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BASIS OF MATERIAL ACCOUNTANCY FOR SAFEGUARDS IN A CENTRIFUGE PLANT [+)]

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Summary

The paper deals with two areas of interest in connection with the safeguarding of a centrifuge plant, namely, a) a critical analysis of a few characteristics of centrifuge plants which are relevant to safeguards and b) a record-report system for such a plant.

Some characteristics of a centrifuge plant are conducive to safeguards. The gas phase inventory in the separating part of the cascade is very low. The feed, product and tail streams are all pure UF_6 and are among the most accurately measurable process streams in a nuclear cycle (this is true for all enrichment facilities). These factors permit a simplified balancing system for safeguards. It is not possible to establish the separative work of a centrifuge plant directly during normal operation. However, it is not necessary to have an independent knowledge on separative work for safeguards purposes.

Only two material balance areas are required for a record-report system in the reference centrifuge plant with the capacity of 600 tU SW/yr. The EDP system can be built up in such a way that it can be used for the records and reports for safeguards and for the plant requirement. The same structure can be used for a much simplified record-report system in a smaller size plant.

Zusammenfassung

Im vorliegenden Bericht werden zwei Interessenbereiche für die Überwachung einer Zentrifugenanlage gestreift, nämlich a) eine kritische Analyse einiger überwachungsrelevanter Eigenschaften der Zentrifugenanlage und b) ein Protokoll- und Berichterstattungssystem für eine solche Anlage.

Einige Eigenschaften einer Zentrifugenanlage sind überwachungsfreundlich. Das Gasinventar der Trennkaskade einer solchen Anlage ist sehr niedrig. Die Eingangs-, Produkt- und abgereicherten Ströme aus der Kaskade sind reines UF_6 und gehören zu den sehr genau meßbaren Verfahrensströmen im Brennstoffzyklus. (Dies gilt jedoch für alle Anreicherungsanlagen.) Sie gestatten die Erstellung eines einfachen Bilanzierungssystems zum Zwecke der Überwachung. Es ist nicht möglich, die Trennleistung einer Zentrifugenanlage während des Betriebs direkt zu erfassen. Für die Überwachung ist jedoch eine unabhängige Kenntnis der Trennleistung nicht erforderlich.

Zwei Mengenbilanzzonen sind für das Protokoll- und Berichterstattungssystem für die Referenzanlage mit 600 tU TA/a ausreichend. Das EDV System kann so aufgebaut werden, daß es sowohl für die Überwachungsprotokolle und Berichte wie auch für den Betrieb verwendet werden kann. Das gleiche Protokoll- und Berichtsystem kann in wesentlich vereinfachter Form für kleine Anlagen eingesetzt werden.

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1. Introduction

With light water type reactors dominating increasingly the commercial field of nuclear energy production, uranium enrichment facilities become more and more an integral part of a peaceful nuclear fuel cycle. Up till now low enriched uranium for energy production has come almost exclusively from the diffusion plants of the United States. However, in recent years strong commercial interest has become evident in the centrifuge method of uranium enrichment /1, 2/. Systems analytical studies carried out in the recent past on required safeguards measures for enrichment facilities with centrifuges tend to indicate that the basic technical procedures laid down in the IAEA

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document INFCIRC/153 /3/ are adequate for applying international safeguards in such facilities. In this case also material accountancy forms the basic safeguards measure with containment and surveillance as important complementary measures. In the present paper some safeguards relevant characteristics of a centrifuge plant for the enrichment of uranium have been critically examined. Furthermore the structure of a recording system for the establishment and execution of safeguards material accountancy measures has been discussed on the basis of a 600 t SWU/yr reference plant.

2. Safeguards relevant characteristics of a centrifuge facility

2.1 Separative work

Uranium enrichment facilities are in general unique in the sense that in the open part of the fuel cycle (conversion, fabrication, reprocessing, enrichment) only this type causes an increase in the effective kg output. This fact has several safeguards relevant implications. With the installed separative work capability of an enrichment facility, it is theoretically possible to produce higher U-235 enrichment than the design value. However, commercial and technological conditions require that relatively small cascade sizes (500-600 t SWU/yr) may be operated in parallel on a modular basis in large plants. Any significant amount of high enriched material from such small cascades can be expected to be detected relatively easily by establishing proper material balances and safeguards procedures.

Because of technical and economical limitations it is not possible to obtain sufficiently accurate direct and independent information on the actual separative work performed by a centrifuge cascade. Some of the limitations are enumerated below /6/.

It is necessary to have information on the following points in order to assess the separative work produced in a centrifuge cascade at a given time in an independent manner:

1. Sum of the centrifuges in operation.
2. The separative work produced by individual centrifuges.
3. Mixing losses in the cascade.

2.1.1 Number of centrifuges in operation

It is necessary to have an indication and registration of the operation of each of the centrifuges in a cascade so that the actual number of centrifuges operating at a given time can be known. This is necessary to calculate the total separative work produced in a cascade. Because of the very high number of centrifuges even in a cascade of relatively small capability and high economic penalty associated with instrumentation of individual centrifuges for indication of its operation, no industrially operating centrifuge plant is expected to have such instrumentation. It is therefore, highly probable that the plant operators themselves would not know the exact number of centrifuges operating at a given time in a cascade.

2.1.2 Separative work produced in a centrifuge

Even if the relevant characteristics of a centrifuge were known to the inspection authority (which are clasified at present) it would virtually be impossible for such an authority to deduce the separative work produced by a particular centrifuge in operation at a given time. Manufacturing tolerances can shift the separative work output of a given lot of centrifuges from the expected value on a operation curve in a systematic manner. The aging of a centrifuge on account of (among others) deposition of impurities, residues of chemical reactions etc. on various parts of a centrifuge, may cause different rates of reduction of separative work production for different centrifuges as a function of time. A reduction in the separative work produced in a centrifuge may also be caused by different types of leakages (e.g. welding leakage, leakage because of defective seals etc.) as shown in Fig. 1 or slight changes in the withdrawal system.

2.1.3 Mixing losses in a cascade

The mixing losses in a cascade depends among others, on the type of cascade connections, enrichment obtained and the extent of shifting of the operating point of individual centrifuges caused by some of the factors mentioned under 2.1.2. Since some of the causes for these losses may also cause a change in the stage cut, they may result in a further shift of the operating point of a centrifuge from the optimum. The extent of reduction in the separative work production of a whole cascade depends also on the location at which centrifuge failures take place. This is shown in Fig. 2.

The overall effect of all these factors is always a reduction in the separative work production of a cascade from the design value. Since the plant operators themselves will not be in a position to know in a quantitative manner the magnitude of these influences, their only means of knowing the separation work produced in a cascade is the calculation on the basis of the production rates and concentrations of the product and the tail streams - that is by establishing material and isotopic balances. Besides, the centrifuge plants differ in one respect from the gas diffusion plants. There is no single characteristic (in diffusion plants, the energy consumption) which can indicate directly the separation work produced in a cascade with any reasonable accuracy.

2.2 Classification of information

At present some information on centrifuge technology is classified. This classification will pose some limitations on the safeguards organisations with regard to the access of some technical information and locations such as the separation area of the cascades and the maintenance area for centrifuges. Detailed analyses of safeguards problems /4/ indicate that such limitations need not hamper the proper and effective functioning of an international safeguards system.

2.3 Conditions for material accountancy measures

The feed, product and tail streams in an enrichment facility are pure UF_6 and are among the most accurately measurable process streams in a nuclear fuel cycle. They are normally measured in discrete batches consisting of cylinders containing UF_6. Besides, in a commercial centrifuge plant, the gas phase inventory in the separating part of the cascade is expected to be exceedingly low. With proper plant layout and storage arrangements, the inventory taking in a facility can be simplified. Because of these reasons, a centrifuge plant is ideally suited for the execution of material accountancy measures. However, such a facility may also have some other MUF problems which are discussed below.

2.4 Problems of MUF

An analysis of various components of the MUF in some of the facilities belonging to the open part of the fuel cycle indicated /7/ that they may have their origin both in measurement and in process components. It is to be expected that in a centrifuge plant this will not be different. Since the accuracy of measurement for the three main process streams are expected to be high, some important contribution to the variance of MUF may come from the measurement errors associated with the various waste streams (not the tails) leaving the plant. Also, besides the gas phase inventory inside the cascade which can be considered to be small, some solid phase deposition of uranium in various parts of the separating and non-separating parts of the cascade may be expected. Since such deposits cannot be balanced directly, they may be considered as a hidden inventory and will contribute to the expectation value of the MUF. Another temporary contribution to such a hidden inventory may be from the amounts accumulating in the traps of the vacuum system so long they are not discharged into the decontamination or waste systems. Results obtained sofar indicate that these values will be small and may remain in the range of the measurement uncertainties. However, careful analysis of these components on the basis of historical performance of a facility is necessary to keep a safeguards system based mainly on material accountancy effective.

2.5 Problems of maintenance

A centrifuge plant may require regular maintenance and replacement activities for centrifuges throughout the year. This will necessitate availability of maintenance and test areas near the operating cascades. Such areas will also not be accessible to inspection personnel.

3. Reference plant

A reference centrifuge plant with a separative work capability of 600 t U/yr. has been considered to analyse the basic requirements of a record system. The important data for the plant are presented in Table 1. The schematic layout of the plant is shown in Fig. 3. The product concentration has been chosen to be 3 % U-235 i.e. the average concentration for LWR type fuels. The tails are assumed to contain 0.3 % U-235. The area lined around the cascade containing the separating units and maintenance and test area is assumed to be inaccessible for inspection. It is to be noted that all intermediate storage vessels, sublimators, traps, vaccuum system, effluent treatment systems etc., i.e. those parts which may contain large amounts of intermediate inventory of uranium, are accessible to inspection.

3.1 Material Balance Areas

The reference plant has been assumed to be devided into two MBAs for safeguards purposes, as indicated in Fig. 4, i.e. one storage and one process MBA. The actual numbers of MBAs depend among others, on the specific characteristics of the plant, the possibility of measurement of transfers from one MBA to the other and the accuracy of measurements. For large plants consisting of a number of parallelly connected modules, it might be advantageous to have multiple number of MBAs provided of course, independent input and output systems exist for each of the modules.

Two MBAs per module offer a number of operational and safeguards advantages. The personnel responsibilities for material in the plant are divided in the same way namely, one group being responsible for the storage part and the other for the process part. For safeguards it requires low reporting activities. It is to be noted that the process MBA has been divided into an accessible and an inaccessible part. The centrifuge cascade, maintenance and testing areas for centrifuges are located within the latter area.

4. Basic structure of a probable recording system

In the present paper a computerized record system has been considered. For smaller size plants, a much simpler record system may be economically more advantageous. Some thoughts to a possible structure of a record system are summarized here.

4.1 Storage MBA

This MBA is expected to have feed, product and tail cylinders and waste containers. Each of the cylinders or containers represent a batch for the recording system. At the key measurement point A, every feed cylinder entering this MBA is registered in the record system with information on:

Cylinder number
Tare cylinder weight
Weight of UF_6
Weight of total uranium
Weight of U-235
Weight percentage of U-235

These entries are the batch data for each cylinder and are taken over from the shippers data.

Similar information is registered for outgoing cylinders or containers for products, tails and waste amounts at the KMPs D1-D4. These batch data correspond to the data generated at the KMPs C1-C4.

4.2 Process MBA (accessible part)

At the KMP-B, UF_6 from a cylinder are to be measured and after purification fed into the cascade. The measurement consists of a) Brutto and Tare weighing of the cylinder, b) if necessary, taking of a UF_6 sample for the analysis of impurities and isotopic composition. The differences in the measurement values between the key measurement points B and A are shipper-receiver differences (SR/D) and may be caused by difference in measurement errors (or other types of errors if any) and cylinder heels, caused by incomplete evaporation or solid residues of uranium compounds. The batch data are the same as at KMP A with additional information on impurities. Also the identity of samples taken are to be recorded. At this point the source data for a given batch are also to be registered to the extent they are generated. They may consist of information on weighing, chemical and isotopic analysis and the corresponding data on measurement calibration and standards.

Different types of waste amounts (HF/UF_6 wastes from purification stations, decontamination wastes from effluent treatment etc.) are supposed to be measured at the KMP C1 and C2. These wastes may correspond to approximately 0.5 % of the feed stream with mainly natural uranium concentration. They may be collected in suitable containers and each of the containers sampled for very rough estimation of uranium and occasionally of U-235 content. The batch data are similar to those obtained at KMP-B.

Tail streams from the cascade containing depleted U-235 are supposed to be registered at the KMP-C3. More than 80 % of the feed appears as the tail stream (Table 1) in the reference plant considered here. Therefore, empty feed cylinders will probably be used for storing the tails.

For material accountancy purposes knowledge on the amount and isotopic composition is required for each of the cylinders containing tails if such cylinders are considered as a batch. However, since the tails represent a very low economic value, they may not be measured by the plant operators as rigorously as the product streams. The tails may be expected to be stored at the facility for a long time. Some containment measures for the the tail cylinders will be required to avoid recycling. Batch data for the tails are the cylinder number, total uranium amount and the weight percentage of U-235. The chemical composition may be taken to be the ratio $U/UF_6 = 0.68$ since all gaseous impurities are expected to be concentrated at the product end.

The product streams are measured and registered at the KMP-C4. Since the product amount is approximately $1/6^{th}$ of the feed amount, smaller size of product cylinders (i.e. 2 t) may be expected to be used. Accurate measurements (weighing, chemical and isotopic analysis) are to be made for each batch. Samples may be taken from the product lines instead of from the product cylinders to avoid reheating and homogenization of the product in the latter. However, representativeness of the samples for a batch has to be ensured.

The batch data are similar to those at the KMP-B.

4.3 Inventory taking

The inventory taking for the storage MBA is simple and can be carried out by making tag verification of cylinder data. In the accessible part of the process MBA in which all the intermediate storage vessels traps etc. are located, two types of inventory taking have been envisaged. One is of the accurate type (probably once in a year) during which the sublimators and a part of the traps are emptied and the content measured with the same accuracies as are available at the corresponding key measurement points /5/. In the other case, rough estimates of the contents of the sublimators are made on the basis of plant operational data. For this purpose it is assumed that rough flow measurement points before the sublimators will be available around the KMPs B, C3 and C4 (Fig. 4). The nuclear material inventory of the vacuum traps in the accessible parts of the process MBA, the gas phase inventory in the cascade as well as the solid phase inventory in the cascade and in other parts of the plant in the inaccessible process MBA are expected to be estimated on the basis of historical data and experience.

4.4 EDP-system

The electronic data processing system can be built up in such a way that it can be used for both record and report system for safeguards and for financial calculations for the production in a plant. The block diagram for such a computer based system is shown in Fig. 5. The measured values relevant to safeguards generated at a KMP are registered on punch cards for further processing. Typical punch cards for the source data on material identification and weighing are shown in Fig. 6. The EDP produces an accounting record in the form of a listing per batch and KMP, whenever a movement of one batch from one MBA to the other takes place. Such a listing is shown in Fig. 7. Besides, these data are stored in an intermediate storage (e.g. magnet tape) for establishing a material balance at the time of a physical inventory taking. The batch data for all the movements of cylinders from and to a MBA are printed out every month and can be sent as an inventory change report to the relevant safeguards organisation. At the time of a physical inventory taking, all the inventory batches for the two MBAs will be registered and the EDP establishes a material balance on the basis of historical data on measurement errors, the stored data on inventory change since the last inventory and the starting and the physical inventory data. A summarized print out of all the physical inventory batches (PIL) and the material balancing may form the basis for the respective PIL and material balance reports.

Besides the accounting record, the operating record is to contain information among others, on calibration of measuring instruments, measurement errors, inventory taking procedures, procedures for analysis of losses etc. /3/. They are not elaborated here.

5. Concluding Remarks

At present no commercial centrifuge plants are in operation. Information on the extent and magnitude of a number of problems relevant to safeguards are still required. The loss rate of UF_6 from a cascade, the hidden inventories, the accuracy of measurement for waste materials etc., belong to such problem areas. However, systems analytical results and experimental experience indicate that these problems though have to be solved, do not pose any significant hazard to international safeguards. The inherent characteristics of a centrifuge plant associated with proper layout conditions would present a good basis for the effective execution of material accounting measures.

Acknowledgement

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Table 1

Data on the Reference Centrifuge Plant

Items	Numbers
Separative work capability [t U/yr]	600
Feed natural [t UF_6/yr]	1705
Product [t UF_6/yr]	259
U-235 Conc. of product [%]	3
Tails [t UF_6/yr]	1446
U-235 Conc. of tails [%]	0.3
Waste streams [t UF_6/yr] (decontamination of cold traps instruments, HF/UF_6 discards etc.)	8.5
U-235 Conc. in waste streams [%]	natural
Feed storage [t UF_6] (one month capacity)	140

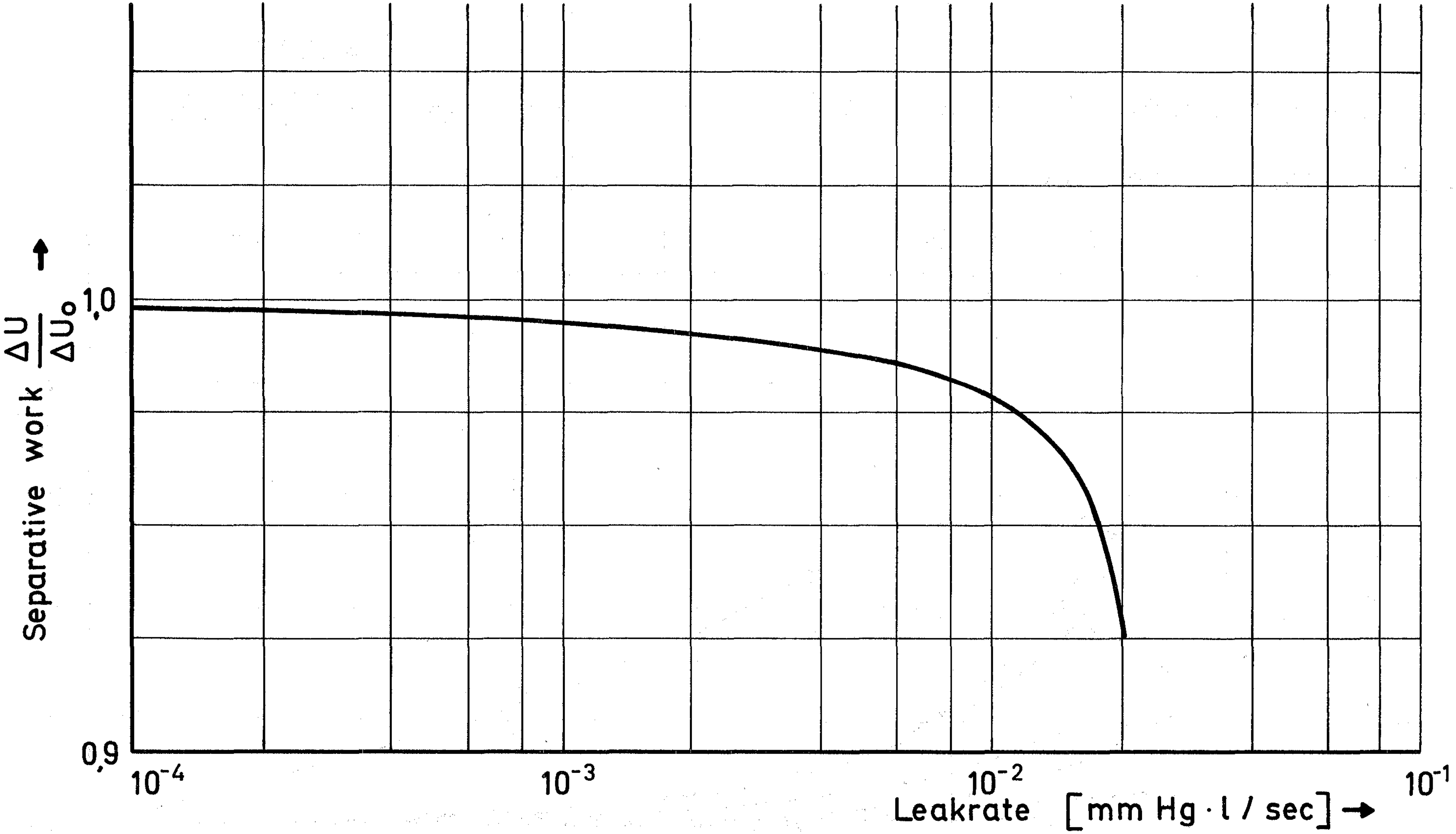


Fig. 1: Measured separation work in an experimental cascade as a function of leakrate.

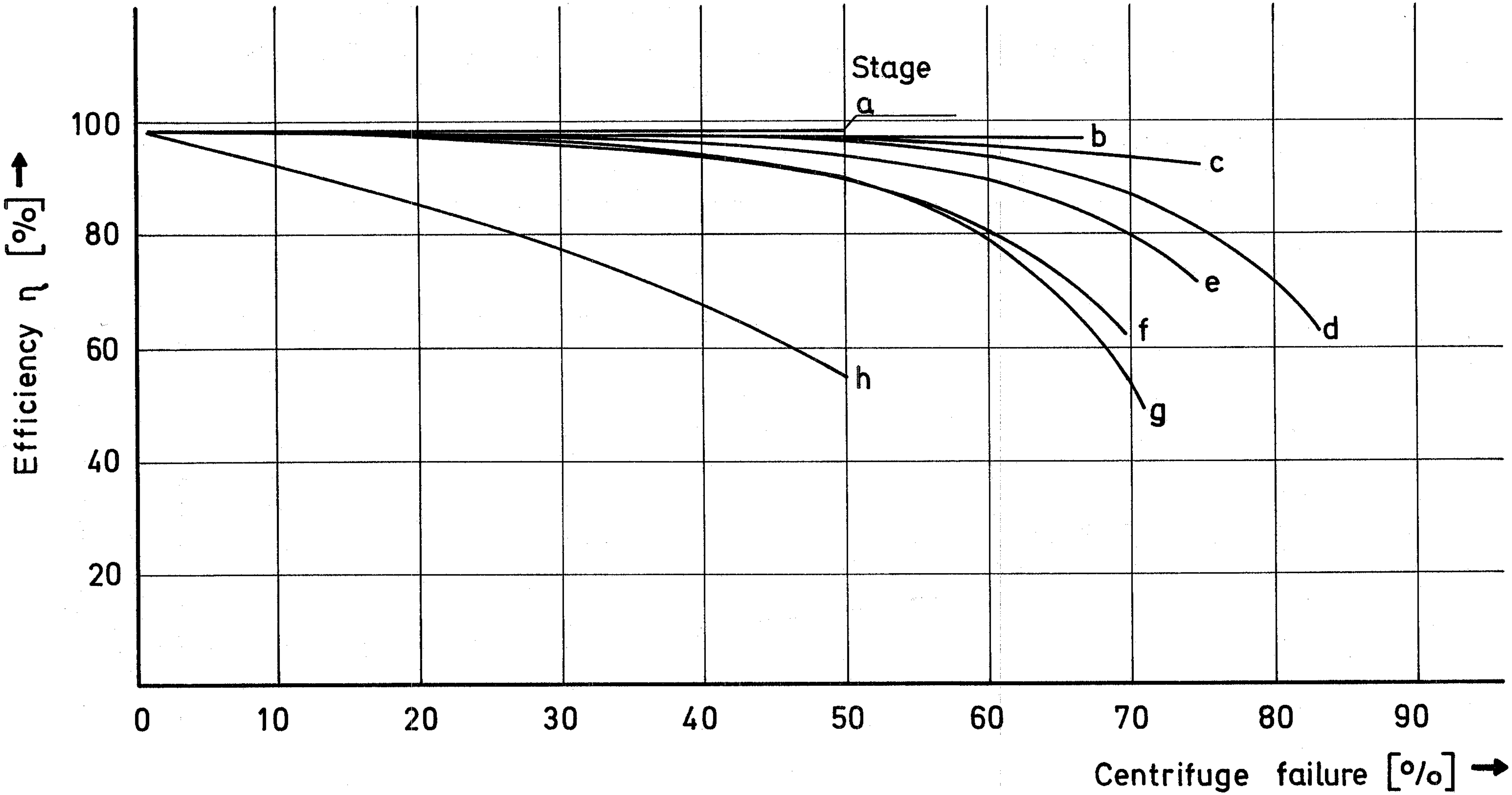


Fig. 2: Calculated efficiency η as a function of % centrifuge failures in a stage.

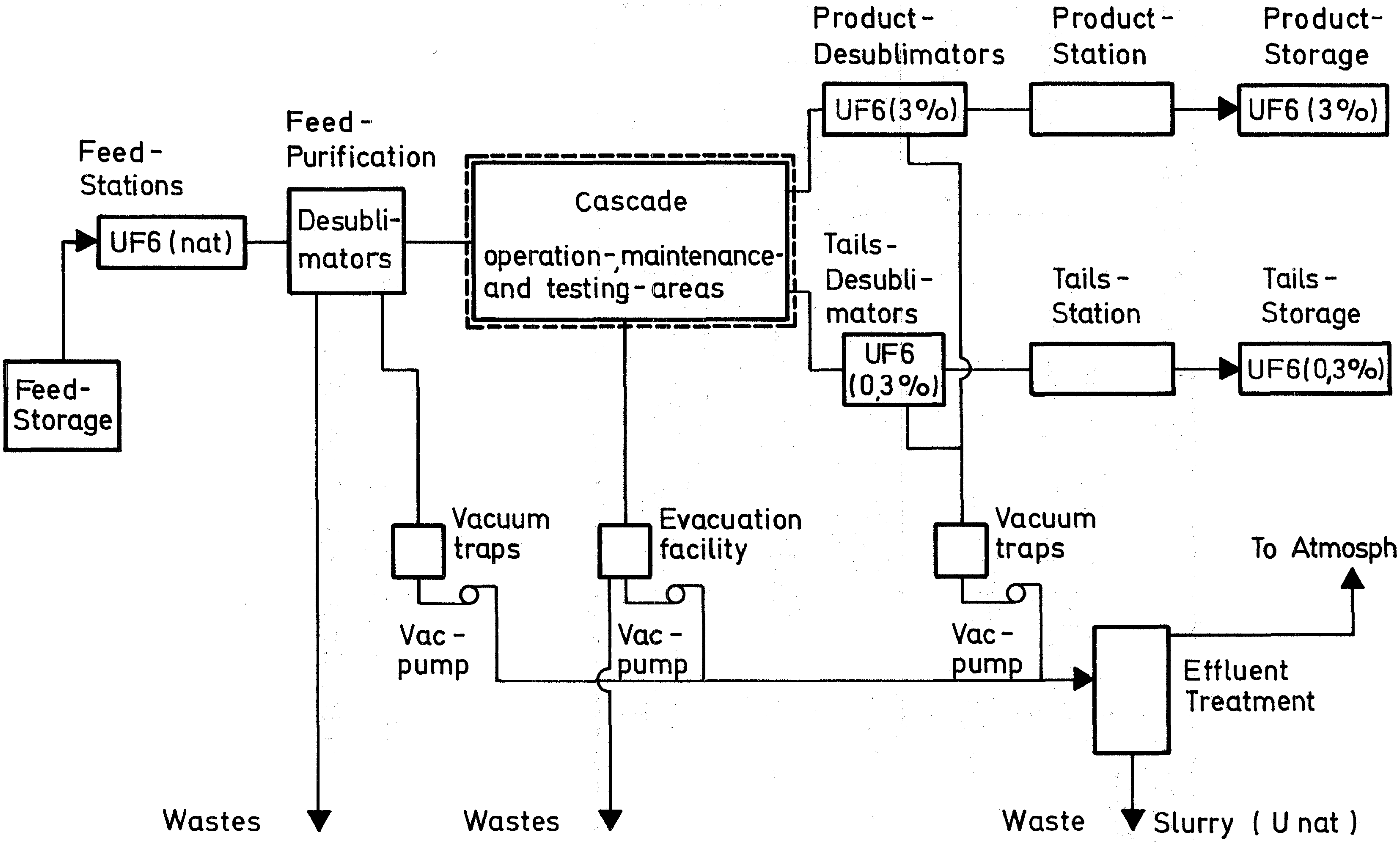


Fig. 3 Schematic flow - sheet for the reference centrifuge plant

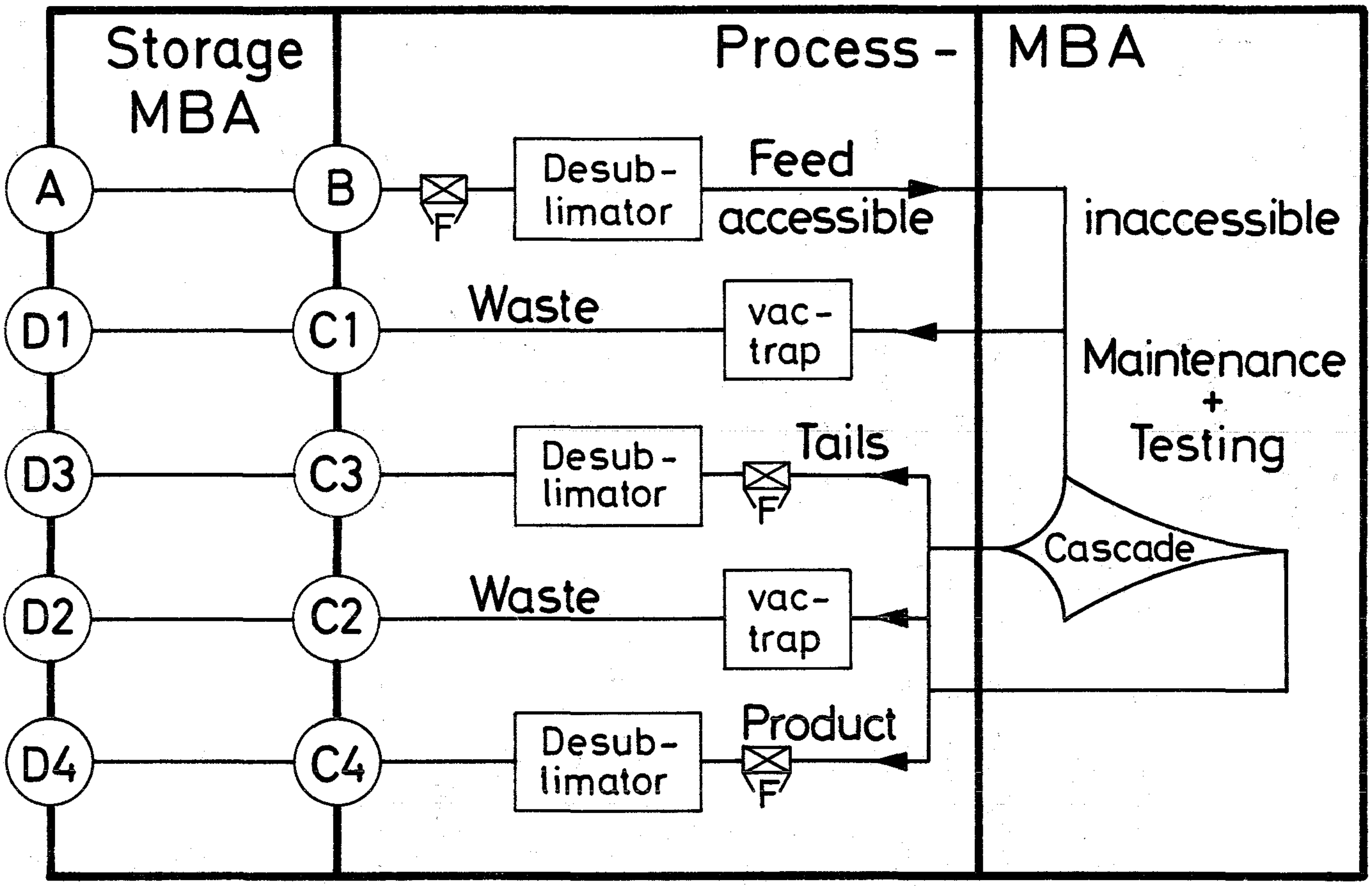


Fig. 4 MBAs and Location of KMPs in the reference centrifuge plant

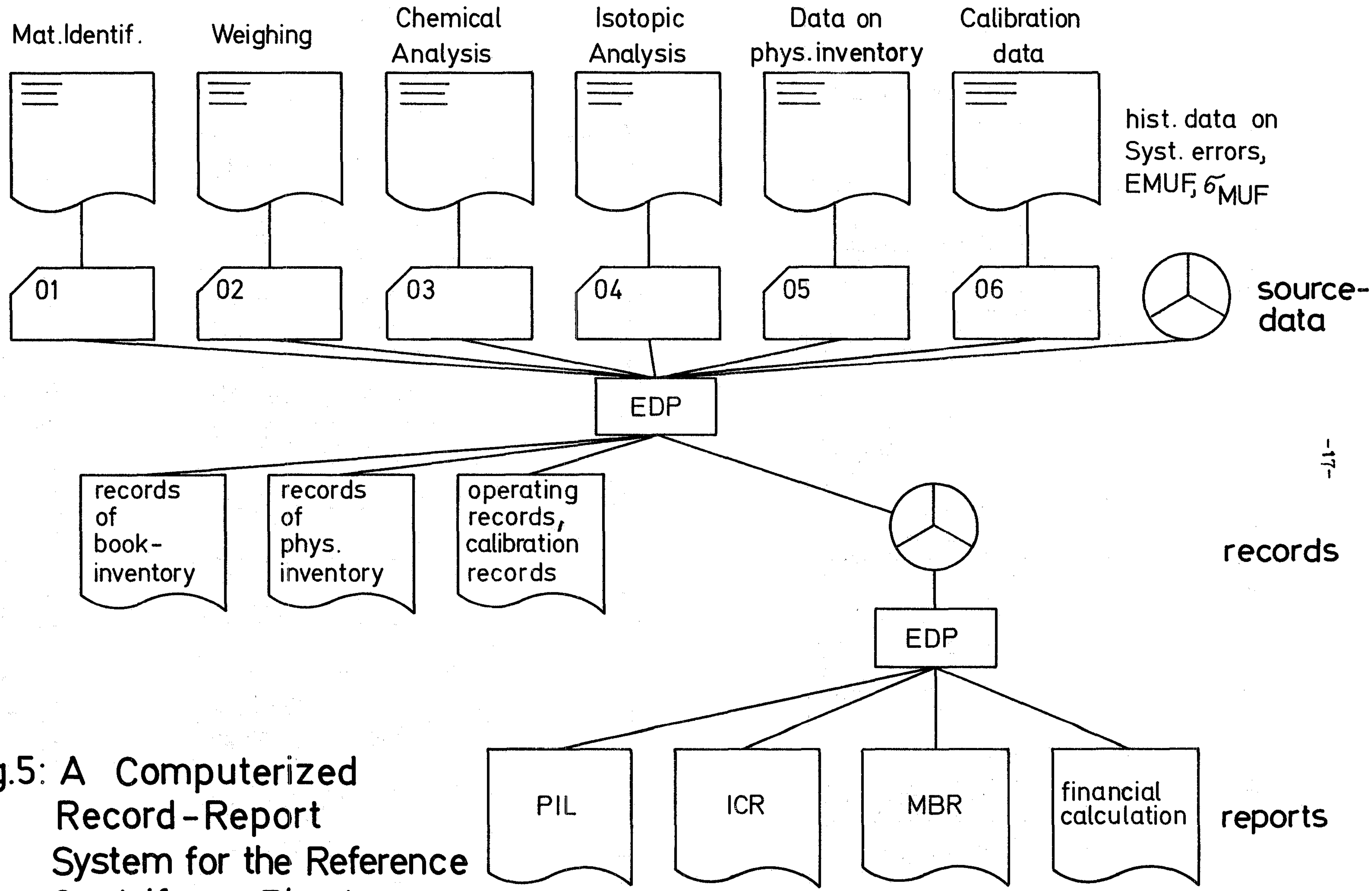
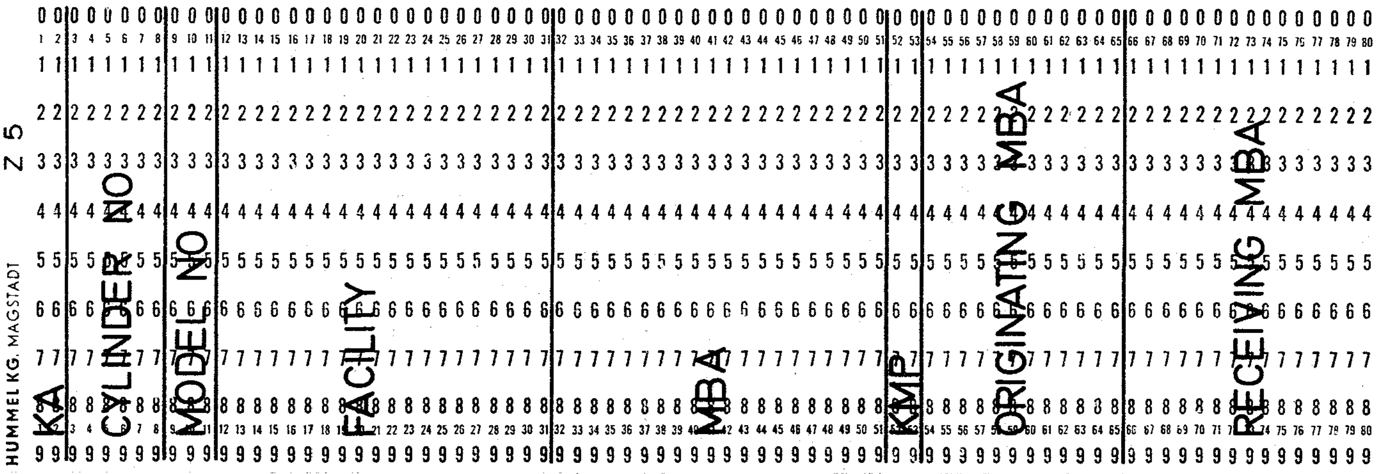


Fig.5: A Computerized Record-Report System for the Reference Centrifuge Plant

01456123301 ISOTOPE SEPARATION PROCESS C4PROCESS STORAGE



02456123301 1300. 9400. 1302. 16 1364220689 WEIGHING

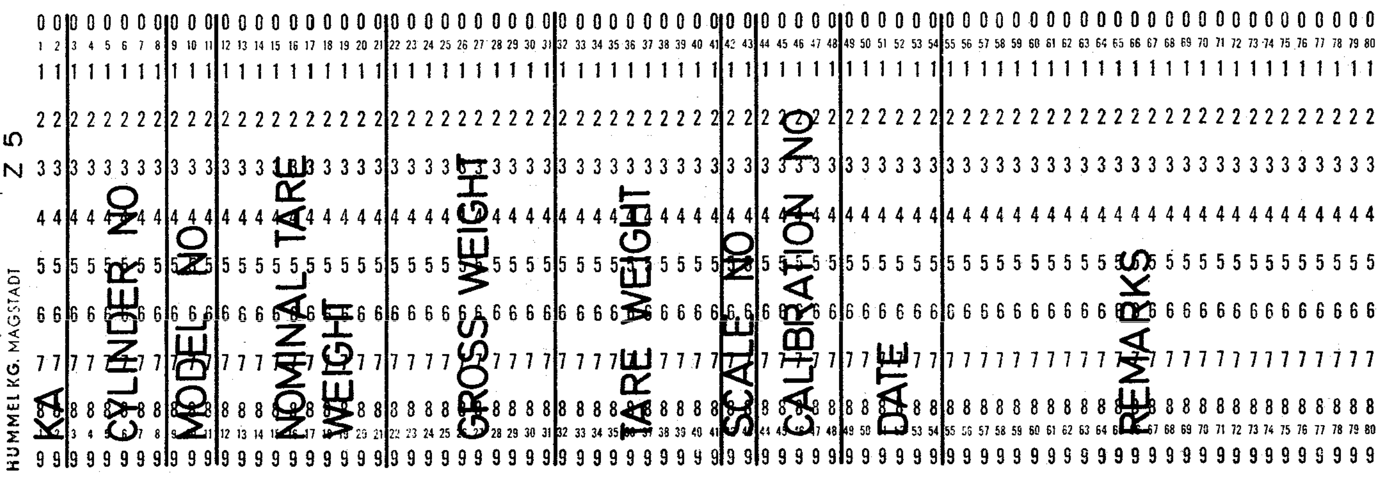


Fig. 6 Source data for material identification and weighing on punch cards

DORNIER SAFEGUARD RECORD NO. 101

1. MATERIAL IDENTIFICATION

FACILITY :ISOTOPE SEPARATION

MATERIAL BALANCE AREA :STORAGE
KEY MEAS. POINT NO.C4
ORIGINATING BALANCE AREA : PROCESS
RECEIVING BALANCE AREA: STORAGE

DATE OF INVENTORY CHANGE : 2/ 6/89

2. BATCH DATA

SHIPPING CYL.NO. 456123
SAMPLE NO. 543287
SAMPLE NO. 124531

MOD.NO. 301
SAMPLE CYL.MOD.NO. 11
SAMPLE CYL.MOD.NO. 11

WEIGHT OF URANIUM ELEMENT 5496.92KG

WEIGHT OF FISSILE ISOTOPES : 159.64KG WEIGHT- PERCENT OF FISSILE ISOTOPES : 2.9041

HEEL : 2.00KG

3. SOURCE DATA

3.1 WEIGHING
GROSS WEIGHT : 9400.00
TARE WEIGHT : 1302.00
NET WEIGHT : 8098.00
SCALE NUMBER :16
DATE 22/ 6/89

NOMINAL TARE WEIGHT : 1300.00
CALIBRATION NO. 1364

3.2 ANALYTICAL MEASUREMENT
SAMPLE NO. 543287

SAMPLE CYL.MOD.NO. 11

SPECIFIC GRAVITY OF SAMPLE : 237.580
WEIGHT-PERCENT U : 67.8 C
INSTRUMENT-NO. 17
DATE 23/ 6/89

CALIBRATION-NO.43219

3.3 ISOTOPIC ANALYSIS
SAMPLE NO. 124531
U235/U238 : 2.9910

SAMPLE CYL.MOD.NO. 11

MSP-NO.14
DATE 24/ 6/89

CALIBRATION NO. 45219

Fig.7 Inventory change in an accounting record