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Institut für Angewandte Reaktorphysik

Development of Safeguards Procedures and Simulation of Fissile Material Flow for an ALKEM Type Plant Fabricating Plutonium Fuel Elements for Fast Breeder Reactors

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This research has been carried out in the framework of a contract between the International Atomic Energy Agency (IAEA) and the Gesellschaft für Kernforschung mbH., Institut für Angewandte Reaktorphysik, Karlsruhe, Federal Republic of Germany.
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Der vorliegende Bericht wurde im Rahmen eines Forschungsvertrages mit der International Atomic Energy Agency (IAEA) in Wien angefertigt. In enger Zusammenarbeit mit der einschlägigen Industrie wurden darin Maßnahmen zur Überwachung des Spaltstoffflusses in Schnellbrüter-Brennelementherstellungs-Anlagen vom ALKEM-Typ entwickelt. Dazu wurden zunächst die Anlagenpläne analysiert und die für ein Kontrollsystem relevanten strategischen Bereiche abgegrenzt. Besonderes Gewicht wurde auf das Studium der zu verwendenden Meßinstrumente gelegt. Ein wesentlicher Aspekt war, daß die Spaltmaterialkontrolle ohne Beeinträchtigung des Betriebsablaufes erfolgen sollte. Außerdem wurde ein Simulationsprogramm entworfen, das Informationen über den Prozeßablauf liefern und so zur Kontrolle herangezogen werden kann. Auch ein Protokoll- und Berichterstattungssystem wurde entwickelt. Für die Materialbilanz wurde der Unsicherheitsbereich untersucht, um die Entdeckungswahrscheinlichkeit einer möglichen Entwendung abschätzen zu können. Der Bericht schließt mit einem Ausblick auf Verbesserungen bei Instrumenten, Verfahren und Anlageauslegung, die die Spaltstoffflußkontrolle weiter erleichtern könnten.

The present report was prepared in the framework of a research contract with the International Atomic Energy Agency in Vienna. In close collaboration with competent representatives of industry, safeguards procedures for ALKEM type plants fabricating fast breeder reactor fuel have been developed. For this aim first of all the plant layout was analysed and the strategic areas relevant for safeguards control were established. Special stress was laid on the study of instruments which can be applied. One main aspect in doing all this was that safeguards control should not hamper the normal operating procedures. In addition a simulation program was developed which can give information on the process features and can be of help for the control. Also a system of records and reports was designed. For the material balance the variances of MUF have been studied in order to give an estimate of the detection probability for a possible diversion. The report ends with an outlook on improvements of instruments, measures and plant layout which could facilitate safeguards control.

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1. Summary

The present report describes the work and the results obtained in the framework of the IAEA contract No. 790/RB on "Development of Safeguards Procedures for an ALKEM Type Plant Fabricating Plutonium Fuel Elements for Fast Breeder Reactors" and constitutes the final report of the contract. This work has been carried out at the Institut für Angewandte Reaktorphysik, Kernforschungszentrum Karlsruhe, in close collaboration with the representatives of the ALKEM plant, Hanau, Federal Republic of Germany.

After an analysis of the layout of the ALKEM type plant, the operators' material balance areas (MBA) and their accountability system, the MBAs and the strategic points for safeguards purposes have been established. Three MBAs, namely, the storage area, the process area and the analytical laboratory have been found to be sufficient. The safeguards procedures have then been developed based mainly on the lines laid down in the IAEA document Gov/Com.22/164, containing the recommendations of the Safeguards Committee of the Board of Governors. It has been shown that with the use of already available measuring instruments and sealing and identification techniques, the net time of insepctions at the plant for a full coverage (maximum inspection time) would be fairly low, i.e. in the range of about 3100 hrs.

A number of instruments, which are of interest for safeguarding an ALKEM type fabrication plant, have been discussed in some detail. They are a) calorimeter for Pu-assay in birdcages and finished unirradiated fuel pins; b) neutron-counting unit for different types of wastes and c) a γ-lock for the control of Pu carried on a person. The time for development till the industrial application of these instruments and the associated development costs have also been estimated. The first two are expected to be available by the end of 1972; the last one is available today.

A mathematical model has been developed to simulate roughly the operation of the ALKEM type plant. Although some interesting conclusions can be drawn, the actual use of such simulation can be properly assessed only after comparing the results of the simulation with the actual operation of the plant.

Since the objective of the safeguards measures is to make a statement with regard to MUF (material unaccounted for), the variance of the MUF has been calculated for two different campaigns. It has been shown that for all practical purposes the variance is determined almost entirely by the relative standard deviation of the systematic error component of measurement for the feed and the product streams. The relative threshold value above which a diversion can be detected with 0.95 probability (with an error probability of 5 %) has been found to be approximately the same for all the campaigns considered and is in the range of 0.9 % of the feed stream.

In the final part of the report, a number of possible improvements have been discussed, in the context of which a sketch of the possible layout of the same ALKEM type plant, which will be advantageous for safeguards activities, has been presented.

2. Introduction

The growth of nuclear power generation throughout the world has been fairly rapid and the requirement for nuclear fuel has been increasing continuously. Since the amount of plutonium produced during the coming years is also expected to be high, a significant part of the nuclear fuel fabricated in the civil sector, particularly if expressed in eff. kg, is expected to be plutonium based. In a fabrication plant plutonium remains in an accessible form through a large part of the process steps. It is therefore, desirable to analyse in detail the possibilities and implications of safeguards in such a plant.

2.1 Basic considerations

The objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacturer of nuclear weapons or of other nuclear devices or for purposes unknown, and deterrence of such diversion by the risk of early detection.

It is now generally agreed that the basic safeguards measures required to attain the above mentioned objective are material balance accountancy supplemented by containment and surveillance measures. Following steps are required for the implementation of these measures:

a) Verification of design information from a nuclear facility mainly to select the strategic points and the corresponding material balance areas (MBA) and to set up the safeguards procedures.

b) A record system at the facility in which information with regard to the movements of the amounts of fissile material from and to a MBA will be kept. The source data on a given amount of material are also registered in this system.

c) Reporting system according to which the information on the movement of nuclear material from or to a MBA will be sent to the safeguards organisation.

d) Inspection system with which the safeguards organisation can verify mainly the consistency of reports and records, and the location, identity, quantity and composition of all nuclear material subject to safeguards.

The safeguards procedures developed in this report correspond to the four steps mentioned above.

3. Description of the plant

The development of safeguards procedures for a plutonium fuel fabrication plant needs a realistic basis, i.e. a plant, the design and operation of which correspond to the present state of technology. Only in this way a direct applicability of the procedures is ensured. The following investigation is based on a plant design similar to that of the plant ALKEM, which is under construction and is expected to go into operation in the course of 1971.

3.1 General identification and main facility data

3.1.1 Purpose and type of the facility

The production program of the fairly automatized fabrication plant considered comprises of fuel pins both for thermal (0.5-4% Pu) and for fast reactors (10-16% Pu). Besides, excess amounts of PuO_2, possibly scrap, and irrecoverable waste (<0.5% Pu) for final storage will be shipped from the plant.

3.1.2 Operating mode of the facility

The fabrication plant will be operated normally during one shift and is expected to have 200 working days per year. The daily throughput of plutonium lies in the order of 10 kg of PuO_2.

3.1.3 Layout of the plant

The complete production equipment is installed in one large hall, in which the different working areas, namely

Conversion
Powder preparation
Pellet production
Pin production
Quality control
Analysis and
Scrap recovery

are subdivided by so called caissons. The sketch of a layout of the plant containing also the main routes followed by nuclear material is given in Fig. 3-1. Because of the caisson type layout, the active part of the plant can be considered to be within a double containment.

On one side an additional building is connected with the production hall in which cloak and rest room, laundry and operational offices are provided. The connection is formed as a bottle neck. Personnel entering and leaving the production hall has to pass the bottle neck, in which a gamma-lock is installed. This device controls plutonium containing material carried by a person.

On the other side, another building is connected with the production hall in which rooms for storages for uranium and plutonium, for fuel pins and waste are provided.

3.2 Flow, handling, and location of nuclear materials

A general flowsheet of the fuel pin production is shown in Fig. 3-2. The plant operator may like to divide the process into 15 MBAs . Although, for safeguards purposes, the number of MBAs will be only three (see chapter 5), the relevant information on the operator's MBAs are presented below.

3.2.1 Pu storage

At the Pu storage area the following items are stored:

a) PuO_2 powder in 2.5 kg containers from the arrival at the facility up to processing,

b) PuO_2 powder in 2.5 kg containers from the production at the conversion area up to further processing or shipment.

The Pu content of the powder is 88 %.

3.2.2 Conversion

A part of the fissile material to be processed at the fabrication plant will be received as Pu-nitrate solution. The Pu content of the solution is 10-20 %.

Besides the PuO_2 powder, the Pu nitrate solution arriving in 10 l bottles will also be stored in a 800 l homogenization tank located at the conversion area. This solution will be subsequently converted to plutonium oxide in 40 l batches by the process of oxalate precipitation, filtration, and calcination. 3-5 % of the fissile material are transfered from the conversion area to the waste storage.

Tab. 3-1 and 3-2 give information on flow, intermediate storages, production steps and accountability procedures of the conversion area. The respective numbers of the MBAs according to the plant operator's subdivision are also indicated in the tables.

3.2.3 Powder preparation

The Pu powder, coming from the storage area in 2.5 kg containers is calcined in batches of 25 kg at 700-1000°C, in the powder preparation area. The sinterable powder (BET surface 5 m^2/g; density 1.7-2.3 g/cm^3) is screened and homogenized in batches of 50 kg. The powder is then mixed with sinterable UO_2 powder and the recycle scrap and homogenized in batches of 120 kg. This corresponds to an accumulation of about one week.

The density of the pressed pellets is 4.8-5.8 g/cm^3, the Pu content 2.5-16%.

In this area 4-8% of the feed is expected to be produced as waste.
Tab. 3-3 to 3-5 give further informations in the sequence of operations.

3.2.4 Pellet production

The sintering process carried out here at 1700°C needs about 24 hours. The final density of the sintered pellets is 9.2-10.6 g/cm^3. Grinding and measurement of dimensions and surface of the pellets complete the pellet production step. About 2-4 % are expected to be produced as scrap during the sintering step and a similar amount as waste during the grinding step.

Table 3-6 and 3-7 give further information.

3.2.5 Pin production

The columns of pellets are dried and introduced into the cladding. After decontamination, the cladding is closed by welding. The amount of scrap is expected to be 2-4 %.

Further information is given in Tab. 3-8 and 3-9.

3.2.6 Quality control

Before storing and shipping the produced fuel pins are subjected to several tests and measurements to ensure that they meet the specifications of the customer.

The tests are: pressure test, leak test and X-ray test. Besides, the contamination and the total geometry are measured. 3-5% are expected as scrap.

Further information is given in Tab. 3-10.

3.2.7 Pin storage

The finally tested and measured fuel pins are stored at the pin storage area until shipping.

3.2.8 Analysis

At the analysis area the samples coming from different areas are analysed by different methods: Potentiometry, X-ray fluorescence, mass spectrometry and weighing. The accumulated samples are filled after analysis into a bottle and transfered periodically to the waste storage as a separate batch.

3.2.9 Scrap recovery

Dirty and not defined wastes cannot be recycled directly. Reprocessing is required before. The steps carried out at the scrap recovery area are: dissolution, reduction and ion exchange. The final product is Pu nitrate solution which is transfered to the conversion area for further processing. Waste is expected to be 10-25 % out of which 75 % can be processed again.

Further information is given in Tab. 3-11.

3.2.10 Waste storage

The wastes from different areas are stored here. Before final discharge it has to be decided (for example by use of passive neutron and γ-interrogation) whether or not they are recoverable.

Further information is given in Tab. 3-12.

3.3 Nuclear materials accounting and measurement system

3.3.1 Accounting system

The fuel fabrication plant for accounting purposes has been subdivided by the plant operator in 15 MBAs. With regard to the production, the plant is operated in such a way, that the fissile material passes successively through one or more processing steps per day. After completion of the respective processing steps of one day, the fissile material has to be controlled qualitatively and quantitatively to ensure that the material is qualified for the subsequent processing steps (of the next day). This means that the respective number of processing steps to be passed per day forms a MBA.

Informations on input, output and the book inventory of each MBA are generated daily.

As long as no computer is installed (which is an option for the operator) the data are filled into the records, a copy of which is given to the accountability section for hand-computed evaluation.

3.3.2 Measurement system

In Tables 3-1 to 3-12 for the different MBAs, the last rows give information on the measurement system in connection with the production and other steps for that MBA. Additional information is given in the following sections.

3.3.2.1 Control of input

An agent from the fabrication plant is present, when sample taking, filling and sealing of the fissile materials is done at the shipper's facilities. He receives there one of the three samples taken.

The incoming containers are only counted and the seals identified. The results are compared with the records having been filled before shipping.

The contents of the containers are randomly analysed in the production area.

3.3.2.2 Storage

At the storage, containment measures are applied. Only authorized staff members can enter the storage areas in presence of the storage guard. The numbers of containers are counted and identified daily, in- and outgoing containers are checked immediately.

3.3.2.3 Recovery

At the waste storage, the gross weight of the ingoing material is registered. The solid waste is contained in welded PVC bags of about 1 kg. The Pu content of these is determined by counting of spontaneous fission neutrons. The liquid waste is transfered in 10 l plastic bottles. The Pu content is measured by counting the emitted γ-rays.

At the exit of the recovery area, a random analysis of the concentrate is possible.

3.3.2.4 Conversion

The volume and density of Pu nitrate solution of each bottle is determined at the entrance of the conversion area. The Pu content and the isotopic composition are analysed randomly. The analytical results can be obtained 2 days later.

By gross weighing of the shells with fissile material, before and after the calcination step, possible losses due to calcination can be found out. Their tara-weight is known. Random analyses can be carried out.

3.3.2.5 PuO_2-powder

The gross and tara weights of the containers with PuO_2-powder coming into the powder preparation are registered. Random samples for the determination of the Pu content can be taken there. This is done particularly if PuO_2 is received from the shipper. The calcination losses can be found out by the same method as that under conversion.

After each homogenization a sample is taken for the determination of the Pu concentration and the isotopic composition. The analytical results can be obtained 2 days later.

3.3.2.6 Scrap

The gross and tara weights of containers with scrap, including those from green pellets are taken at the entrance of the dry recovery area. From the outgoing, recovered scrap a sample is taken. The X-ray fluorescence spectrometric determination of the Pu/U ratio takes one hour, the isotopic analysis two days. The containers with recovered scrap powder are finally weighed netto.

3.3.2.7 Green pellets

After mixing the Pu/U ratio is determined once more by X-ray fluorescence spectrometry. The containers with the mixed powder are weighed before and after the filling operation.

3.3.2.8 Sintering area

The baskets with pellets are weighed before and after the sintering step to find out losses in this step.

3.3.2.9 Grinding area

The sintering baskets after unloading are weighed tara. Before the grinding step, weight and height of the pellets are determined randomly.

3.3.2.10 PuO_2 pellet columns

At the entrance of the area involved, the weight and diameter of all pellets are measured, so that the amount of grinding waste can be found out. Besides, the Pu/U ratio and the isotopic composition is determined using the usual statistical techniques. The length and the weight of the pellet columns is measured.

3.3.2.11 Cladding technique

The length of the pellet columns as pushed into the cladding tubes is measured finally. The finished fuel pins are counted when they leave the area.

3.3.2.12 Output control

Within the framework of the production-oriented output control, only qualitative control measures are provided.

At the quality control area the fuel pins are counted and marked. At the pin storage containment measures are applied, the fuel pins are counted and identified.

3.3.3 Other matters connected with nuclear materials accounting

3.3.3.1 Physical inventory

Dependent on the type of campaigns physical inventories are carried out 2 to 10 times per year. With regard to the production line the fissile material is pushed out of the various MBAs and measured as (if necessary temporary) output.

3.3.3.2 Control of measurement accuracy

Controls of the measurement accuracy are performed daily to monthly by use of self produced standards.

3.4 Instruments

In the framework of the activities of the project on fissile material control at the Karlsruhe Research Center, a considerable amount of effort is being devoted to the development of different types of measurement instruments. During the course of the last three years a number of measurement methods have been developed and further research work on these and other methods will be carried out in the future. In developing safeguards procedures for the plutonium fabrication plant, in this report a number of such methods has been assumed to be used for measuring plutonium in different streams. Although no development work was carried out in the framework of this contract, some relevant data on the following methods have been summarized in this chapter.

1. Calorimetry together with n-counting: This is considered for the measurement of Pu in input (PuO_2 in birdcages), in products (fuel pins or subassemblies), and in recoverable scraps.
2. Mass-spectrometry: A short description of the development work on this method has been included here only because this method has to be used to establish the isotopic vector required for calorimetry.
3. Neutron counting: Both passive and active methods of neutron counting have been considered. They are used in measuring plutonium in different types of waste streams.
4. Γ-lock: This is more a containment than a measuring method. It is used to control small amounts of plutonium carried along by a person.

Standard physical and chemical methods for material control such as chemical determination of plutonium in solutions, weighing, measurement of length of Pu-columns etc., have not been discussed here.

3.4.1 Calorimetry

The production of heat by plutonium is a function of the half life time and the energy of the α-particles after the decay. Since these energies are very near to each other for the different interesting nuclides, the half life times are important in connection with the measurement errors. Table 3-13 gives a survey on the heat release of the different components of breeder reactor fuel, the related nuclear data are given in [3.1-3.3]. By the calorimetric method the total heat production by plutonium is measured, so that the isotopic composition of the fuel material has to be known before. The relative concentrations of α-decaying isotopes with short half life times as Pu-238 and Am-241 must be known with better accuracy than normally needed (e.g. with the isotopic composition of Table 3-13, a Pu-238 concentration of 0.1 % leads to 15 % of the total heat production, a concentration of 0.5 % would bring 45 % of the total heat. The Am 241-amount can be evaluated if the date of Americium separation is known exactly. An uncertainty of 50 days in this time interval gives an error of 0.8 % in the total heat flux).The total measuring error (coefficient of variation of 1 σ-value) consists of 3 different types of errors:

a) reproducibility (function of calorimeter set-up)
b) errors in the determination of Pu isotopes
c) error in the determination of the age of Am-241

The overall error lies between 0.8 and 1.2 % [3.6]. For a) it can be reduced to about 0.12 % and for b) to 0.35 %, so that an overall error of 0.4 % appears to be attainable. In these considerations systematic errors have not been taken into account. They may lie in the same range.

In Table 3-14 one can see the influence of the single isotope on the total error of calorimetric measurement, which is due to isotope measurement errors, and the error on account of reproducibility [3.7]. The determination of the isotopic vector is done by the mass spectrometric method which is therefore important in this connection, and some details are given under paragraph 3.4.2 below.

The concentration of Pu-238 can be determined by α-spectrometry also - this method seems to be better for breeder fuel (in general for Pu-238 concentrations smaller than 0.1 %) under the condition that the Am-241 can be separated before [3.8]. By the latter method the relative accuracy (1σ) of the Pu-238 compared to Pu-239 and Pu-240 is about 1 %.

An improvement in the systematic error of calorimetry could be achieved if more accurate values of the half life times and specific heat productions of the different isotopes could be obtained. By this and by an improvement of the determination of the isotopic composition of the material, the overall accuracy of the method could be improved.

The main advantages and disadvantages of this method are:

Advantages: The method is simple and can be adapted to different geometries. It does not depend on self-shielding effects (heterogenities), it can be applied for subassemblies also.

Disadvantage: The isotopic composition of plutonium must be known. The result is very sensitive to uncertainties in the Pu-238 and Am-241 fractions.

The method can not be used for U-235 and U-238.

In a collaboration of ALKEM and GfK different types of calorimeters have been developed. Some types (for SNEAK-platelets, for birdcages and pins) have been tested and used, it is planned to construct calorimeters for pins and subassemblies, which can be built on an industrial scale, and a combined device for calorimetry and n-counting (see below).

Table 3-15 gives a survey of the existing calorimeters, the respective number of measuring units, the normal Pu-content of one of these units, the measuring times and the attained accuracies; the latter are the calorimeter accuracies, it has to be kept in mind, that the accuracy is lowered about 0.5% due to uncertainties about the isotopic composition of the material and the errors in the specific heat values.

Table 3-16 gives two typical examples for calibration values of the calorimeter for pins. They were obtained in a study of the parallelity of different regression curves (straight lines) [3.10]. Each one of these curves is given by $y_i = a + bx_i$.

The y_i are given in [mV], the x_i in [Watt]. It was found by these studies that the curves could be looked upon as parallel, which means that the calorimeter has a good reproducibility. Anyhow - for each new series of measurements - new calibration curves have to be produced.

It is planned to make the calorimetric method more tamperproof by a combination with n-counting. Pu of fixed composition has a defined heat production [W/g] and a defined decay rate [n-decays/g sec.]. The quotient of both can be used for checking the determined isotopic composition.

Some details about the studies on this method are given in paragraph 3.4.3 below.

3.4.2 Mass spectrometry

The method is being automized in order to allow instrumental safeguards control and to get better reproducibility of the results [3.11]. The automatic analytical laboratory (AAL) is subdivided in four basic processes:

1. Sampling process
   (Samples are diluted gravimetrically)
2. Chemical processing
   (Mixing of samples with tracer for the isotopic dilution analysis, U and Pu are separated on an ion exchanger)
3. Mass spectrometer
   (Isotopic composition is determined)
4. Data processing
   (The gravimetric, tracer and mass spectrometric data are evaluated)

As a consequence of the high activity of the samples and of the sensitivity of the method (requiring 10^{-7}g of U and 10^{-8} g of Pu) only small sample quantities in about 1 ml samples can be admitted.

The mass-spectrometer, after automation, is expected to carry out two measurements per hour or 48 measurements per day. Each sample is measured four times in two parallel assays, each with and without a tracer, leading to 12 analyses a day. All the other steps of the process are adapted to this throughput.

3.4.3 Neutron counting

The basic idea of using the spontaneous fission for safeguards is to determine the amount of Pu-240 by this method. In fact it is not only the Pu-240 which is detected in this case but also other nuclides like Pu-238, Pu-242, Am-242 and Cm-244 (see Table 3-17). The Pu-239 content can be deduced provided that the isotopic composition of the material is known. Since neutrons from (α,n)-reactions can not be considered as a tamperproof signal, they have to be suppressed by a coincidence technique.

The coincidence counting rate is proportional to the square of the detector efficiency which, therefore, should be high.

Advantages and disadvantages of the method:

Advantages:	The method is simple and cheap, the transparence of the fission neutrons is good.
Disadvantages:	By addition of a very small amount of Cm the result can be falsified. For bigger amounts of fuel (subassemblies) one has the problem of n-multiplication.

Some details about this method have been described in a report of ALKEM [3.13] in which the use of this method in connection with calorimetry has been discussed. In this case, the counting is done by 20 BF_3-elements which are put in paraffin wax as moderating substance. The sensitivity of the BF_3-elements is about 70 Imp/(n/cm^2). The measuring time is about 20 minutes.

The ALKEM is working on the electronic device which is needed for measuring the coincidences, the first test measurements are planned for 1971. The device shall be part of the so-called kilo-calorimeter, in which the Pu-content in birdcages is measured.

Another high sensitivity n-counter was built at the "Institute for Neutron Physics" of the GfK [3.14]. High efficiency can be achieved best with thermalized neutrons. However, in that case the relatively long neutron lifetime requires wide coincidence gates which can lead to serious dead-time losses, thus reducing the reliability of the measurement. Dead-time losses can be avoided when the delayed coincidence technique of Rossi-α-measurements is applied [3.15]. With adequate multi-channel analyzers every detector signal opens the coincidence gate and for the counting rate in a gate of the width Δt at delay time t [3.16] this results in

$$n_{\Delta t}(t) = \gamma_1 \left[\gamma_2 \varepsilon_f^2 S_f \frac{\overline{\nu(\nu-1)}}{2} \alpha e^{-\alpha t} + (\varepsilon_f S_f + \varepsilon_s n_s)^2 \right] \Delta t$$

with

S_f = number of fissions per second

ε_f = detector efficiency

ε_s = detector efficiency for (α,n) neutrons

n_s = number of (α,n)-neutrons emitted per second

α = fundamental mode decay constant of the detector, higher modes being neglected

γ_1,γ_2 = constants which are unity for dead-time free equipment and smaller than unity in other cases

The amplitude of the exponential term is proportional to S_f and can be used for the ^{240}Pu-determination.

Preliminary test measurements were made with a number of test pins with varying plutonium concentration, inserted in a 120 cm x 51 cm x 51 cm block of polyethylene which consisted of 3 cm x 3 cm and 1 cm x 1 cm prisms of 120 cm length. Four ^{3}He-counters were set around the pins. Measurements with different pin-to-counter distances were made and a 32 channel analyzer based on the shift register principle was used.

At the ALKEM-plant a neutron counting method is used for wastes [3.13]. In collaboration with the GfK, investigations are carried out by ALKEM to improve the performance of this method. The studies are concentrated on different topics concerning the conditions under which the determination of the amount of Pu should be possible:

i) Inside uranium or other shielding materials,
ii) In waste-packages like those coming from glove boxes,
iii) In polyethylen bottles (4000 ml) for liquid wastes,
iv) For different arrangements and concentrations of fissile materials and absorbers,
v) For different density and chemical form,
vi) Independent from geometrical order,
vii) With inexpensive devices with which quick and simple evaluation can be made.

These requirements led to a measuring chamber covered by paraffin which is located in the center of a group of BF_3-elements.

Proportional counters with 600 cm^2 of active area each are installed for external contamination control. The γ-measuring instruments are located in the upper part of the lock. Lamp panels indicate the following modes of operation: Measurement on, end of measurement, repeat measurement, please wait, α-alarm, γ-alarm. In addition to the α- or γ-alarms the electronic system actuates another alarm upon failure of the measuring instruments or when a door has been opened by force; this alarm is indicated in a control room.

If an unduly high α-contamination is measured, a door facing the controlled area opens. If plutonium carried along is detected, the doors are locked and an alarm is actuated.

The limit for detection of α-contamination is 50µCi/100 cm^2 and for Pu carried along it is 2 g shielded by 10 mm of lead (standard type) or 1 g shielded by 10 mm of lead (special type) or 100 mg in PVC.

It is planned [3.13] to study if the sensitivity for measurements on samples which are shielded by a greater amount of lead can be improved by a combination with n-measurements. The problem which material is the best for moderating the neutrons before entering the BF_3-counters is under investigation.

This device has been used in two safeguards experiments and its accuracy has been found out to be about 10 %. It is planned to automatize and improve the method with respect to tamper-proofness. Some results about the origins and values of errors have been published in [3.13].

The reproducibility of the method seems to be quite good, the standard deviation for a series of measurements was found to be 1-2 %. These results are valid only for nearly the same amount of Pu under constant conditions. The influence of a different spatial distribution has also been studied. It came out that the measuring device should be modified in order to allow a good determination of the Pu content of a sample independent from the position of the Pu inside the sample. Until now in different tests, standard deviations due to the different positions in the order of 5-10 % were found. The influence of an addition of other materials will also be studied.

For the analysis of waste by n-counting, Table 3-18 gives a survey of the attained coefficients of variation as a function of the Pu-amount under study. The results are reproduced from [3.6].

In another investigation [3.17] the detection of fissile material in a simulated scrap barrel was studied with a pulsed source of neutron and the delayed n-technique. The sensitivity of the result with respect to the location of the fissile material in the barrel and the density of the filling material (iron and paraffin) was investigated. Moderated and unmoderated targets were used.

This active method looks promising for the future.

3.4.4 Γ-Lock

An effective control for small amounts of plutonium carried along by a person is possible by means of a γ-lock developed by ALKEM in collaboration with the GfK [3.10, 3.13].

The lock can be installed at any place. It consists of a cell with two pneumatically operated swivel doors opposite to each other, the required pneumatic system and an electronic control unit. When set up in the entrance and exit of a control area it can be used to control all the in- and outgoing personnel. The necessary measuring instruments are installed and connected with the automatic system so that they cannot be evaded.

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MBA 2 Conversion (Interim storage)

Inventory : 16o kg Pu
Waste: = .5 %
Residence time: 3o - 58 d

Flow	Interim storage	Production	Control
E: 5-1o b/d 1o-2o kg/d			
		Locking in 5-1o b/d 1o-2o kg/d	
			M: Volume 1o l ± 1 cm^3 Density ± . 1%
A: Samples			A: Pu Reclamation
A: Bottles			
	Mixing tank 16o kg	Mixing 2 d: 16o kg	
A: Waste 0 - .5 %			
A: 1-2 b/d 5.3-8 kg/d			

E = Input
A = Output
b/d = batches per day
M = Measurement
A = Analysis

Tab. 3 - 1 : Informations on the plant operator's MBA 2

MBA 5 Conversion

Inventory : 9 kg Pu Waste : 3 - 5 % Residence time: 8 - 16 h

Flow	Interim Storage	Production	Control
E: 1-2 b/d 5.6-9.1 kg/d			
		Precipitation 1-2 b/d 5.6-9.1 kg/d	
R: Precipitation 5-1o %			
		Calcination 1-2 b/d 5.6-9.1 kg/d	
E: Containers			
			Empty containers W: 3 kg ± .1 g
			Full containers W: 3 kg ± .1 g
A: Sample			A: Pu Random samples
A: Waste 3-5 %			
A: 1-2 b/d 5.4-8.6 kg/d			

R = Recycling

W = Weighing

Tab. 3 - 2: Informations on the plant operator's MBA 5

MBA 6 PuO_2-powder (Powder preparation)

Inventory: 45 kg Pu
Waste : = 1%
Residence time : 7 - 9 d

Flow	Interim storage	Production	Control
E: 1 b/6-8 d 22 kg/d			
		Locking in 5-1o b/d 22 kg/d	
	Containers 22 kg		
			W:Full containers 3 kg ± .1 g
A: Sample			A: Pu,Isotopes Random samples
			W:Empty containers 3 kg ± .1 g
A: Containers			
			W: Full shells 5 kg + .1 g
		Calcination 1 b/d: 22 kg/d	
			W: Full shells 5 kg + .1 g
R: Calcination			
	Homogenizator 44 kg	Homogenization 1 b/d: 44 kg/h	
A: Sample			A: Pu, Isotopes
		Determination of doses; 2-5 b/d 5.4-8.5 kg/h	W: PuO_2-powder 2 kg ± .1 g
A: Waste = 1 %			
A: 1 b/d 5.4-8.5 kg/d			

Tab. 3 - 3: Informations on the plant operator's MBA 6

MBA 7 Scrap (Powder preparation)

Inventory : 8 kg Pu
Waste: 1 - 2 %
Residence time: 1 - 5 d

Flow	Interim storage	Production	Control
E: 5 - 2o b/d 6 - 1.6 kg/d			
			W. Full containers 8 kg ± .1 g
	Containers 8 kg		
		Milling 2-5 b/5 d .6-1.6 kg /d	
			W:Empty containers 8 kg ± .1 g
A:Containers			
		Screening 1 b/ 5 d .6-1.6 kg/h	
R: Milling 5 - 1o %			
		Homogenization 1 b / 5 d .6 - 1.6 kg/h	
	Containers 8 kg		
A: Sample			A: Pu/U
		Determination of doses 2-5 b/d .6-1.6 kg/h	W: scrap 2 kg ± .1 g
A: Waste 1 - 2 %			
A: 1 b/d .6-1.5 kg/d			

Tab. 3 - 4 : Informations on the plant operator's MBA 7

MBA 8 Green pellets (Powder preparation)

Inventory: 1o kg Pu
Waste : 2 - 4 %
Residence time : 8 h

Flow	Interim storage	Production	Control
E: 1 b/d 6-1o kg/d			
	Storage 1o kg		
		Mixing 4 b/d 6-1o kg/d	
		Mixing 1 b/d 6-1o kg/h	
A: Sample			A: Pu/U
			W: Empty containers 8kg ± 1 g
			W: Full containers 8 kg ± 1 g
	Containers 1o kg		
		Pressing 4oo b/h 6-1o kg/d	
A: Waste scrap 2-4%			
E: Baskets			
	Baskets 4 kg		
A: continuously 5.8-9.6 kg/d			

Tab. 3 - 5: Informations on the plant operator's MBA 8

MBA 9 Sintering area (Pellet production)

Inventory : 1o kg Pu
Waste : -
Residence time : 24 h

Flow	Interim storage	Production	Control
E: continuously 5.8-9.6 kg/d			
			W: Full baskets 15 kg $\pm$ .1 g
	Storage 5 kg		
		Sintering 1 b/h 5.8-9.6 kg/d	
			W: Full baskets 15 kg $\pm$ .1 g
A: 1 b/h 5.8-9.6 kg/d			

Tab. 3 - 6: Informations on the plant operator's MBA 9

MBA lo Grinding area (Pellet production)

Inventory: lo kg Pu
Waste: 3 - 6%
Residence time : 3 - 5 h

Flow	Interim Storage	Production	Control
E: 1 b/h 5.8-9.6 kg/d			
	Storage lo kg		
			W: Empty baskets 8 kg $\pm$ .1 g
A: Basket			
			W: Pellets 5o g $\pm$ .ool g
			M: Height 2 cm $\pm$ .ool cm Random samples
A: Waste scrap 1-2%			
		Grinding continuously 5.8-9.5 kg/d	
A: Grinding waste 2 - 4 %			
A: continuously 5.7-9.1 kg/d			

Tab. 3 - 7: Information on the plant operator's MBA lo

MBA 11 Pellet columns (Pin production)

Inventory: 9 kg Pu
Waste: 2 - 4 %
Residence time: 4 - 5 h

Flow	Interim storage	Production	Control
E: continuously 5.7-9.1 kg/d			
			Z: Pellets
			M: Pellet-Geom. 2 cm ± .001 cm W: Pellets 50 g ± .001 g
A: Sample			A: Pu, Isotopes Random samples
		Composition of columns 1-3 b/min .4-1.5 kg/h	
	Transfer device 1 kg		
			M: Length of columns 30cm ±.01cm
	Compensating pellets 6 kg		
			W: Columns 5 kg ± .05 g
E: Palette			
	Lifting device 2 kg		
A: Scrap 2-4 %			
A: 4 b/h 5.6-8.7 kg/d			

Z = Counting

Tab. 3 - 8 : Information on the plant operator's MBA 11

MBA 12 Cladding technique (Pin production)

Inventory: 5 kg Pu
Waste: 2 - 4 %
Residence time: 5 - 6 h

Flow	Interim Storage	Production	Control
E: 4 b/h 5.6-8.7 kg/d			
		Drying 4 b/h 5.6-8.7 kg/d	
E:Cladding			
		Filling 1o-15 b/h 5.6-8.7 kg/d	
			Length of column 4.5 m ± .3 cm
A: Palettes			
			M: Contamination
		Decontamination 1o - 15 b/h 5.6 - 8.7 kg/d	
E: End caps			
		Welding 1o - 15 b/h 5.6-8.7 kg/d	
			M: Contamination
		Decontamination 1o - 15 b/h 5.6-8.7 kg/d	
		Locking out 1o - 15 b/h 5.6-8.7 kg/d	
E: Palettes			
	Fuel pins 2 kg		
A: Scrap 2 - 4 %			
A: 5-16 b/d 5.5-8.4 kg/d			

Tab. 3 - 9: Information on the plant operator's MBA 12

MBA 13 Quality control

Inventory: 5 kg Pu
Waste: 3 - 5 %
Residence time: 4 - 8 h

Flow	Interim storage	Production	Control
E: 5-16 b/d 5.5-8.4 kg/d			
			M: Pressure 3-5 b/h 5.5-8.4 kg/d
			M: Leak 1-3 b/h 5.5-8.4 kg/d
			M: Splits 1 b/h 5.5-8.4 kg/d
	Palette 2 kg		
			M:Contamination 2 b/h 5.5-8.4 kg/d
			M:Geometry 4-1o b/d 5.5-8.4 kg/d
A: Scrap 3-5 %			
A: 4-1o b/d 5.3-7.9 kg/d			

Tab. 3 - 1o : Information on the plant operator's MBA 13

MBA 4 Recovery

Inventory: 8 kg Pu
Waste: 1o-2o %
Residence time: 5 - 17 d

Flow	Interim storage	Production	Control
E: 2-4 b/d .3-1.1 kg/d			
			W: Waste 2 kg ± 1 g
		Dissolving 2-4 b/d .3-1.1 kg/2 d	
	Tank 1 kg		
		Reduction 1 - 2 b/d .3-1.1 kg/d	
		Purification 1-2 b/d .3-1.1 kg/d	
		Concentration 1-2 b/d .3-1.1 kg/d	
A: Sample			A: Pu Random samples
R: Reduction 1o - 4o %			
	Tank 5 kg		
A: Waste 1o-2o %			
A: 1 b/5-17 d 5 kg/d			

Tab. 3 - 11: Information on the plant operator's MBA 4

MBA 3 Waste storage

Inventory: lo kg Pu
Waste: 5 - 2o %
Residence time: 2 - 8 d

Flow	Storage	Production	Control
E: 5-2o b/d .3-1.2 kg/d			
			n-measurement 5 g ± .1 g
		Identification 5-2o b/d .3-1.2 kg/d	
	Storage lo kg		
A: Loss 5-2o %			
A: 2-4 b/d .3-1.1 kg/d			

Tab. 3 - 12 : Information on the plant operator's MBA 3

Table 3 - 13: Heat release due to α- decay

Nuclid	Heat production of decay [W/g]	Relative fraction in Na-breeder fuel [% of total fuel weight]	Heat per g of fuel [W/g]
U-235	$5.6\cdot 10^{-8}$	0.23	$0.000001\cdot 10^{-4}$
U-238	$8.5\cdot 10^{-9}$	82.1	$0.00007\cdot 10^{-4}$
Pu-238	$5.7\cdot 10^{-1}$	0.018	$1.04\cdot 10^{-4}$
Pu -239	$1.9\cdot 10^{-3}$	12.3	$2.34\cdot 10^{-4}$
Pu -240	$7.0\cdot 10^{-3}$	4.5	$3.15\cdot 10^{-4}$
Pu -241	$3.6\cdot 10^{-3}$	0.7	$0.25\cdot 10^{-4}$
Pu -242	$1.2\cdot 10^{-4}$	0.14	$0.002\cdot 10^{-4}$
Am-241	$1.1\cdot 10^{-1}$	$4.8\ 10^{-3}$	$0.053\cdot 10^{-4}$
Cm-242	$\sim 1.21\cdot 10^{2}$		
Cm-244	$\sim 2.9\cdot 10^{0}$		
		100	$6.84\ 10^{-4}$

The Pu isotopic vector of breeder material is:

Isotope	%
Pu-238	0.1
Pu-239	69.6
Pu-240	25.5
Pu-241	4.
Pu-242	0.8
Am-241	$24.4\ 10^{-3}$

The fraction of Pu-238 was estimated according to [3,4] and [3.5].

The U/Pu quotient in Na-breeder fuel is about 5 : 1.

Table 3 - 14 : Heat production and overall error in the measurement of calorimetry on account of various sources of error

Isotope	% Conc.	error % (1σ- value)	heat production w/g of isotope	watts
Pu_{38}	0.27099	1.3	0.569	0.001542
Pu_{39}	75.492	0.21	0.001923	0.0014517
Pu_{40}	17.9703	0.56	0.00703	0.0012633
Pu_{41}	4.8261	0.97	0.0045	0.0002172
Pu_{42}	1.0704	1.33	0.00012	$1.28\ 10^{-6}$
~~Am_{41}~~	~~0.3699~~	~~1.5~~	~~0.1084~~	~~0.000401~~

Total (on account of Pu-isotopes and Am_{241})	0.45	0.00488 w/[illegible]
Error on account of reproductibility	0.6 - 1.0	
Total error *	0.8 - 1.2	

* In this value systematic errors are not taken into account

Table 3 - 15 Relevant data on existing calorimeters [3.9]

	platelet calorimeter	powder calorimeter	pin calorimeter
volume of one measuring unit	50.7x50.7 x 6.3 mm^3	190 mm diameter 290 mm height (equivalent to one bird cage)	big enough for about 20 pins of 1,2 m length and 15 mm diameter
number of measuring units	5	1	1
amount of Pu per unit	32 g	up to about 3 kg	up to about 20 · 100 g = 2 kg
measuring time	6 h	2 h	6 h
attained accuracy *	± 0.2 %	± 0.1 %	± 0.3 %

* In estimating this value systematic errors were not taken into account

Table 3 - 16 Calibration values for the powder calorimeter

Calibration curve 1

Heat production [Watt]	1,004	2,001	2,499	2,800	3,000
Δu [mV]	318,00 318,22 317,20	120,20 119,43 119,59	21,841 21,690 20,840	-38,865 -38,297 -38,183	- 77,398 - 77,601 - 77,848
y_i	317,81	119,74	21,457	-38,448	-77,616

Calibration curve 2

Heat production [Watt]	1,004	2,001	2,500
Δu [mV]	317,95 317,80 318,47	120,68 120,21 120,62	21,370 21,147 21,216
y_i	318,07	120,50	21,244

Table 3 - 17 Spontaneous fission of different nuclids [3.12]

Element	Spontaneous neutronrate with ref. to Pu 24o [$\frac{n}{g \ sec}$]	Relative composition of Pu for a typical breeder reactor	Relative composition of the rate of spontaneous fission neutrons for a typical breeder reactor
Pu 238	2.46	o.2	1.9
Pu 24o	1.oo +)	25.5	93.1
Pu 242	1.66	o.8	5.o
Cm 242	2.oo · $1o^{4}$	0 ++) 1.7 · $1o^{-2}$ +++)	
Cm 244	1.o3 · $1o^{4}$	0 ++) 1.37 · $1o^{-2}$ +++)	

+) absolute 1.38 · $1o^{3}$

++) fresh fuel

+++) after a burn-up of 8o ooo $\frac{MW}{}$

Table 3 -18 **Coefficients** of variation for the measurement of the waste stream as function of the Pu-amount /_3.6_7

Pu-amount /_ g _7	0.2	0.5	1.0	10.0
Waste /_g_7	9.814	24.534	49.067	490.677
Coefficient of variation /_ %_7	14.6	7.51	4.92	2.04

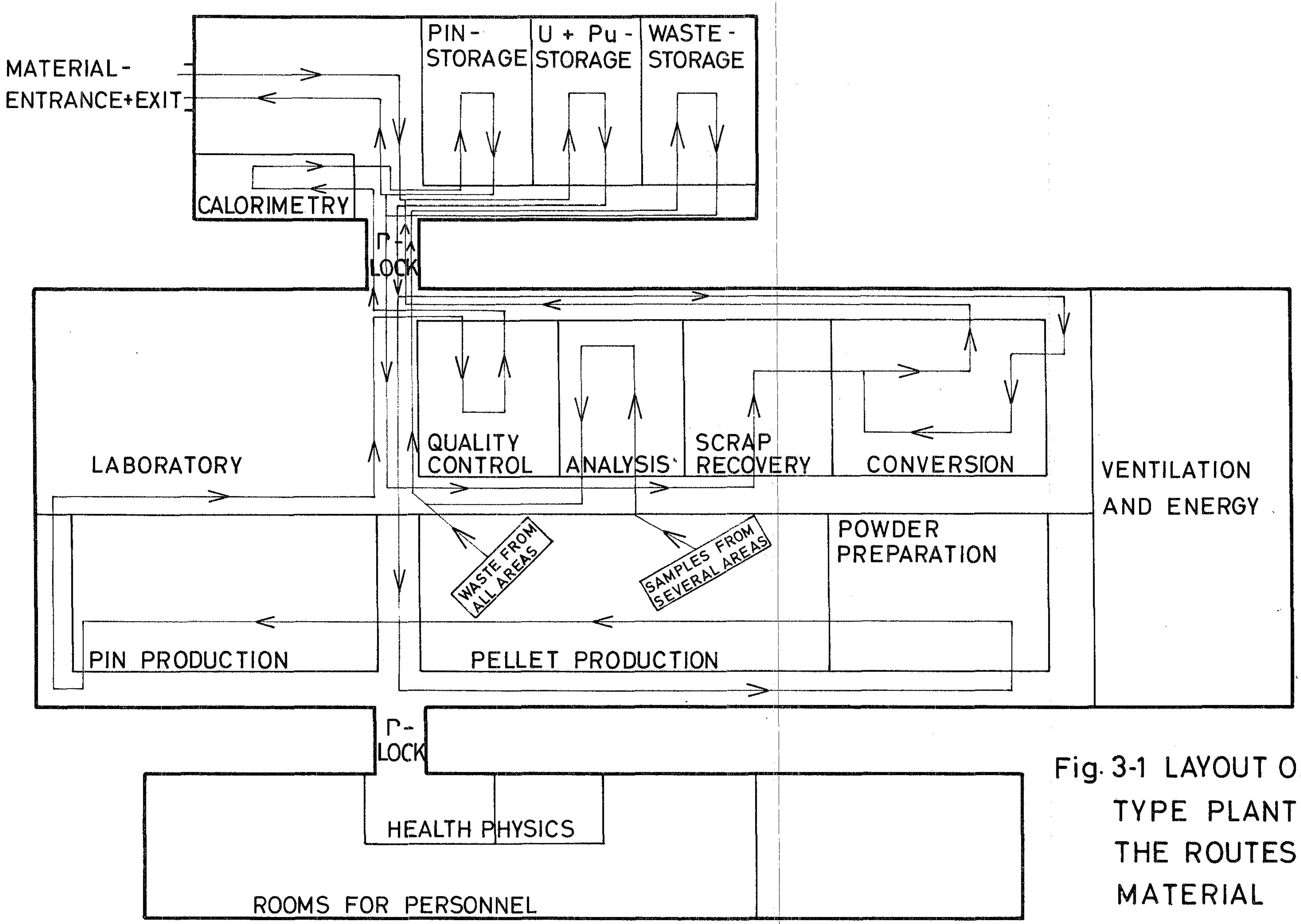

Fig. 3-1 LAYOUT OF AN ALKEM TYPE PLANT INDICATING THE ROUTES OF NUCLEAR MATERIAL

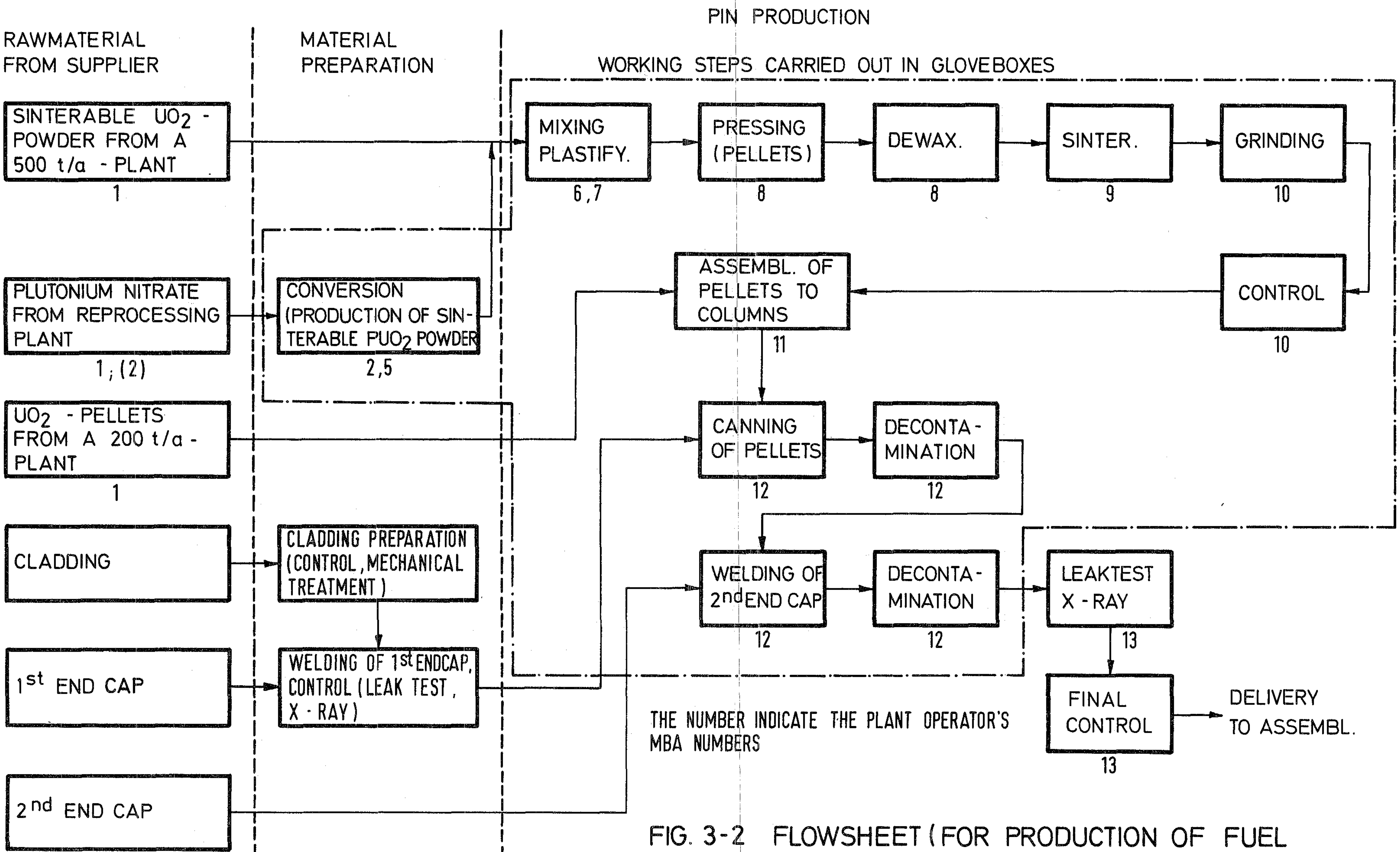

FIG. 3-2 FLOWSHEET (FOR PRODUCTION OF FUEL ELEMENTS FOR A FAST BREEDER REACTOR)

4. Simulation

4.1 General remarks

The simulation can be a tool to find out those parameters of the plant operation which have the biggest influence on the accuracy of the calculated inventory and the detection of an eventual diversion /‾4.1_7.

In the framework of the simulation of a fabrication plant, it is desirable to analyse the design and operation features of such a plant in some detail and in close collaboration with the operators of an industrial plant so that realistic conditions can be used as a basis for simulation. After that the results may be extrapolated for a more general application to other plants of the same type.

4.2 The subdivision of the plant for the model

For the simulation model it appeared desirable to divide the plant into the following MBAs (Fig. 4.1):

0 Input storage
1 Conversion
2 Powder preparation
3 Pellet production
4 Pin production and quality control
5 Analytic laboratories and recovery
6 Product storage

The flows of the main storages were not included in the model studies as the input and output of these can be described very easily and are subject to special safeguards.

It is to be emphasized that the subdivision of the production line into the remaining 5 MBAs would not necessarily lead to 5 MBAs for safeguards purposes. But for the parameter studies it seemed promising to include all information which is available when the plant is running and to decide later which information is really necessary for safeguards. As described in chapter 5 the production units 1-4 can be put together as one material balance area if one excludes 'interim storage parts' inside all these units, which contain the greater part of the material. These 'interim storages' should be considered in the same way as the main storages, as they are safeguarded in the same manner. In unit 5 only small amounts of fissionable material will be present. It gives a third MBA.

The three material balance areas

I Storage area
II Production area
III Analytical and recovery area

are indicated in Fig. 4.1.

The analytical laboratory is not taken into account in the simulation model since it contains a very small amount of nuclear material.

4.3 The mathematical relations used in the model

For the simulation model the formulae from [4.2] were taken as a basis for a first very rough approximation. In this concept the different units of a fabrication plant are considered to consist of a machine and a storage part as shown in Fig. 4.2a. This storage part is not identical with the 'interim storages' mentioned before. The characteristics of these parts describe the behaviour of the units. The 'storage part' has been introduced in this connection because most of the working units of the production line need a minimum content (HMIN (I)) for the production step performed by the machines. This can be a rather small quantity. For the press e.g. it is the amount of fuel to form 11 pellets, for the sintering furnace it may be several hundreds of pellets etc.

In contrast to these, the 'interim storages' have been included in the considerations since the plant operator requires a certain amount of material inside the working units as a sort of reservoir in order to avoid an interruption of the process in the case when one unit does not work regularly. Since these 'interim-storages' contain a large quantity of material, they require special safeguards procedures as discussed in chapter 5.

The working characteristics of the process units are shown in Fig. 4.2b. Each unit has been assumed to start operation only after a certain minimum hold-up has been reached.

In the model the different units are connected sequentially in a flow diagram where, at output k_i of each unit, five possibilities are foreseen for the material flow. They are shown in Figs. 4.1 and 4.3 and also in Table 4-1.

Table 4-1: Main streams in the production line of the model

	Symbol in the text	Symbol in the program (Fig.4.3)
a) Output from unit I [kg/d]	k_i	OKMAX (I)
b) Recycling via recovery [%]	x_i	RKAPPA (I)
c) Recycling to dry recovery in unit 2 [%]	r_i	RDRY (I)
d) Interim-storage of material for a certain time [%]	s_i	ZLS (I)
e) Diversion [%]	d_i	ABZW (I)

For all these flows one has:

$$k_i = k_i(s_i+d_i) + k_i'(x_i+r_i) + k_i''$$

with:

$$k_i' = k_i\ (1-s_i-d_i)$$

$$k_i'' = k_i'\ (1-x_i-r_i)$$

In the simulation program k_i is called OKMAX(I), k_i' = OKMA(I), and k_i''= OKRA(I).

4.4 The main parameters used in the model

The amounts which were taken as possible realistic approximation of the corresponding quantities are listed in Table 4-2.

Table 4-2: Main parameters of the simulation model

Unit: i	k_i (kg PuO_2/day)	x_i (% of k_i')	r_i (% of k_i')	s_i (% of k_i)
1	10.00	4	0	40
2	10.00	3	0	50
3	10.00	0	5	60
4	9.00	7	3	60
5	0.30	20	0	20

The meaning of the different quantities included in the table is indicated in Fig. 4.3, where all the streams which occur between unit I and unit I+1 are given. It is to be noted that a diversion has been assumed to occur from a flow and not from an inventory. Different values for d_i(ABZW(I)) were studied in course of the programm and are discussed below. The program PUFAB is attached in Appendix I.

4.5 Simulated campaigns

For the campaigns of the simulation it was assumed that at the begin of each campaign the whole plant was empty (HOLD = 0) so that the interim-storages had to be filled first. It is clear that the rather big amounts of material which are set as limit values for the contents of the interim storages (HHALB (I) in the program) correspond to a campaign longer than 25 days (this period was chosen for convenience in the computer print-out only). On the other hand, the attained values for the interim-storages show that it could be useful to control these amounts in periods of about 4 weeks.

In the present first approximation of the model, the interim storages are handeled in a very rough manner;they are filled at the beginning of a campaign as reservoirs by introducing a fixed part of the stream into them (ZLS (I)· OKMAX (I)) inside the concerned unit. In the program, a possibility of varying this percentage of the stream is foreseen. These reservoirs are built up in order to allow a more stable running of the plant. When the sum of the recycled stream to the interim storage has reached or exceeded the prescribed value (HHALB (I)) the stream into them is set = 0 (ZLS(I) = 0). But when their content is consumed in course of the campaign they are not filled up again - introducing this operation would be one of the first steps in improving the model.

In running the program the condition of the whole plant is examined in fixed time intervals of 0.5 days. This procedure gives a batch-wise description of the process. In order to give a better approximation of a continuous description, the time intervals could be decreased. At the end of each time interval a decision is made for every unit of the plant on whether an output is possible, i.e. whether the content of the unit has reached the prescribed minimum value (HMIN (I)). According to the conditions at this step the next "batch" is evaluated. For the next time interval the whole procedure is repeated. According to the conditions of the interim storages the flows into them are fixed.

In the following two main possibilities of operating the plant are studied:

1) Diversion free conditions
2) Diversion conditions.

4.5.1 Diversion free conditions

In order to simulate the measuring errors and normal operation variations inside the production line, different flow rates were varied in a series of simulated campaigns. All other parameters listed in Table 4-2 were kept constant during this variation of the one parameter under study.

a) Variation of the input

Under the assumption that the normal input to the production line is a measurable quantity the actual distribution of which can be described by a normal distribution with mean value = a and sum of the variances $= \sigma$ for the two variations mentioned above, normally distributed random numbers for the quantity under study were generated [1]. These generated numbers for the input value were taken one after the other as input quantities for a series of different campaigns. For each campaign the hold-up of the different units and of the whole plant as well as the accumulated recycles to the single interim storages inside the units were calculated and printed as a function of time (see Appendix I). By this model one can study the distribution of the nuclear material inside the plant at each time for a distinct set of parameters, and by a comparison of different campaigns one gets a survey of the influence of the variation of input on the various inventories.

Fig. 4.4 gives the frequencies of the random-generated values for the input quantity XNULL - with 44 events only, this distribution comes very near to the GAUSS distribution with a = 10.0 and σ = 0.05 which is meant to describe the actual distribution. Fig. 4.5 gives the values for the hold-up of unit 1 as a function of time and the three cases XNULL = 9.128 kg/d, XNULL = 10.009 kg/d, and XNULL = 10.834 kg/d. These three values were chosen because they lie at the lower end (9.125 kg/d), in the middle (10.009 kg/d) and at the upper end (10.834 kg/d) of the simulated GAUSS distribution given in Fig. 4.4.

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[1] The subroutines RANDU and GAUSS used for this purpose are taken from [4-3].

If XNULL has the highest value (10.834 kg/d) the content H (1) is a continuously growing function of time - only the slope becomes smaller at time = 21.5 d when the interim storage in unit 1 has reached the prescribed content and therefore no further stream to this storage is necessary so that the output stream of unit 1 becomes greater (Fig. 4.3).

For the case XNULL k= 10.009 kg/d at the time = 21.5 d, a balance of input and output is reached so that no further variation of H (1) can be observed.

For XNULL = 9.128 kg/d after the filling of the interim storage ZL (1) the output OKMA (1) becomes bigger than the input XNULL so that H (1) begins to decrease.

Since the output quantities for all the units have prescribed values and the input flows to the interim storages in the units are fixed percentages of these quantities, this is the only influence of a change in XNULL. Of course the total content of the production line is a linear function of XNULL - at least in the model.

b) Variation of the output capacity of unit 3

In the same way as for XNULL the variation of any of the figures given in Table 4-2 has an influence on the working of the whole production line. As another example, the influence of a variation of the output capacity of unit 3 OKMAX (3) is studied. This unit was chosen since it was learned from the operator that a variation in the running capacity of the sintering furnace inside this unit is quite probable. The results of this study are given in Figs. 4.6a - 8.

It is obvious that a variation in unit 3 can influence unit 3 and the following units only. Since no direct flow from unit 3 to unit 5 has been foreseen (x_3 = 0.00), one has no influence on the content of this unit.

The content of unit 3 H(3) is a rather complicated function of time. According to the running conditions prescribed by the model, the value of H (3) oscillates between different values for times > 11.5 days. (In order to describe this function more accurately it would be necessary to choose smaller time intervals.) The lines, between which the values are oscillating, have different slopes for the three values of the parameter OKMAX (3). Fig. 4.6b is a survey to give these features more clearly.

From Fig. 4.6a one sees that the influence of the variation in the flow inside unit 3 OKMAX(3) is different for different times. To indicate this, error bars have been drawn at the times 12 days (very large difference in H(3) between the three studied cases), 20 days, 21.5 days (very small difference) and 22 days. Following such indications, a convenient day for an eventual physical inventory taking could be choosen.

It is quite clear that the oscillations in the content of unit 3 are an effect of the relation between the limit values for the interim storages of this unit and the units before. In the program they were chosen as HHALB (1) = 80 kg, HHALB (2) = 100 kg and HHALB (3) = 20 kg respectively. Since it takes quite a long time until the interim storages ZL (1) and ZL (2) are filled, it takes the same time until a really steady state for the three units 1,2 and 3 is reached. Up to this time the outputs of units 1 and 2 (input to unit 3) are much smaller than the normal output of unit 3 so that this unit cannot run in a stable manner.

Fig. 4.8 shows that the interim storage of unit 3 ZL(3) is filled until a certain fixed accumulated input (HHALB (3) = 20 kg) is reached or exceeded. Since the test of the flow into the interim storages is done in fixed time intervals (0.5 days in the model) the reached final values can be different. These values are therefore a good indication for the actual value of OKMAX (3).

If one checks the values of ZL (3) and OKMA (3) (see the indicated 'measurement points' in Fig. 4.3) one can evaluate the actual value of OKMAX (3). In some cases it could be possible to draw a conclusion about an irregularity by making these considerations.

c) Considerations on further parameter variations

It would be quite interesting and of course also necessary to study the effect of a variation of all the figures given in Table 4-1 and also the effect of a combined variation of several parameters. Another important variation type which should be studied is a time dependent variation of one or several parameters. But before doing so this first approximate simulation model should be tested by a comparison of theoretical and actual results. However, this can be done only after the production line goes into operation.

The model was constructed to give an outline for studies on the flow characteristics, but it does not seem reasonable to make a sophisticated analysis by a theoretical model without knowing if it is good enough for a real description of the production process.

4.5.2 Diversion case

On the background indicated by the results given in Fig. 4.5-8 the variations according to supposed diversions can be tested. The results are given in Figures 4.9-4.18 and Table 4-4. Table 4-3 gives a summary of the cases without and with diversion which have been studied and the corresponding figure numbers.

Table 4-3: Summary of studied cases

Varied parameter	influence on	see figure
input XNULL	hold-up H (1)	5
working capacity of unit 3	hold-up H (3)	6
OKMAX (3)	hold-up H (4)	7
	interim storage ZL (3)	8
diversion at unit 1	hold-up H (1)	9
	hold-up H (2)	10
ABZW (1)	hold-up H (5)	11
diversion at unit 2	hold-up H (2)	12
	hold-up H (3)	13
ABZW (2)	hold-up H (5)	14
diversion at unit 3	hold-up H (3)	15
ABZW (3)	hold-up H (4)	16
diversion at unit 4	hold-up H (4)	17
	hold-up H (5)	18
ABZW (4)		

It is important to keep in mind that the H (I) are the values which can be computed from the measured OKMA (I) and OKRA (I-1). The theoretically expected contents of the units are HSOLL (I). If there is a diversion between the units I and I+1, one calculates H (I) higher and H (I+1) lower than for the normal case. The actual contents under 'diversion conditions' are HSOLL for unit I (the diversion does not influence the content of the unit before) and H for unit I+1 (for unit I+1 the actual content is calculated because in the model the diversion is supposed to take place before the measurement point for OKRA (I)). This effect can be seen in Fig. 4.9. With ABZW (1) = 0.00 one has the 'normal' case i.e., no diversion. For ABZW (1) = 0.02 or 0.10 it seems that the content of unit 1 is growing faster than normal because at the measurement point in between unit 1 and 2 a smaller output of unit 1 is measured. (OKRA (1) becomes smaller than in the 'normal' case and so a bigger H (1) is calculated as difference between fixed input and changed output.)

For a diversion of more than 10 % at this point (output of unit 1) the input to unit 2 would not be big enough compared to the prescribed output value of this unit; in this case an alarm would occur, which is simulated by an interrupt and printed message in the normal course of the program, cf. also Table 4-4 below.

In Fig. 4.10 the different values of the parameter ABZW (1) are shown together with their influence on the content of unit 2. After 5.5 days the output of this unit begins and so in all three considered cases of ABZW (1) the rate of increase of H (2) changes. In the case ABZW (1) = 0.00 and ABZW (1) = 0.02, only the slopes of the curves are changed. In the third case, where the input to unit 2 is the smallest, the output becomes greater than the input so that H (2) decreases. In this special case H (2) falls down to a value which is smaller than HMIN (2) i.e., the content which is fixed as minimum working content (cf. Fig. 4.2), at this time the output stops and the unit is filled up again so that a new output is possible at time = 13.5 d. At time = 21.5 d the input becomes bigger, since ZL (1) is filled (see above), and due to this fact the input of unit 2 becomes bigger.

Since the output functions of the units 3 and 4 are not changed by a variation between units 1 and 2 (only one parameter of table 4-2 is changed in each of the studied cases) one has no influence on the content of these units by variation of ABZW (1). A timeshift of the filling of these units could be the result of the cange in unit 2. But with the chosen time intervals it could not be observed. For the aspects of this question table 4-4 gives some results which are described below.

The influence of this variation of ABZW (1) on unit 5 is rather small.

For Figs. 4.12-18 one can say in general that each of the studied diversion strategies changes the hold-up functions for some units of the plant. Specially the slope of the curves themselves or of the curves, between which the hold-up is oscillating, is quite sensitive - see e.g. the different slopes in Figs. 4.9, 4.10, 4.12, 4.13, 4.15, 4.16, 4.17. The relation between different slopes in the curves themselves for the variation of one parameter is a direct measure for the different ratios of the diverted streams, see e.g. Fig. 4.9.

4.6 Results

Apart from studying the single figures in which the influence of the change of one parameter on one unit of the plant is shown, one can try to compare the different figures under different aspects.

4.6.1 Diversion cases only

It is interesting to see (a) on which unit a special diversion has the biggest influence or (b) which strategy of diversion has the biggest influence on a special unit.

For (a), it comes out that the influences (if there are influences on the respective units) on units 1 and 2 are quite large; on units 3 and 4 they are smaller but allow also at least the conclusion that there is an irregularity. For unit 5 all the variations have rather a small influence.

On the other hand for (b) one can say that e.g. for the content of unit 2 H(2) a diversion at the output of unit (1) seems to have a greater influence than that at the output of unit 2, cf. Figs. 4.10 and 4.12.

For unit 5 the influence of diversions after units 1 and 2 have more influence than a diversion at the output from unit 4; a diversion at the output of unit 3 would have no influence on the content of unit 5.

For a diversion at unit 1 the influence on the content of unit 5 becomes visible after about 3 days (s. Fig. 4.11), for a diversion at unit 2 after about 7 days (s. Fig. 4.14) and for a diversion at unit 4 after about 14 days - all these time intervals counted from the beginning of a campaign. The indication would be given by a difference between calculated and real inventory at this time.

4.6.2 Diversion free and diversion cases

For all the cases shown in Figs. 4.9-18 one can see a more or less significant difference between the normal cases (ABZW (I) = 0) and those cases in which a diversion has been simulated. In some special cases (see above) one can even decide which kind of irregularity has been introduced.

One of the special aims of this study is to compare the irregularities which originate in diversion with such 'irregularities' which come from the normal variation of process parameters. As has been shown in Figs. 4.5-8 also these variations change the hold-up functions of some units of the plant. In this study only a few particular cases have been investigated.

It comes out that e.g. a diversion of 4 % of the output from 3 changes the normal hold-up values of the unit 3 to the same extent as a normal variation of the output capacity of unit 3 (cf. Figs. 4.6 and 4.15).

This variation in ABZW (3) has a greater influence on the content of unit 4 H (4) than the normal variation in OKMAX (3) - cf. Figs. 4.7 and 4.16.

Another indication for an irregularity can be given by the times at which the different units of the plant begin to work, as indicated in Fig. 4.2. This time is a function of the content of the units.

Table 4-4 gives a review about the influence of supposed diversions on these times for the different units and the influences of different input XNULL as comparison.

Table 4-4 : Influence of diversion (ABZW (I)) on the starting times for the units 1 - 4.

ABZW (1) %	T (1) (d)	T (2) (d)	T (3) (d)	T (4) (d)
0	0.45	4.79	6.85	13.43
2	"	4.93	7.00	13.58
4	"	5.10	7.16	13.74
6	"	5.27	7.33	13.91
8	"	5.46	7.52	14.10
10	"	5.66	7.72	14.30
12	operating conditions instable			
ABZW (2) %				
2	0.45	4.79	6.39	13.51
4	"	"	7.03	13.61
6	"	"	7.13	13.71
8	"	"	7.24	13.82
10	"	"	7.37	13.95
12	operating conditions instable			
ABZW (3) %				
2	0.45	4.79	6.85	13.77
4	"	"	"	14.16
6	operating conditions instable			

For comparison:

XNULL = 9.128 kg/d	0.49	4.88	6.90	13.47
XNULL = 10.009 kg/d	0.45	4.79	6.85	13.43
XNULL = 10.834 kg/d	0.42	4.76	6.82	13.40

Apart form this the table gives the ratios of the diversion streams at the different units for which the model plant cannot work in a steady state. It is to be stressed that this indication of an instability is to be taken to be valid only within the approximations of the model and for the conditions given in Table 4-2.

4.7 Conclusion

As a conclusion one can say that a simulation model can give results about the influence of different variations, which can be due to normal operation changes as well as to diversions, on some characteristic variables of the plant, as e.g. the hold-up of the single units or the content of interim storages. Also the material flows at different points of the production line can be calculated (see 'measurement point' in Fig. 4.3) and compared with actual measurements. Of course the model results can give only indications for the reasons of an irregularity. It is not possible to infer to the special conditions which have led to an irregular state.

/‾4.1_/ E. Drosselmeyer, R. Kraemer, A. Rota
Application of Digital Simulation Techniques for Process Inventory Determination.
IAEA/SM-133/18 (1970)

/‾4.2_/ J. Larisse, H. Winter
Methods for Independent Determination of Process Inventory in Nuclear Facilities - Fabrication Plant.
KFK 903 (1968)

/‾4.3_/ IBM - System 1360 Scientific Subroutine Package (360 A-CM-03X)
Version III, Programmers Manual, H 20-0205-3

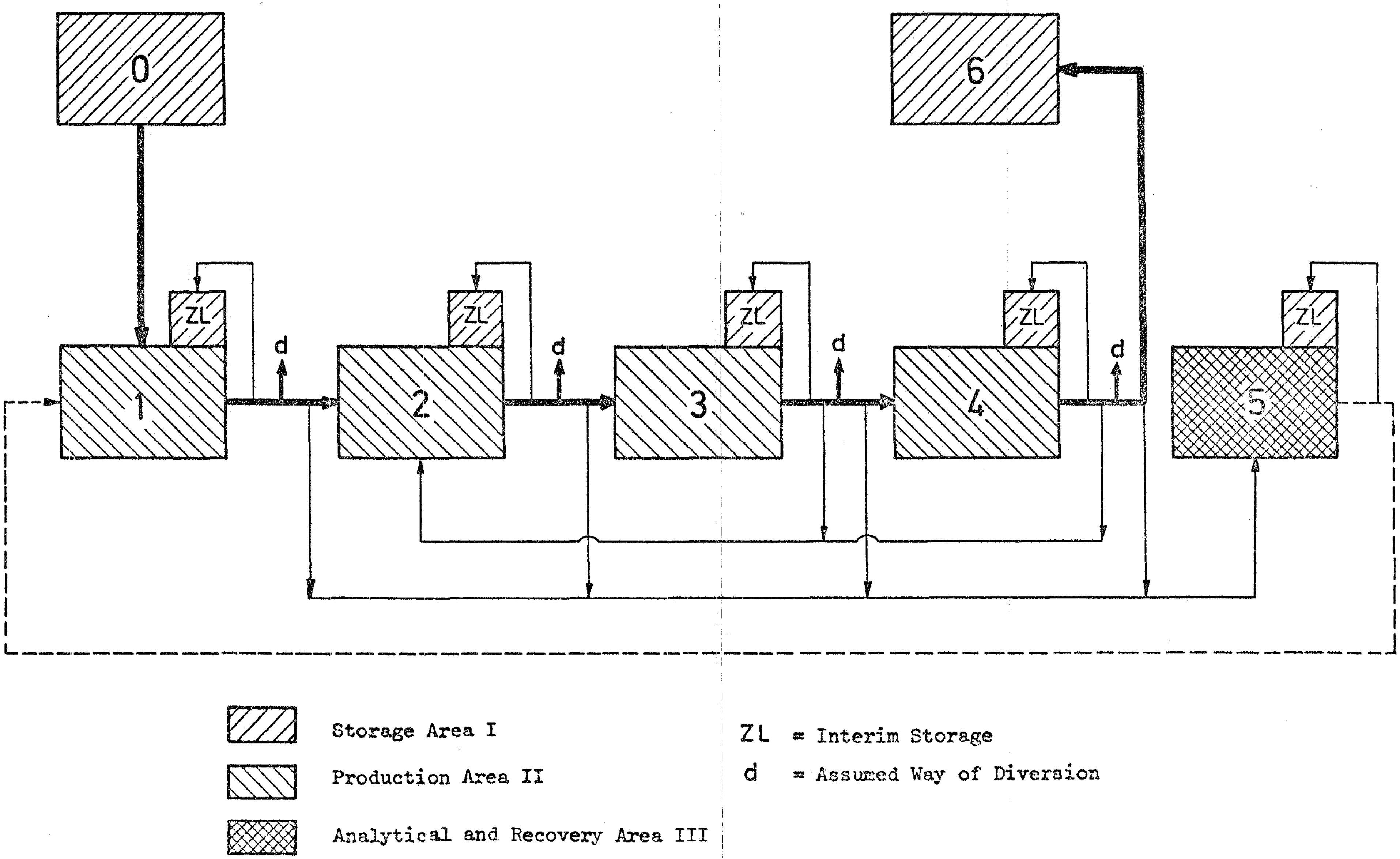


Fig.4.1: Schematic view of a fabrication plant consisting of 7 units

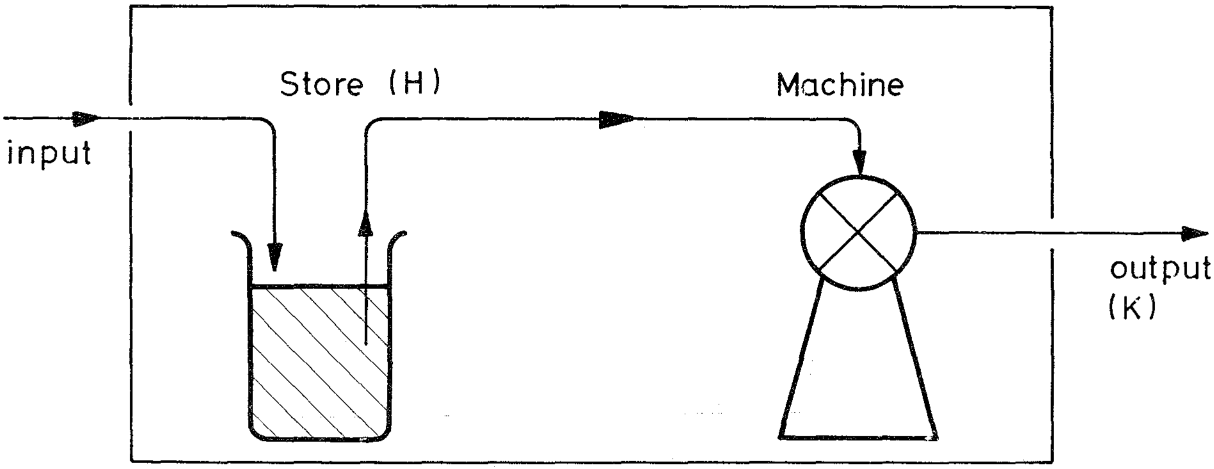


Fig. 4.2a: Schematic representation of a fabrication unit

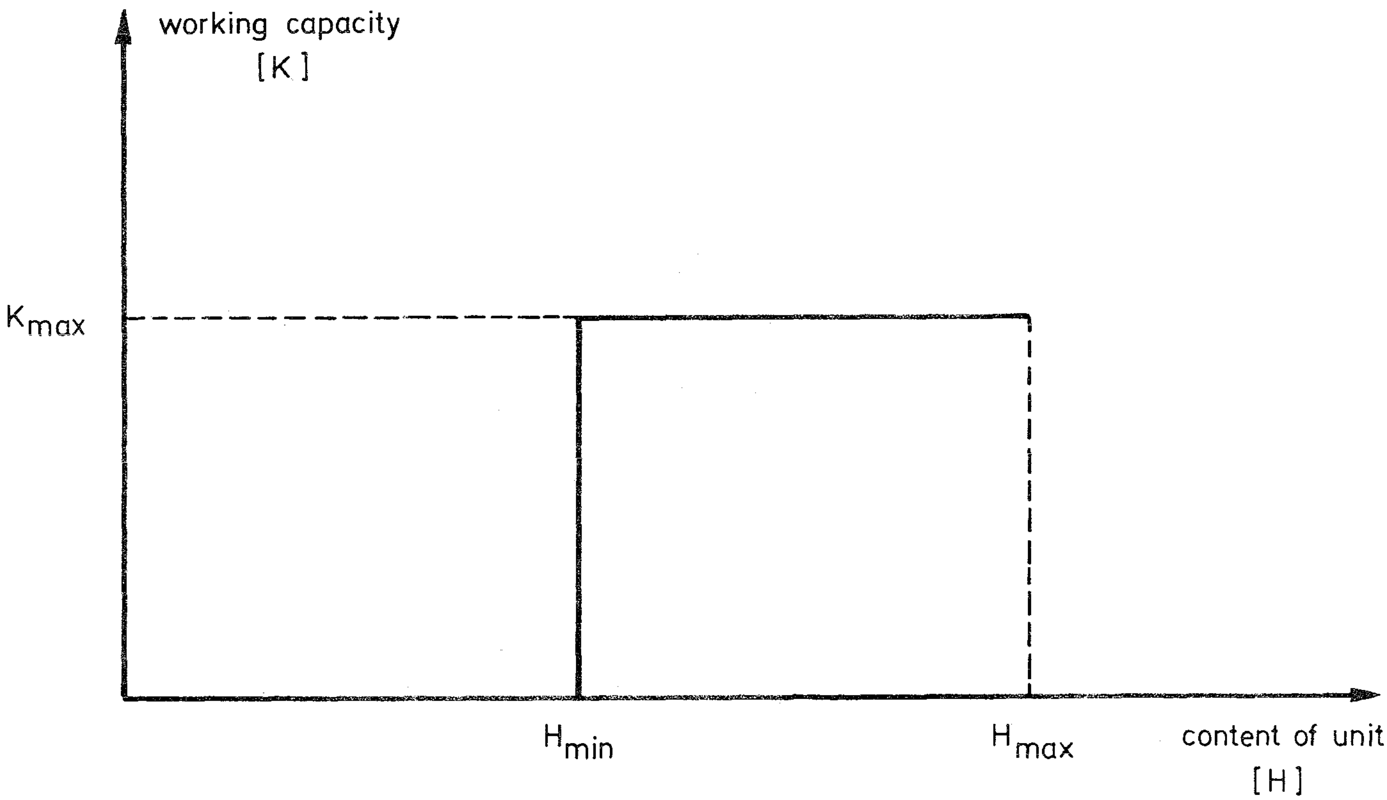
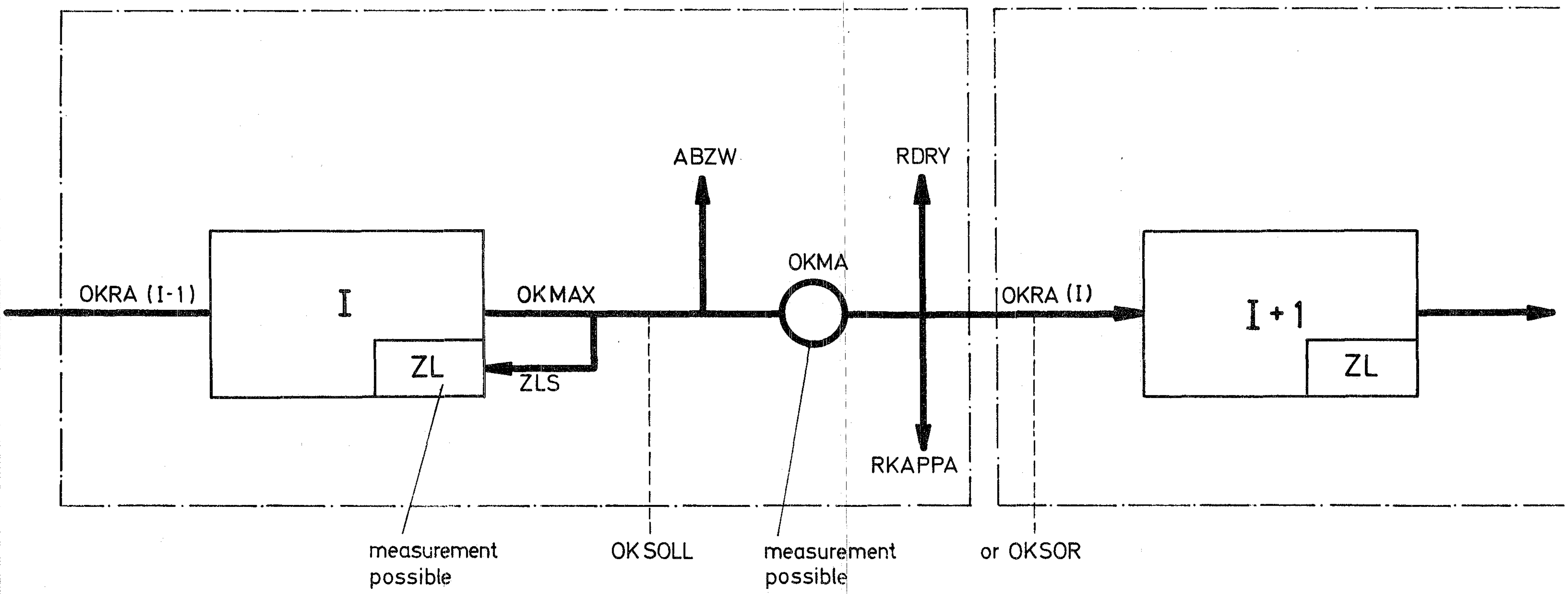
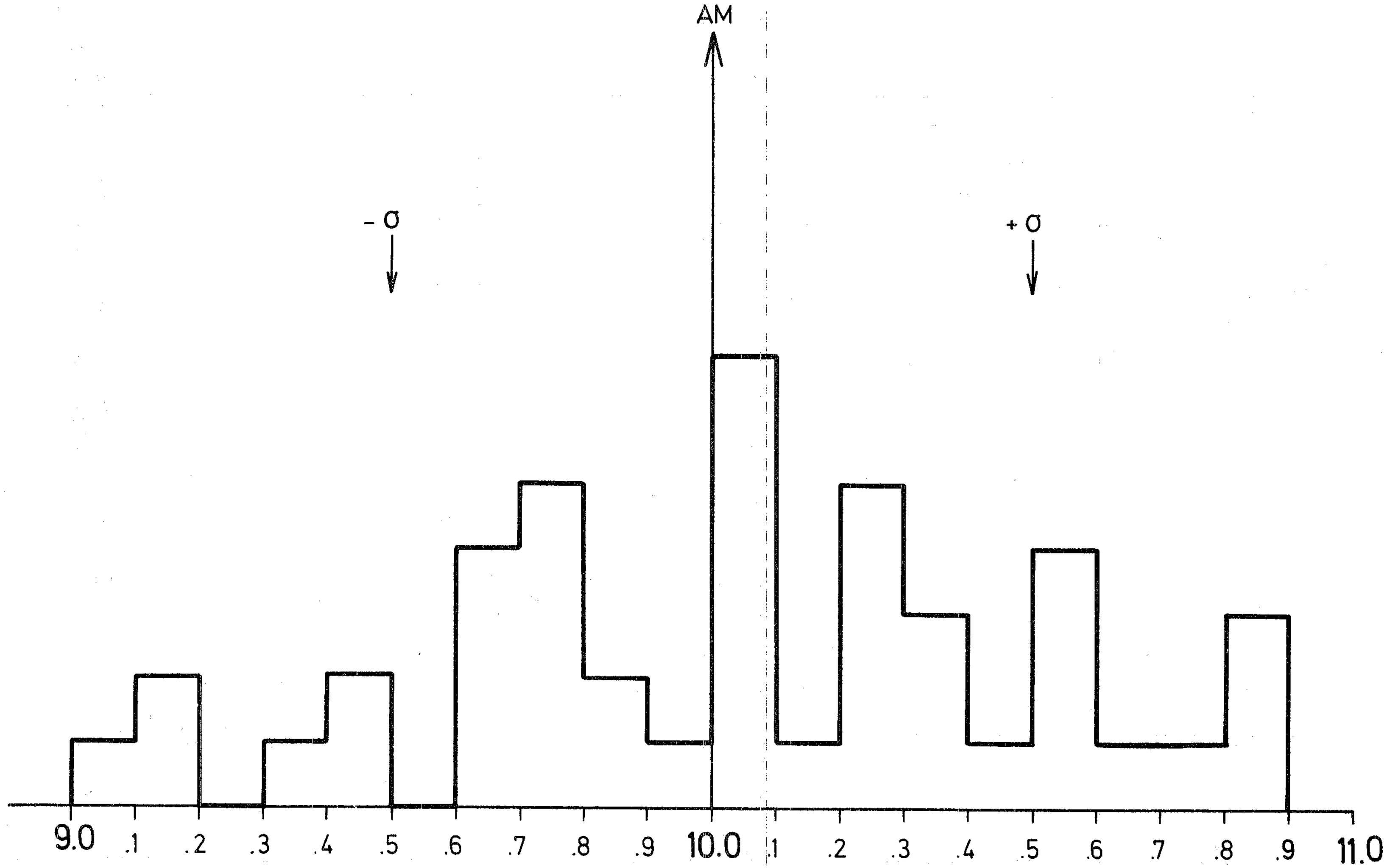


Fig. 4.2b: Machine characteristics for a constant capacity machine



<u>Fig. 4.3</u>: Schematic combination of two units

Fig. 4.4: Frequency histogram of the 44 values used as input stream obtained by a random choice for a Gauss distribution with mean value AM = 10 kg/d and standard deviation σ = 0.5 kg/d



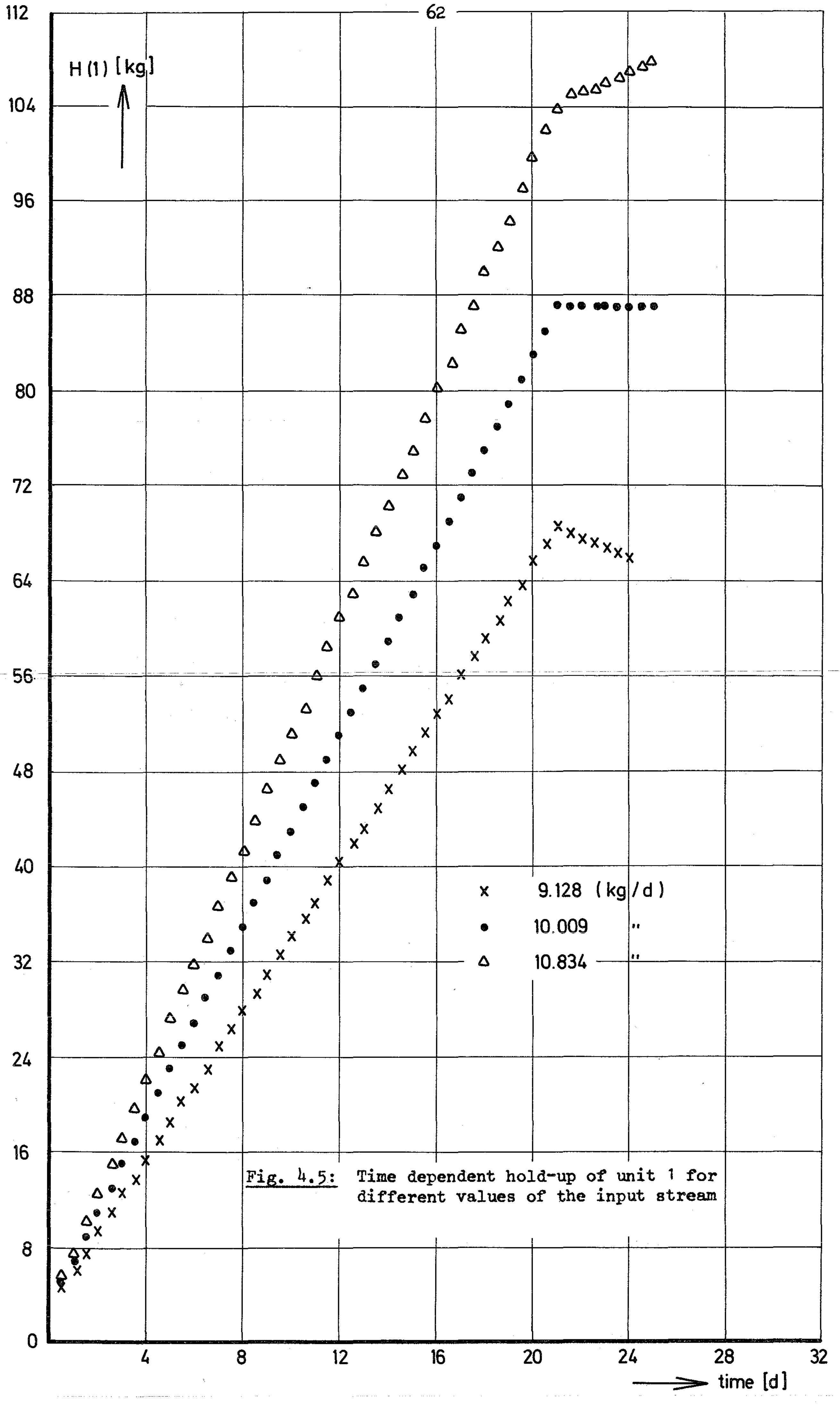


Fig. 4.5: Time dependent hold-up of unit 1 for different values of the input stream

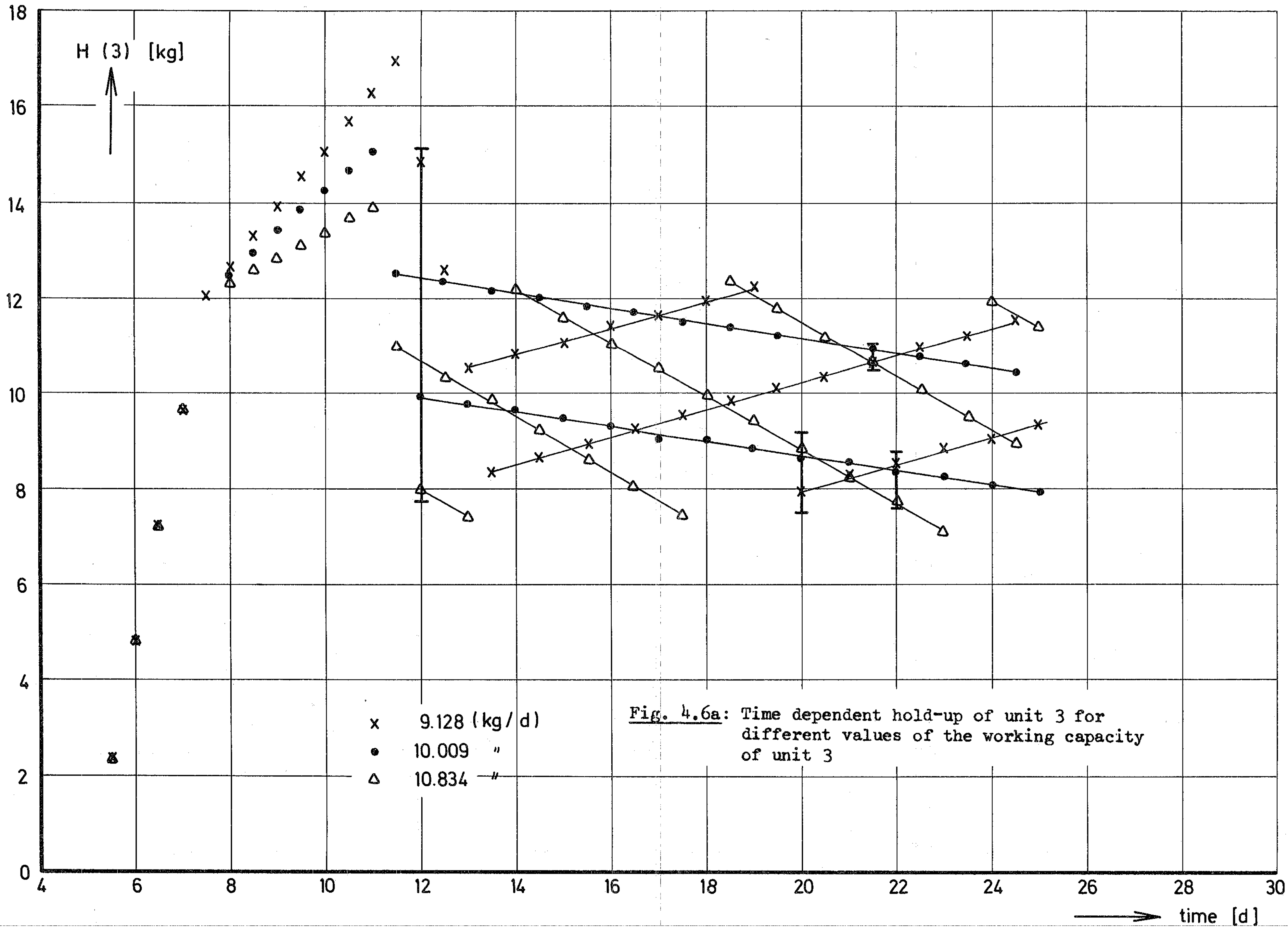


Fig. 4.6a: Time dependent hold-up of unit 3 for different values of the working capacity of unit 3

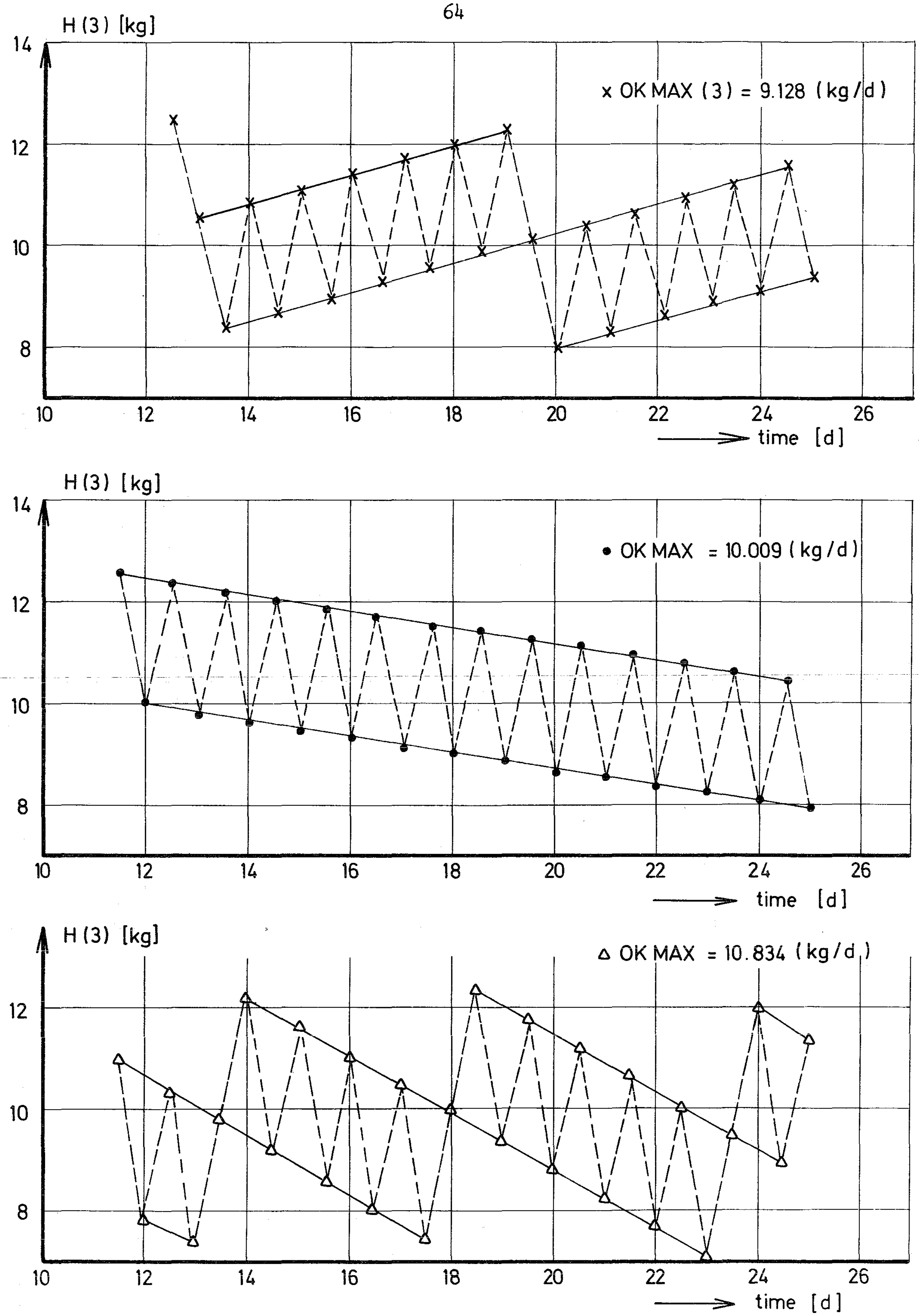


Fig. 4.6b: Details of Fig. 6a

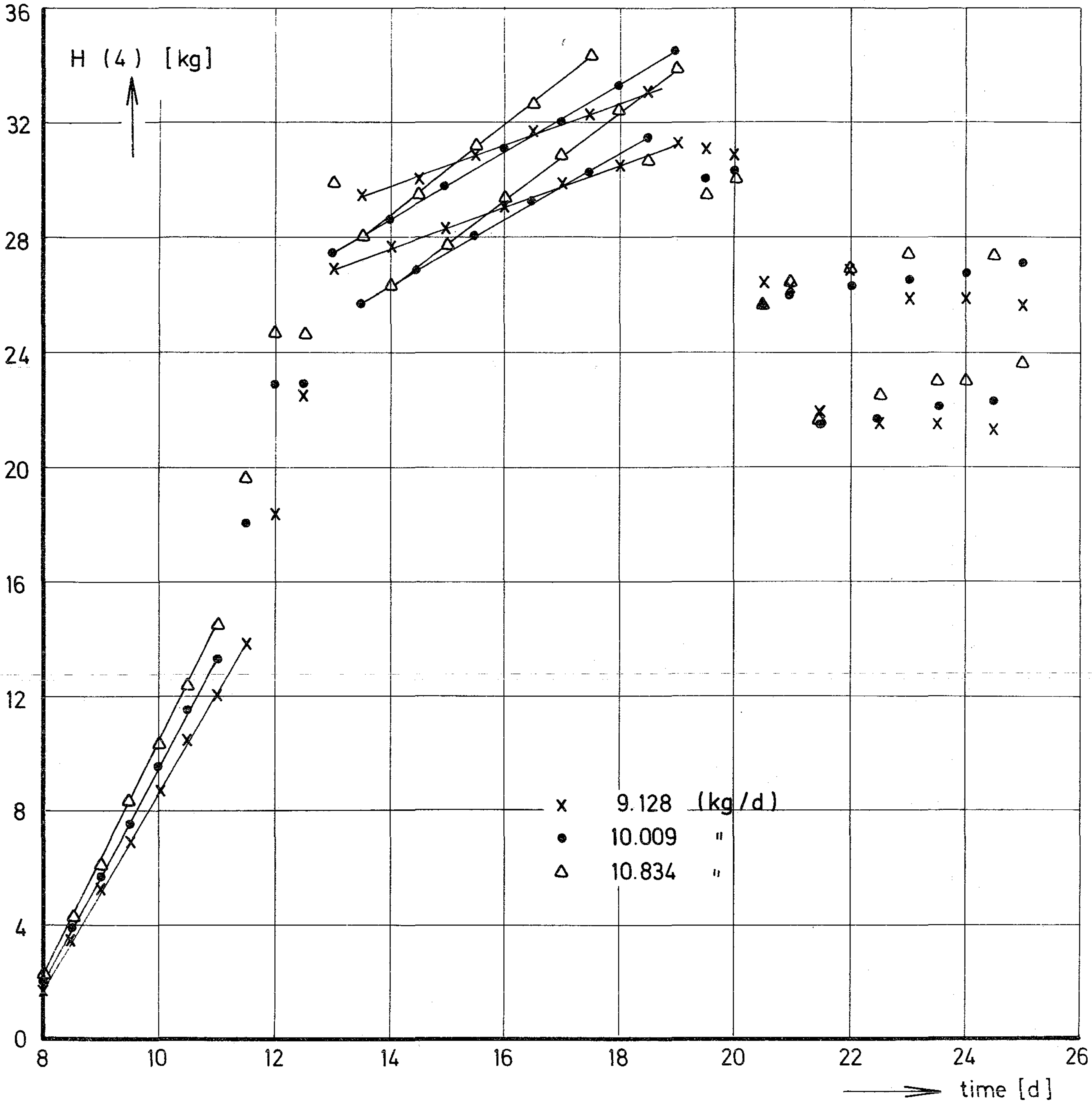


Fig. 4.7: Time dependent hold-up of unit 4 for different values of the working capacity of unit 3

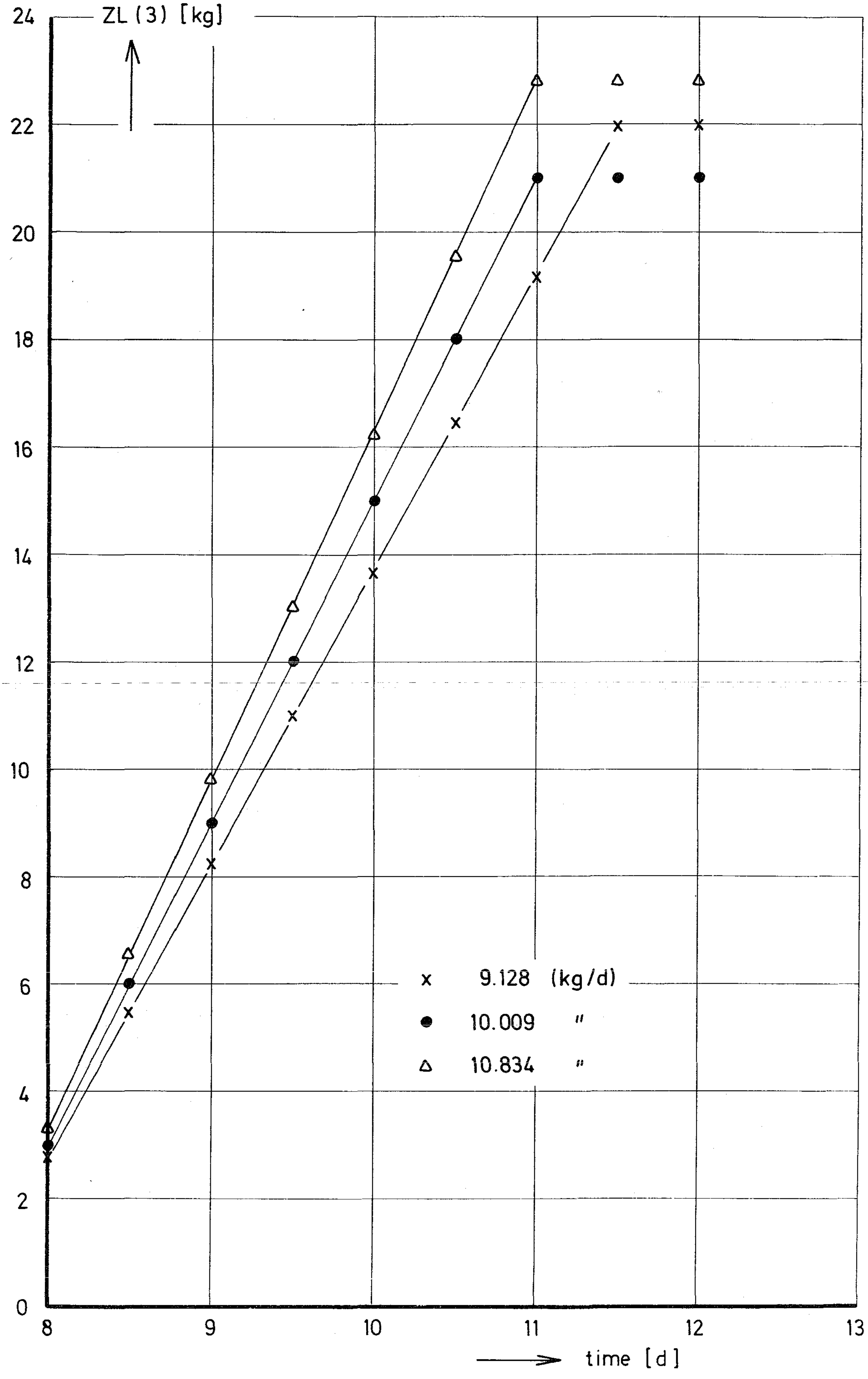


Fig. 4.8: Time dependent accumulated recycle stream to the interim storage of unit 3 for different values of the working capacity of unit 3

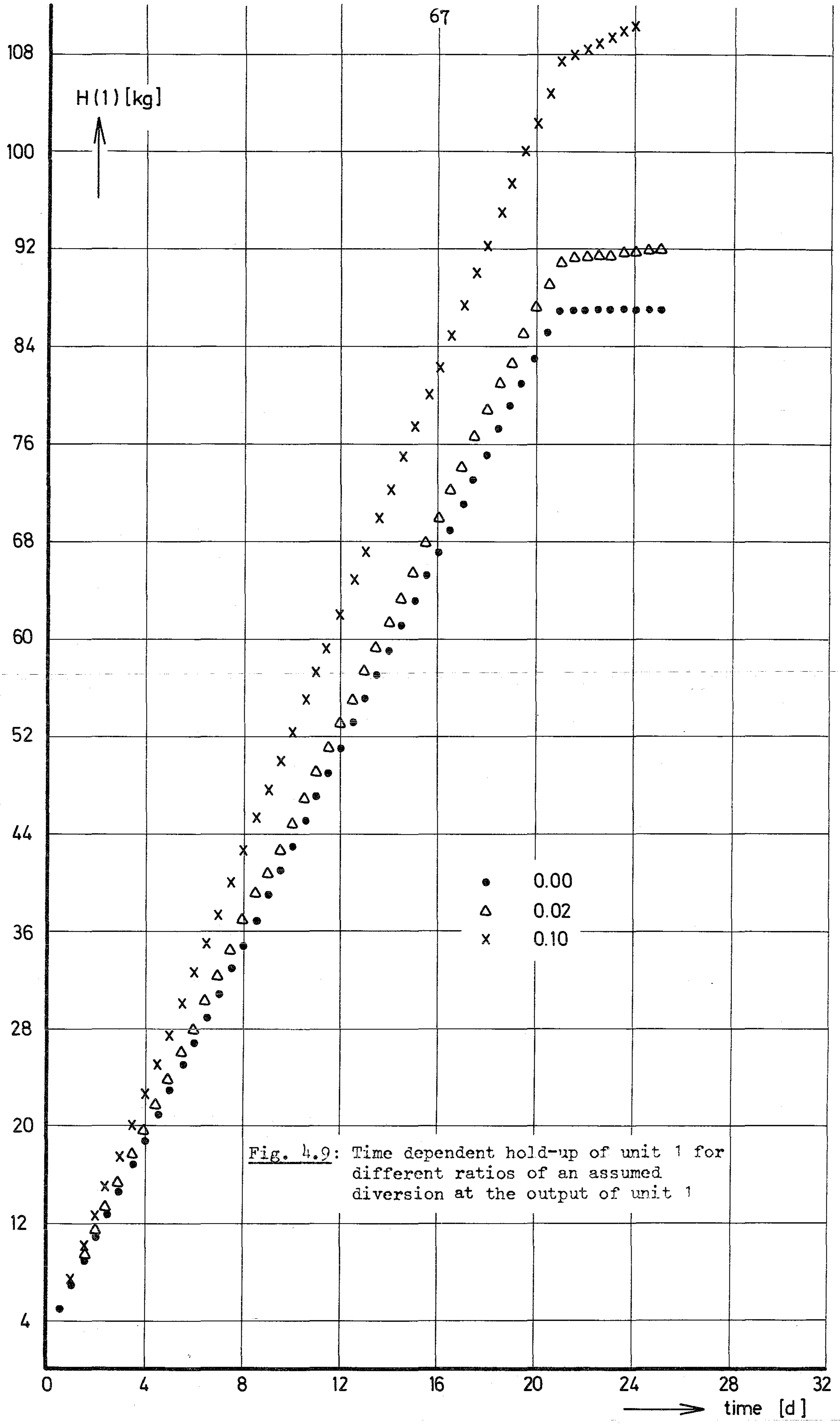


Fig. 4.9: Time dependent hold-up of unit 1 for different ratios of an assumed diversion at the output of unit 1

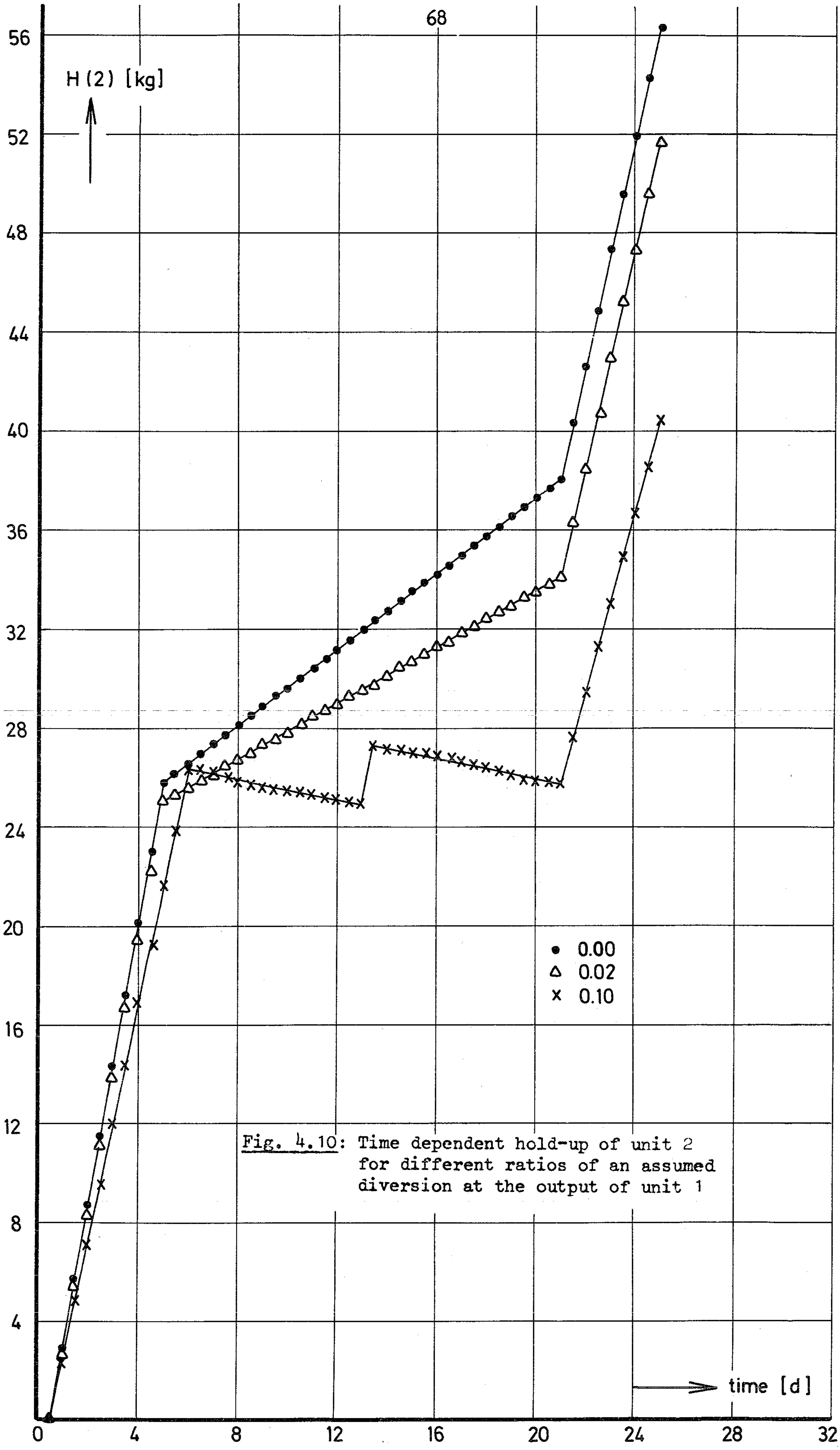


Fig. 4.10: Time dependent hold-up of unit 2 for different ratios of an assumed diversion at the output of unit 1

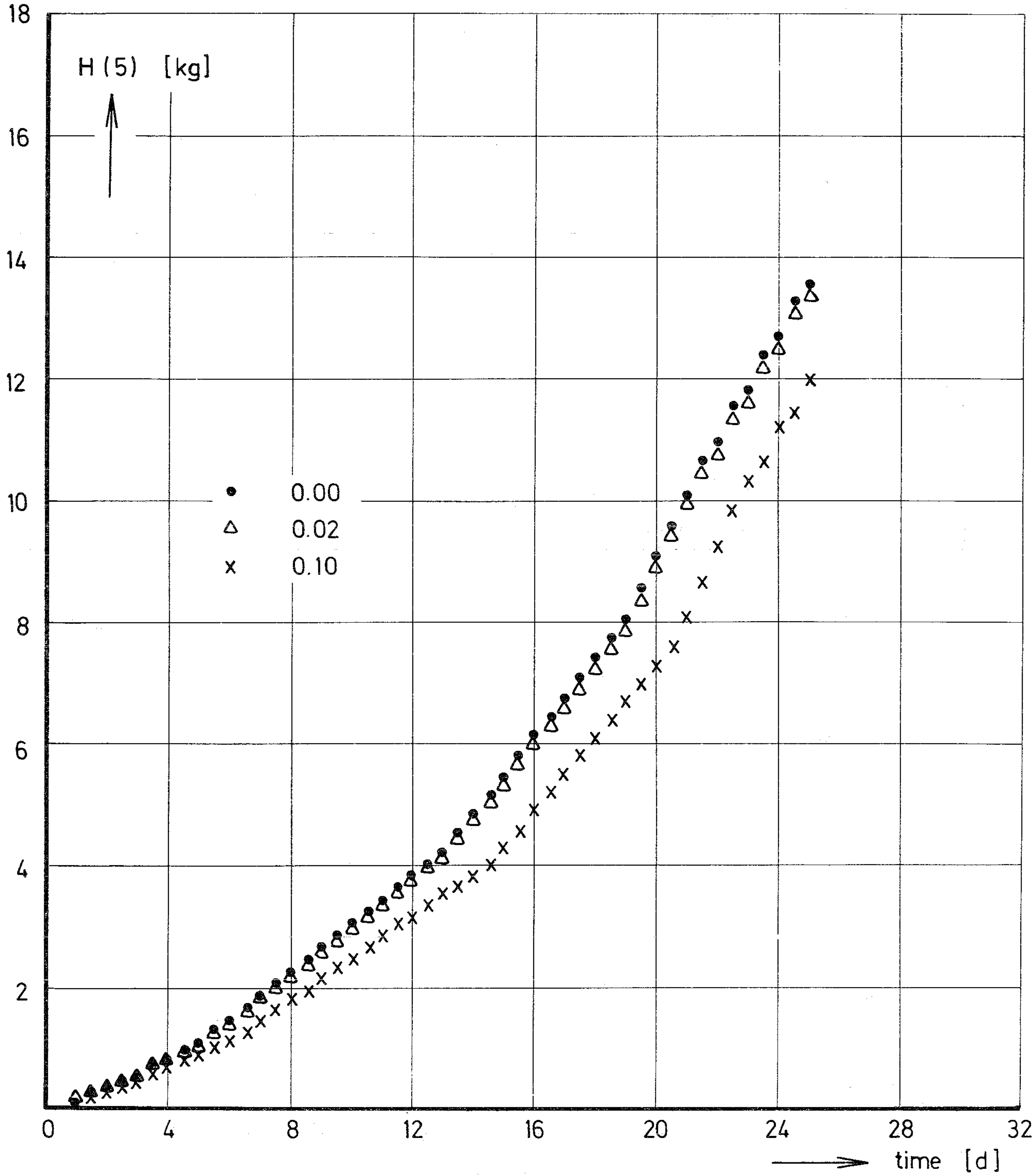


Fig. 4.11: Time dependent hold-up of unit 5 for different ratios of an assumed diversion at the output of unit 1

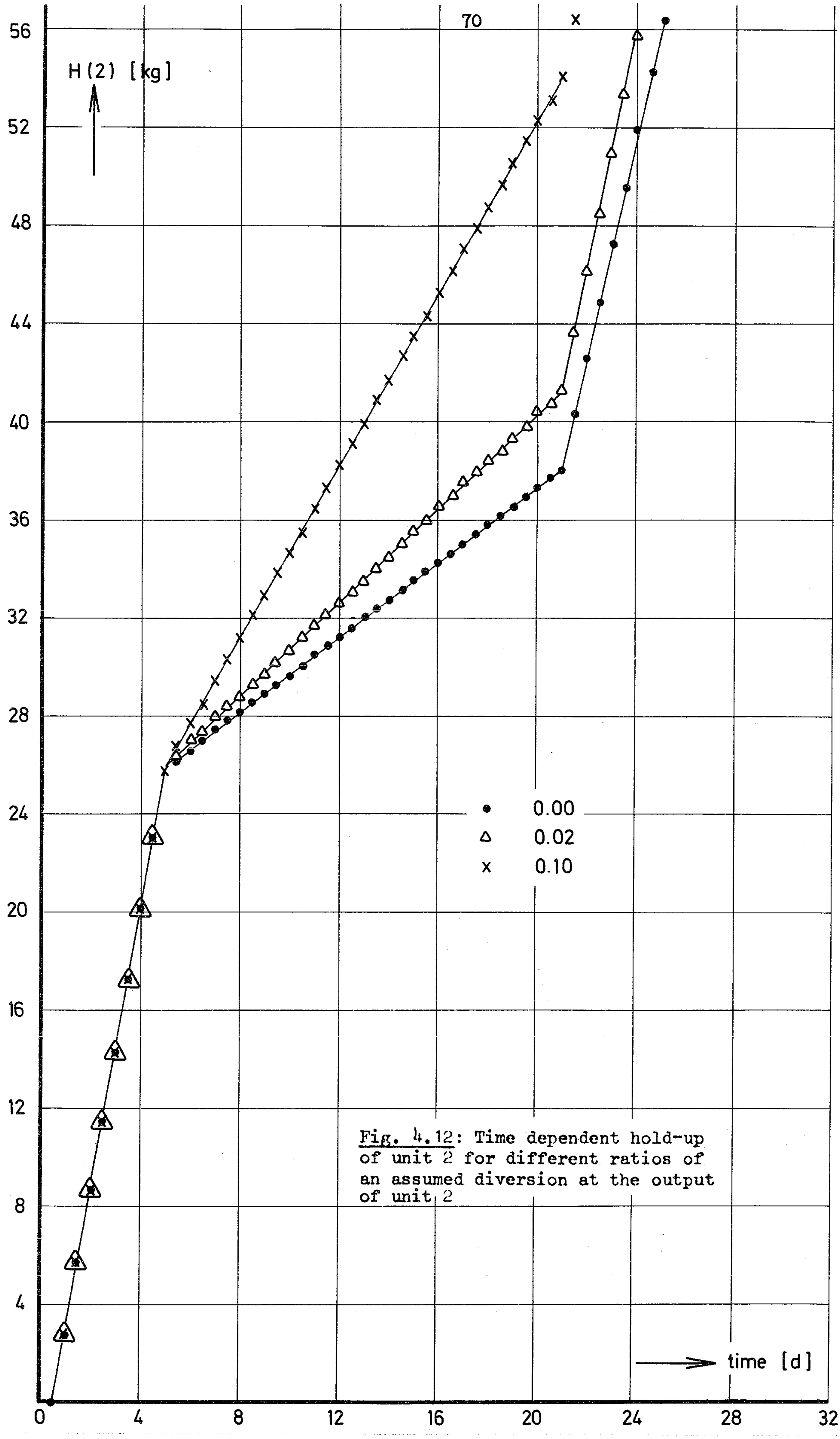


Fig. 4.12: Time dependent hold-up of unit 2 for different ratios of an assumed diversion at the output of unit 2

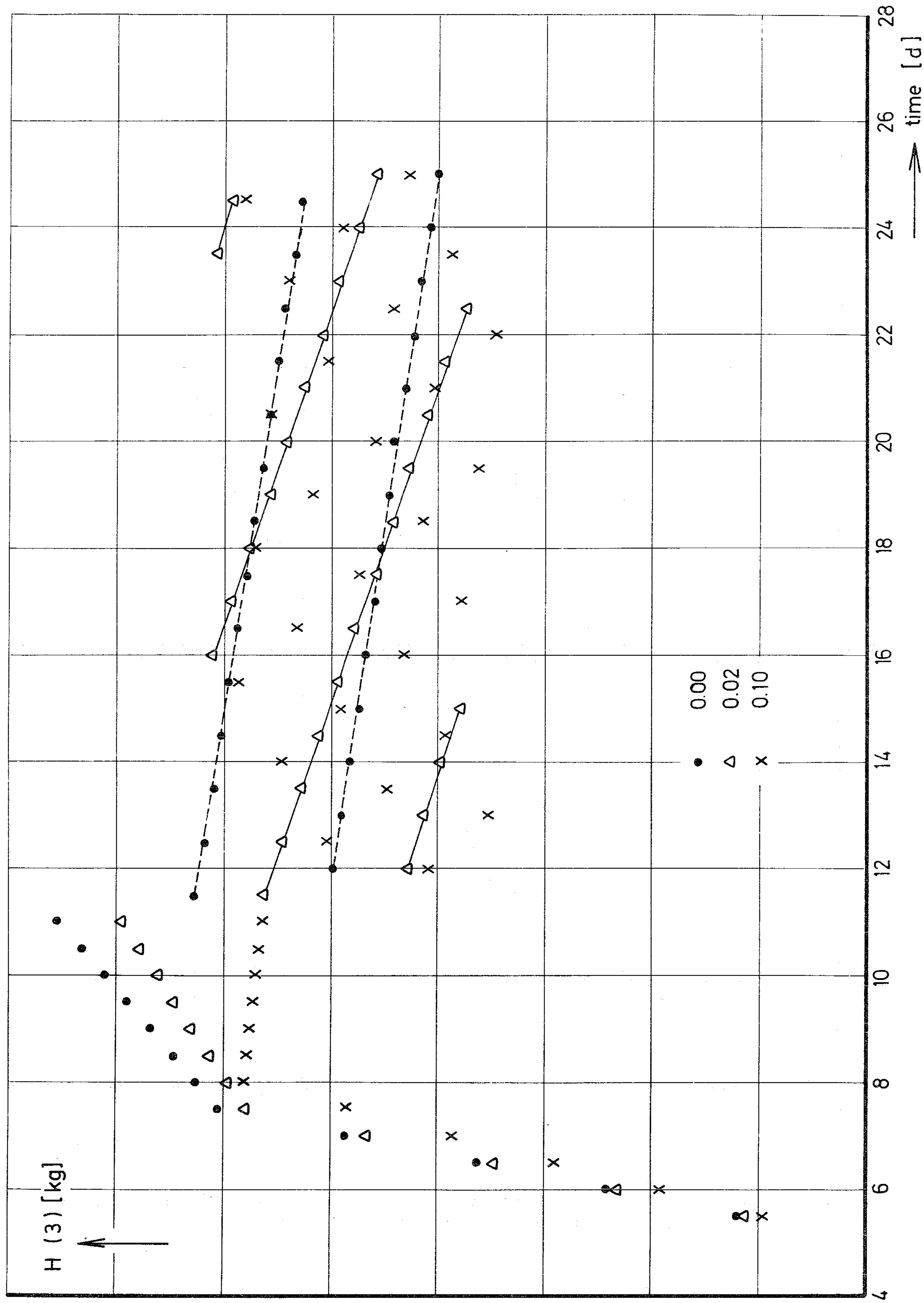


Fig. 4.13: Time dependent hold-up of unit 3 for different ratios of an assumed diversion at the output of unit 2

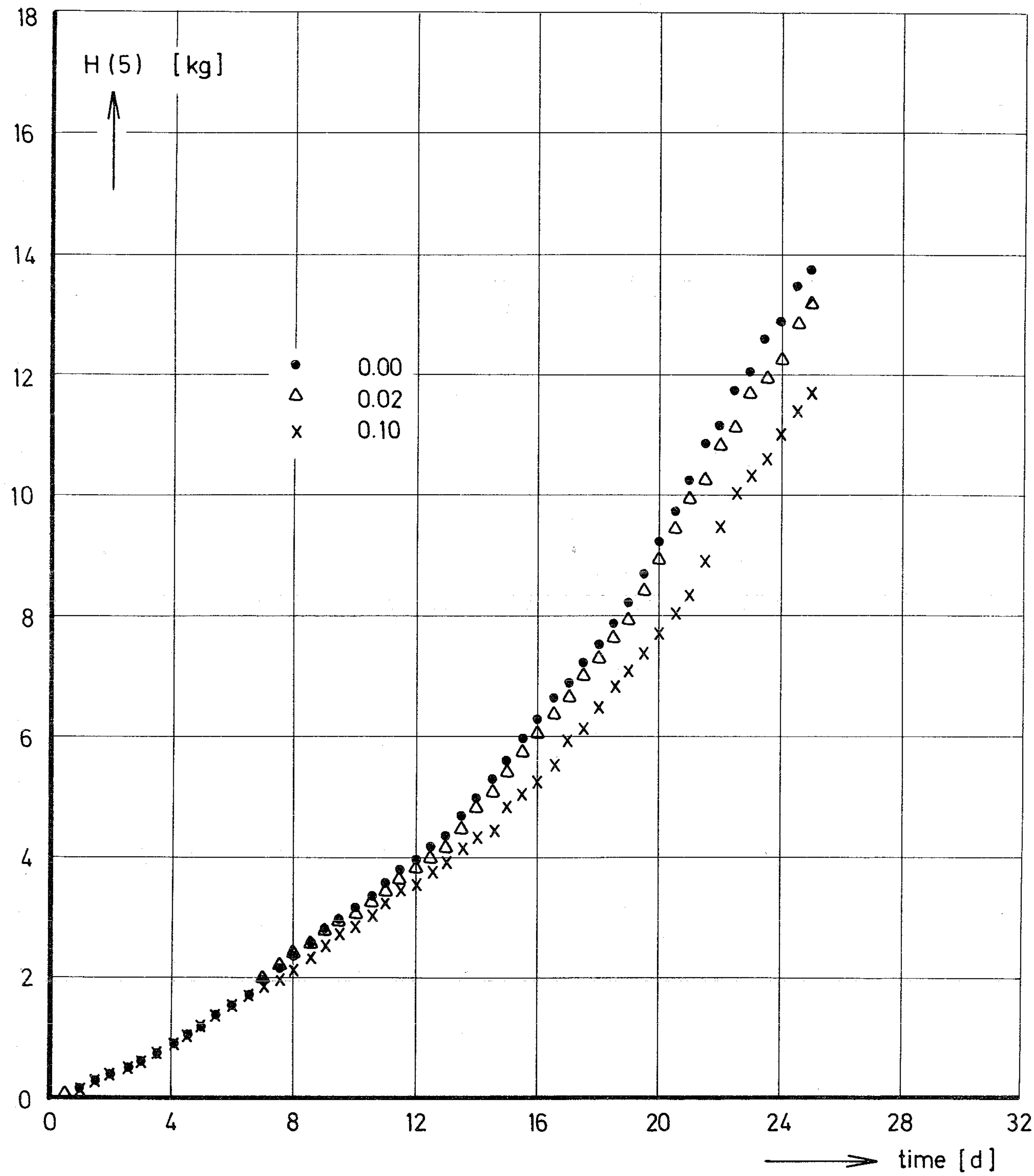


Fig. 4.14: Time dependent hold-up of unit 5 for different ratios of an assumed diversion at the output of unit 2

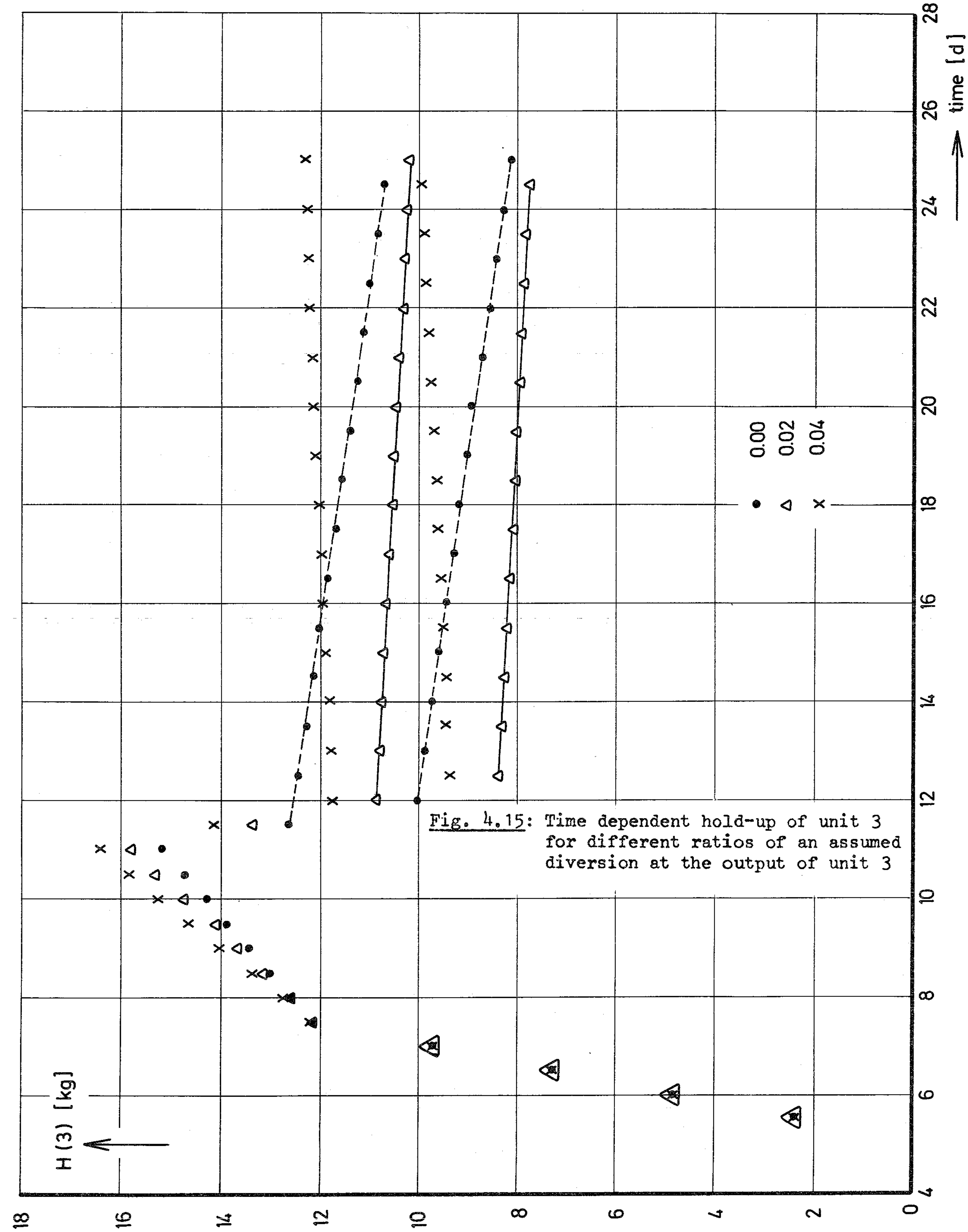


Fig. 4.15: Time dependent hold-up of unit 3 for different ratios of an assumed diversion at the output of unit 3

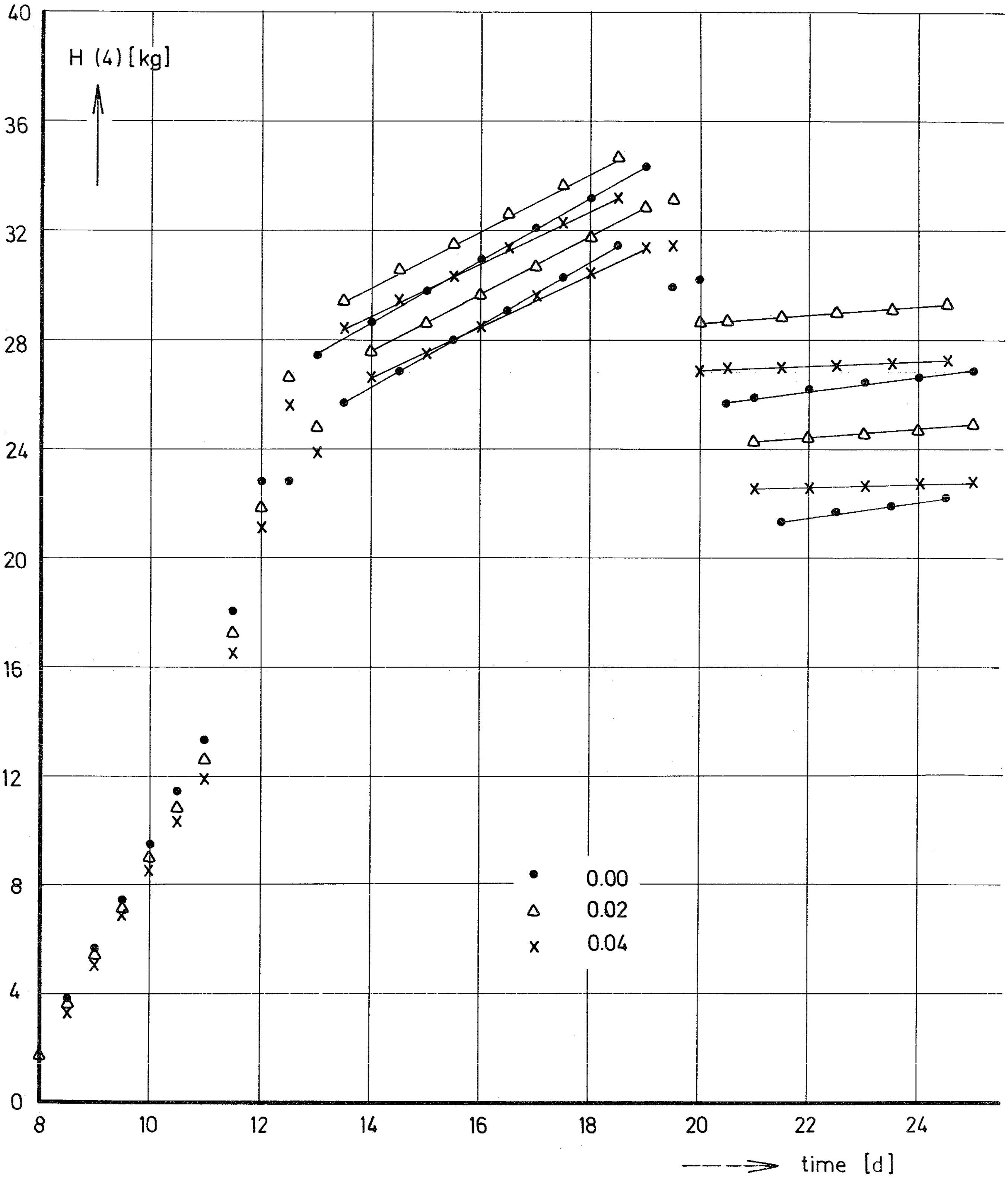


Fig. 4.16: Time dependent hold-up of unit 4 for different ratios of an assumed diversion at the output of unit 3

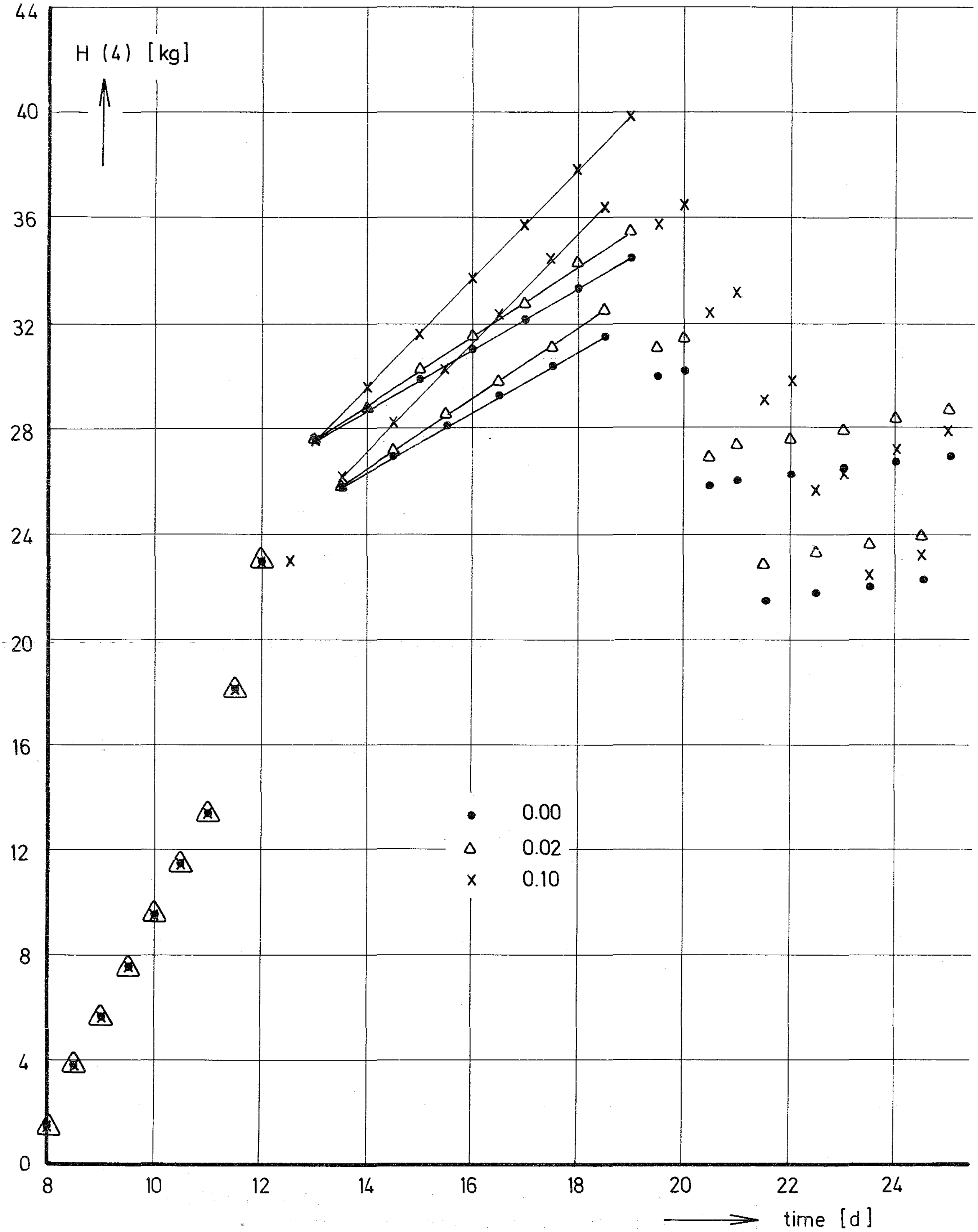


Fig. 4.17: Time dependent hold-up of unit 4 for different ratios of an assumed diversion at the output of unit 4

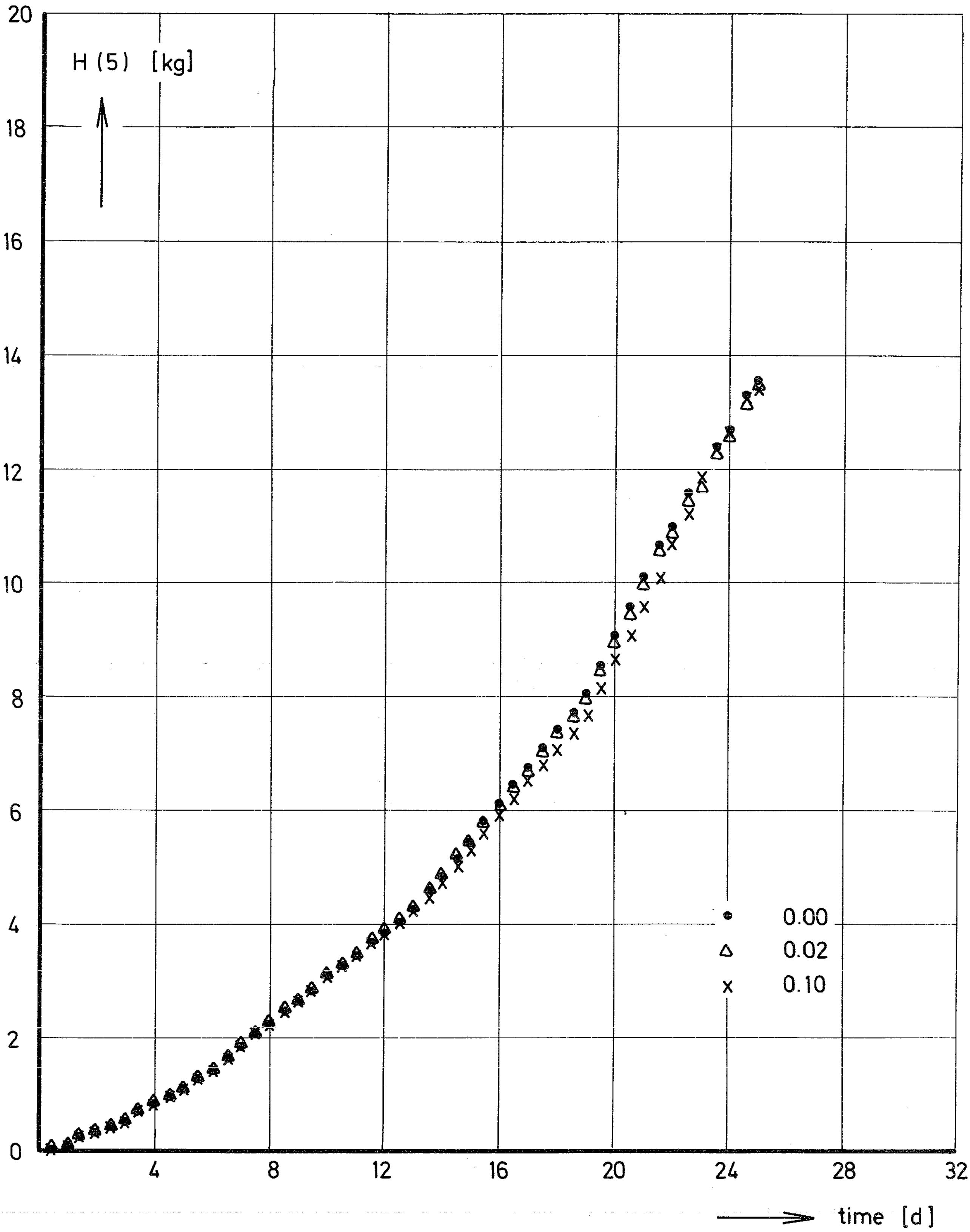


Fig. 4.18: Time dependent hold-up of unit 5 for different ratios of an assumed diversion at the output of unit 4

5. Structure of a safeguards system for the fabrication plant

5.1 Safeguards measures

5.1.1 Containment

As indicated in section 3 the building of the fabrication plant, in which the production and storage parts are housed, forms a containment.

Besides several emergency doors, normally closed and equipped with alarm devices, there are only one entrance and exit for personnel and another for material.

The personnel passage is monitored by a gamma lock (see section 3.4), the material door by an alarm device also. The indicating parts of all devices for monitoring the doors are installed at the safeguards office. These measures therefore ensure that any uncontrolled fissile material leaving or entering the building can be detected with a high probability.

Similar alarm devices as mentioned above are also installed at the main storages within the plant.

5.1.2 Material balance

5.1.2.1 Determination of MBAs

It can be seen in section 3 that for economic and safety reasons 15 MBAs have been provided by the operator in the ALKEM type plant. However, such a large number of MBAs is not required for safeguards purposes. It will be expensive and intrusive. On the other hand, only one MBA in view of the large amounts of fissile material normally being within the plant, would not give sufficient information.

An analysis of the plant layout and operation shows that there are three different kinds of operational activities. These are:

The storage of fissile material,
the production process and
the service installations involved.

According to these activities three MBAs seem to be appropriate for safeguards purposes:

MBA 1 - the storage area (Fig. 5.1-1)
MBA 2 - the production area (Fig. 5.1-2)
MBA 3 - the area of analysis and recovery (Fig. 5.1-3)

5.1.2.2 Flow of fissile material

The places, at which the flow of fissile material into and out of the MBAs has to be safeguarded, are indicated in Figs. 5.1-1, to 5.1-3. A list of these places is given in Tab.5-1.

Two additional measures are provided in this connection:

5.1.2.2.1 Additional installations in the MBA production area

Because of the large amounts of material kept as interim storage at three places (1 in conversion and 2 in powder production), the amounts in these interim storages are recorded at the safeguards office.

Moreover the flows of fissile material from two other places within this MBA (namely green and sintered pellets) are recorded in the same way (see Fig. 5.1-2 and Tab. 5-2). A comparison of this information with the simulation data (section 4) may indicate possible irregularities.

5.1.2.2.2 Random measurements

In accordance with the plant operator's usage for different streams of fissile material, only random measurements are required, e.g. for the input stream of the plant in view of possible shipper receiver differences. The number of random measurements can be calculated in the following way:

The probability of detection is

$$P_D(n,k,r) = 1-(1-\frac{k}{n})^r$$

where

n = total number of units considered
k = number of units to be controlled
r = number of falsified units.

Table 5-1: Places for Execution of Safeguards Activities

MBA	Place (Figs.5.1-1 to 5.1-3)	Safeguards activities
STORAGE	C D E	Accounting of input and output of the pin storage " " " " " " " Pu storage " " " " " " waste storage
PRODUCTION	F G H B	Accounting of input of the conversion area " " output " " " " " " input " " dry production area " " output " " " " "
ANALYSIS and RECOVERY	I K	Accounting of input and output of the analysis area " " " " " " " recovery area

Table 5-2: Additional Installations of the MBA Production Area

Place (Fig.5.1-2)	Installations
a	In the calibrated storage tank instruments for the measurement of level and density of the Pu nitrate solution are installed. These informations are continuously recorded at the safeguards office.
b	At the positions for 2.5 kg PuO_2-containers of the interim storage rack installed micro switches indicate on a record at the safeguards office, whether or not the positions are empty.
e	The homogenisator is equipped with a level (or weighing) device, which indicates continuously on a record at the safeguards office the level (or weight) of the fissile material being in the homogenisator.
c	Counter for green pellets transfered from the powder preparation to the pellet production. The time dependent number of pellets is recorded at the safeguards office.
d	Counter for sintered pellets transfered from the pellet production to the pin production. The time dependent number of pellets is recorded at the safeguards office.

As criterion for k is assumed: With a probability of detection of 95 % (P_D = 0.95) a falsification of more than 5 % (r = 0.05 n) of the units should be detected. In the following Tab. 5.3 for different values of n, the corresponding values of k, calculated according to the equation

$$\frac{k}{n} = 1-0{,}05^{\;1/r}$$

are given

n	k
40	31
80	42
200	52
400	56

Tab. 5-3: Different values for k dependent on n

5.1.2.3 Physical inventory

The frequency of physical inventories will be in the range of 2-10 per year.

In the MBA storage area the physical inventory can be taken by checking the seals of the various containers.

Since the normal inventory of the other MBAs corresponds to only one day's throughput, the inventory can be accounted for as output (product and waste).

However, the fissile material in the interim storages of MBA production has to be measured separately.

5.1.2.4 Identification of strategic area

With the establishment of the MBAs, the strategic areas in the fabrication plant are fixed to a large extent. They are obtained by connecting all the places at which safeguards activities, as developed later, are carried out routinely. These areas are shown in Fig. 5.1-4.

5.1.3 Surveillance

The different surveillance measures to be established within the ALKEM-type plant are given in the context of the safeguards procedures.

The extent of the surveillance measures is of course strongly influenced by the degree of automatization and tamperresistance of the safeguards instruments and techniques used.

A special design feature of the plant which facilitates safeguards is worth mentioning here: The storages, in which the major bulk of the fissile material is located normally, are separated from the production part by a γ-lock. Both storages and the γ-lock are directly adjacent to the safeguards office, thus facilitating the safeguards activity.

5.2 Safeguards procedures

5.2.1 Initial procedures

Before a facility is subject routinely to safeguards, several initial activities have to be undertaken.

At the beginning some design information has to be provided to the safeguards organisation. It should comprise only those data which are relevant to the application of safeguards. The corresponding information for the ALKEM type fabrication plant is given in section 3.

A first initial procedure carried out by inspectors at the plant would be the comparison of the design information with the actual plant.

The design information shall be used for the following purposes:

To determine material balance areas (MBAs) for safeguards,
to select strategic areas,
to establish the records and reports requirements,
to establish requirements and procedures for verification.

Furtheron an initial accounting report on all nuclear material subject to safeguards should be provided and located in the plant.

The comparison of the initial accounting report with the actual situation at the facility would be the second initial inspection procedure.

5.2.2 Procedures during routine operation

The detailed inspection procedures during routine operation of the plant are given in the following for the different MBAs.

On the basis of the annual throughput of the fabrication plant and the batchsize, the frequency of the execution of the procedures has been analysed.

Full coverage by inspection has been assumed. After assessing the time required per unit activity, a lower and an upper limit of the total time for inspections at the boundary of each MBA could be obtained (Tabs. 5.2-1 to 5.2-7). The total inspection efforts are given in Tab. 5.2-8. It is to be noted that these efforts correspond to the net time required to carry out a given activity at the plant. Actual inspection time will be more.

Finally a single form of record is proposed into which the plant operator can enter the informations obtained by qualitative and quantitative accounting of fissile material. This form is designed according to the Agency's requirements. Computerized data processing has been assumed (form no. 1).
It is to be noted that because of similarity of procedures used in recording the inventory changes from and to a MBA, a single form for accounting records can be used. Because of different types of measuring methods used in establishing a material balance for the different MBAs, different types of operating records have to be maintained. No attempt has been made in this report to develop accounting records.

Form no. 1 can also be used for reporting purposes as it meets all the requirements for a reporting system. The rows 15 and 16 need not be filled.

5.2.2.1 MBA 1 - Storage area

For noting down the informations obtained at the MBA storage the plant operator can use form no. 1. The safeguards procedures and efforts for the MBA are given in Tabs. 5.2-1 to 5.2-3.

5.2.2.1.1 Pu storage

Procedure 1

All fissile material coming into or leaving the Pu storage is contained in closed and marked units, either containers or bottles.

The units therefore, have to be counted and identified only by the inspector. He will be informed by the plant operator or the indication device installed at the Pu storage, if a transfer is intended. The amounts contained in these units are taken to be the same as the shipper's data at this point. At MBA 2 a random sampling technique is used to determine the amount in these containers.

Procedure 2

The taking of physical inventory implies counting and identification of the units in the Pu storage.

5.2.2.1.2 Pin storage

Procedure 3

The closed and marked units, tubular containers with one hundred fuel pins each, coming into or leaving the pin storage have to be counted and identified by the inspector. He will be informed by the plant operator or the indication device installed at the pin storage, if a transfer is intended.

Procedure 4

The taking of physical inventory implies counting and identification of the units in the pin storage.

5.2.2.1.3 Waste storage

Procedure 5

The closed and marked units, plastic bags and bottles to be stored, have to be registered, correlated to the respective batch and measured. The bags containing solid waste are measured by n-counting, the bottles containing liquid waste by passive γ-interrogation. If the fissile material content is higher than a preset value, the waste will be recovered later on.

Procedure 6

After measurement the bags are put into separate barrels for recoverable and not recoverable wastes. To prevent repeated measurements of the same units, the marked barrels and the bottles have to be sealed.

Procedure 7

At certain intervals the instruments for waste measurement have to be recalibrated with inspector's standards, so that the correctness of the information can be ensured.

Procedure 8

The closed and marked units, barrels and bottles leaving the waste storage have to be registered by the inspector. He will be informed by the plant operator or the indication device installed at the waste storage, if a transfer is intended.

Procedure 9

The taking of physical inventory implies counting and identification of the units in the waste storage.

5.2.2.2 MBA 2 - Production area

For recording the information obtained at the MBA 2 the plant operator can use form no. 1. The safeguards efforts and procedures for this MBA are given in Tabs. 5.2-4 and 5.2-5.

In case of PuO_2 powder as raw material the production process starts with the powder preparation steps (Procedures 23 onwards).

However, if the fissile material is received as Pu nitrate ($Pu(NO_3)_4$)solution, conversion steps (Procedures 10 onwards) precede the powder preparation.

5.2.2.2.1 Conversion area

Procedure 10

The closed and marked units, bottles with Pu nitrate solution, coming into the conversion area, have to be counted and identified by the inspector. He will be informed by the plant operator if a transfer is intended.

Procedure 11

The level and density measurement for the determination of the amount of solution and the sampling has to be observed by the inspector. He gets also samples of every measured bottle. If PuN bottles are received, only random measurements are carried out. Only in case of significant shipper receiver differences the bottles of the respective campaign are measured completely. The bottles coming directly from the recovery area (recycled material) are measured completely.

Procedure 12

At certain intervals the measuring tank for the determination of the amount of Pu nitrate solution has to be recalibrated in presence of the inspector to ensure the correctness of information obtained.

Procedure 13

From each bottle the inspector gets also samples. A part of them is submitted to the operator's analytic laboratory on a random basis. Since the operator does not know the corresponding bottles from which the inspector's samples have been submitted, a subsequent comparison of the analytic results of the operator's and the inspector's samples would indicate any intentional change. In this way the inspector does not have to observe the actual analysis of the samples.

Procedure 14

The gross-tara weighing of containers with PuO_2 powder leaving the conversion area has to be observed by the inspector. Besides, the containers have to be counted and sealed.

Procedure 15

At certain intervals the balance for the determination of the amount of PuO_2 powder leaving the conversion area has to be recalibrated by use of inspector's standard weights.

Procedure 16

Before transfer to the Pu storage area, samples are taken in the presence of the inspector from each of the PuO_2 containers. He gets samples also.

Procedure 17

From each container, from which samples are taken, the inspector gets his own sample. He obtains the correct analytical results in the same way as described in P-13.

Procedure 18

Twice a day the inspector compares the time dependent level of the homogenization tank (interim storage a Fig. 5.1-2 of the conversion area) which is recorded at the safeguards office with the simulation data. Thereby the inspector gets some continuity of information on the large amount of Pu nitrate solution between physical inventories.

Procedure 19

A physical inventory is normally taken after completion of each small campaign ($\leq$ 200 kg PuO_2) or for larger campaigns twice a year. A complete material balance is established with the uncertainty ranges (chapter 6) after the completion of a physical inventory.

Besides the measurements of the 'pushed out' fissile material the contents of the interim storage a , in which the major bulk of fissile material of the conversion area is stored, has to be measured. The inspector has to observe the measurement of level and density and the sampling. He gets his own sample.

Procedure 20

From the homogenization tank the inspector gets his own sample. Together with a few samples of similar composition it is submitted to the operator's analytic laboratory. The correctness of the result can be ensured according to P-13.

Procedure 21

The taking of a physical inventory comprises both the measurement of fissile material content of the homogenization tank (P-19, P-20) and the measurement of the rest of fissile material, being inside the conversion area, as output after pushing out. With regard to the material already converted, the required procedure is the same as P-14 and P-16, the other material is measured according to P-5.

Procedure 22

The procedure to be carried out with inspector samples obtained according to P-21 corresponds to P-17.

5.2.2.2.2 Dry production area

Procedure 23

The closed and marked units, containers with PuO_2 powder coming into the dry production area, have to be counted and identified by the inspector. He will be informed by the plant operator if a transfer is intended.

Procedure 24

The gross-tara weighing of the containers for the determination of the amount of PuO_2 powder and the sampling has to be observed by the inspector. He gets also samples of every weighed container. If PuO_2 powder is received, normally random measurements are carried out. Only in case of significant shipper receiver differences the containers of the respective campaign are measured completely. No measurement of the incoming units is required if $Pu(NO_3)_4$ was received or in case of recycled material, because it is already measured as output of the conversion area (P-17).

Procedure 25

At certain intervals, the balance for the determination of the respective amounts of PuO_2 powder transfered has to be recalibrated by use of inspector's standard weights.

Procedure 26

From each container, from which samples are taken, the inspector gets his own sample. He obtains the correct analytic results in the same way as described in P-13.

Procedure 27

The calorimetric and n-counting measurements of tubular containers leaving the production area have to be observed by the inspector. Besides, the closed and marked containers have to be counted and sealed.

Procedure 28

At certain intervals the calorimeter with the n-counter has to be recalibrated by use of inspector's standards.

Procedure 29

Twice a day the inspector compares the time dependent

1. content of the container storage (interim storage b Fig. 5.1-2) of the powder preparation area)
2. level (or weight) of the homogenization vessel (interim storage c Fig.5.1-2) of the powder preparation area)
3. number of green pellets transfered from the powder preparation to the pellet production area(d Fig. 5.1-2)
4. number of sintered pellets transfered from the pellet production to the pin production area (e Fig. 5.1-2)

which are recorded at the safeguards office with the corresponding simulation data.

Thereby the inspector gets some continuity of information on the interim storages and on the flows of fissile material inside the dry production area between physical inventories.

Procedure 30

If a smaller campaign (≤ 200 kg PuO_2) is finished or in case of large campaigns twice per year, a physical inventory has to be taken. Besides the measurements of the 'pushed out' fissile material, the contents of interim storages haveto be accounted for separately. On the one hand, the containers with PuO_2 powder being at the interim storage b have to be counted and identified by the inspector. On the other hand,the measurement of the amount of fissile material being in the homogenization vessel c and the sampling has to be observed by the inspector. He gets his own samples.

Procedure 31

The procedure to be carried out with inspector samples obtained according to P-30 corresponds to P-20.

Procedure 32

For taking of a physical inventory not only the fissile material being in the interim storages b and c has to be accounted for, but also the rest of the fissile material being inside the dry production area has to be measured. For this purpose the material will be pushed out. The final product involved is treated as described in P-27, other fissile material is measured corresponding to P-5.

5.2.2.3 MBA 3 - Analysis and recovery

For noting down the information obtained at the MBA analysis and recovery the plant operator can use form no. 1.

The safeguards procedures and efforts at the MBA analysis and recovery are given in Tab. 5.2-6 and 5.2-7.

5.2.2.3.1 Analysis area

Procedure 33

The samples coming from different areas within the plant and the corresponding analytic results of every sample are noted down by the operator into the accounting record. At certain intervals these informations are made available to the inspector.

Procedure 34

If a certain amount of analysed samples has accumulated, they are filled into a bottle. The closed and marked bottles leaving the analytic laboratory have to be registered by the inspector.

Procedure 35

The taking of physical inventory implies reception of information on samples, being in the analysis area, by the inspector. They have to be analysed before completely.

5.2.2.3.2 Recovery area

Procedure 36

The units coming into the recovery area have to be registered by the inspector.

Their contents of fissile material is already known from the foregoing measurement at the waste storage area.

Procedure 37

The closed and marked units, bottles with Pu nitrate solution leaving the recovery area, have to be registered by the inspector.

The units are measured only as input of the conversion area.

Procedure 38

For taking a physical inventory the recoverable waste inside the recovery area has to be recovered completely. The 'pushed out' fissile material is measured as $Pu(NO_3)_4$ according to P-11 and P-13 and as waste according to P-5.

1) a = 2.5 kg PuO_2-container
b = 10 l-bottle
....
2) g = PuO_2-powder
h = Pu nitrate solution
....
3) l = MBA storage
m = MBA production
....
4) r = SRD's
s = Identified mistake
....

PAGE NO. ......

ACCOUNTING RECORD

MBA: ....

LINE	UNIT 1)	IDENTIFICATION	TYPE OF MATERIAL 2)	FROM	TO	PHYSICAL INVENTORY	DATE	HOUR	PU-CONTENT					MEASUREMENT RESULTS		REPLACED	
									239	240	241	242	TOTAL	DETERMINATION OF QUANTITY	ANALYTIC RESULT	BY LINE:	DUE TO: 4)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1																	
2																	
3																	

Form No. 1: Accounting record

Table 5.2-1: Safeguards Procedures and Efforts at the MBA 1-Storage Area (Pu Storage)

No. of procedure	Activity		Units	Contents	Origin	Through-put of Pu-storage /units/yr/	Number of stored units (average)	Number of physical inventories per year	Number of activities per year	Net time required per activity /h/	Total net time for inspector / h/yr / Lower limit	Total net time for inspector / h/yr / Upper limit
1	Counting and identification of units during transfer	Alternative: PuO_2 received	Container	2.5kg PuO_2	Shipper	800			1600	0.025	40	
			"	"	Recov/Conv.	87			174	"	4.35	
		Alternative: PuN received	Bottle	101 PuN ≙ 1.5 kgPu	Shipper	1220			2440	"	-	61
			Container	2.5kg PuO_2	Shipper/Conv	800			1600	"	-	40
			"	"	Recov/Conv.	87			174	"	-	4.35
2	Counting and identification of stored units	Alternative: PuO_2	Container	2.5kg PuO_2			40	2 ÷ 10	80÷400	"	2÷10	-
		PuN	Bottle	101 PuN ≙ 1.5 kgPu			59	2 ÷ 10	118÷590	"	-	2.9÷14.75
									Subtotal / h/a /:		46.35	120.1

Table 5.2-2: Safeguards Procedures and Efforts at the MBA 1-Storage Area (Pin Storage)

No. of procedure	Activity	Units	Contents	Origin	Throughput of pin storage [units/a]	Number of stored units (average)	Number of physical inventor. per year	Number of activities per year	Time required per activity [h]	Total time for inspector [h/a] Lower limit	Total time for inspector [h/a] Upper limit
3	Counting and identification of units during transfer	Tubular containers	100 fuel pins with 4.87 kg PuO_2 in total	Production area	400			800	0.05	40	40
4	Counting and identification of stored units	"	"			20	2÷10	40÷200	0.05	2	10
						Subtotal [h/a]:				42	50

Table 5.2-3: Safeguards Procedures and Efforts at the MBA 1-Storage Area (Waste Storage)

No. of procedure	Activity	Units	Contents (average)	Origin	Throughput of waste storage [units/a]	Number of units stored (average)	Number of campaigns per year	Number of activities per year	Time required per activity [h]	Total time for inspector [h] Lower limit	Total time for inspector [h] Upper limit
5	Registration and measurement of incoming waste units	Plastic bags	68g PuO_2	Product. area Analysis and recovery area	4000 ≙ 273kg PuO_2/a	-	-	4000	0.1	400	400
6	Sealing of barrels with plastic bags and of bottles	Barrels, bottles	-	-	873	-	-	873	0.05	43.7	43.7
7	Recalibration of measuring instruments	-	-	-	-	-	-	200	0.5	100	100
8	Counting and identification of outgoing waste units	Barrels, bottles	-	-	873	-	-	873	0.025	21.8	21.8
9	Counting and identification of stored waste units	"	-	-	-	44	2÷10	88÷440	0.025	2.2	11
									Subtotal [h/a]	567.7	576.5

Table 5.2-4: Safeguards Efforts at the MBA Production Area (Conversion Area)

No. of procedures	Activity	Units	Contents	Origin	Throughput /units/a/	Number of stored units (average)	Number of physical inventories per year	Number of activities per year	Time required per activity /h/	Total time for inspector /h/a/ Lower limit	Total time for inspector /h/a/ Upper Limit
1	2	3	4	5	6	7	8	9	10	11	12
10	Counting and identification of incoming units	Bottles	101 PuN = 1.5kg Pu	Pu-storage: Recovery:	0÷1220 +133	-	-	133÷1353	0.025	3.32	33.8
11	Measurement of incoming units and sampling	"	"	"	"	-	-	PuO_2 received: 133	0.5	67	
								PuN received, SRD's stated: 1353	0.5		677
12	Recalibration of measuring instruments	-	-	-	-	-	-	10	2	20	20
13	Submission of samples and comparison of analytic results	-	-	-	-	-	-	PuO_2 received: 133	0.1	13.3	
								PuN received, SRD's stated: 1353	0.1		135.3

Table 5.2-4 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
14	Counting, sealing and measurement of outgoing units	containers	2.5kg PuO_2	-	87÷887	-	-	87 - 887	0.2	17.4	177.4
15	Recalibration of measuring instrument	-	-	-	-	-	-	40÷200	0.25	10	50
16	Sampling of outgoing units	-	-	-	-	-	2÷10	Throughput 87units 66÷87	0.1	6.6	
								Throughput 887 " 112÷470	0.1		47
17	Submission of samples and comparison of analytic results	-	-	-	-	-	2÷10	"	0.1	6.6	47
18	Comparison of level records from interim storage with simulation	-	-	-	-	-	-	400	0.1	40	40
19	Measurement of amount of solution in the interim storage and sampling	-	-	-	-	-	2÷10	2÷10	0.25	0.5	2.5

Table 5.2-4 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
20	Submission of samples and comparison of analytic results	-	-	-	-	-	2÷10	6÷30	0.1	0.6	3
21	Counting, sealing, measurement and sampling of outgoing units	The total time for inspectors required for procedures 21 and 22 is already contained in procedures 14, 16, 17 and 5									
22	Submission of samples and comparison of analytic results										
								Subtotal /h/a/		185.32	1,233.00

Table 5.2-5: Safeguards Efforts at the MBA 2 - Production Area (Dry Production area)

No. of procedure	Activity	Units	Contents	Origin	Throughput /units/a/	Number of Stored unit (average)	Number of physical inventories per year	Number of activities per year	Time required per activity /h/	Total time for inspector /h/a/ Lower limit	Total time for inspector /h/a/ Upper limit
1	2	3	4	5	6	7	8	9	10	11	12
23	Counting and identification of incoming units	Container	2.5kgPuO_2	Pu-storage	887	-	- -	887	0.025	22.17	22.17
24	Measurement of incoming units and sampling	"	"	"	"	-	-	PuN received: 0		0	
								PuO_2 received SDR's stated 800	0.5		400
25	Recalibration of measuring instrument	-	-	-	-	-	-	0 ÷ 200	0.25	0	50
26	Submission of samples and comparison of analytic results	-	-	-	-	-	-	PuN received: 0		0	
								PuO_2 received SDR's stated 800	0.1		80
27	Counting, sealing and measurement of outgoing units	Tubular containers	100 fuelpins with 4.87kg PuO_2 in total	-	400	-	-	400	$\frac{3}{4}$ $\frac{h}{unit}$	300	300

Table 5.2-5 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
28	Recalibration of measuring instrument	-	-	-	-	-	-	10	3	30	30
29	Comparison of records of interim storages and pellet counters with simulation	-	-	-	-	-	-	1600	0.1	160	160
30	Counting and identification of containers at interim storage (b) Measurement and sampling of PuO_2 powder at interim storage (c)	-	-	-	-	-	2÷10	2÷10	0.5	1	5

Table 5.2-5 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
31	Submission of samples from interim storage c and comparison of analytic results	-	-	-	-	-	2÷10	6÷30	0.1	0.6	3
32	Counting, identification and measurement of outgoing units	The total time for inspectors required for procedure 32 is already contained in procedures 27 and 5									
								Subtotal /h/a/		513.77	1050.17

Table 5.2-6: Safeguards Efforts at the MBA Analysis and Recovery (Analysis Area)

No.of procedure	Activity	Units	Contents	Origin	Throughput [units/a]	Number of stored units (average)	Number of physical inventories per year	Number of activities per year	Time required per activity [h]	Total time for inspector [h/a] Lower Limit	Total time for inspector [h/a] Upper Limit
33	Reception of analytic results	-	-	Different areas of the plant	-	-	-	100	0.25	25	25
34	Registration of outgoing bottles	Bottles	PuN	-	100	-	-	100	0.05	5	5
35	Registration of samples in the analysis area	-	-	-	-	25	2÷10	50÷250	0.025	1.25	6.25
								Subtotal [h/a]:		31.25	36.25

Table 5.2-7: Safeguards Efforts at the MBA Analysis and Recovery (Recovery Area)

No. of procedure	Activity	Units	Contents	Origin	Throughput /units/a/	Number of stored units (average)	Number of physical inventories per year	Number of activities per year	Time required per activity / h /	Total time for inspector /h/a/ Lower limit	Total time for inspector /h/a/ Upper limit
36	Registration of incoming units	**Barrels**, bottles	Recoverable waste	Waste storage area	800 $\hat{=}$250kg PuO_2/a	-	-	800	0.025	20	20
37	Registration of outgoing units	Bottles	Pu nitrate solution	-	133 $\hat{=}$ 200kg Pu/a	-	-	133	0.025	3.36	3.36
38	Measurement of outgoing units	The total time for inspector required for procedure 38 is already contained in procedures 11,13 and 5									
									Subtotal/ h/a/	23.36	23.36

Table 5.2-8: Total Inspection Efforts of an ALKEM Type Fuel Fabrication Plant

	Total time for inspector /¯n/a_/ Lower limit	Upper limit
MBA Storage area		
Pu Storage	46.35	120.1
Pin Storage	42	50
Waste Storage	567.7	576.5
Subtotal:	656.05	746.6
MBA Production area		
Conversion area	185.32	1,233.0
Dry production area	513.77	1,050.17
Subtotal:	699.09	2,283.17
MBA Analysis and recovery		
Analysis area	31.25	36.25
Recovery area	23.36	23.36
Subtotal:	54.61	59.61
TOTAL /¯h/a_/:	1409,75	3,089.38

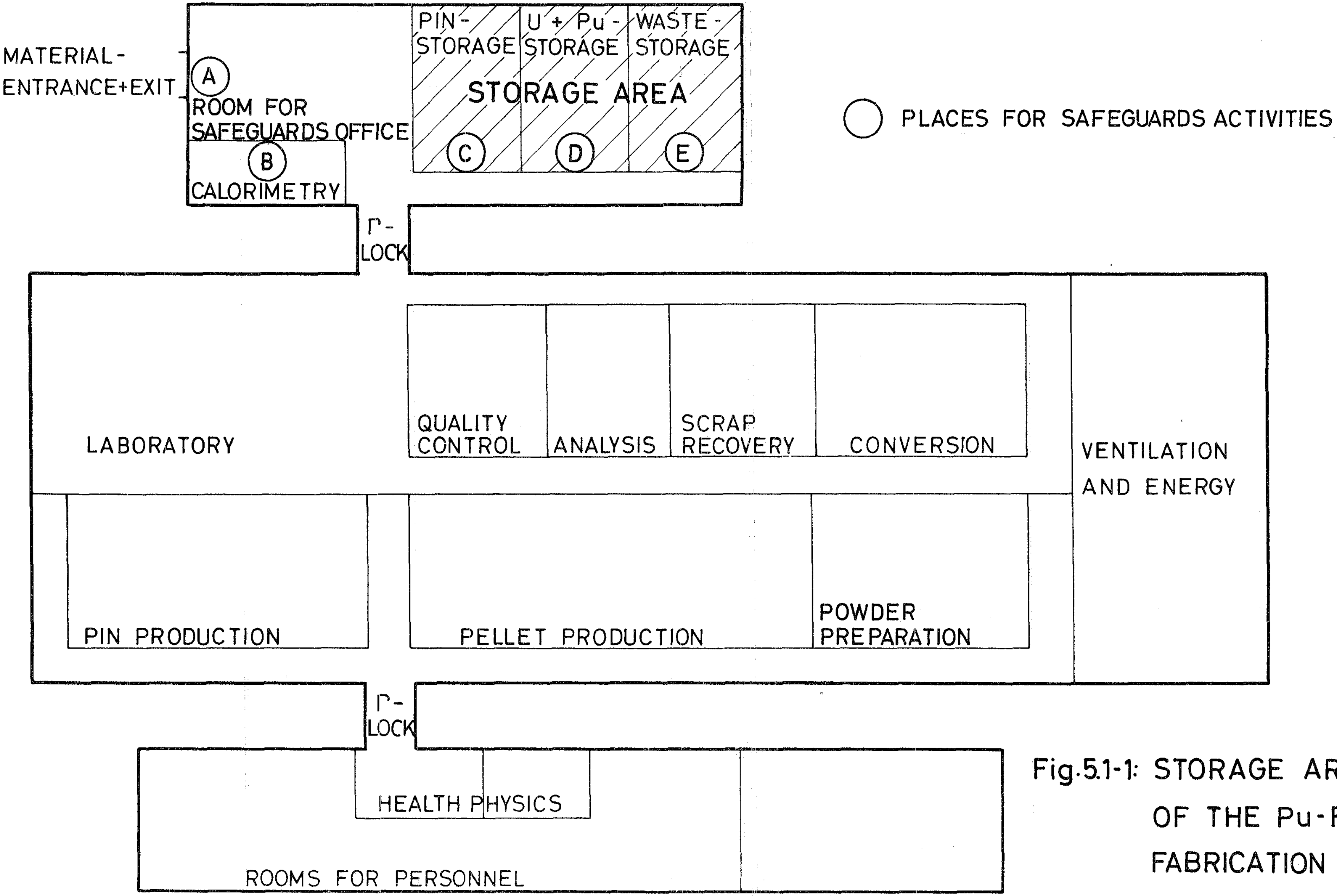


Fig.5.1-1: STORAGE AREA OF THE Pu-FUEL FABRICATION PLANT

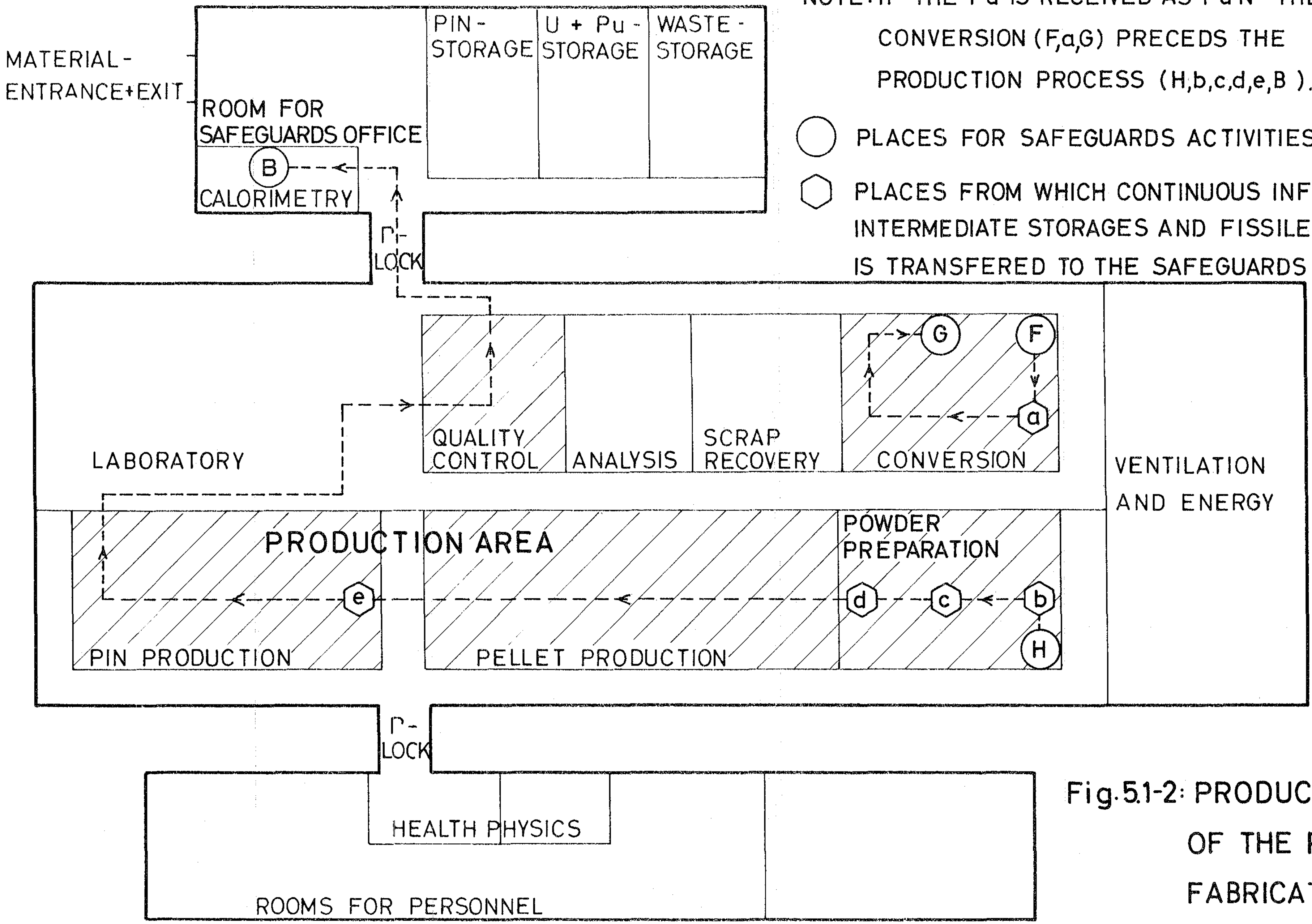


Fig. 5.1-2: PRODUCTION AREA OF THE Pu-FUEL FABRICATION PLANT

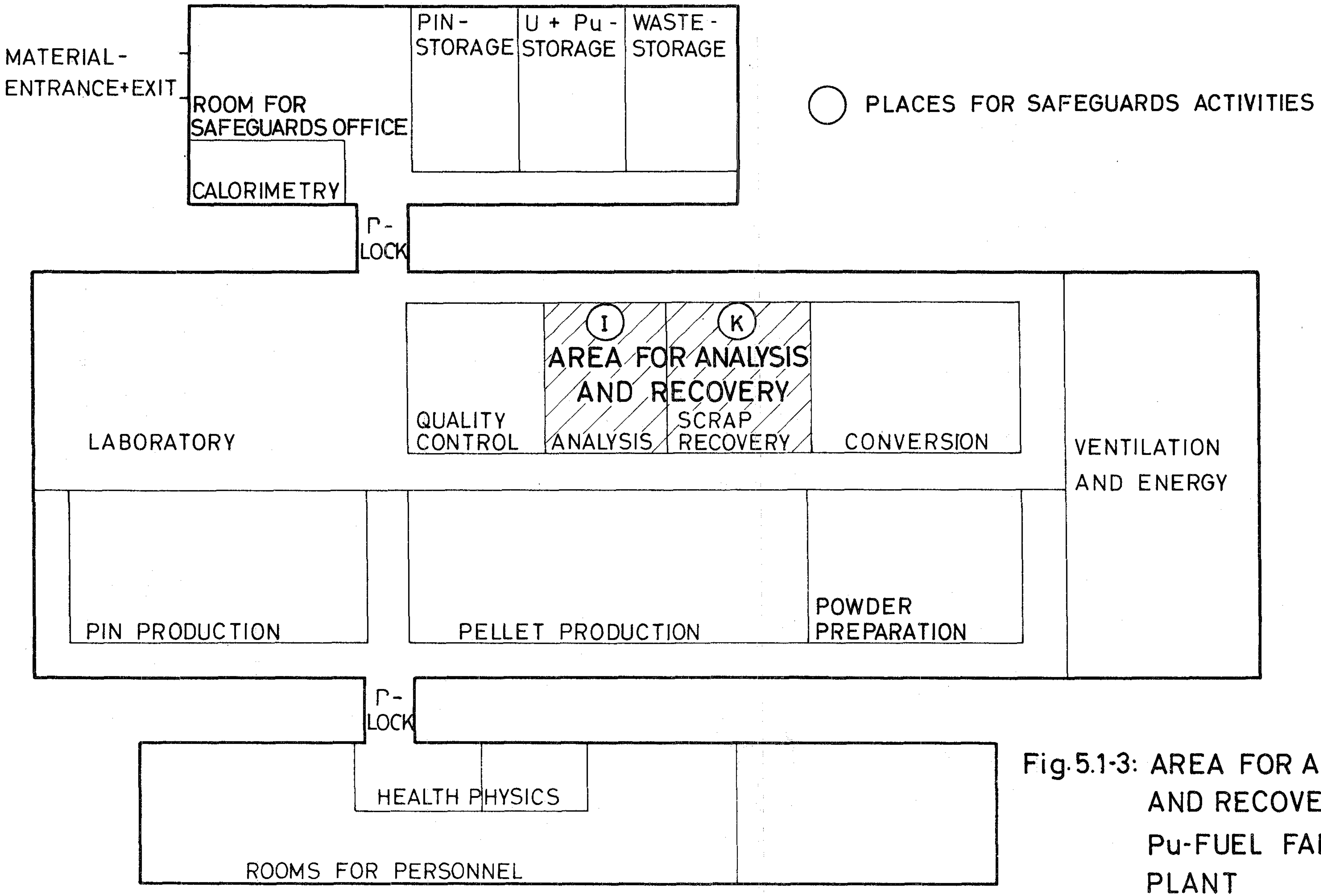


Fig. 5.1-3: AREA FOR ANALYSIS AND RECOVERY OF THE Pu-FUEL FABRICATION PLANT

6. Independent material balance and the probability of detection

The procedures developed in chapter 5 should enable a safeguards organisation to make a statement, in respect of the plant, of the amount of material unaccounted for (MUF) over a specific period, giving the limits of accuracy of the amounts stated. For this purpose, a material balance has to be established, i.e. a physical inventory has to be taken. It has been assumed for the plant under study that material balance will be established 2-10 times a year, depending on the size of the campaign. In this chapter, two examples for two campaigns each with two different types of input forms (PuO_2 and $Pu(NO_3)_4$), have been given with the associated variance of the MUF and the 0.95/0.95 probabilities of detection. These values have been calculated under the assumption that the material balances have been established independently by the safeguards organisation.

6.1 Theoretical considerations

If one assumes that the plant inventory is zero at the beginning and the end of each campaign the MUF-value which is defined as the difference between book inventory and physical inventory is given by

$$\begin{aligned} MUF &= M_{input} - M_{output} = \\ &= M_{input} - M_{prod} - M_{waste} \end{aligned} \qquad (1)$$

Because of measurement errors MUF is a random variable; it can be assumed as normal distributed as it consists of sums of random variables. If no unmeasured losses exist, it can then be taken that the expectation value of the MUF is the amount m of fissile material diverted in the course of the campaign. In formulas

$$MUF \sim n\ (m;\sigma) \qquad (2)$$

where σ^2 is the variance of MUF:

$$\sigma^2 = \text{var } MUF = \text{var } M_{in} + \text{var } M_{prod} + \text{var} M_{waste} \qquad (3)$$

At the end of a campaign, i.e. completion of a material balance, the inspector has to make a statement on whether the MUF value can be considered as significant or not. For this purpose he fixes a threshold x_c for the MUF value in the sense that he considers the MUF as significant if the realized MUF value is greater than x_c. The threshold x_c is connected with a probability of first kind error α by

$$1-\alpha = \Phi(\frac{x_c}{\sigma}) \qquad (4)$$

For a given threshold x_c one can calculate the probability of detection p(m) in the case the amount m will be diverted. One obtains

$$p(m) = \text{prob}(MUF>x_c/m) = \Phi(\frac{m}{\sigma} - \frac{x_c}{\sigma})$$

or, with (4)

$$p(m) = \Phi(\frac{m}{\sigma} - \Phi^{-1}(1-\alpha)) \qquad (5)$$

where Φ^{-1} is the inverse function of Φ.

One can calculate that amount m of fissionable material, the diversion of which leads to a probability of detection of 0.95. For $\alpha = 0.05$ one obtains

$$0.95 = \Phi(\frac{m}{\sigma} - \Phi^{-1}(0.95))$$

or

$$m_{0.95/0.95} = 2\,\Phi^{-1}(0.95)\cdot\sigma = 3.3\sigma \qquad (6)$$

As an example, two campaigns have been considered, the data of which are given in Tab. 6-1. For each campaign, the possibilities of PuO_2 input and $Pu(NO_3)_4$ input are considered separately.

In order to calculate the variance of the MUF one has to give the measurement units, the standard deviations of the random errors of the single measurement and the standard deviations of the systematic errors (calibration errors). These data are given in Table 6-2. According to (1) the variance of the MUF for one campaign is given by

$$\begin{aligned} \text{var (MUF)} = {} & (n_I \delta_{rI} + n_I^2 \delta_{sI}^2) m_I^2 + \\ & + (n_H \delta_{rH}^2 + n_H^2 \delta_{sH}^2) m_H^2 + \\ & + (n_{W1}\ {}^2_{rW1} + n_{W1}^2\ {}^2_{sW1}) m_{W1}^2 + \\ & + (n_{W2} \delta_{rW2}^2 + n_{W2}^2 \delta_{sW2}^2) m_{W2}^2 + \\ & + (n_p \delta_p^2 + n_p^2 \delta_{sp}^2) mp^2 \end{aligned}$$

where n is the number of measurements, δ_r and δ_s the relative standard deviations of the random and the systematic errors of single measurements and m the Pu-content of one measurement unit. The indices denote the different streams according to Tab. 6-1.

In establishing the variance of the MUF a number of conditions has been assumed, which should be mentioned.

i) Two campaigns one small for 200 kgs of Pu and one large for 980 kgs of Pu (the values given in Table 6-1 correspond to Pu-oxide and Pu-nitrate), have been assumed, as they more or less correspond to the low and high throughputs of the plant. The campaigns are for the production of Pu-containing fuel pins for fast breeder subassemblies.

ii) The 'hold-ups' correspond to the excess amounts which remain unused after the completion of a campaign. They are normally available as PuO_2 and can be measured along with the input birdcages, with the help of a calorimeter.The 'wastes' leaving the plant as measured discards, correspond to 1 % of the input stream and are assumed to be distributed equally between barrels and bottles containing wastes. The products are in the form of fuel pins each containing 42.6 gms of Pu; 100 of such pins correspond to one safeguards unit ;they have been assumed to be calorimetried at a time.

iii) A relative standard deviation for the systematic error component per measurement for all the measuring methods has been assumed in addition to the random part. Although in the chapter on instruments (3.4), this component has not been discussed, it appears to be present in all the methods assumed to be used for measurement. Although only limited data are available on the actual values of this part of the deviation, the assumed values (last column, Tab. 6-2) appear to be the ones which can be attained with the present day state of the art.

6.2 Analysis of the results

The results of the calculations are presented in Table 6-3. A number of points are of interest.

i) There is practically no difference in the values of $m_{0.95/0.95}$ for PuO_2 and $Pu(NO_3)_4$.

ii) For the smaller campaign of 200 kgs Pu, any diversion greater than 1.88 kgs of Pu can be detected with a probability of 95 %; this means that 1.88 kgs Pu is the threshhold value of MUF above which the MUF value is considered to be significant. For the larger campaign of 980 kgs, this value is greather than 9.1 kgs Pu.

iii) In all the cases the relative values of $m_{0.95/0.95}$ appear to be constant and correspond to ~ 0.93 % of the input. This is because of the fact that these values are controlled almost entirely by the relative standard deviations of the systematic error assumed in the examples, for the feed and the product streams. Because of the large number of measurements carried out in these streams for the establishment of the corresponding material balances, the influence of the random error on the threshold values of MUF becomes negligible.

Table 6-I: Data of the Campaigns Considered

	Small campaign (1)	Large campaign (2)
Input		
(a) /‾kg PuO_2_7	228	1120
(b) /‾kg $Pu(NO_3)_4$_7	408	2000
Holdup /‾kg PuO_2_7	11.4	22.8
Waste		
W_1; barrels /‾kg PuO_2_7	1.14	5.6
W_2; bottles /‾kg $Pu(NO_3)_4$_7	2.04	10
Product /‾kg PuO_2_7	214	1086

Table 6-II: Relevant Data for Establishing the Variance of MUF

	No.of measurement units in diff.campaigns				Content of one unit	Rel.St.dev.of random error of single measurement [%]	Rel.St.dev.of syst.error of single measurement [%]
	1a	1b	2a	2b			
Input birdcages	80		392		1 birdcage $\hat{=}$ 2.8 kg PuO_2 $\hat{=}$ 2.5 kg Pu	0.5	0.2
bottles		133		653	1 bottle $\hat{=}$ 3.06 kg $Pu(NO_3)_4$ $\hat{=}$ 1.5 kg Pu	0.3	0.25
Product	44	44	223	223	100 pins $\hat{=}$ 4.86 kg PuO_2 $\hat{=}$ 4.26 kg Pu	0.5	0.2
Holdup	4	4	8	8	1 birdcage $\hat{=}$ 2.8 kg PuO_2 $\hat{=}$ 2.5 kg Pu	0.5	0.2
Waste bottles	200	200	980	980	1 bottle $\hat{=}$ 10.2 g $Pu(NO_3)_4$ $\hat{=}$ 5 g Pu	10	2
barrels	100	100	490	490	1 barrel $\hat{=}$ 11.4 g PuO_2 $\hat{=}$ 10 g Pu		

Table 6-III: Standard Deviations of MUF and Amounts m of Diverted Material to be detected with a Probability of 0.95, for different Campaigns

Campaign	Standard dev $\sqrt{\text{var MUF}}$ [kg Pu]	$m_{0.95;0.95} = 3.3\sqrt{\text{var MUF}}$ [kg Pu]	$m_{0.95;\,0.95}$ [% of input]
1a	0.57	1.88	0.94
1b	0.55	1.82	0.91
2a	2.76	9.14	0.93
2b	2.73	9.02	0.92

7. Possibilities of improvements

Safeguards measures to be carried out according to the procedures of chapter 5, should be subject to constant,review with regard to possible improvements. Such improvements may be among others, to increase the objectivity and non-intrusiveness of the measures and the credibility of the information or to reduce the cost. Four types of possibilities have been touched shortly in this chapter. They are:

1. Instruments
2. Shipper-Receiver Correlations
3. Random Sampling
4. Plant Layout

7.1 Instruments

Three types of instruments are of importance for an ALKEM-type plant. They are, a) calorimeter for the determination of plutonium amounts in birdcages, pins, subassemblies or other containers; b) neutron counting setup for Pu-assay in different types of wastes; and c) γ-lock for controlling the personnel movements in and out of the active areas. All these instruments and the problems associated with them, have been discussed in some detail in chapter 3.4.

It is estimated that for the calorimeter, the problems on obtaining accurate half-life data, estimation of systematic errors, construction of the calorimeter and automatic data processing, can be solved by the end of 1972. The time scale and the estimated costs may be as follows:

Complete setup of a large pin-calorimeter with n-coincidence counting and an automatic data processing unit	end of 1972
Estimated costs (1971-72)	DM $600 \cdot 10^3$

The time scale for the neutron counting setup for waste measurements is also estimated to be the same as that for the calorimeter:

Complete setup for an automated n-counting unit for Pu-assay in waste-barrels and bottles	end of 1972
Estimated costs	DM $300 \cdot 10^3$

The γ-lock for personnel control is already available for industrial application.

7.2 Shipper-receiver correlations

Any plutonium, used for fabrication in an ALKEM type plant, has to come from a reprocessing plant. Therefore, if the representatives of the fabrication plant operator and the inspectors of the safeguards organisation are both present during the sampling of plutonium at the reprocessing plant, and the analyses of the samples are carried out by an **unpire laboratory** (which may be the laboratory of the reprocessing plant itself) under suitable observation by the same representatives, any further analysis of the same material for safeguards purposes can be reduced considerably or even eliminated at the input of the fabrication plant. The whole safeguards activity could then be restricted at this point to the checking and identification of container seals, i.e. to containment measures. This possibility has already been taken into account partially in developing the procedures of chapter 5. This causes a very significant reduction in safeguards efforts without reducing in any way the quality of the information obtained at the input of the plant. This is because of the fact that the information on material balance measurements at the product end of the reprocessing plant can be taken over fully at the input of the fabrication plant, without carrying out any measurement. The containment measure of sealing the containers so to say freezes the material balance information during transit of the containers from the reprocessing to the fabrication plant and enables the safeguards organisation to use it again. The efforts for executing containment measures in this connection are considerably less than those required for carrying out measurements.

A similar reduction in safeguards efforts at the input can be obtained if the shipper and the receiver plants are completely independent of each other and both of them measure the same amount of Pu independently and submit the measurement data to the safeguards organisation. If the values of the shipper receiver measurements are found to be within the uncertainties of measurement errors alone (the values of which must be known to the safeguards organisation beforehand), the safeguards organisation need not in that case carry out any additional measurements and can use the data supplied by the two plant operators for safeguards purposes.

7.3 Use of random sampling method

Random sampling is a standard practice in quality control. In chapter 5.1 it was shown that the relative number of samples to be analysed for a 0.95/0.95 probability of detection, decreases very rapidly with increasing number of the total items to be safeguarded. It is to be noted that these numbers are only valid for an assumed value of the first kind error of 5 % and the corresponding value of the probability of detection of 95 %. Both these values are based on a judgement and not on any objective standards. However, under practical conditions, they appear to be reasonable when considered within the restrictions imposed by these practical conditions (costs, threshold values given by attainable measurement errors etc.). It was shown in a recent study /7.1/ that the total safeguards efforts in a reference fuel cycle can be reduced by more than a factor of 2 if instead of a full coverage a safeguards coverage, to ensure 0.95/0.95 probability of detection, is given.

7.4 Plant layout

The information network system, which generates, processes and distributes the information relevant to safeguards in a nuclear facility, may influence the safeguards efforts. If such information is generated throughout the plant and the distribution system is such that the safeguards inspectors have to receive them at various places, a large amount of safeguards efforts may have to be spent to ensure the credibility of the information received.

In the ALKEM type plant used as a base for the present report, the measuring equipment and intermediate storages for fissile material are arranged to a large extent inside the caissons. Instead of this, a better arrangement from the point of view of safeguards appears to be,to have a centralized information network system which is accessible for safeguards, transparent and easily verifiable. Such a system should have properly incorporated containment measures. The information system should not only supply information on the flow of fissile material but also on the amounts of intermediate storage in different caissons,which may exceed certain limits.Some rough estimates indicate that the safeguards efforts for the feed and product streams could be reduced by about 30 % by this arrangement.

A preliminary sketch of a plant is shown in Fig. 7-1 in which this requirement is fulfilled. The figure is self-explanatory. However, further detailed discussions with the operators of the plant are required to ensure that such a layout would also meet the requirements of the plant operation. This sketch is therefore to be considered as only very preliminary.

Literature

/¯7.1_/ R. Avenhaus, D. Gupta,
Effective Application of Safeguards Manpower and Other Techniques in Nuclear Fuel Cycles.
IAEA/SM-133/80 (1970)

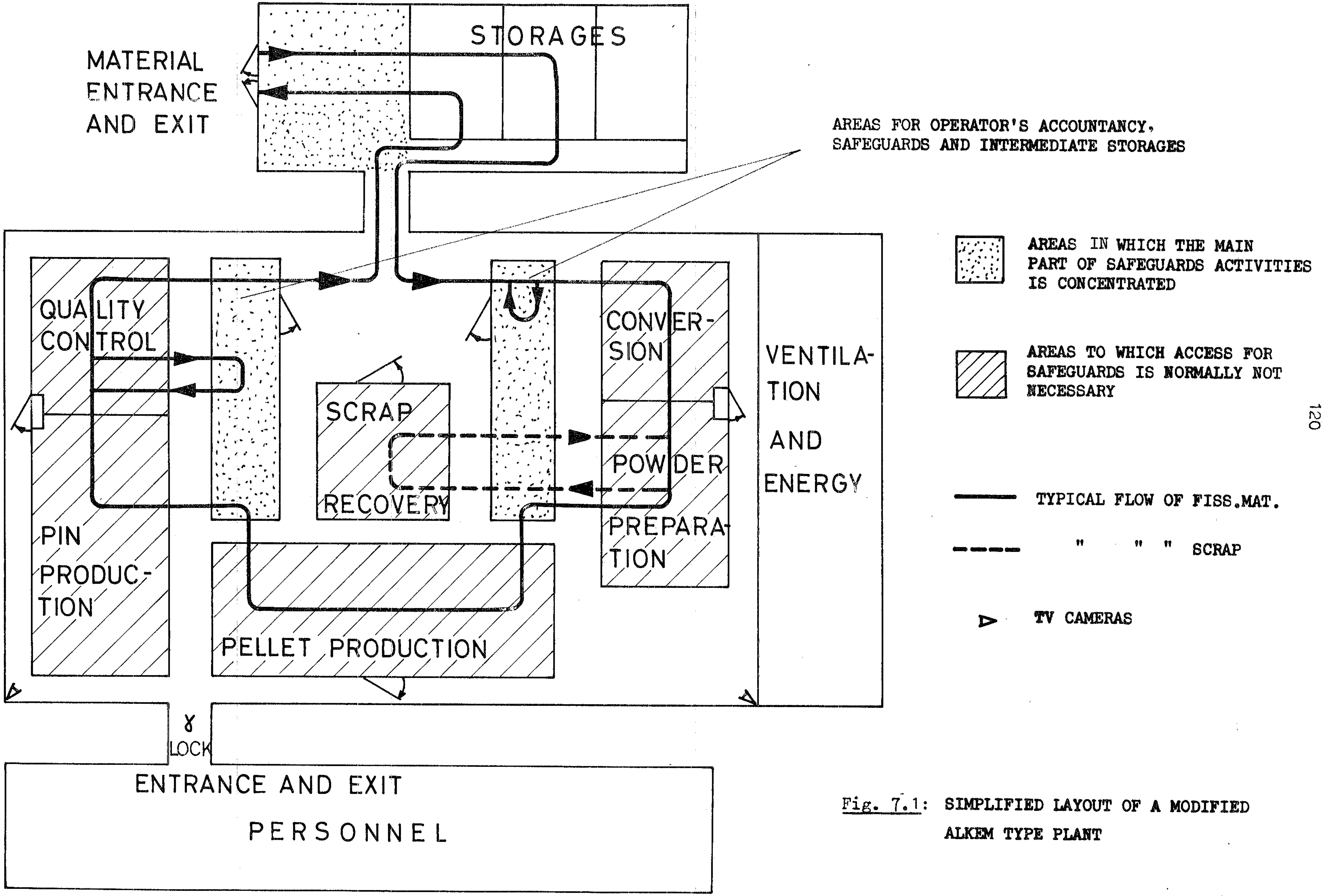


Fig. 7.1: SIMPLIFIED LAYOUT OF A MODIFIED ALKEM TYPE PLANT

Acknowledgement

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APPENDIX I

Simulation Program PUFAB with Subroutines GAUSS and RANDU (for generating normally distributed random numbers)and print-out for one simulated fabrication campaign.

```
            C      PROGRAMM PUFAB5
 0001              CALL FSPIE
            CCCC   THIS ROUTINE IS SPECIFIC FOR THE KARLSRUHE COMPUTER
 0002              DIMENSION RKAPPA(20),HMIN(20),HMAX(20),OKMAX(20),T(20),H(20),
                  1  ZLS(20),ABZW(20),OKMA(20),TREAL(20),ZRS(20),MARK(20),HHALB(20),
                  2 HSOLL(20),        OKSOLL(20),ZLSOR(20),OKRA(20),OKSOR(20),ZL(20),
                  3ZLOR(20),RORY(20)
            C
 0003        1000 FORMAT (I5)
 0004        1001 FORMAT (F10.2)
 0005        1002 FORMAT (8F10.3)
 0006        1003 FORMAT (' XNULL= ',F10.3)
 0007        1004 FORMAT (1H ,' THE INPUT IS NOT SUFFICIENT')
 0008        1005 FORMAT (1H0,'T=',F10.3,',H=',F9.3,' AND DIVERTED QUANTITY DIVERS
                 1= ',F10.3,' .ACCUMULATED PRODUCT =',F10.3)
 0009        1006 FORMAT(1H ,'OVERFLOW  UNIT 1,H(1)=',F10.3)
 0010        1007 FORMAT(1H ,'OVERFLOW  UNIT 2,H(2)=',F10.3)
 0011        1008 FORMAT(1H ,'AFTER STATEMENT 10 IS H(1)=',F10.2,'AND H(2)=',F10.2)
 0012        1009 FORMAT(1H ,'AFTER STATEMENT 12 IS H(1)=',F10.2,'AND H(2)=',F10.2)
 0013        1010 FORMAT('1 AFTER STATEMENT 14 IS IST H(1)=',F10.2,'  AND   H(2)=',
                 1F10.2, /,' WHEREAS',10X,' HSOLL(1)=',F10.2,' AND HSOLL(2)=',F10.2)
 0014        1011 FORMAT ('                    T(1)= ',F10.4,'        T(2)= ',F10.4, '
                 1   T(3)= ',F10.4,'    AND       T(4)= ',F10.4,/,'    WHEREAS    TREAL(1
                 2)',F10.4,'   TREAL(2)= ',F10.4,'  TREAL(3)= ',F10.4,'  AND TREAL(4)
                 4= ',F10.4,/)
 0015        1012 FORMAT (' XNULL = 0.0,THEREFORE T(1)= 0.0')
 0016        1013 FORMAT(/,'*******************')
 0017        1014 FORMAT (///,' NEW CAMPAIGN WITH INCREASED ZLS(I=',I2,')')
 0018        1015 FORMAT (' RKAPPA(I)  HMIN(I)    HMAX(I)    OKMAX(I)  ZLS(I)     ABZW(
                 1I)    HHALB(I)    RORY(I)')
 0019        1016 FORMAT (' AT  OKMA(I=',I2,')=' ,F 6.3,' AND OKMA(I-1=',I2,')=',
                 1 F6.3,' ONE GETS AN UNSTABLE STATE')
 0020        1017 FORMAT('      H(1)=',F10.5,'      H(2)= ',F10.5, '      H(3)= ',F10.5
                 1,'       H(4)= ',F10.5,'      H(5)= ',F10.5)
 0021        1018 FORMAT('1CHANGE OF ZLS(J=',I2,')',/)
 0022        1019 FORMAT (' HSOLL(1)=' ,F10.5,' HSOLL(2)= ',F10.5,' HSOLL(3)= ',F10.
                 15,' HSOLL(4)= ',F10.5,' HSOLL(5)= ',F10.5,/,  ' HOSOLL=',F10.3,'
                 2SUM OF INTERIM STORES   SUMZL=',F10.3,' .PLANNED PRODUCT =',F10.3)
 0023        1020 FORMAT ( ' MARK(1) WAS SET =1')
 0024        1021 FORMAT ( ' MARK(2) WAS SET =1')
 0025        1022 FORMAT ('  OVERFLOW  UNIT 3,H(3)=',F10.3)
 0026        1023 FORMAT(' MARK(3) WAS SET =1')
 0027        1024 FORMAT ('  OVERFLOW  UNIT 4,H(4)=',F10.3)
 0028        1025 FORMAT(' MARK(4) WAS SET =1')
 0029        1026 FORMAT ('     ZL(1)=',F10.5,'     ZL(2)= ',F10.5,'      ZL(3)= ',F10.5
                 1,'      ZL(4)= ',F10.5,'      ZL(5)= ',F10.5)
 0030        1027 FORMAT (' THE THEORETICAL    (T(I)) AND REAL    (TREAL(I)) TIMES,
                 1UNTIL A MINIMAL CONTENT OF THE CORRESPONDING UNITS IS REACHED,ARE
                 2')
 0031        1028 FORMAT (' CONTENT OF INPUT STORAGE =',F10.3)
 0032        1029 FORMAT (F10.3)
 0033        1030 FORMAT('  OKRA(1)=',F10.5,'  OKRA(2)= ',F10.5,'  OKRA(3)= ',F10.5,
                 1'  OKRA(4)= ',F10.5,'  OKRA(5)= ',F10.5)
 0034        1031 FORMAT (' OKSOR(1)=',F10.5,' OKSOR(2)= ',F10.5,' OKSOR(3)= ',F10.5
                 1,' OKSOR(4)= ',F10.5,' OKSOR(5)= ',F10.5)
 0035        1032 FORMAT (' NEW CAMPAIGN WITH INCREASED ABZW(K-1=',I2,')')
 0036        1033 FORMAT (' NOW AT TIME =',F10.3,' 1 KG PU-02 IS DIVERTED  FROM UNIT
                 1 ',I3)
```

```
          C
0037       6001 FORMAT (' SNAP.TIME=',G20.8)
0038            TTT=ZEIT(0)
          C     PREPARATION OF THE COMPUTER
0039            TIME =0.
0040            HOLD=0.
0041            HOSOLL=0.
0042            SUMZL = 0.
0043            PROD=0.
0044            SOLL =0.
0045            DIVERS =0.0
0046            R2REAL =0.
0047            R2SOLL=0.
          C
          C     READING OF PROCESS PARAMETERS
0048            READ (5,1029) HMAIN
0049            PRINT 1028,HMAIN
          C     HMAIN=CONTENT OF INPUT STORAGE (KG)
0050            READ (5,1000) N
0051            PRINT 1000,N
          C     N=NUMBER OF  FABRICATION UNITS
0052            READ(5,1001) DTD
0053            PRINT 1001,DTD
          C     DTD= TIME INTERVAL FOR SUMMATION (DAYS)
0054            READ (5,1002) (RKAPPA(I),HMIN(I),HMAX(I),CKMAX(I),ZLS(I),ABZW(I),
               1HHALB(I),RDRY(I),I=1,N)
          C     RKAPPA=FRACTION OF RECYCLE FROM UNIT I
          C     HMIN=MINIMAL CONTENT OF THE UNITS (KG)
          C     HMAX=MAXIMAL CONTENT OF THE UNITS (KG)
          C     OKMAX=MAXIMAL CAPACITY OF THE UNITS (KG/DAY)
          C     OKMAX(I) IS NOT ALLOWED TO BE GREATER THAN CKMAX(I-1)
          C     ZLS=FRACTION OF TNE OUTPUT STREAM WHICH IS USED TO BUILD UP THE
          C     INTERIM STORAGE OF THE UNIT
          C     ABZW=FRACTION OF DIVERSION FROM THE OUTPUT STREAM FROM UNIT I
          C     IT IS MEANT THAT THIS DIVERSION IS MADE BEFORE THE OUTPUT STREAM IS
          C     MEASURED
          C     MARK=MARKER WHICH INDICATES IF  THE INTERIM STORAGE SHALL BE USED
          C     (MARK=1) OR NOT (MARK=0)
          C     HHALB(I)=MAXIMUM ALLOWED CONTENT OF THE INTERIM STORAGE IN UNIT I
          C     RDRY(I)=FRACTION OF OUTPUT GOING TO THE DRY RECOVERY IN UNIT 2
0055            READ (5,1029) XNULL
0056            PRINT 1003 ,XNULL
          C     XNULL= CONSTANT INPUT (KG/DAY)
          C
          C
          C     ZLSOR ARE THE ORIGINAL VALUES  FOR THE FRACTIONS GOING TO INTERIM  STORES
0057            DO 10 I=1,N
0058            ZL (I) =0.
0059         10 ZLSOR(I) = ZLS(I)
          C
          C     INPUT DATA FOR SUBROUTINE GAUSS
0060            IX=333333333
0061            S= 0.5
0062            AM=10.
          C     BIGGEST DO LOOP FOR USING GAUSS
0063            DO 80  KI=1,100
0064            CALL GAUSS(IX,S,AM,V)
          C     AT ONE OF THE FOLLOWING CARDS THE C IN COLUMN 1 CAN BE EXTINGUISHED
```

```
              C      AT REQUEST
              CCCCCC DUMMY,ONLY FOR THE MOMENT TO SPARE TIME
              C      XNULL = V
              C      CKMAX(3) = V
              C      VERY BIG DO LOOP FOR VARIATION OF THE ABZW(I)
 0065                DO 70 K=1,5
 0066             14 IF (K.EQ.1)  GO TO 1
 0067                ABZW(K-1) = ABZW(K-1) + 0.02
              C
              C      BIG DO LOOP FOR VARIATION OF THE ZLS(I)
              C
              C      THE DO-INDEX WAS SET =1 IN ORDER TO SPARE OUTPUT FOR THE MOMENT
 0068              1 DO 63  J = 1,1
 0069                PRINT 1018,J
 0070                ZLS(J) = ZLS(J) + 0.01
 0071                PRINT 1003,XNULL
 0072                PRINT 1015
 0073                PRINT 1002,    (RKAPPA(I),HMIN(I),HMAX(I),CKMAX(I),ZLS(I),ABZW(I),
                    1HHALB(I),RDRY(I),I=1,N)
              C
              C      AT TIME=0 ALL H(I) ARE SET =0
              C      H= INVENTORY OF THE UNITS
              C      IF ZLS(I) OR ABZW(I) NOT EQUAL 0,THE ORIGINAL CKMAX(I) ARE SET TO OKMA(I)
 0074              2 DO 3 I = 1,N
              C      OKRA(I) MEANS THE REAL INPUT TO THE UNIT I+1
              C      OKSOR MEANS THE THEORETICAL INPUT TO THE UNIT I+1
 0075                OKMA(I) = OKMAX(I) *(1.-ZLS(I) - ABZW(I))
 0076                OKRA(I)=OKMA(I)*(1.-RKAPPA(I)-RDRY(I))
 0077                OKSOLL(I) = OKMAX(I) *(1.-ZLS(I))
 0078                OKSOR(I) = OKSOLL(I)*(1.-RKAPPA(I)-RDRY(I))
 0079             32 IF (I.EQ.1)  GO TO 33
 0080                IF (I.EQ.5)  GO TO 33
 0081                IF (OKMA(I).GT. OKMA(I-1)) GO TO 75
 0082             33 H(I) =0.
 0083                INST = 0
 0084                PROD = 0.
 0085                SOLL = 0.
 0086                R2REAL =0.
 0087                R2SOLL=0.
 0088                HSTORE = HMAIN
 0089              3 HSOLL(I) =0.
              C      EVALUATION OF TIME INTERVALS
              C      T(I) = THEORETICAL FILLING TIMES
              C      TREAL(I) = REAL FILLING TIMES
 0090                IF (XNULL.LE.0.0) GO TO 901
 0091                T(1)=HMIN(1)/XNULL
 0092                TREAL(1) = T(1)
 0093                IF (XNULL.LT.OKMA (1)) GO TO 900
 0094                GO TO 4
 0095            900 PRINT 1004
 0096                GO TO 999
 0097            901 T(1) = 0.
 0098                PRINT 1012
 0099              4 T(2)=T(1)+HMIN(2)/(OKSOR (1))
 0100                TREAL(2)=TREAL(1)+HMIN(2)/OKRA(1)
 0101                T(3)=T(2)+HMIN(3)/OKSOR(2)
 0102                TREAL(3)=TREAL(2)+HMIN(3)/OKRA(2)
 0103                T(4) = T(3) + HMIN(4)/OKSOR(3)
```

```
            TREAL(4) = TREAL(3) + HMIN(4)/OKRA(3)
            PRINT 1027
            PRINT 1011,T(1),T(2),T(3),T(4),TREAL(1),TREAL(2),TREAL(3),TREAL(4)
C
C           FOR THE DIFFERENTIAL EQUATIONS SEE KFK-REPORT 903,PAGE 19
          5 DO 18  I=1,N
            IF (H(I).GE.HMIN(I))  GO TO 16
            OKMA(I)=0.
            CKRA(I) =0.
            OKSOLL(I) =0.
            OKSOR(I) =0.
            GO TO 18
         16 IF(MARK(I).NE.1)  GO TO 17
            OKMA(I) = OKMAX(I)*(1.-ABZW(I))
            CKRA(I)=OKMA(I)*(1.-RKAPPA(I)-RDRY(I))
            OKSOLL(I) = OKMAX(I)
            CKSOR(I) = OKSOLL(I)*(1.-RKAPPA(I)-RDRY(I))
C           IF (I.EQ.1)  GO TO 18
C           IF (I.EQ.5)  GO TO 18
C           IF (OKMA(I).GT.OKMA(I-1))  GO TO 75
            GO TO 18
         17 CONTINUE
            OKMA(I) = OKMAX(I) *(1.-ZLS(I) - ABZW(I))
            OKRA(I)=OKMA(I)*(1.-RKAPPA(I)-RDRY(I))
            OKSOLL(I) = OKMAX(I) *(1.-ZLS(I))
            CKSOR(I) = OKSOLL(I)*(1.-RKAPPA(I)-RDRY(I))
C           IF (I.EQ.1)  GO TO 18
C           IF (I.EQ.5)  GO TO 18
C           IF (OKMA(I).GT.OKMA(I-1))  GO TO 75
         18 CONTINUE
C
C           NOW PRODUCTION CAN BEGIN
C           FOR THE FORMULAE SEE KFK-REPORT 903,PAGE 20
C
         15 IF (TIME.LE.0.)  GO TO 52
C           THE H(I) ARE EVALUATED USING THE "MEASURED" VALUES OKRA AND OKMA
C           HSOLL(I) DESIGNS THE PLANNED INVENTORY OF EACH UNIT
C           BOTH VALUES INCLUDE THE INTERIM STORAGES.
C           EMPTYING OF INPUT STORE
            HSTORE = HSTORE - XNULL*DTD
            IF (HSTORE.LE.0.)  GC TO 999
            H(1)=H(1)+XNULL*DTD-OKMA (1)*DTD
            HSOLL(1)=HSOLL(1)+XNULL*DTD -OKSOLL(1)*DTD
C           RECYCLE TO DRY RECOVERY IN UNIT 2
            DO 48 I=1,N
            R2REAL=OKMA (I)*RDRY(I) *DTD
            R2SOLL=CKSOLL(I)*RDRY(I)*DTD
         48 CONTINUE
            H(2)=(OKRA (1) - OKMA (2)) * DTD+H(2)+R2REAL
            HSOLL(2)=(OKSOR (1)-OKSOLL(2))*DTD+HSOLL(2)+R2SOLL
            H(3)=H(3)+(OKRA(2)-OKMA (3))*DTD
            HSOLL(3)=HSOLL(3)+(OKSOR(2)-OKSOLL(3))*DTD
            H(4)=H(4)+(OKRA(3)-OKMA (4))*DTD
            HSOLL(4)=HSOLL(4)+(CKSOR(3)-OKSOLL(4))*DTD
            PROD= PROD+OKRA(4)*DTD
            SOLL = SOLL + CKSOR (4)*DTD
            NN=N-1
            DO 49 I=1,NN
```

```
                H(5)=H(5)+RKAPPA(I)*OKMA(I)*DTD
             49 HSOLL(5)=HSOLL(5)+RKAPPA(I)*OKSOLL(I)*DTD
      C         THE OUTPUT OF UNIT 5 MUST BE CONSIDERED LATER
             50 DO 51 I=1,N
                IF(OKMA (I).EQ.0.)  GO TO 511
                DIVERS = DIVERS +ABZW(I) * OKMAX(I)*DTD
            511 HOSOLL=HOSOLL+HSOLL(I)
                IF(MARK(I).EQ.1)  GO TO 51
                IF(OKMA(I).EQ.0.) GO TO 51
                ZL(I) = ZLS(I)*OKMAX(I)*DTD + ZL(I)
            513 SUMZL = SUMZL + ZL(I)
             51 HOLD=HOLD+H(I)
      C
      C         HOLD = TOTAL INVENTORY OF THE PLANT,EVALUATED FROM "MEASURED"
      C         OKRA(I) AND KNOWN OKMAX(I) AND ZLS(I),INTERIM STORAGES ARE INCLUDED
      C         HOSOLL= PLANNED TOTAL INVENTORY
                PRINT 1005,TIME,HOLD,DIVERS,PROD
                PRINT 1017,(H(I),I=1,N)
                PRINT 1019,(HSOLL(I),I=1,N),HOSOLL,SUMZL,SOLL
                PRINT 1030,(OKRA(I),I=1,N)
                PRINT 1031,(OKSOR(I),I=1,N)
                PRINT 1026,(ZL(I),I=1,N)
      C
             52 CONTINUE
                TIME=TIME+DTD
                HOLD=0.
                HOSOLL=0.
                SUMZL = 0.
                IF (H    (1).GT.HMAX(1)) GO TO 54
                IF(ZL(1).LT.HHALB(1))  GO TO 55
                IF (MARK(1).EQ.1)  GO TO 55
                MARK(1) = 1
                PRINT 1020
                GO TO 55
             54 PRINT 1006,H(1)
                GO TO 999
             55 IF (H    (2).GT.HMAX(2)) GO TO 57
                IF(ZL(2).LT.HHALB(2)) GO TO 56
                IF (MARK(2).EQ.1)  GO TO 56
                MARK(2) = 1
                PRINT 1021
                GO TO 56
             57 PRINT 1007,H(2)
                GO TO 999
             56 IF (H(3).GT.HMAX(3)) GO TO 58
                IF(ZL(3).LT.HHALB(3)) GO TO 59
                IF (MARK(3).EQ.1)  GO TO 59
                MARK(3)=1
                PRINT 1023
                GO TO 59
             58 PRINT 1022,H(3)
                GO TO 999
             59 IF (H(4).GT.HMAX(4)) GO TO 60
                IF(ZL(4).LT.HHALB(4))  GO TO 61
                IF (MARK(4).EQ.1)  GO TO 61
                MARK(4)=1
                PRINT 1025
                GO TO 61
```

```
   60 PRINT 1024,H(4)
      GO TO 999
   61 IF(TIME.GT.25.) GO TO 999
C     THIS TIME LIMIT SHOULD BE INCREASED FOR REAL CAMPAIGNS
      GO TO 5
C
  999 CONTINUE
      IF ( ZLS(J).GE.0.2) GO TO 62
      PRINT 1013
      PRINT 1014,J
C     AT THE BEGINNING OF A NEW CAMPAIGN TIME IS SET =0
      TIME = 0.
      DIVERS = 0.
      ZLS(J) = ZLS(J) + 0.01
      DO 74  I=1,N
      ZL(I) =0.
   74 MARK(I) =0
      PRINT 1015
      PRINT 1002,    (RKAPPA(I),HMIN(I),HMAX(I),OKMAX(I),ZLS(I),ABZW(I),
     1HHALB(I),RDRY(I),I=1,N)
      GO TO 2
   75 II= I-1
      INST = 1
      PRINT 1016,I,OKMA(I),II,OKMA(II)
   62 ZLS(J) = ZLSOR(J)
      TIME = 0.
      DIVERS=0.
      SUMZL = 0.
      DO 76 I=1,N
      ZL(I) =0.
   76 MARK(I) =0
   63 CONTINUE
C
      TTT1=ZEIT(TTT)
      PRINT 6001,TTT1
      IF (INST .EQ.1)  GO TO 64
      IF (K.EQ.1)  GO TO 70
      KK = K-1
      IF (ABZW(KK).GE.0.5)  GO TO 64
      ABZW(KK) = ABZW(KK) +0.02
      PRINT 1013
      PRINT 1032,KK
      GO TO 1
   64 ABZW(K-1) = 0.
   70 CONTINUE
   80 CONTINUE
C
 9999 CONTINUE
      STOP
      END
```

```
FORTRAN IV G LEVEL  18                GAUSS              DATE = 71035         19/58/16               PAGE 0001

0001               SUBROUTINE GAUSS(IX,S,AM,V)
             C     PURPOSE
             C     COMPUTES A NORMALLY DISTRIBUTED RANDOM NUMBER WITH A GIVEN
             C     MEAN VALUE AND STANDARD DEVIATION
             C     USE
             C     CALL GAUSS(IX,S,AM,V)
             C
             C     DESCRIPTION OF PARAMETERS
             C     IX---MUST CONTAIN AN ODD INTEGER NUMBER WITH NINE OR
             C     LESS DIGITS ON THE FIRST ENTRY TO GAUSS.THEREAFTER
             C     IT WILL CONTAIN A UNIFORMLY DISTRIBUTED INTEGER RANDOM
             C     NUMBER GENERATED BY THE SUBROUTINE FOR USE ON THE NEXT
             C     ENTRY TO THE SUBROUTINE
             C     S---THE DESIRED STANDARD DEVIATION OF THE NORMAL DISTRIBUTION
             C     AS ABSOLUTE VALUE
             C     AM---THE DESIRED MEAN OF THE NORMAL DISTRIBUTION
             C     V---THE VALUE OF THE COMPUTED NORMAL RANDOM VARIABLE
             C     REMARKS
             C      THIS SUBROUTINE USES RANDU WHICH IS IBM/360 SPECIFIC
             C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
             C     RANDU
             C
             C     METHOD
             C      USES 12 UNIFORM RANDOM NUMBERS TO COMPUTE NORMAL RANDOM
             C      NUMBERS BY CENTRAL LIMIT THEOREM
             C     THE RESULT IS THEN ADJUSTED TO MATCH THE GIVEN MEAN VALUE AND
             C     STANDARD DEVIATION.
             C     THE UNIFORM RANDOM NUMBERS COMPUTED WITHIN THE SUBROUTINE
             C      ARE FOUND BY THE POWER RESIDUE METHOD
0002               A=0.
0003               DO 50 I=1,12
0004               CALL RANDU(IX,IY,Y)
0005               IX=IY
0006            50 A=A+Y
0007               V=(A-6.)*S+AM
0008               RETURN
0009               END
```

```
FORTRAN IV G LEVEL  18               RANDU              DATE = 71035         19/58/16             PAGE 0001

0001                SUBROUTINE RANDU(IX,IY,YFL)
              C     PURPOSE
              C     COMPUTES UNIFORMLY DISTRIBUTED RANDOM REAL NUMBERS BETWEEN
              C     0. AND 1. AND RANDOM INTEGERS BETWEEN ZERO AND 2**31.
              C     EACH ENTRY USES AS INPUT AN INTEGER RANDOM NUMBER AND PRODUCES
              C     A NEW INTEGER AND REAL RANDOM NUMBER
              C
              C     USE
              C     CALL RANDU(IX,IY,YFL)
              C
              C     DESCRIPTION OF PARAMETERS
              C     IX---FOR THE FIRST ENTRY THIS MUST CONTAIN ANY ODD INTEGER
              C     NUMBER WITH NINE OR LESS DIGITS.AFTER THE FIRST ENTRY
              C     IX SHOULD BE THE THE PREVIOUS VALUE OF IY COMPUTED BY THIS
              C     SUBROUTINE
              C     IY---A RESULTANT INTEGER RANDOM NUMBER REQUIRED FOR THE NEXT
              C     ENTRY TO THIS SUBROUTINE.THE RANGE OF THIS NUMBER IS
              C     BETWEEN ZERO AND 2**31
              C     YFL---THE RESULTANT UNIFORMLY DISTRIBUTED,FLOATING POINT,RANDOM
              C     NUMBER IN THE RANGE 0. TO 1.
              C     REMARKS
              C     THIS SUBROUTINE IS SPECIFIC TO SYSTEM IBM 360
              C     THIS SUBROUTINE WILL PRODUCE 2**29 TERMS BEFORE REPEATING
              C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED:
              C     NONE
              C     METHOD
              C     POWER RESIDUE METHOD DISCUSSED IN IBM MANUEAL C20-8011,
              C     RANDOM NUMBER GENERATING AND TESTING
              C
0002                IY=IX*65539
0003                IF(IY) 5,6,6
0004              5 IY=IY+2147483647+1
0005              6 YFL=IY
0006                YFL=YFL*.4656613E-9
0007                RETURN
0008                END
```

```
CCNTENT OF INPUT STORAGE = 10000.000
   5
     0.50
XNULL=      10.000
```

```
CHANGE CF ZLS(J= 1)

XNULL=      10.000
RKAPPA(I)  HMIN(I)    HMAX(I)    OKMAX(I)  ZLS(I)     ABZW(I)    HHALB(I)    RDRY(I)
    0.040      4.500   160.000    10.000     0.400      0.0         80.000      0.0
    0.030     25.000   110.000    10.000     0.500      0.0        100.000      0.0
    0.0       10.000    30.000    10.000     0.600      0.0         20.000      0.050
    0.070     25.000   100.000     9.000     0.600      0.0         30.000      0.030
    0.200      0.050     6.000     0.300     0.200      0.0          0.600      0.0
THE THEORETICAL   (T(I)) AND REAL   (TREAL(I)) TIMES,   UNTIL A MINIMAL CONTENT OF THE CORRESPONDING UNITS IS REACHED,ARE
              T(1)=      0.4500       T(2)=      4.7903        T(3)=      6.8521    AND      T(4)=      13.4311
  WHEREAS   TREAL(1)     0.4500  TREAL(2)=      4.7903  TREAL(3)=        6.8521  AND TREAL(4)=       13.4311


T=      0.500,H=     5.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=    5.00000        H(2)=    0.0             H(3)=     0.0            H(4)=     0.0           H(5)=     0.0
HSCLL(1)=    5.00000 HSOLL(2)=    0.0         HSCLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.0
HCSCLL=      5.000  SUM OF INTERIM STORES    SUMZL=      0.0   .PLANNED PRODUCT =       0.0
 OKRA(1)=   0.0        OKRA(2)=     0.0       OKRA(3)=     0.0          CKRA(4)=    0.0        CKRA(5)=     0.0
CKSOR(1)=   0.0       OKSOR(2)=     0.0      OKSOR(3)=     0.0         OKSOR(4)=    0.0       OKSOR(5)=     0.0
   ZL(1)=   0.0          ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.0

T=      1.000,H=    10.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=    7.00000        H(2)=    2.88000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.12000
HSCLL(1)=    7.00000 HSOLL(2)=    2.88000 HSCLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.12000
HCSCLL=     10.000  SUM OF INTERIM STORES    SUMZL=      2.000 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   CKRA(2)=     0.0        OKRA(3)=     0.0          CKRA(4)=    0.0        OKRA(5)=     0.0
CKSCR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0         CKSOR(4)=    0.0       OKSOR(5)=     0.0
   ZL(1)=   2.00000     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.0

T=      1.500,H=    15.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=    9.00000        H(2)=    5.76000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.24000
HSCLL(1)=    9.00000 HSOLL(2)=    5.76000 HSOLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.24000
HCSOLL=     15.000  SUM OF INTERIM STORES    SUMZL=      4.030 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   CKRA(2)=     0.0        CKRA(3)=     0.0          CKRA(4)=    0.0        OKRA(5)=     0.19200
CKSOR(1)=   5.76000 CKSCR(2)=     0.0      OKSOR(3)=     0.0         CKSOR(4)=    0.0       OKSOR(5)=     0.19200
   ZL(1)=   4.00000     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.03000

T=      2.000,H=    20.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=   11.00000        H(2)=    8.64000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.36000
HSOLL(1)=   11.00000 HSOLL(2)=    8.64000 HSOLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.36000
HOSCLL=     20.000  SUM CF INTERIM STORES    SUMZL=      6.060 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   CKRA(2)=     0.0        OKRA(3)=     0.0          OKRA(4)=    0.0        OKRA(5)=     0.19200
CKSOR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0         CKSCR(4)=    0.0       OKSOR(5)=     0.19200
   ZL(1)=   6.00000     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.06000

T=      2.500,H=    25.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=   13.00000        H(2)=   11.52000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.48000
HSCLL(1)=   13.00000 HSOLL(2)=   11.52000 HSCLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.48000
HCSOLL=     25.000  SUM OF INTERIM STORES    SUMZL=      8.090 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   CKRA(2)=     0.0        OKRA(3)=     0.0          OKRA(4)=    0.0        OKRA(5)=     0.19200
CKSCR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0         CKSCR(4)=    0.0       CKSOR(5)=     0.19200
   ZL(1)=   8.00000     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.09000

T=      3.000,H=    30.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=   15.00000        H(2)=   14.40000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.60000
HSCLL(1)=   15.00000 HSOLL(2)=   14.40000 HSOLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.60000
HCSOLL=     30.000  SUM OF INTERIM STORES    SUMZL=     10.120 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   OKRA(2)=     0.0        OKRA(3)=     0.0          CKRA(4)=    0.0        CKRA(5)=     0.19200
CKSCR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0         CKSCR(4)=    0.0       OKSOR(5)=     0.19200
   ZL(1)=  10.00000     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.12000

T=      3.500,H=    35.000 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT =        0.0
    H(1)=   17.00000        H(2)=   17.28000        H(3)=     0.0            H(4)=     0.0           H(5)=     0.72000
HSCLL(1)=   17.00000 HSOLL(2)=   17.28000 HSCLL(3)=     0.0        HSCLL(4)=     0.0       HSOLL(5)=     0.72000
HOSCLL=     35.000  SUM OF INTERIM STORES    SUMZL=     12.150 .PLANNED PRODUCT =       0.0
 CKRA(1)=   5.76000   OKRA(2)=     0.0        OKRA(3)=     0.0          CKRA(4)=    0.0        CKRA(5)=     0.19200
CKSOR(1)=   5.76000 CKSOR(2)=     0.0      OKSOR(3)=     0.0         CKSCR(4)=    0.0       OKSOR(5)=     0.19200
   ZL(1)=  11.99999     ZL(2)=     0.0         ZL(3)=     0.0            ZL(4)=    0.0          ZL(5)=     0.15000
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T=     4.000,H=   40.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  19.00000      H(2)=    20.15999      H(3)=     0.0          H(4)=     0.0          H(5)=    0.84000
HSOLL(1)=  19.00000 HSOLL(2)=    20.15999 HSOLL(3)=     0.0       HSOLL(4)=     0.0      HSOLL(5)=    0.84000
HOSOLL=     40.000  SUM OF INTERIM STORES    SUMZL=    14.180 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     0.0       OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  13.99999    ZL(2)=     0.0         ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.18000

T=     4.500,H=   45.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  21.00000      H(2)=    23.03998      H(3)=     0.0          H(4)=     0.0          H(5)=    0.96000
HSOLL(1)=  21.00000 HSOLL(2)=    23.03998 HSOLL(3)=     0.0       HSOLL(4)=     0.0      HSOLL(5)=    0.96000
HOSOLL=     45.000  SUM OF INTERIM STORES    SUMZL=    16.210 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     0.0       OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  15.99999    ZL(2)=     0.0         ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.21000

T=     5.000,H=   50.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  23.00000      H(2)=    25.91997      H(3)=     0.0          H(4)=     0.0          H(5)=    1.08000
HSOLL(1)=  23.00000 HSOLL(2)=    25.91997 HSOLL(3)=     0.0       HSOLL(4)=     0.0      HSOLL(5)=    1.08000
HOSOLL=     50.000  SUM OF INTERIM STORES    SUMZL=    18.240 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     0.0       OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     0.0      OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  17.99998    ZL(2)=     0.0         ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.24000

T=     5.500,H=   55.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  25.00000      H(2)=    26.29996      H(3)=     2.42500      H(4)=     0.0          H(5)=    1.27500
HSOLL(1)=  25.00000 HSOLL(2)=    26.29996 HSOLL(3)=     2.42500 HSOLL(4)=     0.0      HSOLL(5)=    1.27500
HOSOLL=     55.000  SUM OF INTERIM STORES    SUMZL=    22.770 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  19.99997    ZL(2)=     2.50000     ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.27000

T=     6.000,H=   60.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  27.00000      H(2)=    26.67995      H(3)=     4.85000      H(4)=     0.0          H(5)=    1.47000
HSOLL(1)=  27.00000 HSOLL(2)=    26.67995 HSOLL(3)=     4.85000 HSOLL(4)=     0.0      HSOLL(5)=    1.47000
HOSOLL=     60.000  SUM OF INTERIM STORES    SUMZL=    27.300 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  21.99995    ZL(2)=     5.00000     ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.30000

T=     6.500,H=   65.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  29.00000      H(2)=    27.05994      H(3)=     7.27500      H(4)=     0.0          H(5)=    1.66500
HSOLL(1)=  29.00000 HSOLL(2)=    27.05994 HSOLL(3)=     7.27500 HSOLL(4)=     0.0      HSOLL(5)=    1.66500
HOSOLL=     65.000  SUM OF INTERIM STORES    SUMZL=    31.830 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  23.99994    ZL(2)=     7.50000     ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.33000

T=     7.000,H=   70.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  31.00000      H(2)=    27.43993      H(3)=     9.70000      H(4)=     0.0          H(5)=    1.86000
HSOLL(1)=  31.00000 HSOLL(2)=    27.43993 HSOLL(3)=     9.70000 HSOLL(4)=     0.0      HSOLL(5)=    1.86000
HOSOLL=     70.000  SUM OF INTERIM STORES    SUMZL=    36.360 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  25.99992    ZL(2)=    10.00000     ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.36000

T=     7.500,H=   75.000 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  33.00000      H(2)=    27.81992      H(3)=    12.12500      H(4)=     0.0          H(5)=    2.05500
HSOLL(1)=  33.00000 HSOLL(2)=    27.81992 HSOLL(3)=    12.12500 HSOLL(4)=     0.0      HSOLL(5)=    2.05500
HOSOLL=     75.000  SUM OF INTERIM STORES    SUMZL=    40.890 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     0.0       OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     0.0      OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  27.99991    ZL(2)=    12.50000     ZL(3)=     0.0         ZL(4)=     0.0         ZL(5)=    0.39000

T=     8.000,H=   79.900 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  35.00000      H(2)=    28.19991      H(3)=    12.55000      H(4)=     1.90000      H(5)=    2.25000
HSOLL(1)=  35.00000 HSOLL(2)=    28.19991 HSOLL(3)=    12.55000 HSOLL(4)=     1.90000 HSOLL(5)=    2.25000
HOSOLL=     79.900  SUM OF INTERIM STORES    SUMZL=    48.420 .PLANNED PRODUCT =      0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000   OKRA(3)=     3.80000   OKRA(4)=     0.0       OKRA(5)=    0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000  OKSOR(3)=     3.80000  OKSOR(4)=     0.0      OKSOR(5)=    0.19200
   ZL(1)=  29.99989    ZL(2)=    15.00000     ZL(3)=     3.00000     ZL(4)=     0.0         ZL(5)=    0.42000
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T=    8.500,H=   84.800 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  37.00000      H(2)=    28.57990      H(3)=    12.97499      H(4)=     3.80000      H(5)=     2.44500
HSOLL(1)=  37.00000 HSOLL(2)=    28.57990 HSOLL(3)=    12.97499 HSOLL(4)=     3.80000 HSOLL(5)=     2.44500
HOSOLL=    84.800  SUM OF INTERIM STORES    SUMZL=    55.950 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  31.99988     ZL(2)=    17.50000     ZL(3)=     6.00000     ZL(4)=     0.0          ZL(5)=     0.45000

T=    9.000,H=   89.700 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  39.00000      H(2)=    28.95988      H(3)=    13.39999      H(4)=     5.70000      H(5)=     2.64000
HSOLL(1)=  39.00000 HSOLL(2)=    28.95988 HSOLL(3)=    13.39999 HSOLL(4)=     5.70000 HSOLL(5)=     2.64000
HOSOLL=    89.700  SUM OF INTERIM STORES    SUMZL=    63.480 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  33.99986     ZL(2)=    20.00000     ZL(3)=     9.00000     ZL(4)=     0.0          ZL(5)=     0.48000

T=    9.500,H=   94.600 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  41.00000      H(2)=    29.33987      H(3)=    13.82499      H(4)=     7.60000      H(5)=     2.83500
HSOLL(1)=  41.00000 HSOLL(2)=    29.33987 HSOLL(3)=    13.82499 HSOLL(4)=     7.60000 HSOLL(5)=     2.83500
HOSOLL=    94.600  SUM OF INTERIM STORES    SUMZL=    71.010 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  35.99985     ZL(2)=    22.50000     ZL(3)=    12.00000     ZL(4)=     0.0          ZL(5)=     0.51000

T=   10.000,H=   99.500 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  43.00000      H(2)=    29.71986      H(3)=    14.24999      H(4)=     9.50000      H(5)=     3.03000
HSOLL(1)=  43.00000 HSOLL(2)=    29.71986 HSOLL(3)=    14.24999 HSOLL(4)=     9.50000 HSOLL(5)=     3.03000
HOSOLL=    99.500  SUM OF INTERIM STORES    SUMZL=    78.540 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  37.99983     ZL(2)=    25.00000     ZL(3)=    15.00000     ZL(4)=     0.0          ZL(5)=     0.54000

T=   10.500,H=  104.400 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  45.00000      H(2)=    30.09985      H(3)=    14.67499      H(4)=    11.40000      H(5)=     3.22500
HSOLL(1)=  45.00000 HSOLL(2)=    30.09985 HSOLL(3)=    14.67499 HSOLL(4)=    11.40000 HSOLL(5)=     3.22500
HOSOLL=   104.400  SUM OF INTERIM STORES    SUMZL=    86.070 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  39.99982     ZL(2)=    27.50000     ZL(3)=    17.99998     ZL(4)=     0.0          ZL(5)=     0.57000

T=   11.000,H=  109.300 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  47.00000      H(2)=    30.47984      H(3)=    15.09999      H(4)=    13.30000      H(5)=     3.42000
HSOLL(1)=  47.00000 HSOLL(2)=    30.47984 HSOLL(3)=    15.09999 HSOLL(4)=    13.30000 HSOLL(5)=     3.42000
HOSOLL=   109.300  SUM OF INTERIM STORES    SUMZL=    93.600 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     3.80000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     3.80000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  41.99980     ZL(2)=    30.00000     ZL(3)=    20.99997     ZL(4)=     0.0          ZL(5)=     0.60000
MARK(3) WAS SET =1

T=   11.500,H=  114.050 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  49.00000      H(2)=    30.85983      H(3)=    12.52499      H(4)=    18.04999      H(5)=     3.61500
HSOLL(1)=  49.00000 HSOLL(2)=    30.85983 HSOLL(3)=    12.52499 HSOLL(4)=    18.04999 HSOLL(5)=     3.61500
HOSOLL=   114.050  SUM OF INTERIM STORES    SUMZL=    77.130 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  43.99979     ZL(2)=    32.50000     ZL(3)=    20.99997     ZL(4)=     0.0          ZL(5)=     0.63000

T=   12.000,H=  118.800 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  51.00000      H(2)=    31.23982      H(3)=     9.94999      H(4)=    22.79999      H(5)=     3.80999
HSOLL(1)=  51.00000 HSOLL(2)=    31.23982 HSOLL(3)=     9.94999 HSOLL(4)=    22.79999 HSOLL(5)=     3.80999
HOSOLL=   118.800  SUM OF INTERIM STORES    SUMZL=    81.660 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000  OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000 OKSOR(4)=     0.0       OKSOR(5)=     0.19200
   ZL(1)=  45.99977     ZL(2)=    35.00000     ZL(3)=    20.99997     ZL(4)=     0.0          ZL(5)=     0.66000

T=   12.500,H=  123.800 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=  53.00000      H(2)=    31.61981      H(3)=    12.37499      H(4)=    22.79999      H(5)=     4.00499
HSOLL(1)=  53.00000 HSOLL(2)=    31.61981 HSOLL(3)=    12.37499 HSOLL(4)=    22.79999 HSOLL(5)=     4.00499
HOSOLL=   123.800  SUM OF INTERIM STORES    SUMZL=    86.190 .PLANNED PRODUCT =       0.0
 OKRA(1)=   5.76000  OKRA(2)=     4.85000  OKRA(3)=     0.0      OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=   5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     0.0     OKSOR(4)=     0.0       OKSOR(5)=     0.19200
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  ZL(1)=  47.99976     ZL(2)=    37.50000      ZL(3)=    20.99997      ZL(4)=     0.0          ZL(5)=      0.69000

T=     13.000,H=  128.550 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      0.0
    H(1)=  55.00000       H(2)=    31.99980       H(3)=      9.79999      H(4)=     27.54999        H(5)=      4.19999
HSOLL(1)=  55.00000 HSOLL(2)=    31.99980 HSOLL(3)=      9.79999 HSOLL(4)=     27.54999 HSOLL(5)=      4.19999
HOSOLL=   128.550  SUM OF INTERIM STORES    SUMZL=     90.720 .PLANNED PRODUCT =      0.0
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      9.50000  OKRA(4)=      0.0          OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      9.50000 OKSOR(4)=      0.0         OKSOR(5)=      0.19200
  ZL(1)=  49.99974     ZL(2)=    40.00000      ZL(3)=    20.99997      ZL(4)=     0.0          ZL(5)=      0.72000

T=     13.500,H=  131.876 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      1.620
    H(1)=  57.00000       H(2)=    32.37979       H(3)=     12.22499      H(4)=     25.74998        H(5)=      4.52099
HSOLL(1)=  57.00000 HSOLL(2)=    32.37979 HSOLL(3)=     12.22499 HSOLL(4)=     25.74998 HSOLL(5)=      4.52099
HOSOLL=   131.876  SUM OF INTERIM STORES    SUMZL=     97.950 .PLANNED PRODUCT =      1.620
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      0.0          OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      0.0         OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  51.99973     ZL(2)=    42.50000      ZL(3)=    20.99997      ZL(4)=     2.70000      ZL(5)=      0.75000

T=     14.000,H=  134.952 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      3.240
    H(1)=  59.00000       H(2)=    32.75978       H(3)=      9.64999      H(4)=     28.69998        H(5)=      4.84199
HSOLL(1)=  59.00000 HSOLL(2)=    32.75978 HSOLL(3)=      9.64999 HSOLL(4)=     28.69998 HSOLL(5)=      4.84199
HOSOLL=   134.952  SUM OF INTERIM STORES    SUMZL=    105.180 .PLANNED PRODUCT =      3.240
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      9.50000  OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      9.50000 OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  53.99971     ZL(2)=    45.00000      ZL(3)=    20.99997      ZL(4)=     5.40000      ZL(5)=      0.78000

T=     14.500,H=  138.278 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      4.860
    H(1)=  61.00000       H(2)=    33.13977       H(3)=     12.07499      H(4)=     26.89998        H(5)=      5.16299
HSOLL(1)=  61.00000 HSOLL(2)=    33.13977 HSOLL(3)=     12.07499 HSOLL(4)=     26.89998 HSOLL(5)=      5.16299
HOSOLL=   138.278  SUM OF INTERIM STORES    SUMZL=    112.410 .PLANNED PRODUCT =      4.860
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      0.0          OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      0.0         OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  55.99969     ZL(2)=    47.50000      ZL(3)=    20.99997      ZL(4)=     8.10000      ZL(5)=      0.81000

T=     15.000,H=  141.354 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      6.480
    H(1)=  63.00000       H(2)=    33.51976       H(3)=      9.49999      H(4)=     29.84998        H(5)=      5.48399
HSOLL(1)=  63.00000 HSOLL(2)=    33.51976 HSOLL(3)=      9.49999 HSOLL(4)=     29.84998 HSOLL(5)=      5.48399
HOSOLL=   141.354  SUM OF INTERIM STORES    SUMZL=    119.640 .PLANNED PRODUCT =      6.480
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      9.50000  OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      9.50000 OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  57.99968     ZL(2)=    50.00000      ZL(3)=    20.99997      ZL(4)=    10.80000      ZL(5)=      0.84000

T=     15.500,H=  144.680 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      8.100
    H(1)=  65.00000       H(2)=    33.89975       H(3)=     11.92499      H(4)=     28.04997        H(5)=      5.80499
HSOLL(1)=  65.00000 HSOLL(2)=    33.89975 HSOLL(3)=     11.92499 HSOLL(4)=     28.04997 HSOLL(5)=      5.80499
HOSOLL=   144.680  SUM OF INTERIM STORES    SUMZL=    126.870 .PLANNED PRODUCT =      8.100
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      0.0          OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      0.0         OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  59.99966     ZL(2)=    52.50000      ZL(3)=    20.99997      ZL(4)=    13.50000      ZL(5)=      0.87000

T=     16.000,H=  147.756 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =      9.720
    H(1)=  67.00000       H(2)=    34.27974       H(3)=      9.34999      H(4)=     30.99997        H(5)=      6.12599
HSOLL(1)=  67.00000 HSOLL(2)=    34.27974 HSOLL(3)=      9.34999 HSOLL(4)=     30.99997 HSOLL(5)=      6.12599
HOSOLL=   147.756  SUM OF INTERIM STORES    SUMZL=    134.100 .PLANNED PRODUCT =      9.720
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      9.50000  OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      9.50000 OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  61.99965     ZL(2)=    55.00000      ZL(3)=    20.99997      ZL(4)=    16.20000      ZL(5)=      0.90000

T=     16.500,H=  151.082 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =     11.340
    H(1)=  69.00000       H(2)=    34.65973       H(3)=     11.77499      H(4)=     29.19997        H(5)=      6.44699
HSOLL(1)=  69.00000 HSOLL(2)=    34.65973 HSOLL(3)=     11.77499 HSOLL(4)=     29.19997 HSOLL(5)=      6.44699
HOSOLL=   151.082  SUM OF INTERIM STORES    SUMZL=    141.330 .PLANNED PRODUCT =     11.340
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      0.0          OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      0.0         OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
  ZL(1)=  63.99963     ZL(2)=    57.50000      ZL(3)=    20.99997      ZL(4)=    18.89999      ZL(5)=      0.93000

T=     17.000,H=  154.158 AND DIVERTED QUANTITY DIVERS  =       0.0    .ACCUMULATED PRODUCT =     12.960
    H(1)=  71.00000       H(2)=    35.03972       H(3)=      9.19999      H(4)=     32.14996        H(5)=      6.76799
HSOLL(1)=  71.00000 HSOLL(2)=    35.03972 HSOLL(3)=      9.19999 HSOLL(4)=     32.14996 HSOLL(5)=      6.76799
HOSOLL=   154.158  SUM OF INTERIM STORES    SUMZL=    148.560 .PLANNED PRODUCT =     12.960
 OKRA(1)=    5.76000  OKRA(2)=      4.85000  OKRA(3)=      9.50000  OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=      4.85000 OKSOR(3)=      9.50000 OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
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  ZL(1)= 65.99962      ZL(2)=    60.00000     ZL(3)=   20.99997      ZL(4)=   21.59999      ZL(5)=    0.96000

T=     17.500,H=  157.484 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      14.580
   H(1)=  73.00000       H(2)=    35.41971       H(3)=    11.62499       H(4)=    30.34996       H(5)=      7.08899
HSOLL(1)=  73.00000 HSOLL(2)=    35.41971 HSOLL(3)=    11.62499 HSOLL(4)=    30.34996 HSOLL(5)=      7.08899
HOSOLL=    157.484  SUM OF INTERIM STORES    SUMZL=    155.790 .PLANNED PRODUCT  =      14.580
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=      0.0        OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=      0.0       OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
   ZL(1)=  67.99960      ZL(2)=    62.50000      ZL(3)=    20.99997      ZL(4)=    24.29999      ZL(5)=      0.99000

T=     18.000,H=  160.560 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      16.200
   H(1)=  75.00000       H(2)=    35.79970       H(3)=     9.04999       H(4)=    33.29996       H(5)=      7.40999
HSOLL(1)=  75.00000 HSOLL(2)=    35.79970 HSOLL(3)=     9.04999 HSOLL(4)=    33.29996 HSOLL(5)=      7.40999
HOSOLL=    160.560  SUM OF INTERIM STORES    SUMZL=    163.020 .PLANNED PRODUCT  =      16.200
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000   OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000  OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
   ZL(1)=  69.99959      ZL(2)=    65.00000      ZL(3)=    20.99997      ZL(4)=    26.99998      ZL(5)=      1.02000

T=     18.500,H=  163.886 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      17.820
   H(1)=  77.00000       H(2)=    36.17969       H(3)=    11.47499       H(4)=    31.49995       H(5)=      7.73098
HSOLL(1)=  77.00000 HSOLL(2)=    36.17969 HSOLL(3)=    11.47499 HSOLL(4)=    31.49995 HSOLL(5)=      7.73098
HOSOLL=    163.886  SUM OF INTERIM STORES    SUMZL=    170.250 .PLANNED PRODUCT  =      17.820
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=      0.0        OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=      0.0       OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
   ZL(1)=  71.99957      ZL(2)=    67.50000      ZL(3)=    20.99997      ZL(4)=    29.69998      ZL(5)=      1.05000

T=     19.000,H=  166.962 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      19.440
   H(1)=  79.00000       H(2)=    36.55968       H(3)=     8.89999       H(4)=    34.44995       H(5)=      8.05198
HSOLL(1)=  79.00000 HSOLL(2)=    36.55968 HSOLL(3)=     8.89999 HSOLL(4)=    34.44995 HSOLL(5)=      8.05198
HOSOLL=    166.962  SUM OF INTERIM STORES    SUMZL=    177.480 .PLANNED PRODUCT  =      19.440
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000   OKRA(4)=      3.24000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000  OKSOR(4)=      3.24000 OKSOR(5)=      0.19200
   ZL(1)=  73.99956      ZL(2)=    70.00000      ZL(3)=    20.99997      ZL(4)=    32.39998      ZL(5)=      1.08000
MARK(4) WAS SET =1

T=     19.500,H=  167.777 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      23.490
   H(1)=  81.00000       H(2)=    36.93967       H(3)=    11.32499       H(4)=    29.94995       H(5)=      8.56198
HSOLL(1)=  81.00000 HSOLL(2)=    36.93967 HSOLL(3)=    11.32499 HSOLL(4)=    29.94995 HSOLL(5)=      8.56198
HOSOLL=    167.777  SUM OF INTERIM STORES    SUMZL=    149.610 .PLANNED PRODUCT  =      23.490
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=      0.0        OKRA(4)=      8.10000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=      0.0       OKSOR(4)=      8.10000 OKSOR(5)=      0.19200
   ZL(1)=  75.99954      ZL(2)=    72.50000      ZL(3)=    20.99997      ZL(4)=    32.39998      ZL(5)=      1.11000

T=     20.000,H=  168.342 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      27.540
   H(1)=  83.00000       H(2)=    37.31966       H(3)=     8.74999       H(4)=    30.19995       H(5)=      9.07198
HSOLL(1)=  83.00000 HSOLL(2)=    37.31966 HSOLL(3)=     8.74999 HSOLL(4)=    30.19995 HSOLL(5)=      9.07198
HOSOLL=    168.342  SUM OF INTERIM STORES    SUMZL=    154.140 .PLANNED PRODUCT  =      27.540
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000   OKRA(4)=      8.10000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000  OKSOR(4)=      8.10000 OKSOR(5)=      0.19200
   ZL(1)=  77.99953      ZL(2)=    75.00000      ZL(3)=    20.99997      ZL(4)=    32.39998      ZL(5)=      1.14000

T=     20.500,H=  169.157 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      31.590
   H(1)=  85.00000       H(2)=    37.69965       H(3)=    11.17499       H(4)=    25.69995       H(5)=      9.58198
HSOLL(1)=  85.00000 HSOLL(2)=    37.69965 HSOLL(3)=    11.17499 HSOLL(4)=    25.69995 HSOLL(5)=      9.58198
HOSOLL=    169.157  SUM OF INTERIM STORES    SUMZL=    158.669 .PLANNED PRODUCT  =      31.590
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=      0.0        OKRA(4)=      8.10000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=      0.0       OKSOR(4)=      8.10000 OKSOR(5)=      0.19200
   ZL(1)=  79.99951      ZL(2)=    77.50000      ZL(3)=    20.99997      ZL(4)=    32.39998      ZL(5)=      1.17000

T=     21.000,H=  169.722 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      35.640
   H(1)=  87.00000       H(2)=    38.07964       H(3)=     8.59999       H(4)=    25.94995       H(5)=     10.09198
HSOLL(1)=  87.00000 HSOLL(2)=    38.07964 HSOLL(3)=     8.59999 HSOLL(4)=    25.94995 HSOLL(5)=     10.09198
HOSOLL=    169.722  SUM OF INTERIM STORES    SUMZL=    163.199 .PLANNED PRODUCT  =      35.640
 OKRA(1)=    5.76000  OKRA(2)=     4.85000  OKRA(3)=     9.50000   OKRA(4)=      8.10000  OKRA(5)=      0.19200
OKSOR(1)=    5.76000 OKSOR(2)=     4.85000 OKSOR(3)=     9.50000  OKSOR(4)=      8.10000 OKSOR(5)=      0.19200
   ZL(1)=  81.99950      ZL(2)=    80.00000      ZL(3)=    20.99997      ZL(4)=    32.39998      ZL(5)=      1.20000
MARK(1) WAS SET =1

T=     21.500,H=  170.537 AND DIVERTED QUANTITY DIVERS  =        0.0    .ACCUMULATED PRODUCT  =      39.690
   H(1)=  87.00000       H(2)=    40.37962       H(3)=    11.02499       H(4)=    21.44995       H(5)=     10.68198
HSOLL(1)=  87.00000 HSOLL(2)=    40.37962 HSOLL(3)=    11.02499 HSOLL(4)=    21.44995 HSOLL(5)=     10.68198
HOSOLL=    170.537  SUM OF INTERIM STORES    SUMZL=     83.730 .PLANNED PRODUCT  =      39.690
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 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    0.0        OKRA(4)=     8.10000  OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    0.0       OKSOR(4)=     8.10000 OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    82.50000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.23000

T=     22.000,H=  175.287 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     39.690
    H(1)=  87.00000     H(2)=    42.67961     H(3)=    8.44999      H(4)=    26.19995     H(5)=    10.95698
HSOLL(1)=  87.00000 HSOLL(2)=    42.67961 HSOLL(3)=    8.44999 HSOLL(4)=    26.19995 HSOLL(5)=    10.95698
HOSOLL=    175.287  SUM OF INTERIM STORES   SUMZL=     86.260 .PLANNED PRODUCT =      39.690
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    9.50000   OKRA(4)=    0.0         OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    9.50000 OKSOR(4)=    0.0        OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    85.00000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.26000

T=     22.500,H=  176.102 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     43.740
    H(1)=  87.00000     H(2)=    44.97960     H(3)=   10.87498      H(4)=    21.69995     H(5)=    11.54698
HSOLL(1)=  87.00000 HSOLL(2)=    44.97960 HSOLL(3)=   10.87498 HSOLL(4)=    21.69995 HSOLL(5)=    11.54698
HOSOLL=    176.102  SUM OF INTERIM STORES   SUMZL=     88.790 .PLANNED PRODUCT =      43.740
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    0.0         OKRA(4)=    8.10000  OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    0.0       OKSOR(4)=     8.10000 OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    87.50000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.29000

T=     23.000,H=  180.851 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     43.740
    H(1)=  87.00000     H(2)=    47.27959     H(3)=    8.29998      H(4)=    26.44995     H(5)=    11.82198
HSOLL(1)=  87.00000 HSOLL(2)=    47.27959 HSOLL(3)=    8.29998 HSOLL(4)=    26.44995 HSOLL(5)=    11.82198
HOSOLL=    180.851  SUM OF INTERIM STORES   SUMZL=     91.320 .PLANNED PRODUCT =      43.740
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    9.50000   OKRA(4)=    0.0         OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    9.50000 OKSOR(4)=    0.0        OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    90.00000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.32000

T=     23.500,H=  181.666 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     47.790
    H(1)=  87.00000     H(2)=    49.57957     H(3)=   10.72498      H(4)=    21.94995     H(5)=    12.41198
HSOLL(1)=  87.00000 HSOLL(2)=    49.57957 HSOLL(3)=   10.72498 HSOLL(4)=    21.94995 HSOLL(5)=    12.41198
HOSOLL=    181.666  SUM OF INTERIM STORES   SUMZL=     93.850 .PLANNED PRODUCT =      47.790
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    0.0         OKRA(4)=    8.10000  OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    0.0       OKSOR(4)=     8.10000 OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    92.50000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.35000

T=     24.000,H=  186.416 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     47.790
    H(1)=  87.00000     H(2)=    51.87956     H(3)=    8.14998      H(4)=    26.69995     H(5)=    12.66698
HSOLL(1)=  87.00000 HSOLL(2)=    51.87956 HSOLL(3)=    8.14998 HSOLL(4)=    26.69995 HSOLL(5)=    12.66698
HOSOLL=    186.416  SUM OF INTERIM STORES   SUMZL=     96.380 .PLANNED PRODUCT =      47.790
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    9.50000   OKRA(4)=    0.0         OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    9.50000 OKSOR(4)=    0.0        OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    95.00000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.38000

T=     24.500,H=  187.231 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     51.840
    H(1)=  87.00000     H(2)=    54.17955     H(3)=   10.57498      H(4)=    22.19995     H(5)=    13.27698
HSOLL(1)=  87.00000 HSOLL(2)=    54.17955 HSOLL(3)=   10.57498 HSOLL(4)=    22.19995 HSOLL(5)=    13.27698
HOSOLL=    187.231  SUM OF INTERIM STORES   SUMZL=     98.910 .PLANNED PRODUCT =      51.840
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    0.0         OKRA(4)=    8.10000  OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    0.0       OKSOR(4)=     8.10000 OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=    97.50000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.41000

T=     25.000,H=  191.981 AND DIVERTED QUANTITY DIVERS  =       0.0   .ACCUMULATED PRODUCT =     51.840
    H(1)=  87.00000     H(2)=    56.47954     H(3)=    7.99998      H(4)=    26.94995     H(5)=    13.55198
HSOLL(1)=  87.00000 HSOLL(2)=    56.47954 HSOLL(3)=    7.99998 HSOLL(4)=    26.94995 HSOLL(5)=    13.55198
HOSOLL=    191.981  SUM OF INTERIM STORES   SUMZL=    101.440 .PLANNED PRODUCT =      51.840
 OKRA(1)=   9.60000  OKRA(2)=     4.85000  OKRA(3)=    9.50000   OKRA(4)=    0.0         OKRA(5)=     0.19200
OKSOR(1)=   9.60000 OKSOR(2)=     4.85000 OKSOR(3)=    9.50000 OKSOR(4)=    0.0        OKSOR(5)=     0.19200
   ZL(1)=  81.99950    ZL(2)=   100.00000    ZL(3)=   20.99997      ZL(4)=    32.39998    ZL(5)=     1.43999
MARK(2) WAS SET =1
SNAP.TIME=       0.25958377
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CHANGE OF ZLS(J= 1)

XNULL=     10.000
RKAPPA(I)  HMIN(I)   HMAX(I)   OKMAX(I)  ZLS(I)    ABZW(I)   HHALB(I)   RDRY(I)
    0.040    4.500   160.000    10.000     0.400     0.020     80.000     0.0
    0.030   25.000   110.000    10.000     0.500     0.0      100.000     0.0
    0.0     10.000    30.000    10.000     0.600     0.0       20.000     0.050
    0.070   25.000   100.000     9.000     0.600     0.0       30.000     0.030
    0.200    0.050     6.000     0.300     0.200     0.0        0.600     0.0
THE THEORETICAL   (T(I)) AND REAL   (TREAL(I)) TIMES,   UNTIL A MINIMAL CONTENT OF THE CORRESPONDING UNITS IS REACHED,ARE
             T(1)=     0.4500      T(2)=     4.7903      T(3)=     6.8521   AND     T(4)=     13.4311
  WHEREAS   TREAL(1)     0.4500  TREAL(2)=      4.9399  TREAL(3)=      7.0018  AND TREAL(4)=     13.5807


T=    0.500,H=    5.000 AND DIVERTED QUANTITY DIVERS  =        0.0   .ACCUMULATED PRODUCT =       0.0
   H(1)=   5.00000      H(2)=     0.0           H(3)=     0.0           H(4)=     0.0           H(5)=     0.0
HSOLL(1)=  5.00000 HSOLL(2)=      0.0       HSOLL(3)=     0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.0
HOSOLL=    5.000  SUM OF INTERIM STORES   SUMZL=      0.0   .PLANNED PRODUCT =      0.0
 OKRA(1)=  0.0       OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.0
OKSOR(1)=  0.0      OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.0
  ZL(1)=   0.0         ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.0

T=    1.000,H=   10.000 AND DIVERTED QUANTITY DIVERS  =        0.100 .ACCUMULATED PRODUCT =       0.0
   H(1)=   7.10000      H(2)=     2.78400       H(3)=     0.0           H(4)=     0.0           H(5)=     0.11600
HSOLL(1)=  7.00000 HSOLL(2)=      2.88000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.12000
HOSOLL=   10.000  SUM OF INTERIM STORES   SUMZL=      2.000 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.0
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.0
  ZL(1)=   2.00000     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.0

T=    1.500,H=   15.000 AND DIVERTED QUANTITY DIVERS  =        0.200 .ACCUMULATED PRODUCT =       0.0
   H(1)=   9.20000      H(2)=     5.56800       H(3)=     0.0           H(4)=     0.0           H(5)=     0.23200
HSOLL(1)=  9.00000 HSOLL(2)=      5.76000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.24000
HOSOLL=   15.000  SUM OF INTERIM STORES   SUMZL=      4.030 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.19200
  ZL(1)=   4.00000     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.03000

T=    2.000,H=   20.000 AND DIVERTED QUANTITY DIVERS  =        0.300 .ACCUMULATED PRODUCT =       0.0
   H(1)=  11.30000      H(2)=     8.35200       H(3)=     0.0           H(4)=     0.0           H(5)=     0.34800
HSOLL(1)= 11.00000 HSOLL(2)=      8.64000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.36000
HOSOLL=   20.000  SUM OF INTERIM STORES   SUMZL=      6.060 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.19200
  ZL(1)=   6.00000     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.06000

T=    2.500,H=   25.000 AND DIVERTED QUANTITY DIVERS  =        0.400 .ACCUMULATED PRODUCT =       0.0
   H(1)=  13.39999      H(2)=    11.13600       H(3)=     0.0           H(4)=     0.0           H(5)=     0.46400
HSOLL(1)= 13.00000 HSOLL(2)=     11.52000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.48000
HOSOLL=   25.000  SUM OF INTERIM STORES   SUMZL=      8.090 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.19200
  ZL(1)=   8.00000     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.09000

T=    3.000,H=   30.000 AND DIVERTED QUANTITY DIVERS  =        0.500 .ACCUMULATED PRODUCT =       0.0
   H(1)=  15.49998      H(2)=    13.92000       H(3)=     0.0           H(4)=     0.0           H(5)=     0.58000
HSOLL(1)= 15.00000 HSOLL(2)=     14.40000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.60000
HOSOLL=   30.000  SUM OF INTERIM STORES   SUMZL=     10.120 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.19200
  ZL(1)=  10.00000     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.12000

T=    3.500,H=   35.000 AND DIVERTED QUANTITY DIVERS  =        0.600 .ACCUMULATED PRODUCT =       0.0
   H(1)=  17.59996      H(2)=    16.70399       H(3)=     0.0           H(4)=     0.0           H(5)=     0.69600
HSOLL(1)= 17.00000 HSOLL(2)=     17.28000  HSOLL(3)=      0.0       HSOLL(4)=     0.0       HSOLL(5)=     0.72000
HOSOLL=   35.000  SUM OF INTERIM STORES   SUMZL=     12.150 .PLANNED PRODUCT =      0.0
 OKRA(1)=  5.56800   OKRA(2)=     0.0        OKRA(3)=     0.0        OKRA(4)=     0.0        OKRA(5)=     0.19200
OKSOR(1)=  5.76000  OKSOR(2)=     0.0       OKSOR(3)=     0.0       OKSOR(4)=     0.0       OKSOR(5)=     0.19200
  ZL(1)=  11.99999     ZL(2)=     0.0          ZL(3)=     0.0          ZL(4)=     0.0          ZL(5)=     0.15000
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