23.58


   BLANKET
      DU(METAL)           165.01
```

Fig. 3 A Display for the Material Weight in a "JOYO" Fuel Pin

```
S/A NO.    :  PPJD00
PARTS NO.  :    012     (91)    (90)    (89)    (88)    (87)    (86)
------------------     00458   00457   00455   00452   00451   00450
                    (79)    (80)    (81)    (82)    (83)    (84)    (85)
                   00449   00447   00181   00180   00178   00177   00172
                (78)    (77)    (76)    (75)    (74)    (73)    (72)    (71)
               00448   00129   00166   00167   00168   00170   00171   00174
            (62)    (63)    (64)    (65)    (66)    (67)    (68)    (69)    (70)
           00119   00120   00121   00122   00124   00125   00126   00127   00128
        (61)    (60)    (59)    (58)    (57)    (56)    (55)    (54)    (53)    (52)
       00118   00115   00114   00113   00111   00108   00106   00105   00104   00103
    (41)    (42)    (43)    (44)    (45)    (46)    (47)    (48)    (49)    (50)    (51)
   00066   00067   00101   00102   00045   00050   00051   00052   00054   00055   00123
        (40)    (39)    (38)    (37)    (36)    (35)    (34)    (33)    (32)    (31)
       00063   00060   00059   00058   00057   00044   00043   00042   00041   00039
            (22)    (23)    (24)    (25)    (26)    (27)    (28)    (29)    (30)
           00028   00029   00030   00031   00032   00033   00034   00036   00037
                (21)    (20)    (19)    (18)    (17)    (16)    (15)    (14)
               00027   00026   00025   00024   00023   00022   00021   00020
                    (07)    (08)    (09)    (10)    (11)    (12)    (13)
                   00013   00014   00015   00016   00017   00018   00019
                        (06)    (05)    (04)    (03)    (02)    (01)
                       00012   00011   00010   00009   00008   00007
                          VISUAL SECTION FROM ENTRANCE-NOZZLE
```

Fig. 4 A Display for Pin Numbers in a "JOYO" Fuel Assembly