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Institut für Angewandte Reaktorphysik

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Development of Safeguards Procedures for a Reprocessing Plant Similar to the WAK Type.

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This research has been carried out in the framework of a contract between the International Atomic Energy Agency Vienna/Austria and the Institut für Angewandte Reaktorphysik Kernforschungszentrum Karlsruhe, Gesellschaft für Kernforschung mbH. Karlsruhe, Federal Republic of Germany.

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Der Bericht, der im Rahmen eines Forschungsauftrages mit der International Atomic Energy Agency Wien angefertigt wurde, enthält einen Vorschlag zur Kontrolle des Spaltstoffflusses in einer Anlage wie der Wiederaufarbeitungsanlage Karlsruhe (WAK).

Nach einer Analyse der WAK wurden zunächst die für ein rationales Kontrollsystem wichtigen Bereiche, die strategischen Bereiche, abgegrenzt.

Es wurden die Maßnahmen angegeben, mittels der die Spaltmaterialkontrolle ohne Beeinträchtigung des Betriebsablaufs von den strategischen Bereichen aus durchgeführt werden kann. Detaillierte Anweisungen wurden der Inspektionstätigkeit zugrunde gelegt.

Die Materialbilanz als eine der wesentlichen Maßnahmen wurde hinsichtlich ihres möglichen Unsicherheitsbereichs aufgrund von Meßfehlern sowie möglicher Fehlbeträge untersucht.

Nach einer Abschätzung der mit dem vorgeschlagenen System verbundenen Kontrollkosten schließt der Bericht mit einem Ausblick auf Verbesserungen im Hinblick auf Kontrollmethoden, Instrumente, Techniken und Anlagenentwürfe.

The report made within the framework of a contract between the International Atomic Energy Agency Vienna and the Gesellschaft für Kernforschung Karlsruhe contains a proposal for safeguarding the flow of the fissile material in a reprocessing plant similar to the Wiederaufarbeitungsanlage Karlsruhe (WAK).

After an analysis of the WAK at first the areas relevant to a rational safeguards system, the strategic areas, have been defined.

The measures at these strategic areas have been developed by which the fissile material can be safeguarded in a non-intrusive manner and without hampering the normal plant operation.

The activities of the inspectors are based on detailed procedures.

The material balance as one of the most important measures has been investigated in view of the possible uncertainty range on account of measurement errors and in view of possible deficits.

After an estimation of the costs of the proposed system in the final report several possible improvements concerning methods, instruments, techniques, and a plant layout have been discussed.

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1. Summary

The present report describes the work and the results obtained in connection with the IAEA contract No. 712/RB on the 'Development of Safeguards Procedures for a Reprocessing Plant Similar to the WAK Type'. This work has been carried out at the Institut für Angewandte Reaktorphysik, Kernforschungszentrum Karlsruhe.

After a detailed analysis of the WAK plant layout and process steps as well as demarcation of the plant operation and areas, which are relevant to a rational safeguards system, the strategic areas in the plant have been defined. At these areas all the information required for safeguards purposes can be obtained in a non-intrusive manner and without hampering the normal operation of the plant.

The detailed safeguards measures at these strategic areas have been developed and the procedures for carrying out these measures have been been laid out.

The error propagation mechanism, after taking into consideration both the random and the systematic components of measurement error, has been analysed and its influence on the establishment of a material balance has been shown with the help of a numerical example.

An effort has also been made to estimate the costs to be expected for the safeguards system proposed in this report. It is shown that they may be about 3 % of the reprocessing costs from the plant. Chemical analyses form a major part of the total costs. Means of reducing these costs have been discussed.

In the final part of the report, a number of possible improvements with regard to safeguards methods instruments and techniques have been discussed. Some estimates on the development time and efforts have also been made. Besides, some relevant features in a reprocessing plant, which may be of interest for safeguards, have been described with the help of a reference plant layout.

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2. Introduction

The rapid expansion of nuclear industries for the production of nuclear power as evidenced during the past few years in a large number of countries, indicate that the production of plutonium will increase at an extremely rapid rate during the coming years. For example, on the basis of recent nuclear power forecasts /‾1, 2_7, the total accumulated plutonium in irradiated fuel elements in 1980, is expected to be around 20 t in Germany, 60 t in Europe and 85 t in the USA. Most of these fuel elements will be processed in reprocessing plants so that, large amounts of plutonium are expected to be present in such plants in fairly accessible form. Therefore it is desirable to investigate and develop rational methods for safeguarding the flow of such fissile materials in these plants.

3. Basic Considerations

3.1 Objective of the safeguards system

The objective of a fissile material safeguards system for a reprocessing plant is to prevent or to detect a diversion of a significant amount of fissile material from the plant.

It has been shown in a number of publications /‾3-10_7 that this objective can be attained with three basic safeguards measures namely, containment, material balance (comprising of throughput and inventory measures) and other redundant measures (surveillance, television, mechanical registration of movements and activities etc.). A balanced combination of these three measures are required to develop an effective safeguards system. However, the material balance plays a key-role in any safeguards system, as it can detect in a quantitative manner a diversion of fissile material, although with a time lag depending on the method of carrying out the inventory.

Integral safeguards exercises executed in existing nuclear facilities /‾7,8,9_7 and a number of computer simulations of fissionable material flow in such facilities /‾4, 11_7, have shown definitely that all safeguards measures required to fulfill the objective of an effective safeguards system, can be carried out in strategic areas under normal conditions.

Definition of strategic areas: The first objective therefore, of this report is to identify and demarcate the strategic areas. In this context, the strategic areas have been defined as those areas in a nuclear facility, in which all the relevant information required to execute safeguards measures, are made available to inspection authority. These areas are so chosen, that the safeguards activities can be carried out non-intrusively and without in anyway hampering the normal operation of the plant.

Before identifying the strategic areas some knowledge on the layout as well as on the operation characteristics of the plant is required.

3.2 Characteristics of a reprocessing plant

A reprocessing plant of the WAK type can be divided into three important plant sections according to the flow of fissile material through it:

a) the fuel element storage
b) the chemical process and
c) the product and waste storage.

These sections appear to be well suited for analysing a WAK type plant from the point of view of safeguards. In a) and c) no processing of material takes place, and the fissile material is contained in well defined forms of fuel subassemblies or fissile material containers. Therefore containment measures consisting of identification of seals or sealing of containers appear to be well suited and sufficient safeguards measures for these areas in ensuring that the fissile material reaches the endpoint of the plant section in question. Because of the definition in 3.1, these two sections, namely the fuel element storage and product and waste storage areas can be considered at strategic areas.

For the chemical process area the definition of a strategic area can be fulfilled in an ideal manner, if all the information required to establish an independent material balance can be brought together outside the chemical process area to a room. Such a room could be called an inspection room. This situation is shown in Fig. 3-1.

Two important points in connection with the inspection room should be noted additionally. Firstly, because of the discontinuity of data of material flow between the outgoing material of the fuel element storage area (in the form of fuel elements), and the incoming material of the chemical process area (in the form of solution in the dissolver tank), special containment measures are required at the transfer point. Secondly, because of the separation of the sensing and the recording part of instruments required to obtain data from the chemical process area to the inspection room, some additional electrical lines and conduits are required. Special measures have to be taken to ensure the tamperproofness of these lines and conduits.

4. Description of the WAK plant

4.1 Reprocessing program

The WAK reprocessing plant is designed for a nominal capacity of 200 kg UO_2/d or 40 t UO_2/yr.

According to the present layout, the plant is capable of processing spent fuels enriched up to 3 % U-235 with an average burnup not higher than 20 000 MWd/t heavy metal. A minimum cooling time of 150 d is specified.

The final product of the reprocessing at the WAK plant consists of uranium nitrate solution of about 450 g U/1 and plutonium nitrate solution of about 30-50 g Pu/1.

4.2 Description of the plant

The largest and most important part of the WAK plant is the process building. The layout of the building is shown in Figs. 4-1, 4-2 and 4-3. The major operations start at the southern end of the process building and consist of

the truck passage	(069 Fig. 4-1)
cleaning room for shielding casks	(069a Fig. 4-1)
fuel element storage pool	(164/164a Fig. 4-2)

The core of the plant is represented by a row of 14 concrete cells (I/OI to IX/OIX) in which the active apparatus and components are installed.

At the east side of the cells

the energy and medium supply	(063 Fig. 4-1)
a drainage tank storage	(067 Fig. 4-1)

and in the floors over this

the analytical laboratory	(165 to 188, Fig. 4-2)
and the sampling gallery	(259 Fig. 4-3)

are located.

The west side houses

the ventilation equipment	(052 to 060 Fig. 4-1)
the reagents make up	(156 Fig. 4-2)
valve gallery	(253 Fig. 4-3)
central panel	(251 Fig. 4-3)

A crane hall forms the superstructure on top of the cell block (257 Fig. 4-3).

An appendix at the north side of the process building provides for final product storage (095 to 097 Fig. 4-1).

A separate building at the west side of the process building houses the waste storage tanks and the corresponding measuring equipment.

4.3 Description of the separation process

The aqueous process of solvent extraction by tributylphosphate (Purex process) is used at the WAK plant. The different process steps are shown in Figs. 4-4 and 4-5.

The head-end step consists of a chop-leach process for single pins after disassembling the subassemblies.

Mixer settlers are used for the chemical separation of uranium and plutonium from the fission products.

The process comprises of several consecutive extraction cycles. In the first cycle, uranium and plutonium are decontaminated and separated by reduction. A second extraction cycle is used for further decontamination for both uranium and plutonium. For final purification, silicagel is used for uranium and ion exchange for plutonium.

4.3.1 Reception and storage of fuel elements

The shielded casks arriving at the process building are lifted by a 75 ton bridge crane into the cleaning room. After cleaning, the fuel elements are unloaded in the west part of the storage pool and transported by a 1 ton bridge crane to the foreseen storage position.

4.3.2 Headend

For the mechanical treatment and dissolution, the fuel elements are transferred to the head-end cell I through an underwater channel.

At first the fuel elements are disassembled. Then the single pins are chopped in sections of about 5 cm length dropping in a basket of the dissolver. After selective dissolution of fuel by nitric acid the leached hulls are removed and filled in barrels which are locked out of cell I. A measurement of fissile material content is foreseen in cell II. The barrels are lifted then in a shielded cask and temporarily stored in cell OII. Dissolver solution is measured and adjusted in cell OI.

The following steps inside the process area are unimportant from the point of view of safeguards measures:

4.3.3 First extraction cycle
4.3.4 Second uranium cycle
4.3.5 Uranium end purification
4.3.6 Second plutonium cycle
4.3.7 Plutonium end purification

4.3.8 Recycled acid

The nitric acid from the extraction cycles and the plutonium end purification, still containing traces of uranium and plutonium is fed back to the head-end after evaporation. There the recycled acid together with fresh acid is used for dissolution of the spent fuel.

4.3.9 Final product

The U-product is bottled or filled in containers in rooms 095/097 of the appendix. After measurement it can be temporarily stored there before shipping.

The Pu-product is bottled in cell VIII and measured. It is stored in room 096 of the appendix before shipping.

4.3.10 Waste

After measurement, batches of liquid waste are transferred to the waste storage building through a shielded line.

High active waste is permanently stored in a 75 m^3 tank.

Liquid waste of lower activity is temporarily stored in smaller tanks and is transported by trucks equipped with shielded tanks for further concentration and storage.

5. Identification of Strategic Points

On the basis of the considerations in Section 3 and the description of the plant layout and operations in Section 4, the strategic areas for the purposes of safeguards can be identified. The location and function of all the strategic areas are summarized in Tab. 5-1.

5.1 Strategic point 1

The fuel element storage hall can be defined as the strategic area 1 (SP 1).

Fig. 4-2 shows this area as room 164 of the WAK plant.

5.2 Strategic point 2

Strategic point 2 is represented mainly by the inspection room SP2a.
The significant feature of such a room, located in an outer part of the plant, is the possibility to get there the bulk of informations required for safeguarding fissile material.

Because of the special situation at the WAK plant, the inspection room SP2a is supplemented by a place belonging to the analytical laboratory SP2b, where all the samples arrive automatically from the plant and the inspection samples can be received.

The possible location of SP2a in the WAK plant is shown in Fig. 4-3 and that of SP2b in Fig. 4-2. It is to be noted, that the SP2a does not exist at present.

5.3 Strategic point 3

Strategic point 3 consists of the areas, in which the final product is bottled and stored and shipped and in which the waste is stored and shipped.

Figs. 4-1 and 4-2 show the areas of strategic point 3 at the WAK plant.

6. Safeguards measures at the strategic areas

The safeguards measures and activities foreseen for the 3 strategic areas and their purposes are summarized in Tables 6-1, 6-2, and 6-3.

Several comments on the structure of safeguards measures are given in the following.

6.1 Strategic point 1

The spent fuel coming from a reactor arrives at the fuel element storage hall in a shielded cask. The subassemblies (SA) are unloaded and stored there until processing.

Because the fissile material is contained in SA's the main safeguards measures to be undertaken by inspection are counting and identification against substitution. (Ms. 1-2, 1-4, 1-5)

Improved possibilities for carrying out these measures are given in section 11.1.1 and 11.1.2.

Besides this after arrival the seal of the shielding cask has to be inspected against opening and substitution of the cask. In the same way inspection of the cask to be intact as containment is necessary. The data of the shielding cask particularly the fingerprint of the seal have to be compared with the corresponding data obtained from the shippers inspection. After unloading the cask has to be resealed. (Ms. 1-1, 1-3)

A sealing system, which seems to be usable within relatively short time also is given in section 11.1.4.

6.2 Strategic point 2

The major bulk of safeguards measures particularly with respect to the material balance to be established over the chemical process, where separation of fission products from U and Pu and purification of U and Pu takes place, are to be executed in the inspection room (SP2a). The inspection room was assumed to be constructed near the transmitter gallery. Therefore, the operator's measuring system could be used to a far extent without requiring long connection lines.

As mentioned earlier, the inspection room (SP2a) is supplemented by a place in the analytical laboratory (SP2b) so major additional installations for receiving inspector samples could be avoided. It is optional for the inspection authority to send the samples to some other laboratories for analysis or get the analyses at the operational laboratories if enough capacity and facilities are available.

Comments on the safeguards measures to be undertaken at SP2 are given below.

6.2.1 Information about arrival of a shielding cask

No special measure is required to inform the inspector about arrival of a shielding cask. At all events this has to be done by the plant operator. Only the inspector is allowed to remove the cask seal after inspection (M. 1-1).

6.2.2 Head end cell

Because of the discontinuity of the material data between the SA's transfered from the storage pool to the head end cell and the input measurement containment measures are required for the head end cell.

All the transfers between storage pool and head-end cell are indicated at SP2a by a distance-cum-load instrument installed at the underwater channel crane (M.2-1) supported by a radiation level instrument installed at the underwater channel. Further radiation level instruments are installed at different surfaces of the head-end cell to indicate at SP2a any uncontrolled removal of fissile material through openings from the head-end cell (M. 2-2).

Details about distance cum load and radiation level instruments, which seem to be applicable within a relatively short time are given in section 11.1.3.

A second possible way for uncontrolled removal of fissile material could be the pipe lines connected with the dissolver, which penetrate the containment. The flow or the flow direction inside these lines is therefore indicated at SP2a by liquid indication instruments installed at the lines near the dissolver (M. 2-3).

The liquid indication instrument isntallation can only be effective, if no changes occur. For this purpose a TV camera is installed near the dissolver. The corresponding receiver at SP2a shows any unusual events (M. 2-4). A TV camera in the dissolver cavity does not appear to be intrusive.

The usual products leaving the head-end cell are firstly the solid wastes particularly the leached hulls and secondly, the dissolver solution. When solid waste is locked out from the head-end cell, a neutron generator is automatically switched on. The recording part of this instrument installed at SP2a indicates the fissile material content of the solid waste (M. 2-5).

The dissolver solution is accounted by the input measurement.

6.2.3 Input measurement

The required measuring instruments are installed at SP2a (M. 2-6). At this point measures have to be undertaken to ensure that the possibility of indicating a reduced amount than what actually is the case, should be reduced. Such a condition could be simulated by the plant operator by either

a) an intended incorrect operation or

b) changes of the system.

6.2.3.1 Input tank and adjoined lines

A possibility according to a) could be that during filling of the tank solution is jetted off. Because level indication increases if jett off rate is smaller than filling rate, this fact can not be identified using only the level recorder. Monitoring of the steamjet valves is not sufficient because this installation can be changed according to b). Therefore, all lines connected with the tank except diptubes are to be equipped with liquid indication instruments and corresponding recorders installed at SP2a (M. 2-9). None of the pipe lines excepting the sampling lines have to be inspected with regard to their destination.

Although difficult because of the high radiation level, a possibility according to b) could be to remove liquid indication instruments or to install new pipe connections with the tank and to jett off dissolver solution as described above. As countermeasure TV observation of the tank and adjoined lines seems to be adequate (M. 2-10).

A special possibility in this context would be filling up the input tank with more dissolver solution in such a way that some of it goes to the process area through the overflow. This case is detected also by M. 2-9 but the actual amount is not determined. It would be of mutual interest if this case could be excluded by installation of an automatic device switsching off the feeding steamjet at a preset level.

6.2.3.2 Sampling system

A very simple way according to a) would be taking a sample for inspection from a tank containing solution of lower fissile material concentration. Inspector monitored sampling as countermeasure would be cumbersome and probably not sufficient because of the multiplicity of possibilities according to b) e.g. substitution of filled vials etc.

Countermeasures of the following type appear to be reasonable:
As already mentioned, both the ends of the sampling line near the input tank are equipped with liquid indication instruments. Therefore, inspection is informed about the (correct or uncorrect) time and number of input sampling procedures (Part of M. 2-9).

In the same way the sample line of the input tank (and five other tanks) at the sampler in the sampling gallery are equipped with liquid indication instruments (M. 2-11).

By comparison of the respective records, an inspector can ensure that during input sampling noother needle block of the sampler was in function. Besides this, the installation of liquid indication instruments at three different points along the sampling line ensures sufficient information about the regularity of the sampling procedure.

Since empty vials for the sampler are marked by inspection and under TV observation (M. 2-12), are inserted into the sampler magazine, with a known sequence, the inspector can identify the time a sample was taken.

The time interval from a sampling procedure until arrival of the sample at the box in the analytical laboratory can be considered as constant because of the highly automatized system. The time of arrival of an inspector sample in the box is recorded.

To avoid substitution of the contents of a vial inside the box in the analytical laboratory, inspector samples have to be put into a casing, from which samples can be locked out only by the inspector (M. 2-14).

6.2.3.3 Dip tube system

Possibilities for falsification according to a) could be the incorrect position of valves and rotameters at the transmitter gallery. If no special monitoring equipment is provided, inspector has to verify the position at the time of measurement (M. 2-18).

There are many possibilities according to b). One example would be controlled venting of air from one diptube. Because monitoring equipment does not seem to be realizable in a reasonable manner, dip tube installation has to be inspected (M. 2-18).

6.2.4 Measurement of recycled acid (RA)

Because of the interconnections of the RA measurements with the input measurements they require particular attention and may be treated in the following manner:

The major part of RA which are in tanks No. 48.05 and 48.10 (Fig. 6-1) contains only traces of fissile material (AFA, Tab. 9-1). It can be measured in these tanks and no special precaution needs be taken.

The smaller part of RA which may have a higher fissile material concentration (2 WW, Tab. 9-1), (after measurement in tank No. 46.10 (Fig. 6-1)) is measured in the dissolver once more before a dissolution process is started.

The containment measures for this are basically the same as those foreseen for the input tank (Ms. 2-7, 2-11, 2-12, 2-15, 2-18).

6.2.5 Waste measurement and physical inventory

Besides input and recycled acid the flow of wastes leaving the MBA chemical process during a campaign can also be followed up at SP2a (Ms. 2-8 and 2-16) using the waste catch tanks (Fig. 6-1).

By having information at SP2 from waste catch tanks mentioned above, the following advantages are obtained:

a) An inspector can get information about possible irregularities in the course of a reprocessing campaign with a minimum time lag. Relevant information for starting the process inventory determination, which is a method under development, can be obtained. The accuracy of informations is much better as the tanks concerned are smaller than those installed at SP3.

b) Physical inventory after a campaign can be carried out (Ms. 2-13 and 2-17).

6.3 Strategic point 3

Within the area of SP3 the final product is bottled and stored. Also liquid and solid wastes are stored there.

6.3.1 Final product

Special safeguards efforts are required for the final product as it is available in a well accessible form.

Therefore, all product measurements are to be carried out in the presence of an inspector (Ms. 3-1, 3-5).

Bottles or containers stored afterwards, are safeguarded by means of counting, sealing and identification. Inspectors at the receiver site are to be informed about the bottles and containers shipped (Ms. 3-2, 3-3, 3-4, 3-6, 3-7, 3-8).

Improved possibilities for carrying out these measures particularly in case of Pu product and U product with a U enrichment > 1.6 % are given in section 11.1.1 and 11.1.2.

A sealing system, which seems to be usable within relatively short time is given in section 11.1.4.

6.3.2 Permanently stored liquid waste

The data of measurement of permanently stored liquid waste (M. 3-9) are used in establishing the material balance after a campaign. This measurement can be taken as a countercheck of the corresponding information obtained at SP2 (Ms. 2-8, 2-16).

The installation has to be inspected (M. 3-10) at the time of taking the measurement.

6.3.3 Temporarily stored liquid waste

Measurements of temporarily stored liquid waste (Ms. 3-11, 3-14) also serve both for the establishment of a material balance after a campaign and as countercheck of the informations obtained at SP2 (Ms.2-8, 2-16).

The installations are inspected simultaneously (M. 3-12) at the time of taking the measurements.

The cistern trucks used for shipping the waste have to be counted, sealed and inspected. (M. 3-13)

6.3.4 Solid waste

Solid waste barrels after measurement of fissile material content (M. 2-5) are introduced into shielded containers. These containers are safeguarded by counting and sealing. (Ms. 3-15, 3-16, 3-17)

A sealing system, which seems to be usable within relatively short time is given in section 11.1.4.

7. <u>Safeguards procedures</u>

The detailed procedures required to execute the safeguards measures listed in Tab. 6-1, 6-2, 6-3 are presented in this chapter.

The procedures include schematic forms in which the relevant data can be entered. These forms given on pages 46 to 49 are largely designed in such a manner as to facilitate automatic data processing.

Procedure 1-1

Inspector will be informed about arrival of a shielding cask containing spent fuel subassemblies (SA) by the plant operator. In a well accessible position of the cask fixed at the hook of the 75 ton crane, inspector has to verify that the cask as containment and the cask seal are intact. Cask seal has to be removed. Identification marks found out of the cask seal have to be compared with corresponding data obtained from the shippers inspection, to ensure that cask could not be substituted. In case cask or cask seal are not intact or identification marks do not agree, further investigation has to be started.

Data of the cask and cask seal have to be noted down in form No. 1.

Procedure 1-2

If the lid of the shielding cask is removed SA's are lifted up subsequently by the 1 ton crane. Identification marks (digits, letters etc.) of the SA's suitably positioned under water have to be read by the inspector using operator's telescope. The water surface at the same time is tranquilized by a glass pane. Additionally the state of each SA as containment has to be inspected. Both identification marks provided against substitution and relevant changes e.g. absence of one pin of a SA have to be noted in form No. 1. Noting down also implies counting. The number of incoming SA's represents the input value of a counting balance to be established over the MBA fuel element storage.

Procedure 1-3

After unloading and closing the shielding cask has to be sealed in such a way, that in every case an uncontrolled opening is indicated by the broken seal.

Procedure 1-4

Inspector will be informed if the transfer of a SA to cell I is intended either by the operator or by an instrument, which records distance and load of the underwater crane used for these transfers. In the same manner as under 1-2 the SA's have to be identified and inspected. The data have to be noted down in form No. 1. The number of SA's transfered represents the output value of the counting balance over the MBA fuel element storage.

Procedure 1-5

For closing the counting balance a physical inventory in the storage pool is required. In the same manner as under 1-2 the SA's stored have to be identified and inspected. The data have to be compared with those in form no. 1. The number of stored SA's represents the actual inventory value of the counting balance over the MBA fuel element storage.

Procedure 2-1

It seems to be practicable to transfer SA's from the storage pool to cell I only when inspection is present at the plant i.e. during day. The inspector has to observe the recorder several times a day to get information about such events if he does not get it from the operator and can carry out M. 1-4. Records also indicate if such events took place during night or if anything is brought out from the containment (cell I) using the underwater channel crane.

Procedure 2-2

Because the holes in the western and eastern wall of cell I are not suited for bringing out radioactive material without an increasing radiation level, two monitors installed at the outer surface of each of these walls register such events. In the same way another two monitors installed at the roof of cell I register the increasing radiation level if the hatch is opened. Every transfer of radioactive material via the underwater channel is also registered by a monitor, which is installed there. Inspector has to observe several times a day the recorder connected with all these monitors.

Procedure 2-3

The inspector has to ensure that the dissolver solution reaches the input tank completely. For this purpose all lines in question except the line to the input tank and diptube lines are equipped with liquid indication instruments which show the flow direction also. The inspector has to observe the records several times a day.

Procedure 2-4

The system given under 2-3 is only tamperresistant if it is not changed after installation, e.g. by disconnection of a line equipped with a liquid indication device and direct withdrawal of feed solution from the dissolver. Therefore a TV camera is installed in the dissolver cavity. The receiver has to be observed continuously. During absence of the inspector the picture has to be recorded and observed lateron.

Procedure 2-5

If the door from cell I to cell II is opened for locking procedures, the n-generator is switched on automatically. The switch is sealed by the inspector. The results of the measurements are recorded for inspection. The inspector has to observe the records periodically. If fissile material content is higher than a preset value he has to start further investigation. The preset value is based on experience.

Procedure 2-6

Several instruments provided in the inspection room are connected with the operators system at the transmitter gallery and the central panel for independent measurements of the incoming fissile material solution from dissolver.

Two sets of readings have to be noted down in form No. 2 .
The first set of readings on L+D+T recorder and U tubes and thermometer near the U tubes has to be made when the L has reached its maximum value and the homogenization (air sparging) is completed. The second set of reading has to be made after the decreasing L has reached its minimum value. From the two sets of values, the difference i.e. the amount of dissolver solution transfered to the MBA chemical process can be calculated.

Procedure 2-7

Similar measures as in 2-6 have to be carried out for the recycled acid in the inspection room. However, U tubes and thermometers are not required.
For this purpose three tanks are provided. Besides this recycled acid, batches containing higher amounts of fissile material have to be measured additionally in the dissolver, particularly to avoid repeated measurement of the same batch.

Procedure 2-8

Measures to obtain material balance information for the waste streams can also be carried out on the inspection room. The procedure is the same as that for the input measurement, excepting that U tubes and thermometers are not required. A cross check of this information is obtained in the form of waste solution measurement results from the waste storage tanks.

Procedure 2-9

After the second set of readings of the input measurement (see 2-6), the next batch of feed solution is transfered from dissolver to the input tank. The inspector in a similar way as under 2-3 has to ensure that no uncontrolled withdrawal from the accountability tank takes place.

Procedure 2-10

The system given under 2-9 is only tamperresistant if it is not changed after installation e.g. by disconnection of a line equipped with a liquid indication instrument and direct withdrawal of feed solution from the input tank. Therefore a TV camera is installed at cell OI.

Procedure 2-11

Sample taking, both for the inspector and for the operator is initiated by the operator. The inspector has to ensure that the samples are taken from the correct tanks and at the time indicated by the operator. This is done by checking the records of the liquid indication instruments introduced in the sampling system as explained in chapter 6.

Procedure 2-12

All vials for the feed sampler are marked by the inspector. The inspector has to deliver the vials directly before the operator intends to refill the vial magazine of the feed sampler. The marked vials are packed in a definite array in a sealed box. The inspector has to monitor by the TV system that the seal of the box is not removed by the operator before his arrival at the feed sampler. Furthermore he has to ensure that the vials are inserted in correct sequence and without substitution.

Procedure 2-13

See 2-8.

The total inventory i.e. the solutions containing fissile material which remain in the plant or inside the MBA chemical process after a campaing, have to be measured as a temporary output. The total inventory has to be measured simultaneously to prevent repeated measurement of the same batches. For these measurements twelve waste catch tanks are available.

Procedure 2-14, 2-15, 2-16

To avoid substitution of contents of vials in case of input and recycled acid, arriving samples are stored in a casing, from which they can be locked out only by the inspector. The arrival time of each sample inside the storage casing is recorded.

Once a day the inspector has to collect the samples using a small shielding cask. The records of sample arrival time has to be compared with sampling time recorded under 2-11.

At the same time he has to obtain the plant operators analytical results of the measurements in the twelve waste catch tanks, so that the information obtained under 2-8 is completed.

Generally form 4 has to be used for recording the analytical results.

Procedure 2-17

Inspector has to collect inventory samples using a small shielding cask.

Procedure 2-18

Purely technical methods for tamper proofing the measuring installation in an already existing plant are either expensive or not satisfactory. For this reason the installation has to be inspected for changes in connection with each measurement. For example, different items can be covered by a special paint, so that tampering may become evident.

Procedure 3-1

Inspector will be informed by the plant operator when bottling of Pu product in the form of Pu nitrate solution is intended. Independent readings on the balance of tara and brutto weight of each bottle have to be made and noted down by the inspector in form no. 3. An inspector sample has to be taken immediately after a bottle has been filled completely. From tara and brutto weight and sample concentration the Pu product output value for the material balance over the MBA chemical process can be calculated.

Procedure 3-2

The bottles have to be closed and sealed after the brutto weight determination. The inspector seals are equipped with identification marks. Besides sealing it has to be ensured that the bottles considered as containment remain intact. Identification marks of each bottle seal and other data have to be noted down in form No. 1. Noting down implies also counting of bottles to be transfered to storage. Number of measured and sealed bottles represents the input value of a counting balance to be established over the Pu product storage.

Procedure 3-3

Seals of bottles to be shipped have to be inspected. Also each bottle as containment has to be inspected. Identification mark of each bottle seal and other data have to be noted down in form No. 1. The number of these bottles represents the output value of the counting balance over the Pu product storage. The inspector at the receiving site has to be informed about the data on the shipped bottles.

Procedure 3-4

Seals and integrity of stored bottles have to be inspected and the identification marks of each seal and other data to be checked in form No. 1.

Procedures 3-5, 3-6, 3-7, 3-8

The inspector will be informed by the plant operator when bottling of U-product in the form of U nitrate solution is intended.

The procedures for the measurement of uranium content in these bottles are the same as those for plutonium (M. 3-1, 3-2, 3-3, 3-4).

Procedure 3-9

For independent measurement of waste solution to be stored permanently, the inspector has to make readings on L.+D. recorder and to receive samples after each transfer of high active waste under 2-8 and 2-16 respectively. From the amount of solution and the sample concentration, the integrated amount of fissile material contained in the storage tank can be calculated. The readings have to be noted down in form No. 2.

Procedure 3-10

The measuring and sampling installation of the tank for permanently stored waste is integrated in the separate waste storage building, which forms a part of the strategic area 3. In connection with each measurement, the installation has to be inspected for changes. For example different items can be covered by a special paint, so that any tampering may become evident.

Procedure 3-11

For independent measurement of waste solution to be stored temporarily, the inspector has to make readings on L.+D. recorder of the storage tank and to receive a representative sample after each transfer from the storage tank to the cistern truck. From the amount of solution and the sample concentration, the amount of fissile material remaining in the tank can be calculated. The readings have to be noted down in form No. 2.

Procedure 3-12

The complete measuring and sampling installation of the tanks for temporarily stored waste is integrated in the separate waste storage building which forms a part of the strategic area 3. Some measures as in 3-10 are to be carried out here.

Procedure 3-13

Immediately after filling the tank of the cistern truck is closed and has to be sealed. Identification marks of each tank seal and other data have to be noted down in form No. 1. The receiver inspection station has to be informed about this data.

Procedure 3-14

For independent measurement of the inventory of temporary stored waste in the liquid waste storage, the inspector has to make readings of L.+D. and to get representative samples from all the tanks in question. Readings have to be noted down in form No. 2. From the amount of solution and the sample concentration the fissile material inventory for closing the material balance can be calculated.

Procedure 3-15

After insertion of the solid waste barrel, the shielding container is to be closed and sealed. Inspector seals are equipped with identification marks. The identification marks of each container seal and other data have to be noted down in form No. 1. The number of containers sealed, represents the input value of a counting balance over the solid waste storage.

Procedure 3-16

Seals of shielding containers to be shipped have to be inspected. Identification marks of each container seal and other data have to be noted down in form No. 1. The number of these containers represents the output value of a counting balance over the solid waste storage.

Procedure 3-17

Seals of stored shielding containers have to be inspected. Identification marks of each container seal and other data have to be noted in form no. 1. The number of these containers represents the inventory value of a counting balance over the solid waste storage.

8. Estimation of safeguards efforts

The safeguards efforts required to execute the safeguards measures indicated in section 6 can be divided into three components:

a) Expenditures for instruments and other material

b) Expenditures for inspection personnel

c) Expenditures for analysis of samples.

To a) The expenditures for instruments and other material expressed in cost units are listed according to the safeguards measures in Tab. 8-1, 8-2, 8-3. The investment costs in this context are converted to annual costs using (except in the equipment for measure 1-1) an annuity factor of 14.2 %. This figure implies a depreciation time (= lifetime expected) of 10 years and an interest rate of 7 %.
The summed up annual costs of the different items are given in Tab. 8-4.

To b) The safeguards work was divided into two catagories: The activities to be done mainly in the inspection room by an inspector and the activities to be done mainly at different other places in the plant by a technician.

The man-hours required to execute the safeguards measures are given in Tab. 8-1, 8-2, 8-3.

The summed up man-hours given in Tab. 8-4 show, that one inspector together with two technicians are sufficient for a WAK type plant, if 1600 working hours/a for a safeguards personnel are assumed.

The expenditures for safeguards personnel were assumed to be

50,000 DM/a for an inspector resp.
30,000 DM/a for a technician.

To c) The expected number of samples per year available for the inspection and the respective analysis costs are given in Tab. 8-5.

The summed up costs for analysis in case of individual analysis of each of the samples show an extremely high figure compared with the components a) and b).

For this reason a method of reducing this cost component without decreasing significantly the effectiveness of the safeguards concept is suggested.

An obvious approach consists in the so called composite sample technique. Using this technique the consecutive samples of a stream i.e. one sample of each batch in the corresponding volume proportion are poured together, homogenized and only one sample out of the composed samples is analysed once or repeatedly.

For a representative campaign over 50 operating days Fig. 8-1 and 8-2 show the respective dependence of the relative error on the number of repeated analyses for the product streams. The corresponding uncertainty (σ) and the costs can be obtained by the data specified.

As can be seen from the curves δ increases only by a factor of 2 if the number of analyses, i.e. the costs of analyses are reduced by a factor of 4. This is indicated by dashed lines.

The summed up analysis costs, in which the above mentioned savings are included, also are given in Tab. 8-5.

Tab. 8-6 shows the total expenditures of the safeguards concept proposed.

It should be noted that the resulting specific safeguards costs amount to about 3 % of the expected reprocessing costs for a plant like WAK having a comparatively small annual throughput. A reduction seems to be possible, if the method outlined in section 11.1.8 is applied.

9. Statistical considerations in establishing a material balance

The material balance enables the inspection authority to make statements on the possible withdrawal of fissile material in a quantitative manner.

Measurements of the throughput and the inventory of fissile material form the basis of a material balance. Since no measurement can be carried out without errors the material balance is also associated with an uncertainty. This uncertainty influences the quality of statements.

9.1 Errors of measurement

The errors of measurements can be divided roughly into

a) random errors and

b) systematic errors

The systematic errors according to [12] may be divided further into

ba) systematic errors of random origin (systematic errors of first kind) e.g. the recalibration values of a measuring tank,

bb) systematic errors, which can not be easily reduced to random origin (systematic errors of second kind) e.g. in case of a weighing procedure, if the different air lifting power of weights and the material to be weight is not considered.

To a) The random errors are normally known from experiments.

The relative errors δ of measurements which can be assumed for a WAK type plant are given in Tab. 9-1.

Because $\delta = \sigma/M$, the standard deviation σ can be calculated, if the respective amount M of fissile material per batch is known. Values for M for a WAK type plant are also given in Tab. 9-1.

The error propagation after measurement of k_i batches can be calculated by addition of the respective variances σ_i^2.

In case the amount of fissile material of a batch is obtained by two independent measurements, the measurement of the amount of solution having the variance σ_m^2 and the fissile material concentration having the varinace σ_c^2 can be written

$$\sigma_k^2 = \sum_1^k \sigma_i^2 = \sum_1^k (c_i^2 \sigma_{m_i}^2 + m_i^2 \sigma_{c_i}^2)$$

where c_i is the measured concentration and m_i the measured amount of solution of batch i.

If the k batches of a stream may be assumed to be nearly equal which normally is the case, the following relation is valid.

$$\delta_k^2 = \frac{1}{k} (\delta_m^2 + \delta_c^2)$$

If several independent measurements of the amount of solution and fissile material concentration are foreseen, the variance after k batches is reduced to

$$\delta_k^2 = \frac{1}{k} \left(\frac{\delta_m^2}{n_m} + \frac{\delta_c^2}{n_c} \right)$$

where δ_m = rel. standard deviation of a single measurement of the amount of solution

n_m = number of independent measurements of the amount of solution per batch

δ_c = rel. standard deviation of single analysis

n_c = number of independent analyses per batch

For approximate calculation of the advantages of the composite sampling technique, the above mentioned equation can be used in the following form

$$\delta_k^2 = \frac{1}{k} \left(\frac{\delta_m^2}{n_m} \right) + \frac{\delta_c^2}{n_c}$$

where the variation of n_c from 1 to k implies repeated analysis of the sample taken out of the composite samples of k batches.

<u>To ba)</u> By definition, a distribution can be assumed for the systematic error of 1. kind

$$\sigma^2 = \sigma_r^2 + \sigma_s^2$$

where σ_r^2 = the variance of the random error (a)), and σ_s^2 = the variance of the systematic error of 1. kind (ba)). The error propagation after k batches can be calculated by the expression

$$\delta^2 = \frac{1}{k} (\delta_r^2) + \delta_s^2$$

For large numbers of batches the relative error of the determination of the 'total' fissile material is equal to the sum of the relative variances of the systematic error.

To bb) The systematic error of 2. kind is normally unknown. The error propagation in this case tends to be linear. An approach for investigation of possibly existing systematic errors may consist in a comparison of different measuring installations respectively, by use of standards.

9.2 Material balance

In case of ℓ different fissile material streams, the total variance for the material balance after a campaign can be calculated as

$$\sigma^2_{tot} = \sum_{j=1}^{\ell} \left(\sum_{i=1}^{k} \sigma^2_i\right)_j$$

Tab. 9-1 shows the total variances for a material balance with and without application of the composite sampling technique after a representative campaign over 50 operating days.

9.3 Statements

On the basis of the total standard deviation σ_{tot} a confidence interval can be constructed.

Normally a confidence interval of 95 % is used.

In case the deficit of the material balance (MUF) lies inside this interval it can be stated that with a probability of 95 % 'no withdrawal has taken place'.

In case the deficit of the material balance (MUF) exceeds this interval theoretically it can be stated that 'at least the amount of fissile material is withdrawn by which the confidence limit is exceeded'.

Only systematic practical investigations of the MUF will show, if such statements of the inspection can be made under realistic conditions.

10. Analysis of the problem of MUF

The material unaccounted for (MUF) is considered to be generated by the following components:

1. Propagation of systematic errors in the measurements used for the material balance i.e. calibration errors of tank-volume-measurements, spike- and pipeting-errors in chemical analyses, the influence of sample age etc.

2. Fissile material, which does not participate in fissile material flow through the plant because of plating out at the walls and can not be determined by physical inventory.

3. Unmeasured losses.

4. Gross errors by misreadings in the measurements.

5. Diverted material.

As already indicated in section 9.3,the MUF may influence the statements about diversion to a far extent. Therefore, collection and knowledge of the first three components of the MUF is of great importance from the safeguards point of view.

A most promising investigation particularly in view of 2 will be started at the WAK plant which is expected to go into operation in the near future.

11. Possibilities of improvement

In this chapter, a number of possible improvements with regard to safeguards methods, instruments and techniques have been discussed and the relevant time and costs required for these developments have been estimated. Besides, some relevant features in a reprocessing plant, which may be of interest from the point of view of safeguards, have also been described with the help of a reference plant lay-out.

11.1.1. Photographic accounting of spent fuel subassemblies during transfer

A periscope equipped with a camera could be used to account for both the incoming fuel-subassemblies after unloading from the shipping cask, and those leaving the storage pool for mechanical treatment and dissolution. The equipment could be installed in such a way that all the subassemblies entering or leaving the storage pool, have to pass before it. A water layer could serve as shielding.

If the fuel elements are modified as containments and equipped with tamper-resistant identification marks at their outer surface, several photographs from each fuel element should be taken.

By application of such a technique the frequency of the inspectors presence at the fuel element storage can be reduced, which may result in a reduction of inspection personnel.

The application of this technique at the final product storage of a reprocessing plant could also be considered. At a later phase the information obtained could be processed by a computer.

Estimated development time: 1 year
Estimated development costs: DM 200.000

11.1.2. Photographic accounting of stored fuel subassemblies

In principle the same technique of accounting for spent fuel elements during transfer could be used to carry out physical inventories in the fuel element storage and in the final product storage area.

Normally the fuel elements are positioned on a rectangular grid structure in the storage pool. The pool crane could be provided with the same unit as in 11.1.1. It has to be supplemented by a steering apparatus, which enables the crane to reach automatically the individual fuel elements storage positions.

With such a technique inventory taking at relatively short intervals would be possible also in the absence of an inspector. To some extent this technique would supplement the process inventory determination given under 11.1.7.

Estimated development time: 1 year
Estimated development costs: DM 200.000

11.1.3 Containment measures for the Head-End Cell

In the WAK type plant, a discontinuity in the data on the flow of material exists between the point the spent subassemblies leave the storage pool and enter the head-end cell and the point after the dissolver when they lose their identity completely and appear in a chemical solution. A distance-cum-load measuring instrument, attached to the underwater crane used to transfer the spent fuel elements coupled with radiation and liquid indicators and TV cameras may be used to bridge this discontinuity. The first instrument registers the movement of fissile material between the fuel element storage and the head-end cell. The other instruments indicate any uncontrolled flow of high active material from this area.

These instruments are standard instruments. Development work is required to make them tamperresistant in a highly active surrounding. No estimate for the time and effort for this development has been made.

11.1.4 Tamper indicating sealing technique

A general requirement in safeguards is a sealing system capable of reliable, simple and inexpensive verification in the field [13].

A proposal for such a system, which can be used in a reprocessing plant for shielding casks, containers for products and wastes etc. is summarised below and illustrated in Figs. 11.1.4-1 and 11.1.4-2.

The wire of the seal comprises of a wire rope 1 consisting of a strand of fine wires sheathed in a flexible thin and corrugated tube 2. Both items are readily available and inexpensive. The ends of the corrugated tube containing the wire rope are inserted from the side in the recesses 3 4 of the upper plug 5.After knoting 6 the ends of the wire rope and pushing this arrangement into the lower part of the seal body, the seal is closed and can not be opened without leaving easily detectable marks. The lower part of the seal body comprises of a plexiglass tube 7 a plexiglass lid 8 and a flat spring 9, which are all fixed together. The upper plug 5 is fastened by both ends 11 12 of the prestressed spring 9 at 10.

The seal may be fingerprinted by covering the inner surfaces of plexiglass items 7 and 8 with a transparent varnish containing metal particles of different shape and size. With this, replacement of seal components can be practically excluded. Similarly an undetectable repair of the wire of the seal once broken, can be excluded.

Besides visual inspection of the seal components, a modified camera e.g. polaroid camera is sufficient to identify the fingerprint.

In contrast to other sealing systems the fingerprint of the seal described can be found out by the plant operator. However, because of its random nature an imitation of the fingerprint may be considered to be extremely difficult if not impossible.

For all sealing procedures described in this report a sealing technique of the above mentioned kind served as the basis. A price of DM 10.--/seal has been assumed. A reduction upto DM 1/seal appears feasible if produced in large numbers (e.g. 10,000).

Estimated development time: about 1 year
Estimated development costs: about DM 50,000.--

11.1.5 Input measurement by weighing method

Because of its higher accuracy, the weighing system appeared to be more attractive than the presently accepted volumetric method used for estimating the fissile material content in the accountability tank of a reprocessing plant. However, investigations carried out during the year [14], based on electronic force measuring instruments, did not confirm the expected advantages.

A further possibility of the weighing method based on more conventional type of balance equipment may be considered as useful subject of future development.

Estimated development time: 1 year
Estimated development costs: DM 50,000.--

11.1.6 X-ray fluorescence for analysis of dissolver and waste solutions

The X-ray fluorescence spectroscopy appears to be a most promising method for analysis of U and Pu concentration in high active input and waste solutions [15].

The method is element specific. Some of the advantages of this method are: Independency of the chemical state of Pu and U in solutions; relatively low analysis costs; the method is tamperproof and easy to automatize.

The investigations are directed towards the determination of small amounts of Pu (20-100 μg/g solution) in the presence of large amounts of U in dissolver solutions with an accuracy sufficient for safeguards purposes.

The determination of U in solutions in the range of 0.1 - 20 mg U/g solution with a relative standard deviation below 1 % is possible and appears to be sufficient.

The development of the method can be considered as almost completed. Further work refers to special cases of adaption and automatization.

11.1.7 Process inventory determination by means of isotope analysis

For large campaigns closing of the material balance for safeguards purposes may be required before the campaign is completed. Instead of an additional physical inventory as is normally carried out at the end of the campaign, the process inventory determination (PID) by isotope analysis of input- and output streams seems to be an alternative method for this purpose.

As no shut down or washout of the plant is necessary for this method, the load factor does not decrease and the economics of the plant is not adversely affected. Furthermore PID does not require any unnecessary intrusion in the plant.

The principle of this method lies in the fact that the fissile material process inventory, which is pushed out by the incoming new batches, is measured quantitatively at the exit of the plant by identifying its isotopic composition. This is possible if the concentrations of a limited number of isotopes in the inventory differ sufficiently from those in the input batches which push it out (Fig. 11.1.7-1).

A detailed description of this method is given in [16].

The estimated accuracy of PID at this time is 2-10 %.

The estimated development time will be 2-3 years, with the costs in the range of DM 400,000.--. Further development work is planned to be carried out in connection with a number of integral safeguards experiments at existing reprocessing plants.

11.1.8 Method of reducing input analysis efforts

As indicated in chapter 8, analysis costs for input samples contribute to a large extent to the safeguards costs. The number of analyses can, however, be reduced (and hence the costs) by using a special type of statistically chosen analyses number.

The inspector obtains samples for all the input batches as well as all the operators results of analyses for these samples. However, he analyses only a randomly chosen part of these samples (e.g. 50-60%). He can calculate the confidence level of the uncertainty caused by this reduction knowing the fact that the fissile material content in input batches during a campaign can vary within limits which can be estimated.

Study in this field is in progress and will be published in the near future.

11.2 Layout of plants

In this chapter, a reference design of a reprocessing plant (Fig. 11.2-1) has been described in which all the requirements of controlling the fissile material flow at strategic areas, have been incorporated without reducing the efficiency of or being intrusive to plant operation.

The significant feature of this design is the decentralized arrangement of separate buildings around a strategic area. The separate buildings for execution of the main reprocessing requirements are laid out as tight containments having only entrances and exits for fissile materials. Operational personnel can enter or leave the containment at other entrances or exits monitored by tamperresistant γ-locks [17].

At the strategic area the measurements, counting and identification measures both for the accountability of the plant operator and for safeguarding are carried out. Therefore, some economic advantages may be expected. The automatized installations are designed to indicate tampering. An operator's laboratory for special analyses has been included in the strategic area.

The different process buildings are characterised by the following features:

Chemical process building: Material balance is established by carrying out throughput and inventory measurements (the latter being measured as a temporary output) at the strategic area.

Head-end building: The process steps in the head-end building and the building itself has been contained in such a way that only the design activities are possible.

Waste storage building: Besides the usual balance measure limit of the fissile material concentration for the waste is to be defined beyond which no further safeguarding is required.

Fuel element and final product storage building: Counting and identification of incoming and outgoing material is carried out at the strategic area using the technique given in section 11.1.1; accounting of inventory is carried out inside the buildings using the technique given in section 11.1.2.

A typical safeguards measure e.g. unloading of incoming spent subassemblies, as foreseen in the reference design is given below:

The seal of an arriving shielding cask arrived is automatically inspected by means which do not require an inspector's presence. If the seal is intact and the cask is in the correct position, the hatch of the building can be opened. The opening couples the cask to the building. Similarly, the hatch can only be closed if the lid of the container is inserted. After insertion the cask is automatically locked. The next opening of the lock is only possible if a signal be given by the inspection that the cask seal is intact. The mechanical procedure is shown schematically in Fig. 11.2-2. By this procedure the containment of the building and the shielding cask is ensured.

Fig. 11.2-3 gives the layout of a part of the strategic area.

In conclusion it may be emphasised that effective safeguards measures and procedures can be realized only if they are considered in close collaboration with the plant operator.

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Tab. 5-1: List of strategic points

Strategic point	Location	Function
SP1	Fuel element storage hall	Identification and registration of unloaded fuel elements
SP2 a	Inspection room near transmitter gallery	Collection of information for the complete establishment of an independent material balance around the chemical process area.
SP2 b	Place in the analytic. lab.	
SP3	Product storage Waste storage Cell OII	Analysis of: product stream; liquid waste; - Sealing and registration of: bottled product; liquid waste; solid waste

Tab. 6-1: Safeguards measures at SP1

Place	Measure	No.	Activities	Purpose
Transport cask unloading pool	Containment	1-1	Counting and inspection of arrived shielding casks containing spent fuel subassemblies (SA), inspection and removal of cask seal.	To verify that SA's could not be removed or substituted during transportation.
"	"	1-2	Counting, identification, and inspection of unloaded SA's using glass pane and telescope.	To ensure that SA's or parts of them could not be removed or substituted during storage.
"	"	1-3	Resealing of cask.	Particularly to avoid removal of SA's from the storage pool by this cask.
Isolation pool	"	1-4	Counting, identification, and inspection of a SA's to be transfered to cell I.	See 1-2
Storage pool	Inventory taking	1-5	Counting, identification, and inspection of stored SA's.	See 1-2

Tab. 6-2: Safeguards measures at SP2

Place	Measure	No.	Activities	Purpose
Inspection room	Containment	2-1	Recording of distance cum load instrument installed at underwater channel crane.	To indicate when measure 1-4 has to be carried out or in case of absence of inspectors to record such events, also to indicate removal of fuel from cell I
"	"	2-2	Recording of radiation level monitors installed at the outer surfaces of cell I.	To indicate removal of fuel from cell I.
"	"	2-3	Recording of liquid indication instruments partly including flow direction through dissolver lines.	To indicate removal of unaccounted dissolver solution, in view of measurement of recycled acid: to indicate recycling and falsification of measurement (see 2-7).
"	"	2-4	TV-observation of dissolver installation; camera installed inside dissolver cavity.	To indicate changes of dissolver installation.
"	Throughput measurement of solid waste	2-5	Recording of solid waste measurements by n-generator installed in cell II.	To account fissile material in solid waste.
"	Troughput measurement of feed solution	2-6	Recording of level (L), density (D), and temperature (T). Additionally L and D are indicated by U-tubes, temperature of U-tubes by thermometer.	To establish material balance over the MBA chemical process.
"	Throughput measurement of recycled acid	2-7	See 2-6 (U-tubes and thermometers not required)	See 2-6

Tab. 6-2: Safeguards measures at SP 2 (continued)

Place	Measure	No.	Activities	Purpose
Inspection room	Throughput measurement of waste solution	2-8	See 2-6 (U-tubes and thermometers not required)	To be informed about possible irregularities.
"	Containment	2-9	Recording of liquid indication instruments installed at input tank lines.	To indicate bypassing of feed solution resp. falsification of measurement.
"	"	2-10	TV observation of input tank, camera installed at cell OI.	To indicate changes of input tank installation.
"	"	2-11	Recording of liquid installation, instruments installed at lines of feed sampler.	To verify if the correct needle bloc was in function and to verify the time an inspector sample was taken.
"	"	2-12	TV observation of feed sampler, camera installed at sampling gallery.	To monitor correct insertion of magazine with inspector marked vials in definite sequence; to indicate also subsequent changes.
"	Inventory taking	2-13	See 2-8	To establish resp. to close the material balance over the MBA chemical process.
Analytical laboratory	Throughput measurement of feed	2-14	Reception of samples together with records of arrival time	To establish a material balance over the MBA chemical process.
	recycled acid	2-15	"	"
	waste	2-16	Reception of operators anal.results.	To be informed about possible irregularities.
	Inventory taking	2-17	Reception of samples	See 2-13.
Different places of plant	Containment	2-18	Inspection of installation for L+D measurement of input and recycled acid.	To prevent tampering of installation for falsification of measurements.

Tab. 6-3: Safeguards measures at SP 3

Place	Measures	No.	Activities	Purpose
Pu-bottling station	Throughput measurement of Pu product stream	3-1	Tara-brutto weighing, reception of samples of Pu-product.	To establish a material balance over the MBA chemical process.
	Containment	3-2	Counting sealing and inspection of Pu-bottles to be transfered to storage.	To ensure that Pu-product can not be removed or substituted during storage.
Pu-product storage		3-3	Counting and inspection of Pu-bottles to be shipped, inspection of seals.	See 3-2
	Inventory taking	3-4	Counting and inspection of stored Pu-bottles, inspection of seals.	See 3-2
U-bottling station	Throughput measurement of U product stream	3-5	Tara-brutto weighing, reception of samples of U-product.	To establish a material balance over the MBA chemical process.
	Containment	3-6	Counting, sealing and inspection of U-product containers to be transfered to storage.	To ensure that U-product can not be removed or substituted during storage.
U-product storage	Containment	3-7	Counting and inspection of U-continaers to be shipped, inspection of seals.	See 3-6
	Inventory taking	3-8	Counting and inspection of stored U-containers, inspection of seals.	See 3-6
Waste storage	Measurement of permanently stored waste	3-9	L.+D. measurement, reception of samples of permanently stored waste.	To establish a material balance over the MBA chemical process resp. to countercheck informations obtained under 2-8 and 2-16.

Tab. 6-3: Safeguards measures at SP 3 (continued)

Place	Measures	No.	Activities	Purpose
Waste storage	Containment	3-10	Inspection of installation for L.+D. measurement and sampling of permanently stored waste.	To prevent tampering of installations for falsification of measurements.
	Throughput measurement of temporarily stored waste	3-11	L.+D. measurement, reception of samples of temporarily stored waste.	To establish a material balance over the MBA chemical process and to countercheck informations under 2-8 resp.2-16
	Containment	3-12	Inspection of installation for L.+D. measurement and sampling of temporarily stored waste.	To prevent tampering of installations for falsification of measurements.
Waste storage	Containment	3-13	Counting, sealing,and inspection of the tank of the cistern truck.	To ensure that waste solution can not be removed or substituted during transportation.
	Inventory taking	3-14	See 3-11	To establish resp. to close the material balance over the MBA chemical process.
Cell OII	Containment	3-15	Counting,sealing, and inspection of shielding containers, into which solid waste barrels have been inserted.	To ensure that solid waste can not be removed, or substituted during storage.
		3-16	Counting and inspection of shielding containers to be shipped, inspection of seals.	See 3-15
	Inventory	3-17	Counting and inspection of stored shielding containers, inspection of seals.	See 3-15

Form No. 1

No	Containment	Marks	From MBA	To MBA	Date	Contents	Comments	Photographs of seal fingerprint
1	Shielding cask	Transnuclear XYZ 2345	0	B	1.10.69	No. 2-4	Example	
			B	0	2.10.69	empty	-	
2	Fuel subassembly	VAK 678	0	B	1.10.69	UO_2 irrad.	Example	—
			B	H	1.11.69	"	-	—
3								
4								

Form No. 2
Transfer report

Form No.	
Page No.	
Line	
0=before, 1=after transfer	
Type of material 1)	
from MBA 2)	
to MBA 2)	
Transfer measured in tank No.	
Time of measurement: Month	
Time of measurement: Day	
Time of measurement: Hour	
Time of measurement: Minute	
Last measurement in the same tank: Form No.	
Last measurement in the same tank: Page No.	
Last measurement in the same tank: Line	
Solution temperature [° C]	
Density [kg/l]	
Volume [%]	
U-tube indications: Manometer temperature [° C]	
U-tube indications: Density level [mm H_2O] above	
U-tube indications: Density level [mm H_2O] below	
U-tube indications: Volume level [mm TBE] above	
U-tube indications: Volume level [mm TBE] below	
U-tube indications: Cero point [mm] H O	
U-tube indications: Cero point [mm] TBE	

Comments:

1) 1:Stream (e.g. A.F.U.)
2= . . . .

2) 1=MBA (e.g. fuel el. stor.)
2= . . . .

Page No.

Form No. 3
Transfer report

Comments: 1) 1 = Pu
2 = U>1,6 % U 235
3 = U<1,6 % U 235

2) 1= . . . .
2= . . . .
3 = MBA (e.g. Product storage)

Page No.

Form No.	Page No.	Line		Type of material 1)	MBA 2) from	MBA 2) to	Time of measurement Month	Day	Hour	Minute	Tara weight Pu [g] U [kg]	Brutto weight Pu [g] U [kg]	

Form No: 4

Analysis report

Comments:

1) 1= Stream (e.g. A.F.U.)
2= . . . .
3= . . . .
4= . . . .

Page No:

Form No.	Page No.	Line		Corresponding transfer measurement: Form No.	Page No.	Line	Date of analysis: Month	Day	Mean values: [g/ml] Density I	[g/l] $C_{U_{tot}}$ II	[mg/l] C_{Pu} III	[W/o] IV: U 5	U 6	U 8	[W/o] V: Pu 8	Pu 9	Pu 0	Pu 1	Pu 2	Type of material 1)	Number of analyses for I II III IV V

Tab. 8-1: <u>Safeguards efforts at SP1</u>

Measures	Instruments required	Number of Instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges+) [DM/a]	No.of activities per year	Estimated time required per unit activity [h]	Total time required for inspector [h/a]	for technician [h/a]
1-1	Universal tool	1	30	30	7++)	40	0.5	-	20
	Photographic equipment	1	1000	1000	245++)				
1-2	– (Operator's instruments can be used)	–	–	–	–	40	2	-	80
1-3	See 1-1 Seals	40	10	400	400	40	0.5	-	20
1-4	-	-	-	-	-	400	0.25	-	100
1-5	-	-	-	-	-	4	2	-	8
				Subtotal	652 DM/a			Subtotal	228 h/a

+) normal case: annuity factor (lifetime 10 years) = 14.2 %)
++) special case:annuity factor (lifetime 5 years) = 24.5 %

Tab. 8-2: Safeguards efforts at SP2

Measures	Instruments required	Number of instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges [DM/a]	No. of activities per year	Estimated time required per unit activ. [h]	Total time required for inspector [h/a]	Total time required for technician [h/a]
2-1	Distance cum load instrument+recorder +installation	1	5.000	5.000	710	200	0.05	10	-
2-2	Radiation level monitor+recorder +installation	7	2.000	14.000	2.000	200	0.1	20	-
2-3	Liquid indication instrument+installation	4	200	800	114	200	0.1	20	-
	Liquid indication instrument incl. flow direction+ installation	3	350	1.050	149				
	Electric equipment	1	2.000	2.000	280				
	Recorder	1	2.000	2.000	280				
2-4	Lead glass shielding	1	20.000	20.000	2.800	200	0.1	20	-
	TV camera+receiver+ installation	1	4.000	4.000	570				
	Recorder	1	3.000	3.000	430				
2-5	Recorder+installation	1	1.500	1.500	210	40	0.05	2	-
				Subtotal	7.543 DM/a		Subtotal:	72 h/a	

Tab. 8-2: Safeguards efforts at SP2 (continued)

Measures	Instruments required	Number of Instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges [DM/a]	No. of activities per year	Estimated time required per unit activity [h]	Total time required for inspector [h/a]	Total time required for technician [h/a]
2-6	L+D recorder+ installation	1	2.500	2.500	355	200	0.2	40	-
	U tube (L+D)+ installation	2	250	500	71				
	T recorder+ installation	1	1.000	1.000	142				
	Thermometer	1	10	10	1				
2-7	L+D recorder+ installation	4	2.500	10.000	1.420	280	0.1	28	-
	T recorder+ installation	4		2.500	355				
2-8	L+D recorder +installation	12	2.500	30.000	4.300	220	0.1	22	
	T recorder+ installation	12		7.500	1.070				-
2-9	Liquid indication instrument+install.	8	200	1.600	230	200	0.1	20	
	Electric equipment	1	2.000	2.000	280				
	Recorder	1	2.000	2.000	280				
2-10	Lead glass shielding	1	20.000	20.000	2.800	200	0.1	20	-
	TV camera+receiver +installation	1	4.000	4.000	570				
	Recorder	1	3.000	3.000	430				
				Subtotal:	12.304 DM/a		Subtotal:	130 h/a	

Tab. 8-2: Safeguards efforts at SP2 (continued)

Measures	Instruments required	Number of instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges [DM/a]	No. of activities per year	Estimated time required per unit activity [h]	Total time required for inspector [h/a]	Total time required for technician [h/a]
2-11	Liquid indication instrument+ installation	6	200	1.200	170	200	0.1	20	-
	Electric equipment	1	2.000	2.000	280				
	Recorder	1	2.000	2.000	280				
2-12	TV camera+receiver +installation	1	4.000	4.000	560	200	0.1	20	-
	Recorder	1	3.000	3.000	420				
	Vial markings	2000			200				
	Equipment	1	5.000	5.000	710				
2-13	see 2-8	-	-	-	-	4	0.3	1	-
2-14 2-15 2-16	Storage casing for inspection samples incl. arrival time recorder+install.	1	4.000	4.000	560	200	0.5	-	100
	shielding cask	1	5.000	5.000	710				
2-17	see 2-14 2-15	-	-	-	-	4	0.5	-	2
2-18	—	-	-	-	-	300	0.3	-	90
				Subtotal:	3890 DM/a		Subtotal:	41 h/a	192 h/a

Tab. 8-3: Safeguards efforts at SP3

Measures	Instruments required	Number of instruments	Estimated unit costs /DM/	Total costs /DM/	Annual charges /DM/a/	No.of activities per year	Estimated time required per unit activity /h/	Total time required for inspector /h/a/	for technician /h/a/
3-1	-	-	-	-	-	400	0.25	-	100
3-2	see 1-1 Seals	- 400	- 10	- 4.000	- 4.000	400	0.25	-	100
3-3	see 1-1	-	-	-	-	40	0.5	-	20
3-4	see 1-1	-	-	-	-	4	0.5	-	2
3-5	-	-	-	-	-	836	0.25	-	209
3-6	see 1-1 Seals	- 836	- 10	- 8.360	- 8.360	836	0.25	-	209
				Subtotal:	12.360 DM/a			Subtotal:	640 h/a

Tab. 8-3: Safeguards efforts at SP3 (continued)

Measures	Instruments required	Number of instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges [DM/a]	No.of activities per year	Estimated time required per unit activity [h]	Total time required for inspector [h/a]	for technician [h/a]
3-7	See 1-1	-	-	-	-	136	0.5	-	68
3-8	See 1-1	-	-	-	-	4	0.5	-	2
3-9	(shielding cask for samples) see 2-14,2-15	-	-	-	-	40	0.25	-	10
3-10	–	–	–	–	–	40	0.25	-	10
3-11	(shielding cask for samples) see 2-14,2-15	-	-	-	-	15	0.25	-	4
3-12	-	-	-	-	-	15	0.25	-	4
				Subtotal:	0 DM/a			Subtotal:	98 h/a

Tab. 8-3: Safeguards efforts at SP3 (continued)

Measures	Instruments required	Number of instruments	Estimated unit costs [DM]	Total costs [DM]	Annual charges [DM/a]	No.of activities per year	Estimated time required per unit activity [h]	Total time required for inspector [h/a]	for technician [h/a]
3-13	See 1-1 seals	15	10	150	150	15	0.25	-	4
3-14		-	-	-	-	4	1	-	4
3-15	See 1-1 seals	200	10	2.000	2.000	200	0.25	-	50
3-16	-	-	-	-	-	40	0.5	-	20
3-17	-	-	-	-	-	4	0.5	-	2
				Subtotal:	2.150 DM/a			Subtotal:	80 h/a

Tab. 8-4: Summed up expenditures for instruments and safeguards personnel

Strategic point	Table	Costs for instruments and other material / DM/a /	subtotal	Inspector / Man-hours/a /	subtotal	Technician / Man-hours/a /	subtotal
1	8-1	652		-		228	
			652				228
2	8-2	7.543		72		-	
2	8-2ctd.	12.304		130		-	
2	8-2ctd.	3.890		41		192	
			23.737		243		192
3	8-3	12.360		-		640	
3	8-3ctd.	-		-		98	
3	8-3ctd.	2.150		-		80	
			14.510		-		818
Annual capital charges		Total:	38.247 DM/a	Total:	243 Mh/a+)	Total:	1.238 Mh/a
				No. of safeguards personnel:			
				1 Inspector=50.000 DM/a		2 Technician=60.000 DM/a ++)	

+)Working time for evaluation of data obtained not included.

++)To guarantee sufficient free time during campaigns and for the case of illness 2 technicians were assumed.

Assumption: Working hours for a safeguards personnel per year = 1600

Tab. 8-5: Expenditures for individual analysis of each inspector sample

Assumption: In case inspector samples are not analysed at the laboratory of the plant operator they have to be transported to a neutral laboratory e.g. from the WAK plant to the EURATOM institute for transuranium elements. Distance about 1 km.

Transport costs assumed: 200 [transp./a] 2 [h/transp.] 15 [DM/h] = 6000 DM/a

	Stream	No. of inspector samples/a	Analysis method applied	Estimated unit costs of the analysis method [DM/ analysis]	Annual costs for individual analysis of each inspector sample [DM/a]	Annual costs for analysis composite sampling technique applied for c and e [DM/a]
a	Input	400	Mass spectr.	600	240.000	240.000
b	Recycled acid	80	U:Photometry Pu:α-count.	40 25	5.200	5.200
c	U-product U235>1,6%	1600	Coulometry	40	64.000	12.800
d	U-product U235<1,6%	72	Coulometry	40	2.880	2.880
e	Pu-product	800	Coulometry	40	32.000	8.000
f	Waste	16	U:Photometry Pu:α-count.	40 25	1.040	1.040
g	Perm.stored waste	40	"	40 25	2.600	2.600
h	Temp.stored waste	35	"	40 25	2.275	2.275
				Total	349.995 DM/a	274.795 DM/a

Tab. 8-6: Total annual charges and specific costs for safeguards measures.

1. Annual capital charges	38 247	DM/a
2. Personnel	110 000	"
3. Other operation costs		
analysis charges	274 795	"
transport of samples	6 000	"
maintenance, utilities (2 % of 1)	764	"
4. Miscellaneous (10 % of 1.2.3)	42 980	"
Total annual charges (sum 1./.4))	472 786	DM/a

Total throughput of the WAK plant	40 000	kg UO_2/a
Specific costs for safeguards measures	11.80	DM/kg UO_2

Tab. 9-1 Approximate Reference Campaign 10 t UO_2 / 50 operating days

Stream	Tank No.	Batch size [l]	Rel. error of vol. determ. resp. weigh. δ_v [%]	U-concentration [g/l]	Rel. error of analysis δ_{cU} [%]	Pu-concentration [g/l]	Rel. error of analysis δ_{cPu} [%]	U/batch M_u [kg]	Pu/batch M_{pu} [g]	No. of batches/campaign	U/campaign [kg]	Pu/campaign [g]	Rel. error of integrated amount of U $\delta_{tot\,U}$ [%], composite sampling technique not applied	U $\delta_{tot\,U}$ [%] applied	Pu $\delta_{tot\,Pu}$ [%] not applied	Pu $\delta_{tot\,Pu}$ [%] applied	Standard deviation of integrated amount of U $\sigma_{tot\,U}$ [kg], composite sampling technique not applied	U $\sigma_{tot\,U}$ [kg] applied	Pu $\sigma_{tot\,Pu}$ [g] not applied	Pu $\sigma_{tot\,Pu}$ [g] applied
Feed	37.08	800	1.0	227 +)	0.8	1.3 +)	0.7	181.5	1040	50	9075	52000	0.16	–	0.16	–	14.50	–	83.3	–
2 WW	37.02	125	2.0	2.14	3.0	0.007	50	0.267	0.87	20	5.35	17.5	0.81	–	11.2	–	0.04	–	0.19	–
AFA	48.05	500	2.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
AFA	48.10	500	2.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
U-Product < 1.6 % U-235	SAFRAP	2500	0.1	440 +)	0.1	–	–	1100	–	8	9900	–	0.04	–	–	–	3.96	–	–	–
U-Product 1.6-3 % U-235	Bottle	110	0.1	440 +)	0.1	–	–	48.4	–	200	9680	–	0.009	0.016	–	–	0.87	1.55	–	–
Pu-Product	Bottle	10	0.01	–	–	50 +)	0.1	–	500	100	–	50000	–	–	0.007	0.02	–	–	3.50	10.0
1 HLW	81.21	250	3.0	0.29	5.0	$6 \cdot 10^{-4}$	50	0.073	0.15	10	0.73	1.5	–	–	–	–	–	–	–	–
Different waste streams	82.11, .12, .13, .14, .15		3.0		3.0		50			~ 4	~ 90	~ 500	2.12	–	25	–	1.9	–	125	–

+) 2 analyses/batch if composite sampling technique is not applied.

Standard deviation after campaign:

	composite sampling technique not applied	composite sampling technique applied
Pu	σ_{total} = 150 g	σ_{total} = 151 g
U (1.6-3 % U 235)	σ_{total} = 14.6 kg	σ_{total} = 14.7 kg
U (<1.6 %)	σ_{total} = 15.1 kg	σ_{total} = 21.3 kg

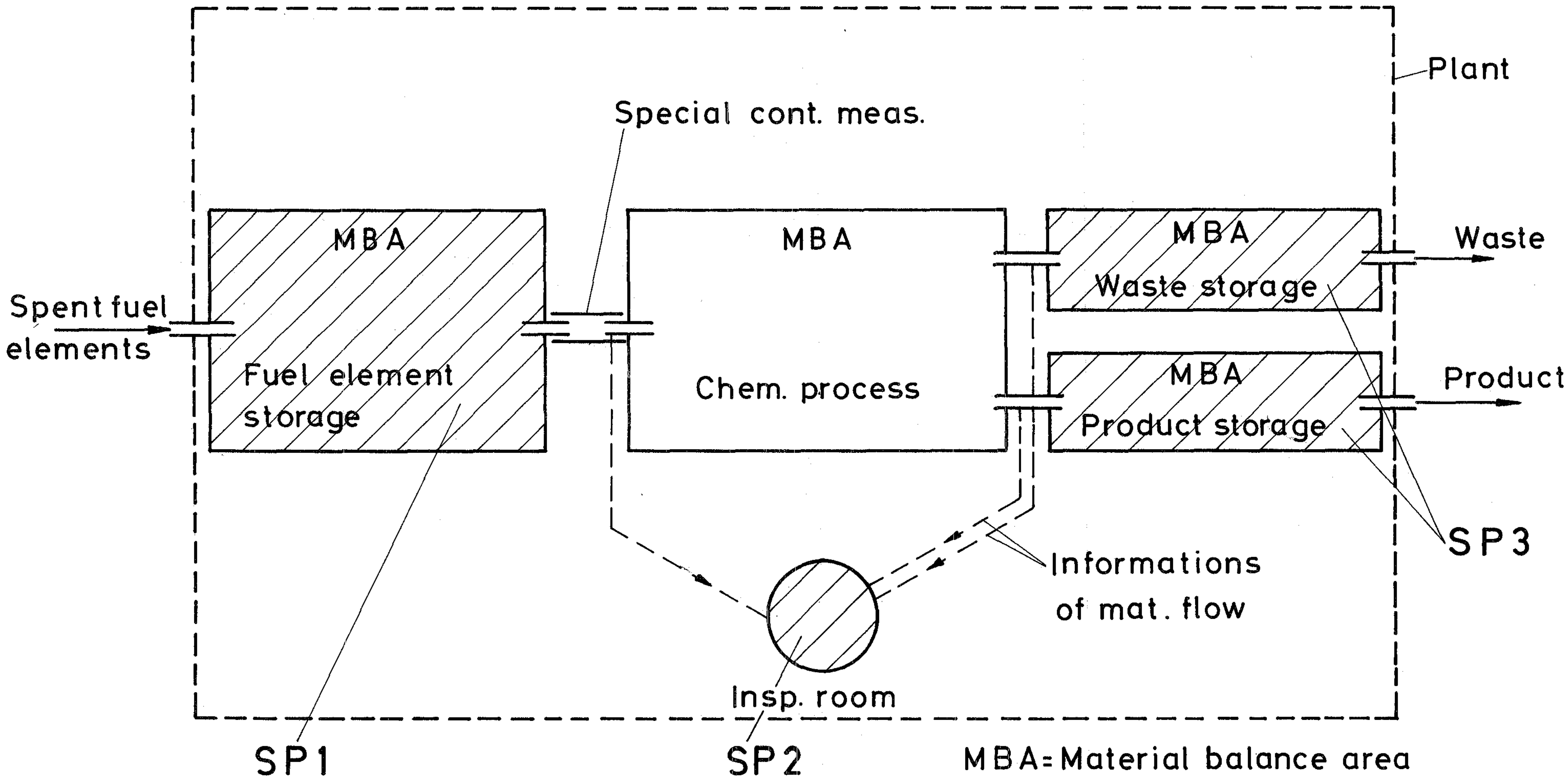


Fig. 3-1 Scheme of three important plant sections

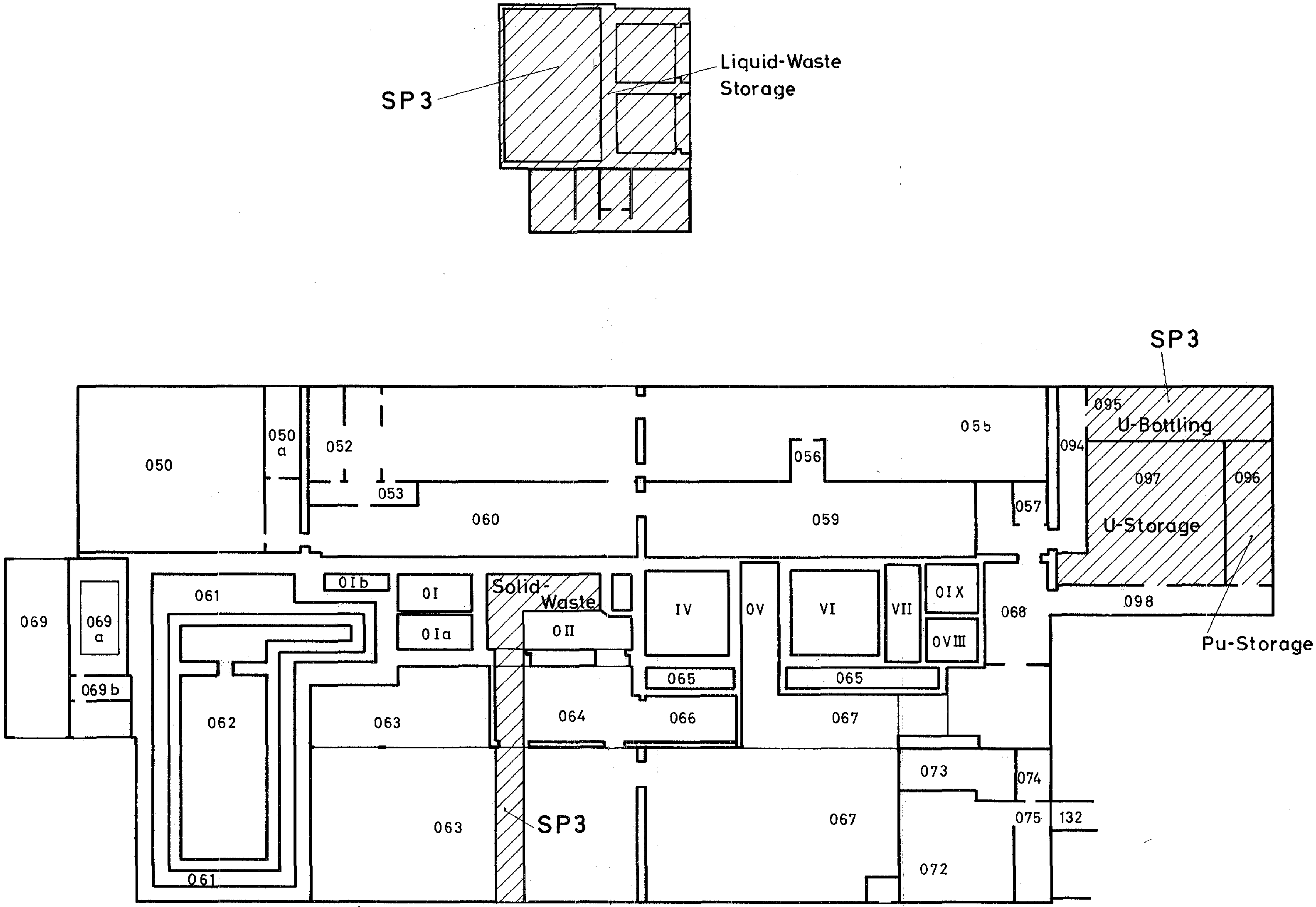


Fig. 4-1 Ground-Floor

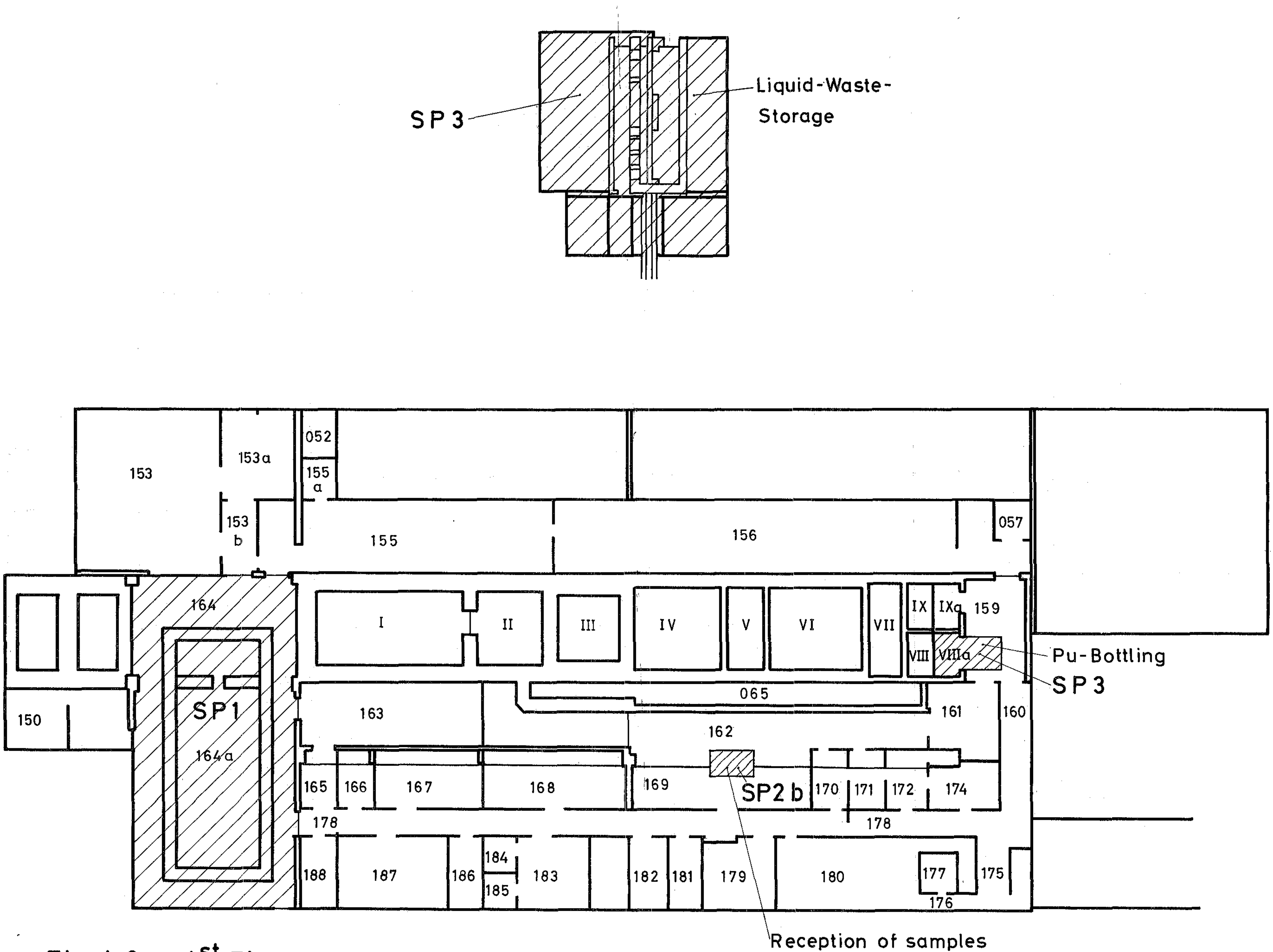


Fig. 4-2 1st Floor

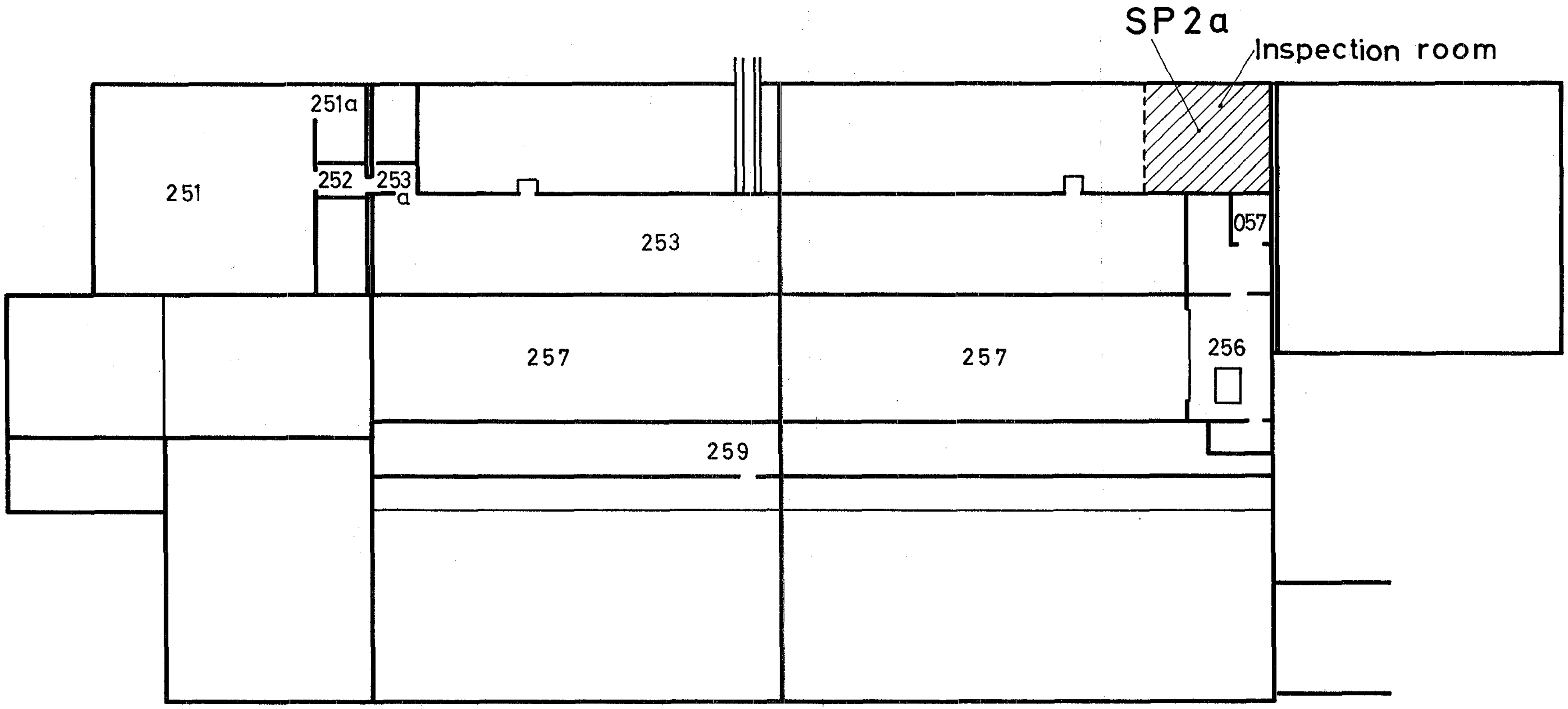


Fig. 4-3: 2nd Floor

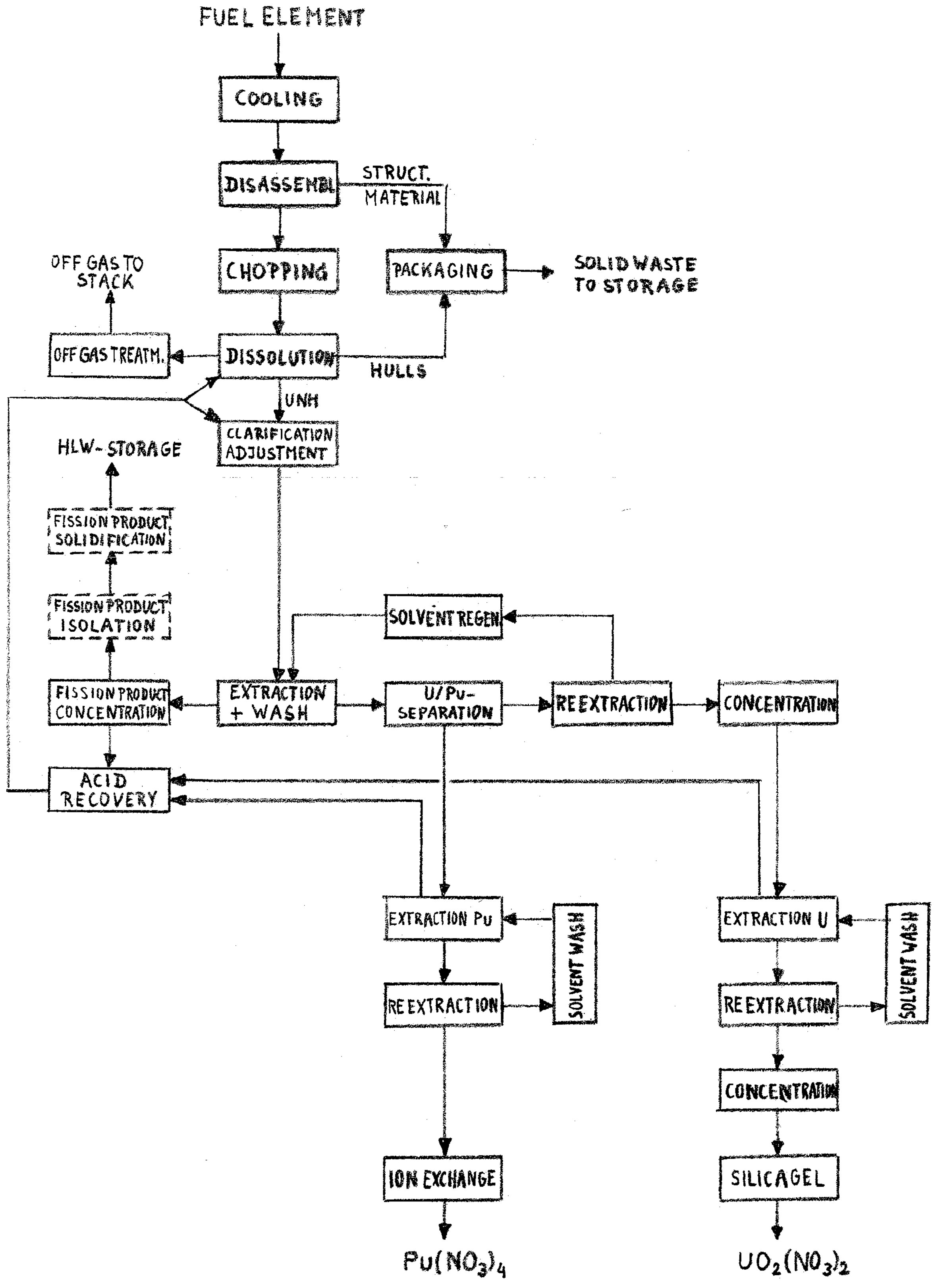


FIG. 4-4 BLOC SCHEME

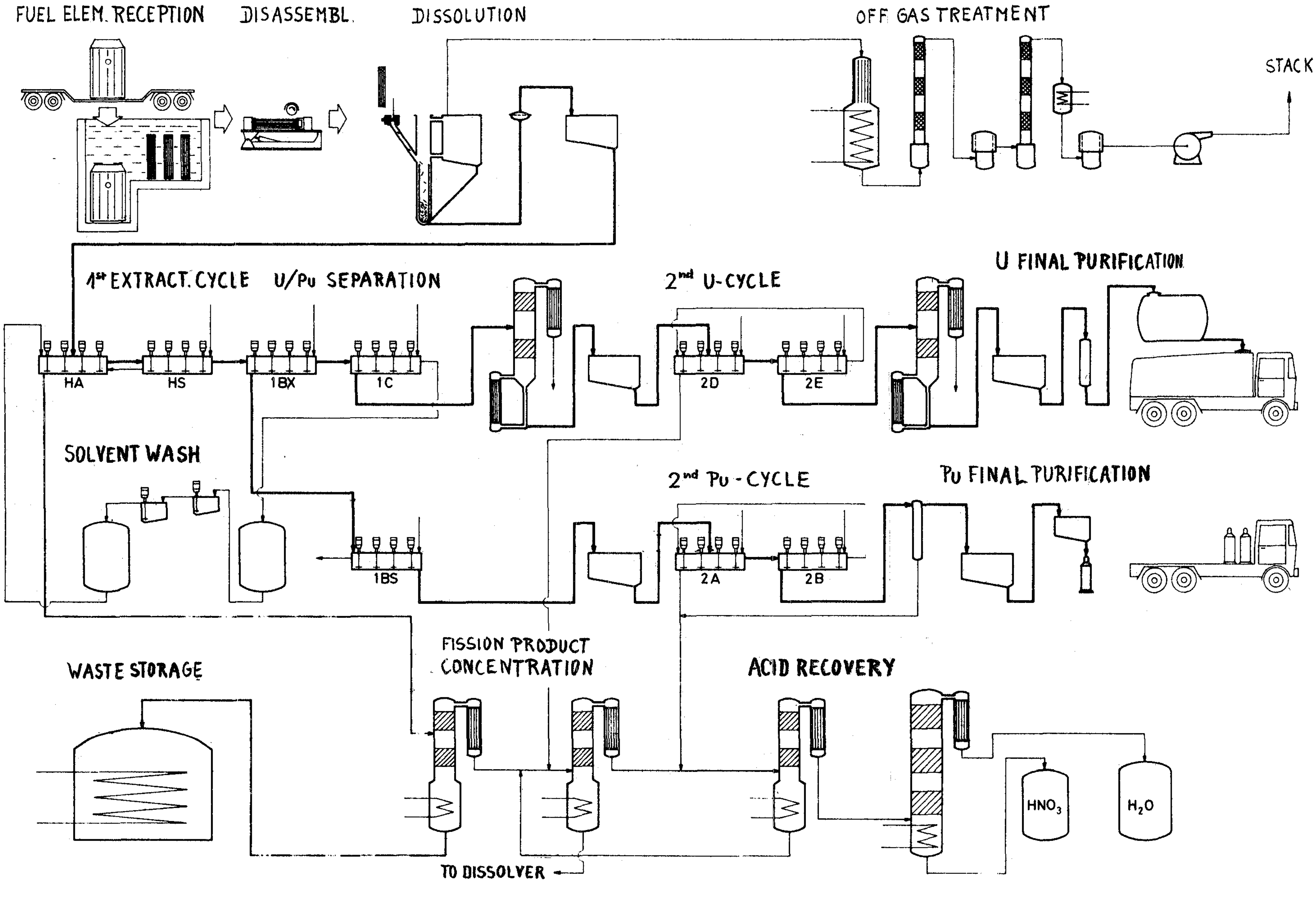
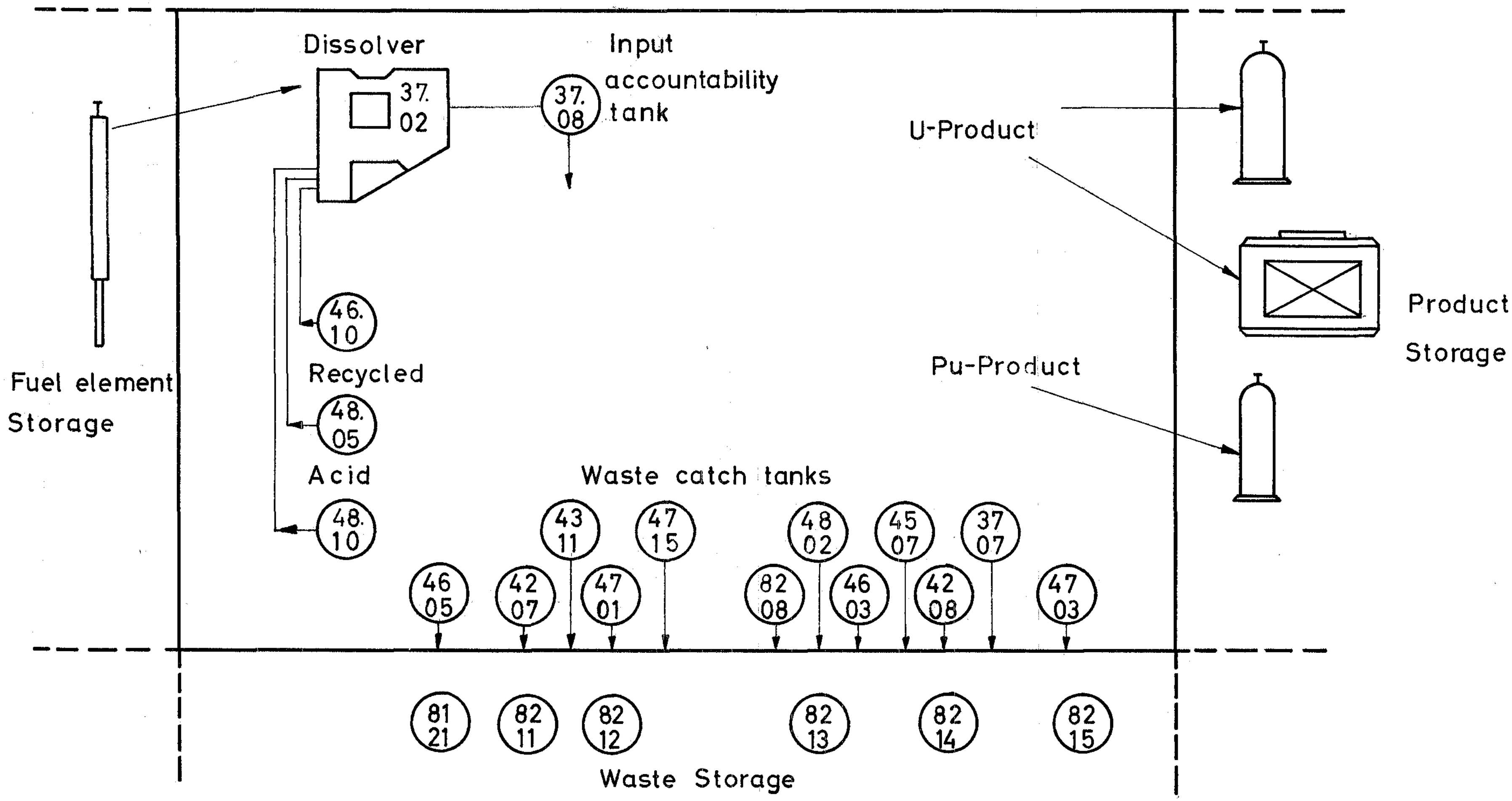


FIG. 4-5 PROCESS SCHEME



From all tanks inside borderline instruments for liquid volume determination are installed at inspection room (SP2a)

Fig. 6-1: Tanks, from which information is obtained in SP 2

			U > 1.6 % U235
Values assumed:	Rel.error of weight meas.	δ_w	0.1 %
	Rel.error of analysis	δ_c	0.1 %
	Number of batches	k	200
	Number of weight meas. per batch	n_w	1
	Number of analyses per sample	n_c	1
Results:	Rel.error after k batches one sample analysed	δ	0.1 %
	Repeated analyses of the same sample	$\delta_a = \delta / \sqrt{1 \div 200}$	see curve

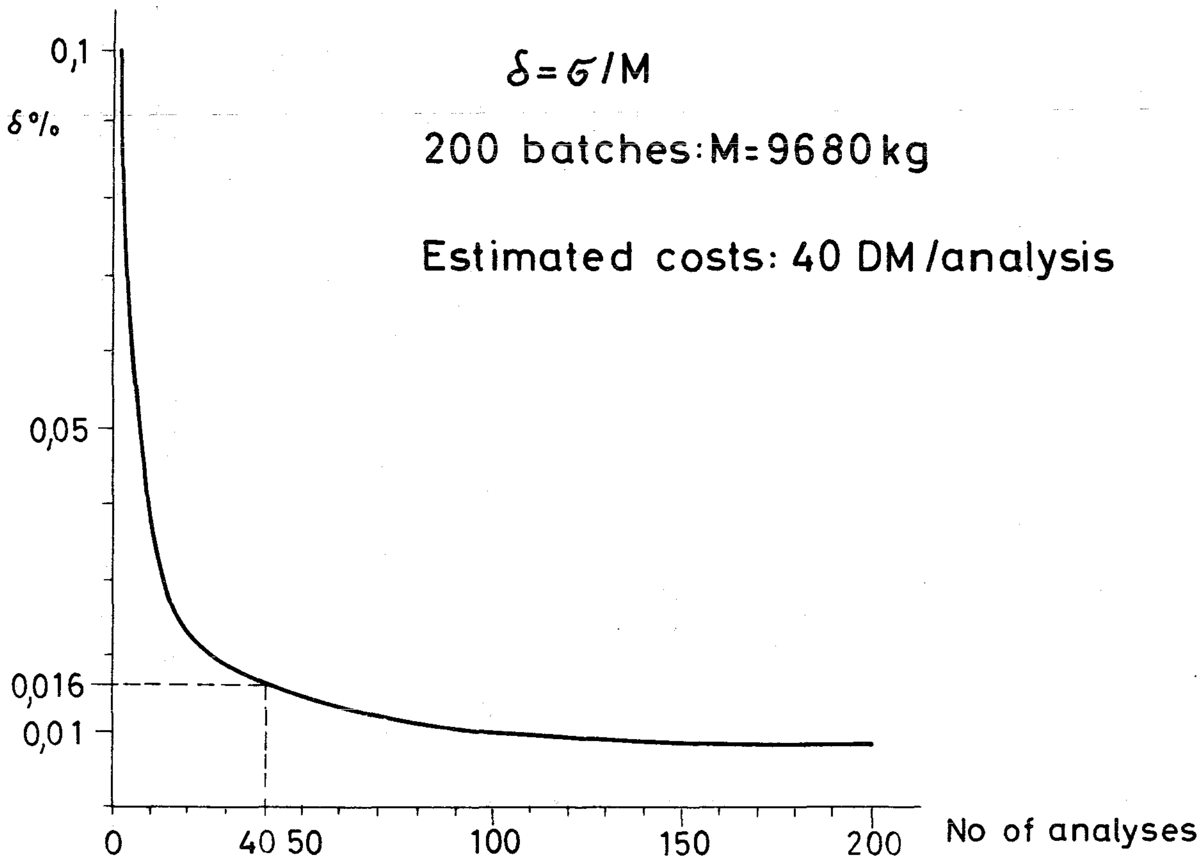


Fig. 8-1: U-product stream: dependence of rel. error on number of analyses

			Pu
Values assumed:	Rel.error of weight meas.	δ_W	0.01 %
	Rel.error of analysis	δ_c	0.1 %
	Number of batches	k	100
	Number of weight meas. per batch	n_w	1
	Number of analyses per sample	n_c	1
Results:	Rel.error after k batches one sample analysed	δ	0.1 %
	Repeated analyses of the same sample:	$\delta_a = \delta / \sqrt{1 \div 100}$	see curve

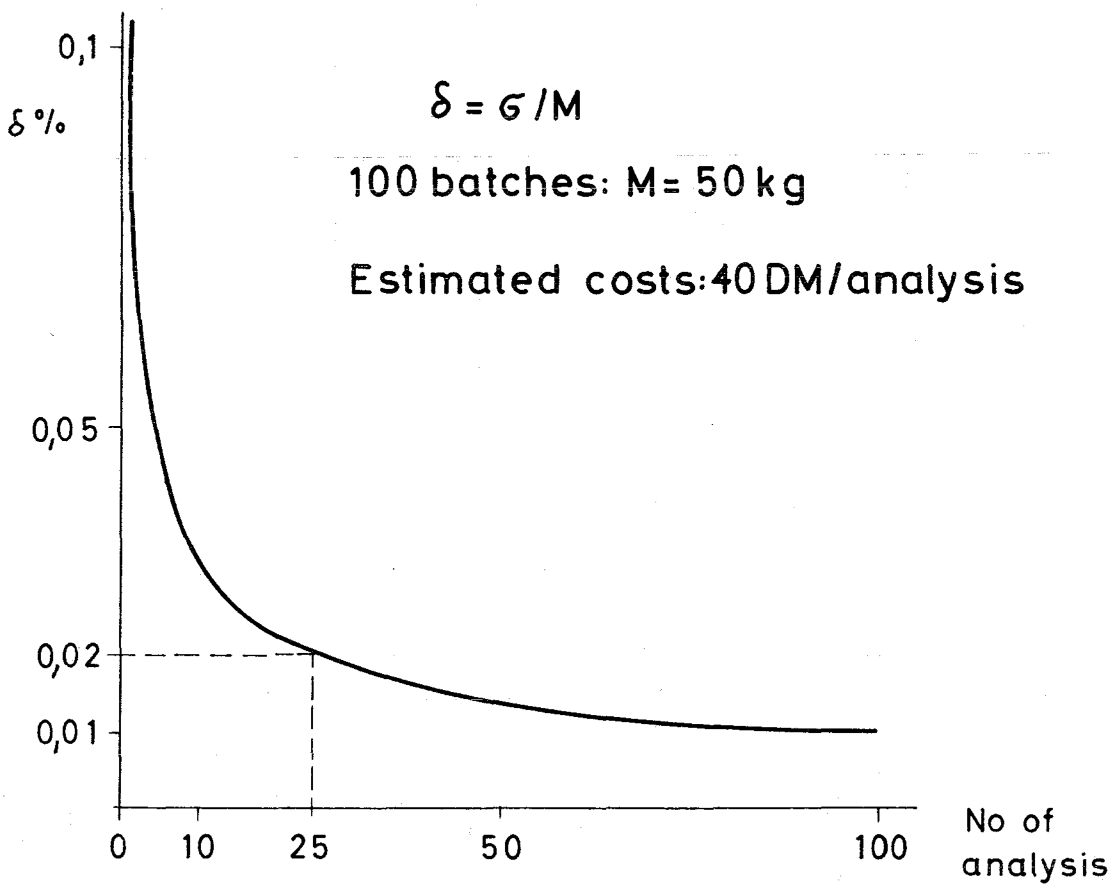


Fig. 8-2: Pu-product stream: dependence of rel. error on number of analyses

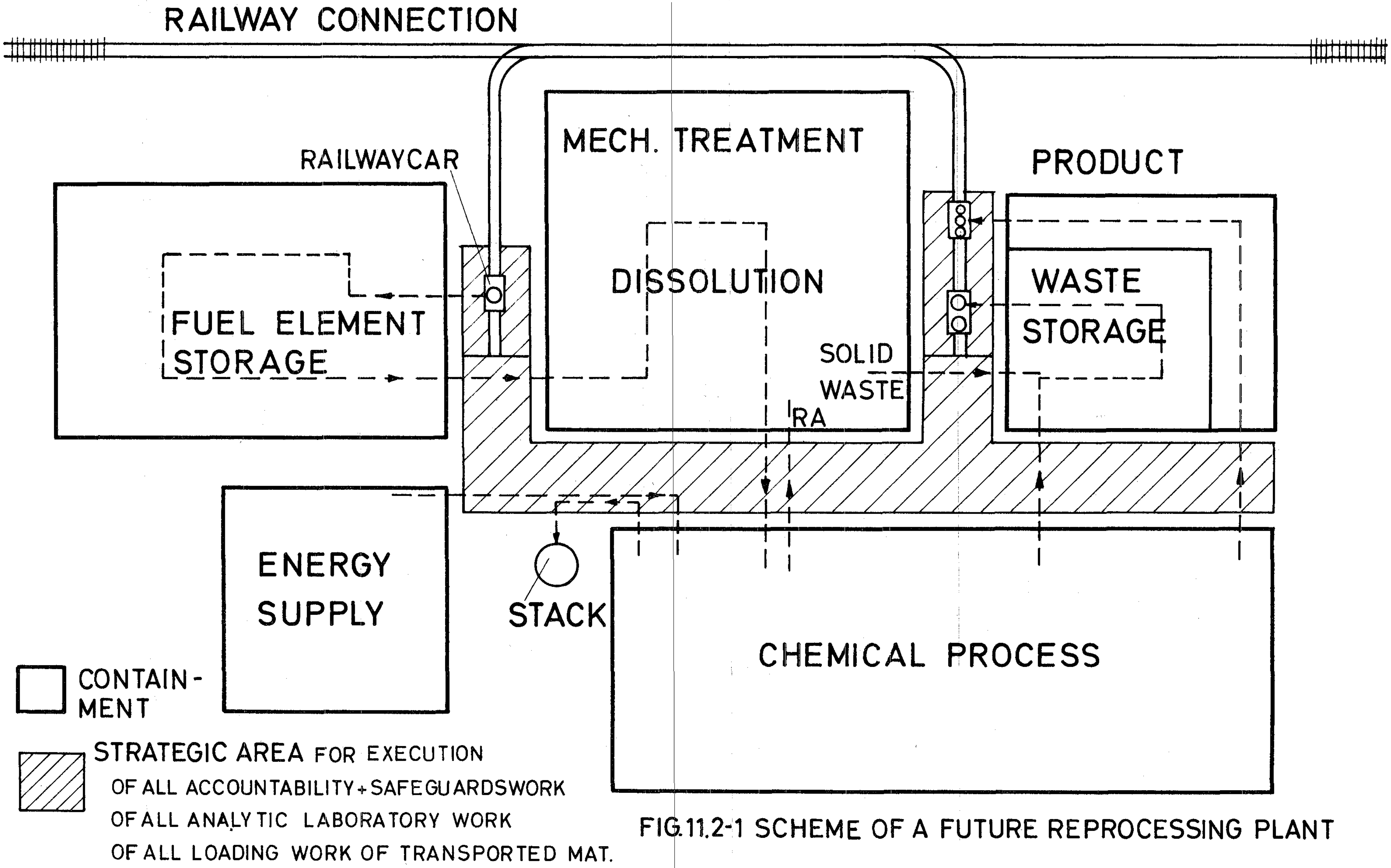


FIG.11.2-1 SCHEME OF A FUTURE REPROCESSING PLANT

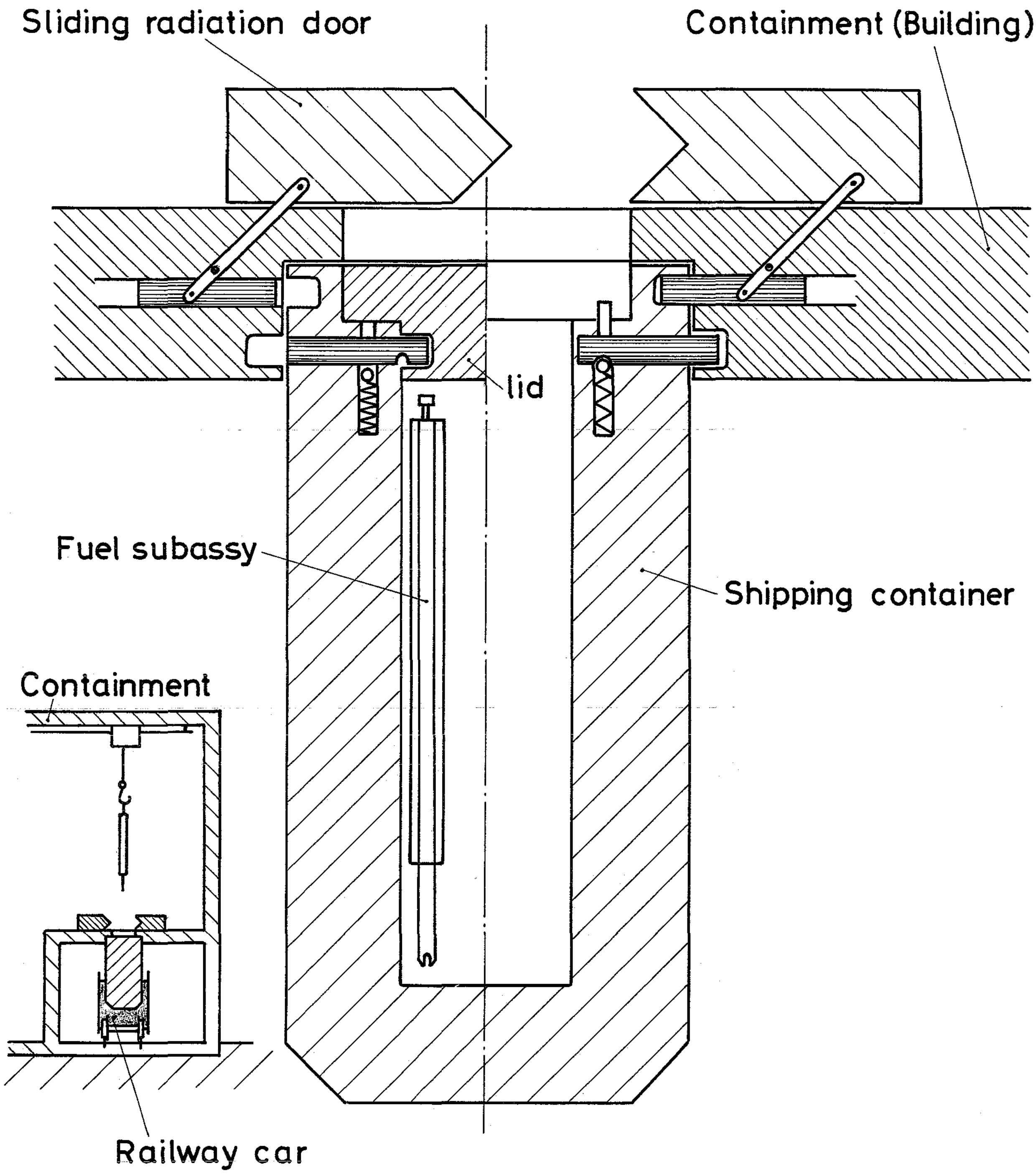


Fig.11.2-2 Scheme of the mechanic part of the shipping container coupling at the unloading hatch of the storage building

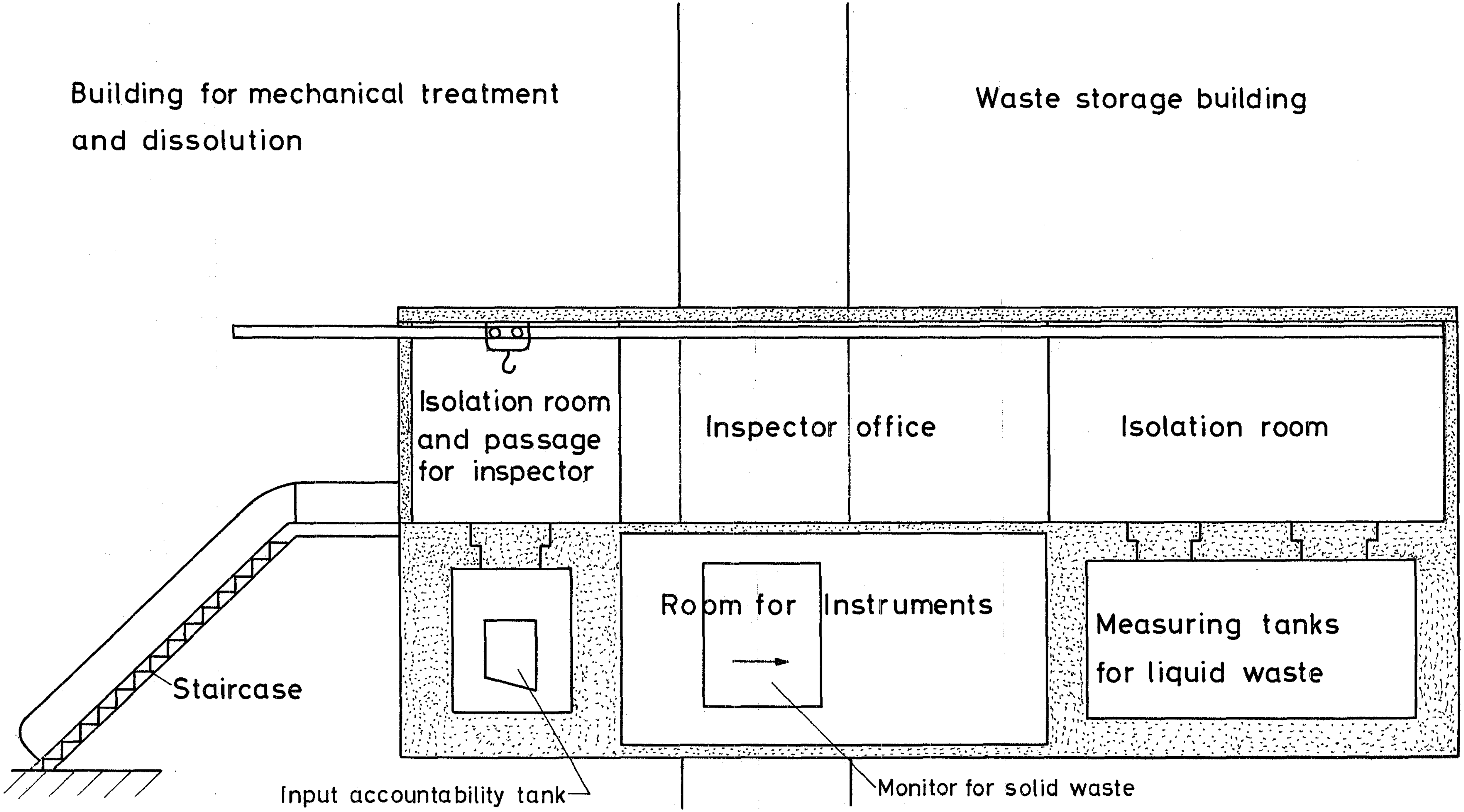


Fig. 11.2-3: Scheme of a part of the strategic area

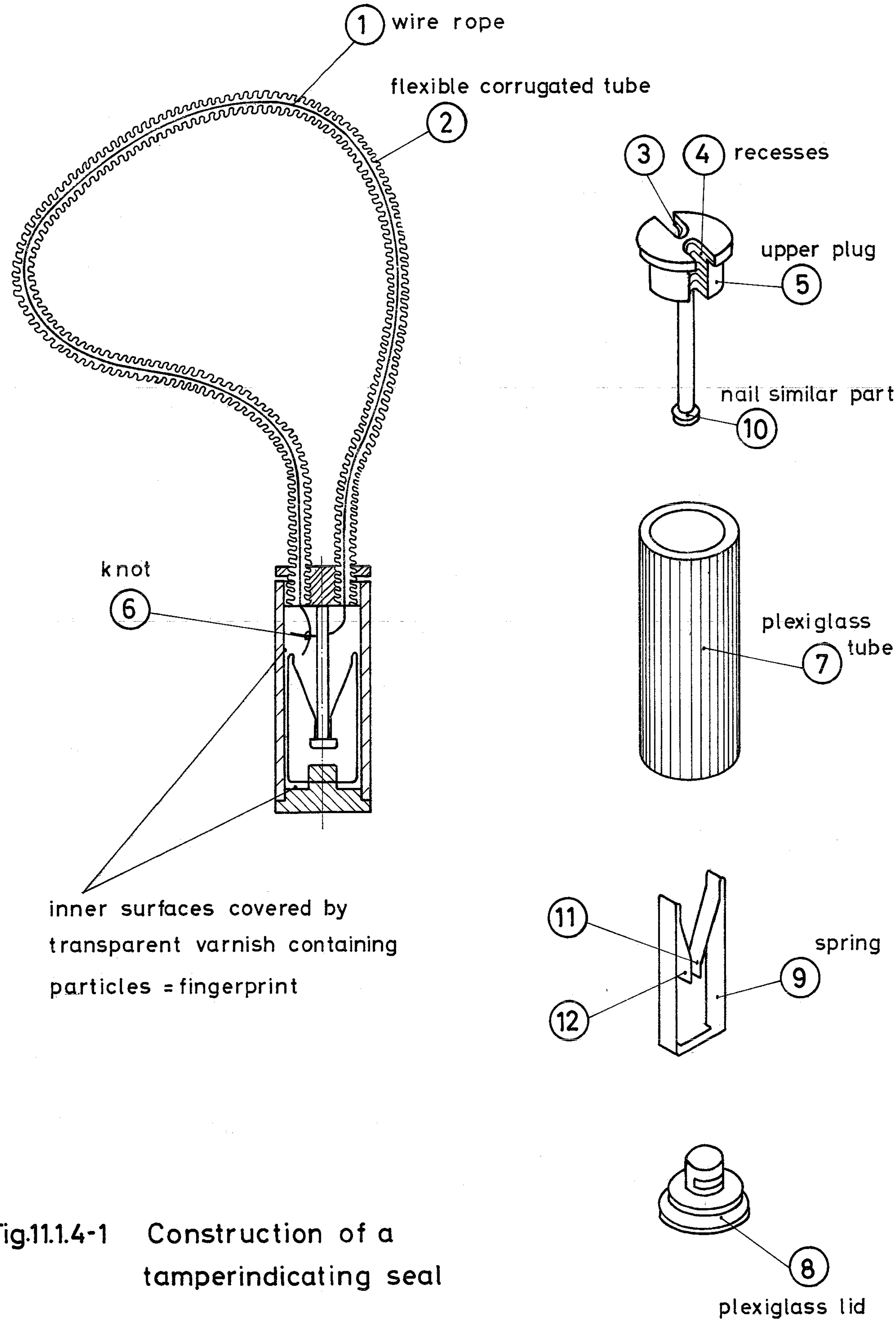
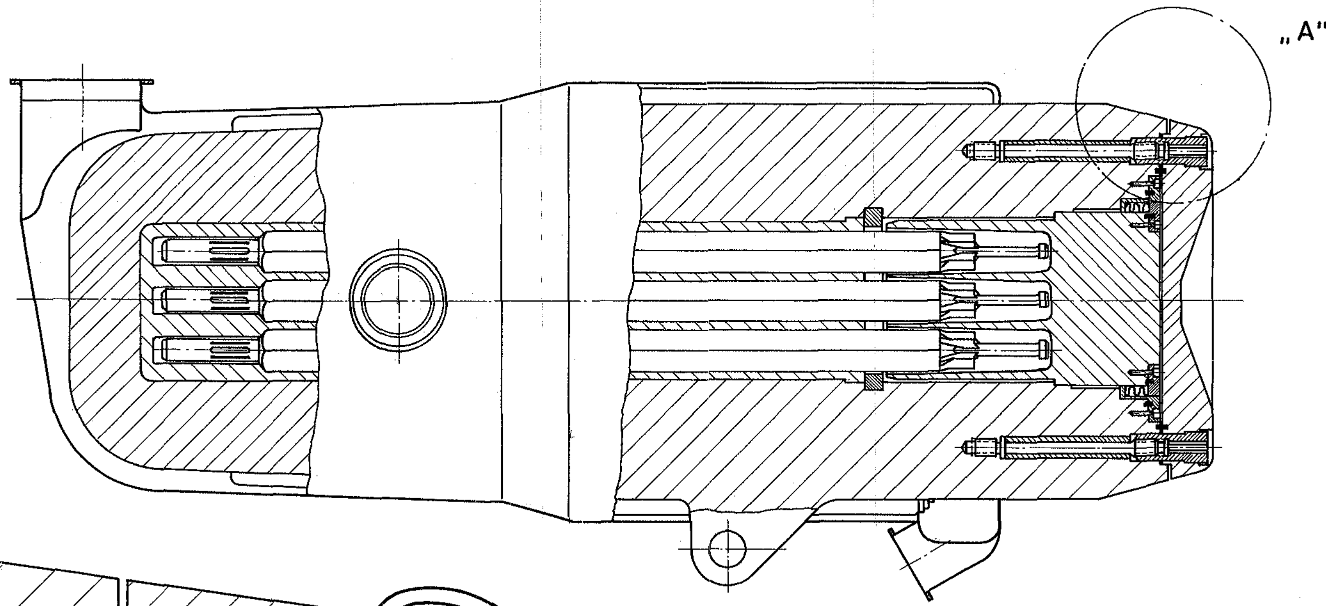
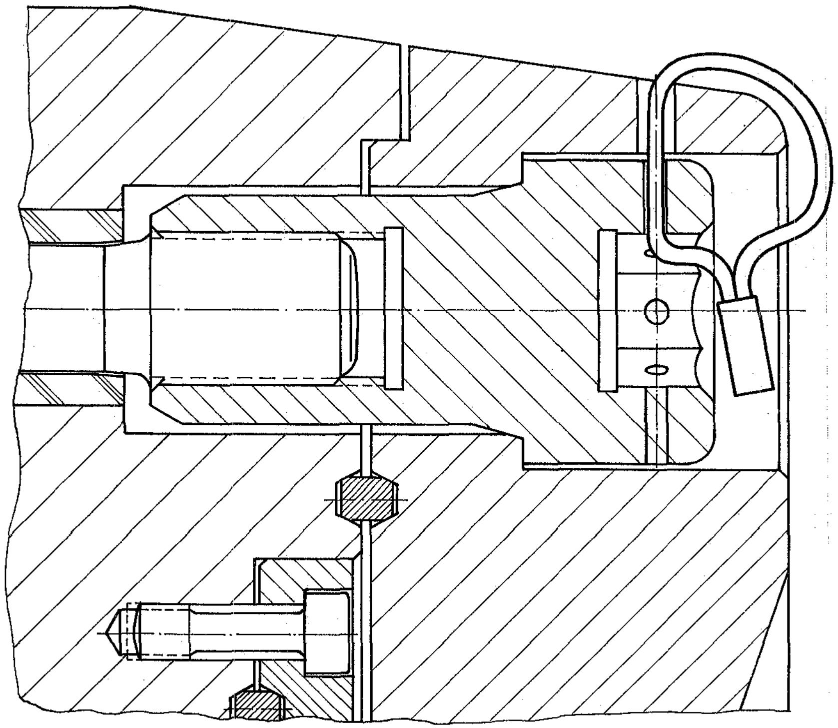


Fig.11.1.4-1 Construction of a tamperindicating seal





Detail „A"

Fig. 11.1.4-2 Example of application of the seal on a shielding cask for spent fuel elements

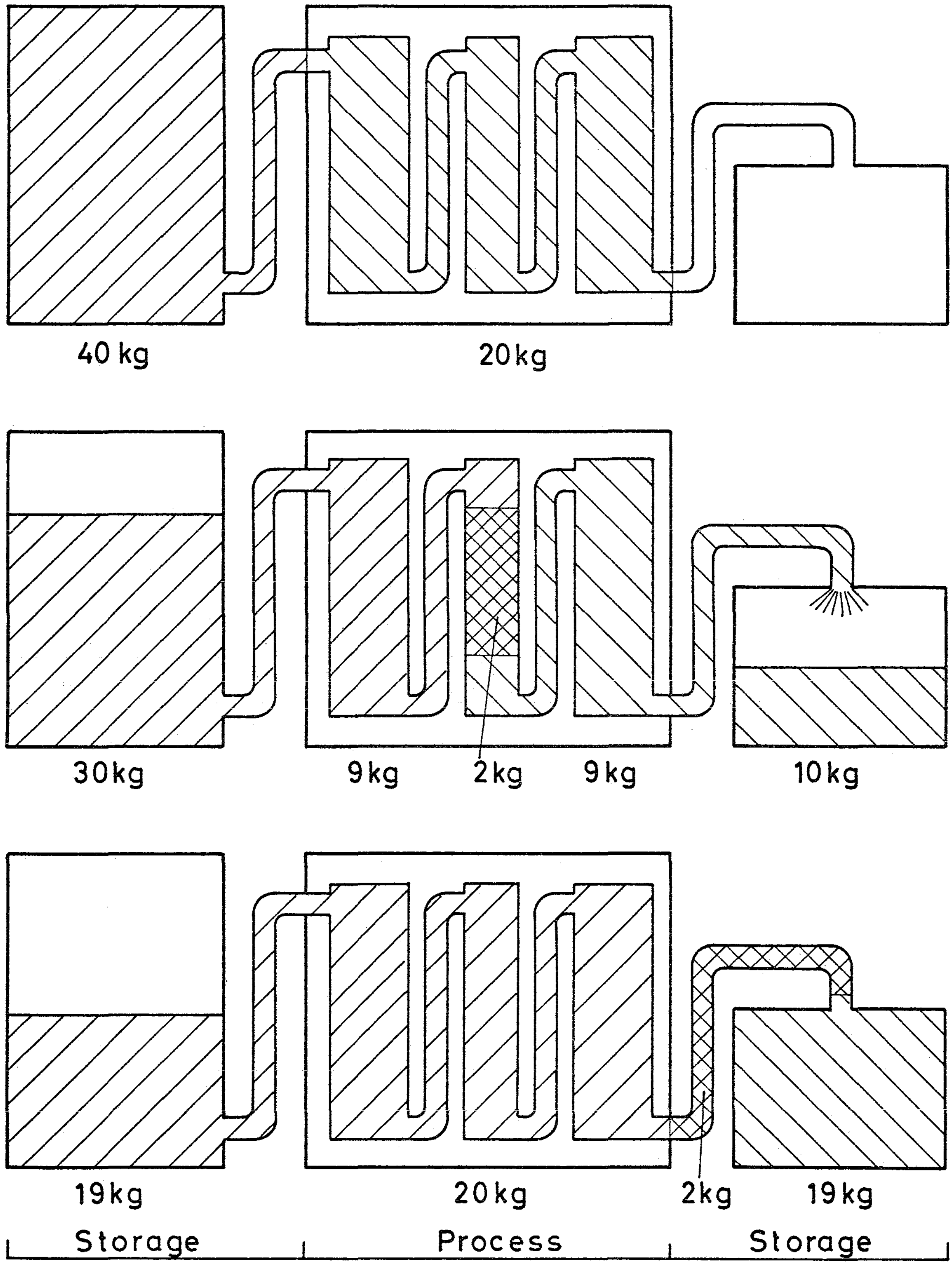


Fig.11.1.8-1 Principle of Process Inventory Determination