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Design Criteria for Reprocessing Plants

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Abstract

The analysis of an existing reprocessing plant, namely of the Wiederaufarbeitungsanlage Karlsruhe (WAK) shows that the major bulk of informations relevant to safeguards is transfered by an extented network system prior to reception at rather different places of the plant.

Besides others, large efforts to guarantee the correctness of the informations are required.

Criteria have been developed for a plant design at which the generation and reception of the essential informations are restricted to an uniform area and for which a reduction of the safeguards costs can be expected.

The principal arrangement of such a plant is given.

Zusammenfassung

Die Analyse einer bestehenden Wiederaufarbeitungsanlage, nämlich der Wiederaufarbeitungsanlage Karlsruhe (WAK) zeigt, daß ein Großteil der für die Spaltstoffflußkontrolle wichtigen Informationen über ein ausgedehntes Informationsnetzwerk läuft, bevor sie an verschiedenen, über die Anlage verteilten Stellen entgegengenommen werden können.

Hieraus ergibt sich u.a. ein erheblicher Aufwand für die Sicherstellung der Richtigkeit der Informationen.

Es werden Kriterien für einen Anlagenentwurf entwickelt, bei dem die Erzeugung und Entgegennahme der wesentlichen Informationen auf einen einheitlichen Bereich beschränkt und damit ein geringer Kontrollaufwand zu erwarten ist. Eine solche Anlage wird in ihren Grundzügen skizziert.

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1. Introduction

One of the important objectives of the systems analytical investigations and containment studies carried out at Karlsruhe, has been to develop design criteria for the layout of principal nuclear facilities, which would facilitate the application of safeguards in an optimum manner [1]. A number of integral exercises [2,4,5] and analyses of layouts of some existing fabrication [6] and reprocessing plants [7] have shown that, a modern safeguards system based on material balance accountancy supplemented by containment and some surveillance measures can be applied to these plants with certain restrictions. However, the intensity and the extent of safeguards efforts would be reduced significantly if some changes were introduced to the plant layouts.

In the present paper, the causes which normally lead to increased safeguards efforts and intensities in an existing reprocessing facility, have been analysed for a WAK (Wiederaufarbeitungsanlage für Kernbrennstoffe, Karlsruhe) type. Some basic design criteria for laying out a reprocessing plant, which would meet the requirements of a modern safeguards system and could lead to reduced safeguards efforts and intensities, have also been discussed and a corresponding layout proposed.

2. Causes for increased efforts in a existing plant

2.1 Information network

The safeguards activities in a nuclear facility are carried out mainly to generate or to test information in connection with the location and movement of fissile materials. In a reprocessing plant, a major part of this information is necessary for the establishment or checking of a material balance around the plant, although supplementary information on some containment and surveillance measures are also required. One of the causes for additional safeguards efforts in an existing plant

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is the manner in which the network for such an information system is laid out. This is shown in a schematic manner in Fig. 1. The points of generation, registration, processing and reception of information in a WAK type plant are indicated in this figure. Fig. 2 gives the same information for the dissolver tank area of this plant.

It is seen from these figures that:

a) The information relevant to safeguards (e.g fissile material amounts for the feed, product and waste streams) are generated almost throughout the plant.

b) Part of the information is received at the point of its generation (product stream) but a major part is registered at the control panel of the plant (e.g. level indication for feed and waste streams).

c) All information on fissile material concentration is generated in or near the relevant process steps (e.g. input accountability, product, waste tanks and sampling from the relevant tanks), processed at the laboratory and sometimes received at some other point (e.g. inspection room).

d) The different accountability tanks, sampling stations, control panel, the analytical laboratory and the inspection room are located at different floors of the process building and are physically widely apart.

In short, it appears that in an existing reprocessing plant the various process steps are arranged in a centralized manner,whereas, the information system is decentralized. Particularly this point leads to a complicated,wide spread information network system. This requires large efforts in ensuring the credibility of the information and receiving them for safeguards purposes.

2.2 Containment problems

It appears difficult to execute adequate containment and surveillance measures particularly during the transition steps between the fuel storage and the accountability measurements in an existing plant. It may be noted that:

a) The fuel elements lose their identity at the dissolver tank.

b) The recycle acid from different process tanks containing various amounts of Uranium and Plutonium (although very small percentage of the feed flow under normal conditions) is fed back at this point.

c) That the leached hulls may leave this point without sufficient measurements with regard to their fissile material content. And finally,

d) Dissolver solution may be introduced to the process area without having the possibility of measuring it at the accountability tank.

Because of these conditions, the necesssity of having good containment and surveillant measures is accentuated at this point.

2.3 Inventory taking

For establishing the material balance around the process area, the fissile material inventory in that area has to be known by direct measurement. In existing plants this inventory can normally be made with some degree of accuracy after a washout. This is expensive and can be carried out only by discontinuing the normal operation.

It appears that the method for process inventory determination during a campaign, which is being developed at Karlsruhe [3,4,5], can be used successfully in existing plants also. However, it may require sample takings at points where they are not foreseen for normal operating purposes.

A part of the safeguards efforts is influenced significantly by the ease with which the process inventory in a plant can be determined.

2.4 Measurement of process flows

In many of the existing plants, analytical facilities are often just sufficient to meet the plant requirement and additional capacity for safeguards measurements are normally not available. This necessitates transport of samples to other laboratories, causing significant and undesirable delays in establishing a material balance. Besides, long storage time of active samples may give rise to effects which may destort the material balance results.

2.5 Safeguarding waste streams

In existing plants, a number of waste streams with different levels of activity and with traces of fissile material is produced. The arrangement of collection and measurement of these streams are generally such that a fairly large effort is required to safeguard these streams effectively, although their fissile material content is low.

3. Procedural requirements of a modern safeguards system

For the proper execution of safeguards activities, a number of safeguards procedures are required which consist of actions both by the safeguards organizeation and the plant operators. The effectiveness with which these procedures can be carried out in practice, depends partly on the design and the layout of a plant. These procedures are summarized below.

3.1 Examination of design review

Some overall information on the design and layout of the plant is to be submitted to the safeguards organization. This should enable the organization to:

a) Define material safeguards areas and select those strategic points which will be used to determine the input and output of nuclear material in these areas for accounting purposes of the safeguards organisation;

b) Establish procedures and convenient frequencies and timing for taking a physical inventory;

c) Establish the recording and reporting requirements and records evaluation procedures;

d) Select appropriate containment and surveillance methods and techniques on the basis of the existing or planned plant layout; and

e) Establish inspection requirements and procedures for verification of the quantities and composition of nuclear material and select the strategic points where inspections shall normally be made.

3.2 Reports and records system

A periodic recording system indicating the status of the fissile material in a plant forms an essential part of the safeguards procedures. Such a system enables the safeguards organization to follow the fissile material flow and inventory pattern in the whole fuel cycle and establish consistancy correlations between the fissile material flows through the different parts of the cycle. Such a report system is to be based on plant records on fissile material flows and inventories and the relevant parts of such records should be available to inspectorate personnel for comparing the records with the reports. The reporting system may also enable the safeguards organization to minimize on-site inspections.

Reports and records systems can be prepared and utilized in an optimum way if the information system on material balance is laid out in a transparent manner.

3.3 Inspections

Some of the more important functions of inspections are:

a) The verification in connection with the design information that the facility will permit the effective application of safeguards;

b) The verification that reports are consistent with records;

c) The verification of recorded inventory and flow by independent measurements of nuclear material or other independent and objective methods;

d) Application of containment and surveillance methods;

e) The verification of reports on abnormal losses of nuclear material or the investigation of an incident that has given rise to a special report.

The effectiveness and the extent of intrusiveness of such inspections may depend to a large extent on the plant design.

4. Design criteria facilitating safeguards

In view of the considerations made under chapters 2 and 3, it is possible to formulate a number of requirements for the layouts and design of a reprocessing plant which would facilitate safeguards procedures.

4.1 The points for the registration and processing of information relevant to safeguards should be concentrated in space and should be reduced to the minimum possible number.

4.2 The information distribution network relevant to safeguards, should be transparent so that effective measures for ensuring correctness of information can be applied easily and an uncomplicated recording and reporting system can be maintained.

4.3 Wherever possible and economically justifiable, the information system should be automated and mechanized.

4.4 Adequate containment and surveillance possibilities should exist to ensure continuity of knowledge at the head end of the plant. Containment for the rest of the plant should ensure a timely detection of an introduction of undeclared fuel or of any other illegal action associated with a diversion.

4.5 The relevant process steps should be arranged in a transparent manner so that both the throughput and the physical inventory can be measured easily, accurately and quickly without undue interference with the normal operation of the plant. In case the physical inventory of a part of the plant can be a ascertained only with the help of a washout, this part should be laid out in such a manner that a complete washout can be undertaken within a short time and that both the residue in the plant and the washed out solution can be measured easily and with sufficient accuracy with respect to their fissile material content.

4.6 It should be possible to safeguard all the waste streams as an integrated whole.

4.7 Sufficient additional space and facility should be available in the plant for the execution of safeguards measures, for example, analysis of additional samples for independent verification, verification of records and report system etc.

4.8 The layout of those parts of the plant which may be industrially sensitive, should be such that the fissile material inventories are relatively small in those parts and that the probability of a diversion of any significant amount of fissile material from these parts, without a timely detection, would be low.

4.9 Finally, the plant layout and the process design should be such that safeguards measures can be executed in the most cost-effective and nonintrusive manner, without hampering unduely the normal operation of the plant.

5. Principle arrangement of a reference reprocessing plant

A schematic and modified layout of the WAK type plant, which could meet the safeguards requirements enumerated under chapter 4, is shown in Fig. 3. The main characteristics of this plant is the decentralization of the different process buildings and a centrally located information building. The possibility of a decentralization in a reprocessing plant was considered at a fairly early stage by the WAK plant management [8] and the present layout leans partly on the earlier concept.

The main process buildings namely, fuel storage (2), head end (3), process (4) and product and waste storage (5/6) are all arranged around the central information building (1) so that fissile material flows from or to any of the main process buildings have to pass through the different strategic points located in the information building. When required the fissile material inventories from the process building can also be brought to storage tanks located at the strategic areas.

5.1 Information building

Under normal conditions, all the safeguards measures can be executed by the inspectorate personnel at the various stratetic areas located in this building. The building is divided into two floors. The ground floor is partitioned into a number of strategic points a)to i)at which all the streams relevant to fissile material balance accountancy, are identified, measured or stored. The upper floor is divided broadly into two areas 1A and 1B. In 1A instrument panels, analytical facilities and records and reports offices are provided for safeguards and plant accountability purposes. Area 1B contains control panels and analytical facilities required mainly for plant operation or process control purposes.

Normally, all the fissile material enters the plant through the entrance of the information building near the fuel storage. The same entrance is used for the removal of the leached hulls as solid waste. The other entrance at the opposite end is meant for the supply of non-nuclear materials and shipment of final products and liquid wastes or their residues. This is also used as the main entrance for the plant personnel. The plant personnel can enter the process buildings only through corridor entrances from the information building.

6. Safeguards activities

The safeguards activities proposed for this plant are based on procedures discussed in chapter 3.

6.1 Fuel storage building

A double storied strategic point a)has been envisaged at the entrance of the information building near the fuel storage. The transport cask for irradiated fuels is supposed to be unloaded here. The counting, identification and intactness-tests for the irradiated fuel elements and similar measures for the cask, can be carried out during the unloading period. With suitable systems, all these measures can be executed from the panel room 1A. The identified fuel elements are stored in the wet storage building 2 in which the same counting and identification systems can be used when required. This building is supposed to be completely accessible to safeguards personnel for physical verification and therefore, can be regarded as a strategic area for safeguards.

The identified fuel elements can enter the head-end building only through the strategic point b) in the information building. At this point, the elements entering the head-end building will be identified once more and debited from the fuel storage inventory. As at a) all the safeguards measures can be carried out from 1A.

6.2 Head-end building

The chop-leach units and the dissolver tanks are located in this building. The fissile material inputs to this building are the fuel elements and the recycle acid from the process building. The output streams consist of the leached hulls in the form of solid waste and the process solution which can enter the process building only through the accountability tank c). Adequate containment and surveillance systems (in the form of liquid indicating sensors, close circuit televisions etc.) are supposed to be incorporated in this building to ensure that all the fissile material containing streams leading or entering the building, can do so only through the strategic points i), b), c) and f). A bypassing of these points is assumed to be indicated with a high probability.

The fissile material content of the leached hulls, which are discharged from the dissolver tank and stored in barrels, is measured with a nondestructive method at the strategic point i). The barrels are all sealed and temporarily stored at this point. At regular intervals, they are removed from the plant on special railway carriages after counting and identification.

6.3 Accountability cell

As a strategic point, the accountability cell 1C in the information building occupies a unique position in the safeguards system proposed for this plant. In this cell sufficient number of calibrated tanks are installed. In these tanks fissile material content of various active process solutions, from or to the process building, which are important from safeguards point of view can be determined with sufficient accuracy. Such solutions may be the input stream for the extraction cycles in the process building, recycle acid to the dissolver, rework solutions containing Uranium and Plutonium, washout solutions from process inventory taking, liquid waste solutions from the process areas and so on. Since all the relevant safeguards information on the fissile material amounts is generated in this cell, and registered, processed or received in the safeguards panel room 1A, the reliability of this information can be ensured relatively easily. Also the reception of all the information is possible in a single room. The tanks in the accountability cell can be calibrated from time to time by the inspectorate personnel.

In case of the dissolver solution, it is filled up in the accountability tank c) located in the accountability cell. The volume (or weight) of the solution is indicated at the panel in 1A and the solution samples are taken automatically and assayed for their fissile material content in the analytical rooms of 1A. The results of these measurements are available both to the inspectors and the operators personnel. The same procedure is used for the recycle acid going from the process to the head-end building (point f of Fig. 3).

6.4 Process building

All the process steps for the purification and separation of Uranium and Plutonium as well as the acid and solvent recovery systems are located in this building. Besides, the building has sufficient space for storage of inactive materials and other auxiliary facilities. The fissile material input is the dissolver solution measured in the accountability tank c). The outputs consist of the purified Uranium and Plutonium products, different types of liquid waste streams (organic and aqueous with different grades of activities) and the recovered acid.

A part of the recovered acid is sent to the dissolver tank through the accountability cell. Different types of liquid waste solutions produced in the process building are sent to intermediate storage tanks (calibrated) located in this cell and after assaying the fissile material amount, transfered to the main waste storage and treatment areas in building 5/6. The safeguards measures for these streams at the accountability cell are the same as those for the dissolver solution.

The purified Plutonium and Uranium products are filled in the respective product containers and are weighted and sampled at the strategic point d). They are also sealed and registered at this point. The samples are analysed in 1A. The sealed containers are sent to the product storage areas in building 5/6.

Adequate containment and surveillance measures are provided for the process building to ensure that no uncontrolled material containing significant amounts of Uranium or Plutonium (e.g. Plutonium containing waste or scraps from a Plutonium fabrication plant),can be introduced to and after purification removed from this building. The emergency exits of this building remain sealed under normal conditions.

6.5 Product and waste storage building

This building is devided in two broad areas, one for the storage of Uranium and Plutonium products and the other, for the storage and treatment of liquid wastes. It is assumed, that different types of waste solutions received in this area, will not be stored there indefinitely. Depending on the type, activity etc., they will either be treated further in this area and shipped periodically for permanent storage elsewhere, or removed from the plant at regular intervals for treatment or storage at some other place. The inputs to this building are the sealed product containers with predetermined amounts of Plutonium and Uranium and known amounts of liquid waste solutions. Outputs are the same sealed containers and discrete amounts of treated or untreated wastes in solid or liquid form.

The seals of the product containers are checked at the strategic point e) before they are sent away from the plant. The amounts of fissile material removed in this way are debited from the inventory of the product storage area.

The strategic point h) is used to register the liquid waste amounts leaving the plant. Depending on their forms, the fissile material content in these amounts may be measured either with direct or with nondestructive methods. These amounts will also be debited from the inventory of the waste storage area.

The waste and the product storage areas are completely accessible to safeguards personnel for physical verification and therefore, can be regarded as a strategic area for safeguards purposes.

6.6 Inventory taking

It is necessary to determine the physical inventory of fissile material in all the process and storage buildings at a given time, to establish a material balance around the plant over a given period of time. It is expected that the inventory taking will be considerably simplified because of the decentralized layout of the plant. Another advantage of decentralisation is that the physical inventory for each process building (which is necessarily smaller than the inventory of the whole plant) can be determined seperately.

The inventory of the fuel storage and the product storage buildings can be determined completely at any time by counting and identifying the fuel elements and the sealed product containers respectively. In the case of fuel elements, the counting and identification system used during the unloading of the transport cask, can also be used in the wet storage area.

With the use of correlation techniques [9], the fissile material content in each fuel element after its discharge from a known type of reactor, can be predicted with fairly high accuracy. Therefore, knowing the number of fuel elements which has entered the head-end building, the fissile material inventory in this building can also be predicted with some acceptable accuracy. This inventory can then be verified by dissolving these fuel elements and measuring the fissile material content of the dissolver solution in the accountability tank c) and in the leached hulls at the strategic point i).

The fissile material inventory of the process building at a given time, can be determined with the help of the isotopic analysis technique [3,4,5] or by washing out the plant at the end of a campaign. In both these cases, the required safeguards measures can be carried out at the strategic areas in the information building and in the fuel storage area.

The fissile material inventory in the liquid waste area is expected to be low. In a WAK type plant, the input of Plutonium to this area will not exceed 2-5 kg/yr. Since it is assumed that the waste solutions will be removed periodically from this area, the Plutonium inventory is not expected to exceed 2-5 kg of Plutonium. Although the probability of diversion at this point is the lowest because of high dilution and high activity (which may be regarded as a self-sealing safeguards measure), provision is made to carry out a rough physical inventory for safeguards purposes once a year. This can be done by measuring the levels of the storage tanks in this area and taking individual samples.

Fissile material containing samples taken to the analytical room 1A and 1B are assumed to be collected at these areas. Every six months the fissile material content of the collected and integrated samples will be measured and removed to one of the process streams after balancing the amounts if they exceed a preset significant value.

7. Improvements

The present layout has been conceived on the existing technology in a WAK type plant. A further reduction in the space and in safeguards efforts may be achieved if certain technological improvements are assumed to be incorporated in the plant. Two such examples may be cited.

a) On-line instrumentation at the accountability tank: If an on-line instrument for determining the fissile material concentration in dissolver solution could be attached to the accountability tank c) and located in the cell indicated after strategic point b), and samples could be fed automatically to this instrument, the results could be registered in the instrument panel located in 1A. In that case all additional analytical facilities for determining the fissile material content at this point could be eliminated from the analytical room 1A.

b) Continuous flow measurement of waste streams: Most of the calibrated waste casked tanks in the accountability cell could be eliminated if liquid waste flows from the process to the waste storage building 5/6 could be continuously assayed with flow and concentration measuring instruments.

8. Conclusions

A modified plant layout for the WAK type plant, which could permit the execution of various measures of a modern safeguards system in an effective manner, has been discussed in this paper. The main features of the layout is a decentralisation of the process building. They are arranged around a central information building in such a manner that all the relevant information can be obtained at the different strategic points located at this building. This requires that any fissile material streams leading or entering a process building have to pass through one of the strategic points. Also all personnel and material entering any of the process buildings have to go through the information building.

Although the layout has been kept fairly flexible and requires a detailed feasibility analysis before one could draw firm conclusions, it permits one to recognize some advantages for the application of safeguards measures.

8.1 Through decentralisation of process buildings there is a clear and physical separation between the inventory intensive areas (fuel and product storage) and the process areas. The inventory intensive areas can be made completely accessible for safeguards purposes. The process areas, namely, the head-end and the process building are expected to have low fissile material inventory compared to the storage areas. This low inventory, coupled with the fact that relatively simple containment and surveillance devices can be used to indicate any uncontrolled movement of fissile material, would mean that the probability of an undetected diversion from these buildings would be very low.

8.2 All the safeguards relevant information are generated, registered, processed and received at the information building. This concentration of information is expected to minimize efforts both in the execution of safeguards measures and in ensuring the reliability of the generated information.

8.3 There is a clear and physical separation between the process steps and the measurement and control steps. This appears to be advantageous to both the plant operators and the safeguards personnel. It is highly desirable to locate the delicate and often sensitive control and measuring instruments away from the process building in which all the heavy process machineries are normally located. Also intrusiveness and hindrance to normal operation of the plant through safeguards activities can be reduced to a minimum by keeping these activities restricted to a completely separate building under normal conditions. On the other hand, the safeguards personnel are mainly interested in the information generated in the different process steps and not in the process steps themselves. Therefore, a separation of such information completely from the process steps, and its accessibility in a single building, would enable the safeguards personnel to concentrate only on those measures which are pertinent to safeguards.

Acknowledgement

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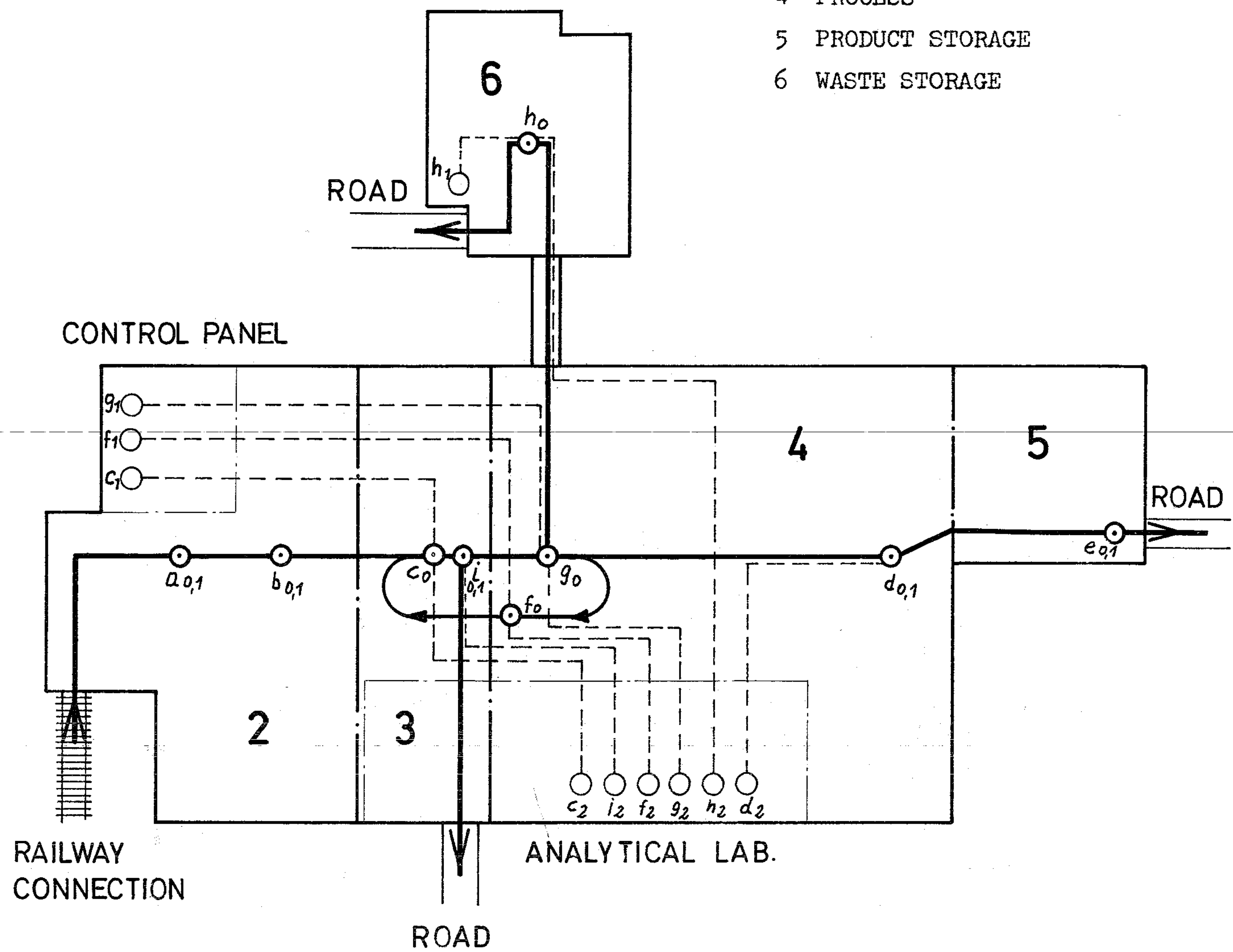
2 FUEL ELEMENT STORAGE
3 HEAD END
4 PROCESS
5 PRODUCT STORAGE
6 WASTE STORAGE



a FUEL ELEMENTS TO BE STORED
b FUEL ELEMENTS TO BE DISSOLVED
c DISSOLVER SOLUTION
d PRODUCT TO BE STORED
e PRODUCT TO BE SHIPPED
f RECYCLED ACID
g LIQUID WASTE TO BE SENT TO STORAGE
h LIQUID WASTE TO BE SHIPPED
i SOLID WASTE TO BE STORED OR SHIPPED

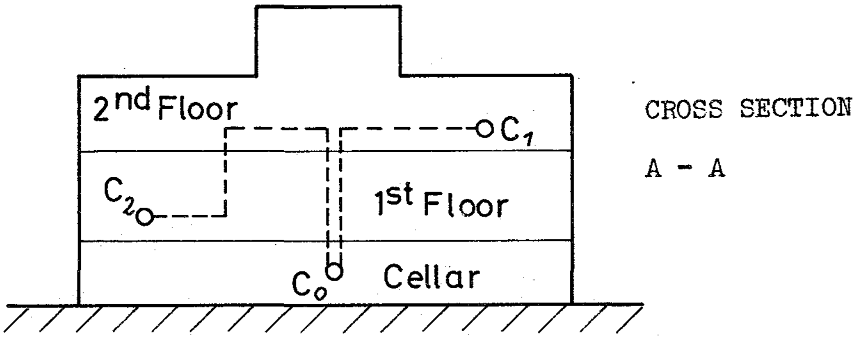
——— FLOW OF MATERIAL

– – – – FLOW OF INFORMATION

INDICES:

0 GENERATION OF INFORMATION
1 RECEPTION OF INFORMATION ON THE AMOUNT OF MATERIALS
2 PROCESSING AND RECEPTION OF INFORMATION ON THE FISSILE MATERIAL CONCENTRATIONS

FIG. 1: INFORMATION NETWORK IMPORTANT TO SAFEGUARDS IN AN EXISTING REPROCESSING PLANT OF THE WAK-TYPE



C_o = GENERATION OF INFORMATION FOR DISSOLVER SOLUTION (D.S.) (COLLECTION OF D.S. IN THE ACCOUNTABILITY TANK, HOMOGENIZATION AND SAMPLE TAKING)

C_1 = RECEPTION OF INFORMATION ON THE AMOUNT OF D.S. (LEVEL, DENSITY AND TEMPERATURE INDICATION AT THE CONTROL PANEL)

C_2 = PROCESSING AND RECEPTION OF INFORMATION ON THE FISSILE MATERIAL CONCENTRATION IN D.S. AT THE ANALYTICAL LABORATORY

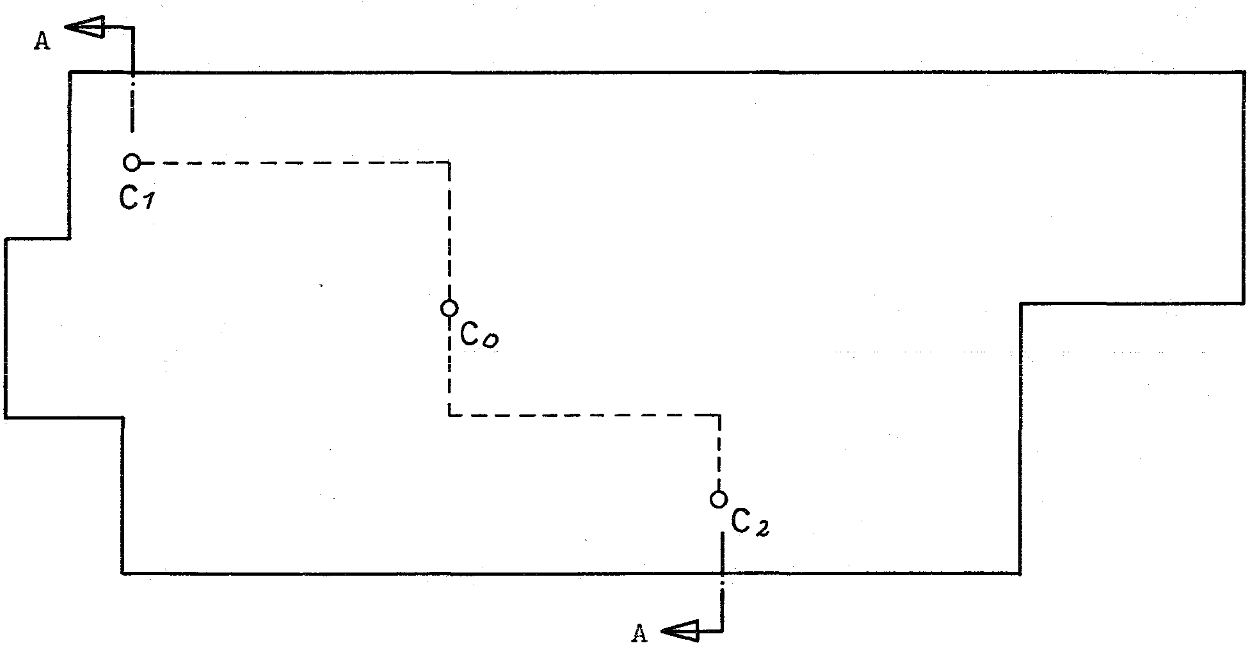
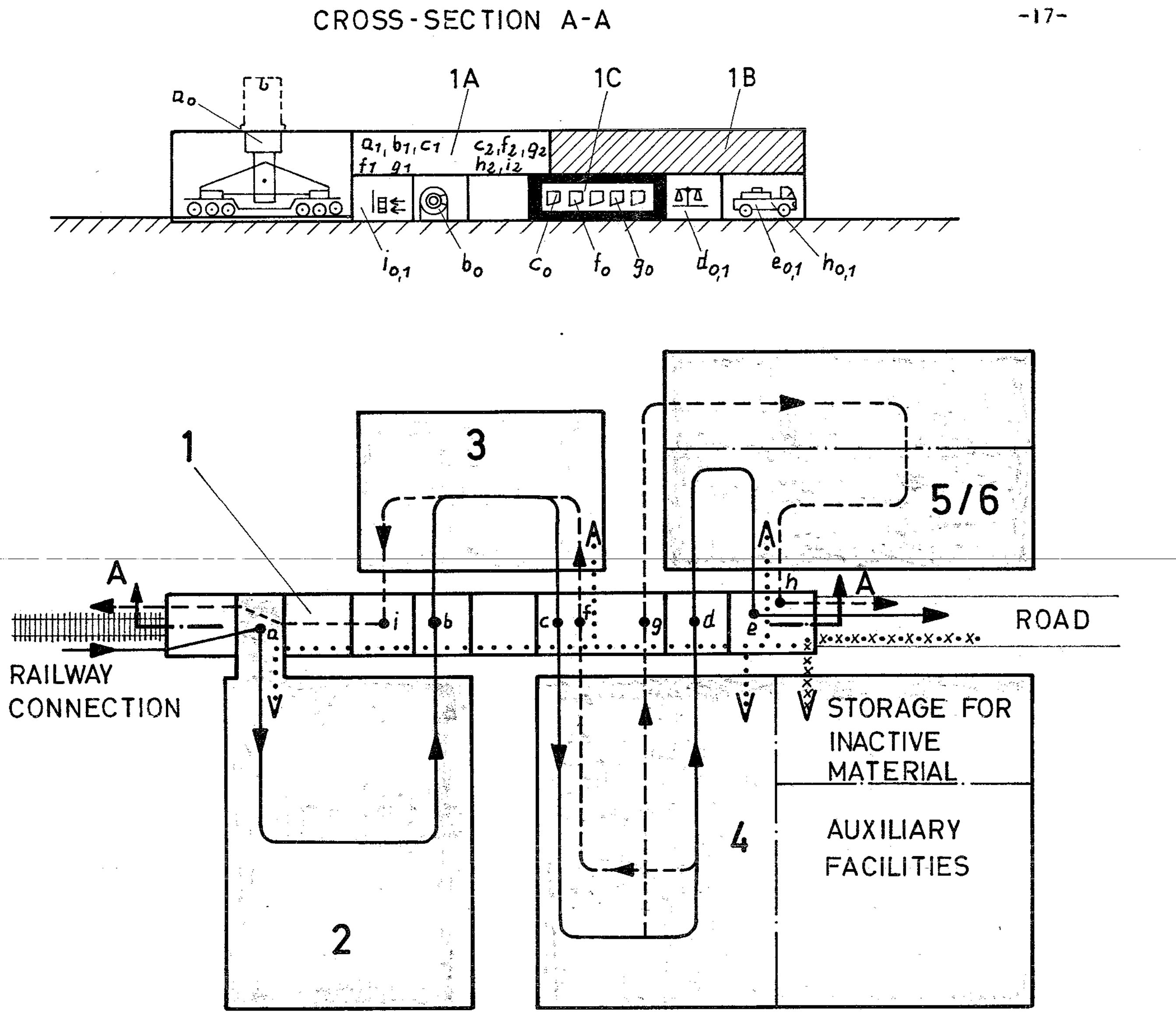


FIG. 2: TYPICAL EXAMPLE FOR GENERATION PROCESSING AND RECEPTION OF MATERIAL BALANCE INFORMATION FOR THE DISSOLVER TANK OF A WAK-TYPE PLANT



ACTIVITIES AT STRATEGIC POINTS

- a REGISTRATION, IDENTIFICATION AND INTACTNESS TEST OF FUEL ELEMENTS ARRIVING
- b REGISTRATION, IDENTIFICATION AND INTACTNESS TEST OF FUEL ELEMENTS LEAVING THE STORAGE
- c INPUT MEASUREMENT OF DISSOLVER SOLUTION
- d REGISTRATION, SAMPLING, SEALING AND INSPECTION OF PRODUCT CONTAINERS TO BE STORED
- e REGISTRATION, IDENTIFICATION AND INSPECTION OF PRODUCT CONTAINERS TO BE SHIPPED
- f RECYCLED ACID MEASUREMENT
- g MEASUREMENT OF LIQUID WASTE TO BE SENT TO STORAGE
- h MEASUREMENT OF LIQUID WASTE TO BE SHIPPED
- i REGISTRATION, MEASUREMENT, SEALING AND INSPECTION OF SOLID WASTE TO BE STORED OR SHIPPED

– – – –	FLOW OF FISSILE MATERIAL
xxxxxxxx	FLOW OF INACTIVE MATERIAL
·······	PERSONNEL

1	INFORMATION BUILDING WITH STRATEGIC POINTS
1A	PANEL AND ANALYTICAL ROOM FOR SAFEGUARDS AND ACCOUNTABILITY
1B	PANEL AND ANALYTICAL ROOM FOR OPERATION
1C	ACCOUNTABILITY CELL
2	FUEL STORAGE
3	HEAD END
4	PROCESS
5/6	PRODUCT AND WASTE STORAGE

FIG. 3: PRINCIPLE ARRANGEMENT OF A MODIFIED WAK TYPE PLANT

(indices see Fig. 1)