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Institut für Angewandte Reaktorphysik

Development of Safeguards Procedures for Heavy Water Moderated, Cooled and Reflected Pressurized Water Type Reactors

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GESELLSCHAFT FÜR KERNFORSCHUNG M.B.H.

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by

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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.

Gesellschaft für Kernforschung m.b.H., Karlsruhe

Der Bericht beschreibt ein im Rahmen des Projektes Spaltstoffflußkontrolle im Auftrag der IAEA entwickeltes Überwachungssystem für D_2O-Reaktoren ähnlich dem in Atucha, Argentinien.

Nach einer Analyse der Reaktoranlage und des Weges der Brennelemente innerhalb der Anlage wird die logische Struktur des Überwachungssystems dargestellt. Die wesentlichen Maßnahmen sind: Kennzeichnung von Brennelementen, Versiegelungsmaßnahmen, die das unbemerkte Auswechseln oder Entnehmen einzelner Brennstäbe aus einem Brennelement verhindern, Überprüfung der Bewegung der Brennelemente innerhalb der Anlage sowie Überwachung des Strahlungspegels in Reaktornähe. Außerdem wurden der Aufsichtsbehörde in regelmäßigen Zeitabschnitten die integrierte Reaktorleistung und die Betriebszeit des Reaktors mitgeteilt.

Der Bericht beschreibt, welche Instrumente und Maßnahmen nötig sind, um das vorgeschlagene Überwachungssystem zu verwirklichen, er macht außerdem Angaben über den Ablauf eines typischen Inspektionsbesuches. Schließlich wird eine Kostenschätzung gegeben, und es werden Vorschläge für eine praktische Erprobung des Systems gemacht.

This report describes a safeguards system for D_2O moderated power reactors of the type presently built in Atucha, Argentina. This work has been done for the IAEA within the frame of the Karlsruhe safeguards project.

After an analysis of the layout of the Atucha Reactor, the logical structure of the proposed safeguards measures has been evolved. The basic measures are: marking of fuel element subassemblies, sealing measures to prevent that single fuel pins can either be replaced by others or be removed without breaking the seal, checking the movement of the subassembly handling mechanisms along the fuel routes, and monitoring the radiation level in the reactor bay area. Besides this, the inspection organisation will receive information on integrated power generated, and shutdown history of the reactor at regular intervals.

The report describes the instruments,accessories and actions required to implement these measures. It also describes a typical inspection visit to the Atucha reactor, presents an estimate of the cost involved, and ends with a proposal for further development and for a field test.

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Development of Safeguards Procedures for Heavy Water Moderated, Cooled and Reflected Pressurised Water Type Reactors.

1. Summary

The present report describes the final results of investigations, carried out at the Institut für Angewandte Reaktorphysik, Kernforschungszentrum Karlsruhe, during the period of the contract 711/RB, on the development of safeguards procedures for heavy water reactors similar to "Atucha".

After an analysis of the layout of the Atucha Reactor, the logical structure of the proposed safeguards measures has been evolved. The basic measures are a) confirmation of the final routes as given by the operator, b) sealing, identification and checking the integrity of the fuel subassemblies, c) checking the movement of the subassembly moving mechanisms along the fuel routes and d) monitoring the radiation level in the reactor bay area. Besides this, the inspection organisation will receive information on integrated power generated, and shutdown history of the reactor at regular intervals.

The report describes the instrument, accessories and actions required to implement these measures. It describes a typical inspection visit to the Atucha reactor and ends with an estimate of the efforts required to carrying out some development work.

Manuskript eingereicht 21.4.70

2. Introduction

The rapid expansion of the nuclear industry in the world today, tends to indicate that a large numberof power reactors will be installed in a large number of countries in the next few years. According to a recent study by the IAEA /‾1_7, more than 280 power reactors are expected to be installed in 21 countries 1975. On account of economic reasons, the number of power reactors may be 10-20 times more than that of the fuel cycle facilities (reprocessing, fabrication and conversion plants) required to support them. Because of the large number, the safeguards system for power reactors should be simple without reducing its effectiveness and economic to ease the burden on the safeguards authority. The commercial nature of the power stations requires that the safeguards system should be non-intrusive and should not hamper the normal operation of the plant.

Although the present trend of power reactor installations indicate that the major part would be of the light water, enriched uranium type, heavy water, natural uranium type reactors are also expected to play an important role, particularly because of the fact that such reactors are independent of enriched uranium requirement.

The present report deals mainly with the development of safeguards procedures for the "Atucha" reactor. This is a heavy water moderated, natural uranium type power reactor, designed by the firm Siemens A.G., Germany. The reactor has been supplied to Argentina. It is being erected at Atucha, Argentina and is expected to go into operation in 1972.

/‾1_7 Power and Research Reactors in Member States.
IAEA publication (1968)

3. Survey of Safeguards Requirements

3.1 General Requirements of the Safeguards System

The type of instruments and the associated methods of evaluation as well as the location of the strategic points have to be selected as

1. to result in sufficient and reliable information, so that the Agency can effectively safeguard the flow of source and special materials
2. to avoid any interference with efficient plant operation.

3.2 Requirements for Reactors

In a reprocessing plant as well as in a fabrication plant, the flow of fissile material can be safeguarded by comparing the measured input with the measured output for each nuclide of interest. This may have to be supplemented by information concerning the process inventory of each individual nuclide.

This principle is difficult to fulfill in reactors, as because of nuclear reactions transformations of nuclides will take place. There are two possible ways to circumvent this difficulty:

1 By means of a combination of input measurements and calculations, a nominal value for the output of each nuclide to be safeguarded will be established. A measurement of the output(for example, in a reprocessing plant) will then serve to compare actual and nominal value. The calculations result in a relation between average burn-up of a fuel element and its isotopic composition. The average burn-up then can either be calculated or measured. Its calculation needs a rather extensive amount of information to produce any results of reasonable accuracy. These data include reactor power level and control rod pattern, as a function of time as well as, detailed information with respect to fuel element reshuffling. This information has to be obtained with sufficient accuracy and in a way as to guarantee its reliability.

2 It is observed, that the fissile material is not easily accessible during its stay in the reactor plant, but it is contained in fuel pins or fuel elements. Therefore, safeguarding the fissile material contained in these

pins, i.e. detecting any diversion, may very well be achieved by applying the safeguards procedures to the pins themselves. This implies, that the pins or fuel elements carry a tamperresistant identification and that their integrity can be checked. To detect any diversion of fissile material, it will then be sufficient to verify that each pin (or fuel element) that has been introduced into the reactor vessel will re-appear in the hot storage area after a reasonable period of time. This counting procedure can be done with an error of measurement equal to zero.

A further problem unique to reactors as opposed to fabrication and reprocessing plants is the so-called "diversion of neutrons". This involves, firstly, the uncontrolled introduction of fertile material into or at least close to the reactor vessel and, secondly, the uncontrolled removal of the same piece of material, after the reactor neutrons have transformed part of it to fissile material.

Fig. 1 shows schematically the "legal" route of fuel through a reactor plant that consists of a cold storage area, the reactor bay area, and the hot storage area. A re-introduction of partially burnt-up fuel is included. The other 3 figures illustrate the possible routes of diversion of fuel.

Fig. 2 deals with the case that a fuel element is withdrawn from the reactor without being transferred to the hot storage area. This could mean, that a crude reprocessing of this fuel element inside the reactor bay is being performed.

Fig. 3 concerns the illegal removal of spent fuel from the reactor plant from the reactor bay or from the hot storage area. The equivalent removal of new fuel from the cold storage area is also shown.

Fig. 4 finally illustrates illegal irradiation of fertile material, i.e. "diversion of neutrons". This material might be also illegally removed from the reactor bay area or be kept there and treated as under 2.

3.3 Particular situation for the Atucha reactor, a D_2O cooled and moderated pressurized water reactor.

The Atucha reactor scheduled to go into operation in Argentina by 1972 was selected as an actual example of a D_2O cooled and moderated pressurized water reactor. There are three points to remind that may have implications on the safeguards for this particular reactor or reactor type compared to others:

1 The reactor uses natural uranium as a fuel. While this still has to be safeguarded, the incentive to divert fresh fuel of this type is rather small.

2 The reactor is fuelled automatically on line.

3 A core loading consists of about 250 fuel elements thus making the task of checking fuel element identifications feasible as far as the number is concerned.

4. Specifications of the Atucha Reactor that are relevant for Safeguards

The Atucha reactor is a heavy water natural uranium power reactor, which is designed by Siemens AG., West Germany and constructed near Atucha, Argentina. It is expected to go into operation in 1972.

4.1 Plant description

Some technical details of this power plant are summarized in Table 1.

Table 1: Technical Details of the Atucha Power Plant

Reactor type	D_2O moderated D_2O cooled pressurized natural uranium fuelled reactor
Reactor power	1100 MW_{th} 340 MW_{el}
Fuel element	253 fuel elements in the core 36 fuel pins /element 5,25 m active lenght 11,9 mm pin diameter
Fuel	UO_2(nat) 153 kg U_{nat}/fuel element average burn-up 7000 MWd/t
Control rods	number 29 material HF-23, Steel-6
Fuel element storage	Capacity to store 1265 irradiated fuel elements

The reactor building is shown in Figs. 5 to 8. The reactor core is located in a double containment. The inner spherical part of the containment is of 20 mm steel (16 in the Figs.) and the outer part is of 60 cm concrete (hemisphere) and 80 cm concrete (cylindrical part). The steel containment is accessible through a personnel door, an emergency door and a welded door for heavy materials.

The reactor vessel is surrounded by the biological shielding (concrete), which contains also the fuelling machine maintenance room (13 in the Figs.). The biological shielding has a concrete roof, which can be removed so that the reactor bay crane can reach the reactor vessel and the fuelling machine repair room (12 in the Figs.). This operation can only take place during reactor shut down.

The fuelling machine maintenance room can be separated from the reactor vessel room by a moveable concrete curtain so that the fuelling machine can be maintained during reactor operation. The maintenance room is accessible through a heavy concrete door.

Fig. 9 shows the reactor vessel. The dimensions are indicated in this figure, the location of fuel elements and control rods is indicated, too.

4.2 Fuel element handling

The reactor is refuelled on load in normal operation. The movement of fresh and irradiated fuel in the reactor can be seen from Fig. 10a and 10b. The fresh and irradiated fuel elements are stored outside the reactor containment building in the fuel element storage hall. The first core loading is brought into the reactor building through the lock for heavy materials. Routine fuelling is carried out as follows: The fresh subassemblies are lowered into the wet storage pond (around J in Fig. 10a) using a light hoist (K in Fig. 10a). They are introduced into the reactor bay through the same transfer system through which the irradiated fuel elements leave the reactor (see below). Alternatively, fresh fuel elements can be introduced into the reactor through the personnel lock and can be inserted into the reactor vessel during reactor shut down with the help of the reactor bay crane (M in Fig. 10b). For this operation, the concrete roof, separating the crane from the reactor vessel has to be removed, which is possible only during reactor shut down.

Irradiated fuel elements under normal conditions are removed on-load with the help of the fuelling machine (5 in Fig. 10a and 5 in Fig. 10b). The fuelling machine is directed by remote control to the position of the fuel element to be discharged. It is positioned over the closure of the subassembly and flooded internally with high pressure heavy water (115 Atm.). The closure is opened remotely with the help of a gripping tool, the fuel element is lifted out of the reactor vessel and a new fuel element out of the fuelling machine's magazine is introduced into the reactor. Then the closure is closed again. The fuelling machine with the irradiated subassembly goes to the tilting flask (6 in Fig. 10a and 6 in Fig. 10b), which is in vertical position, The tilting flask has the following functions:

a) to take over the irradiated fuel element
b) to cool the fuel element by D_2O
c) to dry and to cool the fuel element by gas
d) to change to light water cooling
e) to bring the fuel element in a horizontal position
f) to introduce the fuel element into the fuel transfer tube(12 in Fig. 10a)

The fuel transfer tube brings the fuel element to the wet storage pond, where it is erected to a vertical position and stored in racks provided for this purpose.

The whole loading and unloading procedure is remotely controlled - partly by means of control programs. The fuelling machine can be maintained during reactor operation in the fuelling machine maintenance room (see Fig. 10b+)) which can be separated from the reactor by concrete shielding. In this room a test position for the fuelling machine is located (7 in Fig. 10b). This position, which contains a cooling loop is thought to test the functioning of the fuelling machine.

A second fuelling machine is kept ready in the fuelling machine repair room inside the reactor building. It can be exchanged with the other fuelling machine in case this is out of order, by means of the reactor bay crane. For this purpose the concrete roof, separating the crane from the reactor vessel has to be removed and thus the reactor has to be shut down.

+) the fuelling machine is shown in this position in Fig. 10b

4.3 The fuel element

Fig.11 shows a fuel element of the Atucha reactor in the cooling channel. The fuel is contained in the form of natural uranium dioxyd pellets in Zry-4 pins. 37 pins (36 fuel pins and 1 structural pin) are combined by spacers to form a fuel element. One fuel element contains about 152 kg of natural uranium.

5. Logical Structure of a Safeguards System for the Atucha Reactor

5.1 Safeguards measures by an inspector in the reactor plant

5.1.1 Access of the inspector

During reactor operation, an inspector has access at any time to certain strategic points or areas, namely

1. The fuel element storage hall
2. All places where the output of those instruments are to be read that have been installed for safeguards purposes (s. chapter 6). It is also important to ensure that the proper operation of the safeguards instruments can be checked by the inspector.

Before the first reactor start-up and during operational shutdown, the inspector has also access to the reactor building for visual inspections of the general lay-out of the building.

5.1.2 Use of safeguards instrumentation

The safeguards system to be proposed within the framework of this contract is based on an identification and counting of elements. It will be supplemented by measures suited to detect unauthorized irradiations.

The incoming fuel elements will be identified by visual inspection and brought into the cold storage area, where they stay until transfer to the reactor bay. While in principle, this area could be controlled by continuous visual inspection, in practice this will turn out to be highly impractical considering the great amount of reactor plants to be operated in the near future. Therefore, an occasional check will reveal if all elements that should be in the storage area according to the operator's reports to the agency are really there

The next logic step then is to ensure that each fuel element that leaves the storage area towards the reactor bay will also be introduced into the reactor and, vice versa, that each fuel element that is withdrawn from the reactor will soon reach the storage area. The following measures are planned for this purpose:

1 Automatic recording of the identification mark of each fuel element that leaves the storage bay via the fuel elements transfer mechanism.

2 Automatic recording to decide if an irradiated fuel element is transported in "in" or "out" direction, i.e. towards the reactor or towards the storage bay.

3 Automatic recording of load lifted and distance travelled by the gripper of the fuelling machine hoist, and linear distance travelled by the loading machine itself to ensure that loading and unloading of fuel elements will be noticed and can be correlated to element transfers from and to the storage bay.

Within the hot storage area the identification mark of each fuel element again can be checked by the inspector. Because the Atucha plant provides accomodations for five core loadings, it will be practical that groups of irradiated fuel elements will be put into cages set up in the wet storage area and will be sealed by the inspector after their identification has been checked. This is done to avoid identifying the same fuel elements repeatedly.

There still remain two problems to be solved, the "diversion of neutrons" and the removal of fuel elements by other means than using the loading machine. Concerning the first point, it appears to be extremely impractical to design a device that automatically monitors all goods entering the reactor bay area for open or hidden fertile material. Therefore, it seems to be more promising to concentrate on the removal of such material from the reactor, making use of the accompanying radiation. As the use of the normal loading machine would reveal the illegal measure, one had to use some other crane, and so both problems not covered so far concern the use of loading and de-loading devices other than the loading machine. These two additional measures will be taken:

4 Installing of a distance-load recorder to the heavy cranes in the reactor hall and the storage hall.

5 Installing of radiation survey instruments to reveal in case irradiated fertile material or fuel elements are withdrawn from the reactor without adequate shielding to avoid the use of the loading machine or other heavy cranes. The location of these instruments has been described in chapter 6.

As a further measure, an inspector of the control authority should by visual inspection check **for** the presence of heavy cranes and crude reprocessing devices, first, before starting of the plant and occasionally later on. This inspection has to be scheduled as not to imply a plant shut-down that is otherwise unnecessary.

5.2 Reactor Operator's Reports to the Agency

By monthly reports the reactor operator informs the Agency about fuel elements arriving at, or leaving the plant and internal fuel element movements. Also the Agency should be informed about the integrated reactor power.

Reports about the fuel element movement should contain the exact date of the movement (hour, date). It should be indicated from where to where the fuel element has been moved (fabrication plant, cold storage, reactor vessel, hot storage, etc.); the identification number of the fuel element should be given. These information can be filled into a form, which is described in Tab. 1, in order to facilitate automatic data processing.

Table 1: Form for the reports of the reactor operator to the IAEA about fuel element movement

Date of the report:15.7.69			Time: 14.00	
Hour	Date	Fuel element No.	Moved from+)	Moved to+)
10.30	30.6.69	137	1	2
Example for reporting fuel element movement				

+) 1 = Fabrication plant
2 = Cold storage
3 = Reactor vessel
4 = Hot storage

In a second form the location of all fuel elements of the plant has to be indicated.

Table 2: Form for the reports of the reactor operator to the IAEA about fuel element location

Date of the report: 15.7.69		Time: 14.00	
Fuel element No.	Location+)	Fuel element No.	Location+)
1	2	151	2
2	2	.	.
3	2	.	.
4	2	.	.
.	.	.	.
.	.	253	2
.	.	254	1
.	.	.	.
.	.	.	.
.	.	.	.
150	2	.	.

+) 1 = Cold storage
2 = Reactor vessel
3 = Hot storage

In a third form the integrated reactor power has to be announced to the Agency. Tab. 3 shows an example.

Table 3: Form for reports of the reactor operator to the IAEA about integrated reactor power

Date of the report: 15.7.69		Time: 14.00
Month	Power produced during the month /¯MW_{th} h_7	Hours on line in the month /¯h_7
January	818 400	744
February	712 800	672
March	818 400	744
April	659 100[1)]	600[1)]
May	818 400	744
June	792 000	720

[1)] shut down for maintenance during 5 days

The integrated reactor power will be useful for checking the corresponding activity level over the reactor bay, for cross checking the movements of various loading and unloading mechanisms in the fuel routes, and so on.

Failure of instruments of the inspector, damaging of instruments, seals and fuel elements should be reported to the Agency as soon as the operator gets notice of them.

Routine reactor shut downs, modifications of the plant lay-out and movement of heavy materials other than routinely done in the reactor building, should be announced in advance.

5.3 Logics of the Safeguards System

The safeguards system is based on a comparison between nominal and actual inventory of fuel elements within the reactor plant.
The nominal value is given by the fuel elements that have arrived at the reactor plant (and have been counted and identified by an inspector) minus those that have left the plant for re-processing or other reasons like further storage (those again have been counted and identified by an inspector). The actual inventory can be checked by direct visual inspection at any time, as far as fuel elements in the storage areas are concerned. As a direct check of the actual inventory of fuel elements within the reactor imposes serious problems, this inventory has to be deduced indirectly by means of the measures described under 5.1, i.e. mainly by photography of identification marks and the activities of ingoing and outcoming fuel elements in context with an evaluation of the records of the sensors that monitor the movement of the loading machine. These measures will be backed by records of loading machine load. While these measures serve to control that all fuel elements that should be present, really are so, the other measures mentioned under 5.1, i.e. γ-ray recording within the reactor area and, as a back-up measure, again, distance-load and position recorders for heavy cranes, will serve to detect the presence of unauthorized fuel.

It is important to ensure that safeguarding will still be possible should any of the major measuring devices fail. The easiest way to overcome instrument failure is given by duplication. Therefore, it is proposed to duplicate the camera that takes the photographs of the identification marks. A duplication is also recommended for the sensors that monitor the movement of the loading machine. As far as the γ-detectors are concerned, more than one detector will be provided anyhow in the transfer tube as well as in the reactor bay area. Nevertheless, a duplication may be found desirable.

A duplication of the distance-load equipment, however, is not envisaged, as this only has the character of providing back-up information.

Finally, it may happen, that the identification of some of the fuel elements runs into difficulties. This problem will be overcome by having three independent identification marks on each fuel element.

Furthermore, one may also observe that the alternative to checking the identity of fuel elements is given by performing either burn-up measurements or calculations and connecting those with the calculated relation between burn-up and isotopic composition for the reactors in question. The nominal value for the absolute amount of plutonium contained in the fuel elements that is calculated in this way is subject to an error of at least a few percent, and the actual value to be determined later will also not be free from error. Therefore, one may argue that even if one out of every thirty or fourty fuel elements cannot be identified, the result is still of the same quality as can be obtained by means of burn-up calculations.

One last remark may be made with respect to the use of the operator's data in case of a failure of the safeguards instrumentation. It appears to us, that the use of data that have been produced by means of unsafeguarded instruments is of very little value, as an operator who intends to divert fissile material will find a way to produce false but consistent data.

5.4 Comparison with a Previously Proposed System

Under the IAEA research contract Nr. 519/RB Dilworth, Secord, Meagher and Associated Limited Consulting Engineers, Toronto-Vancouver, Canada have developed safeguards procedures for heavy water moderated and cooled power reactors with continuous refuelling. The safeguards system which has been proposed is based on three measures

- Review of operating records by the inspector
- Tamperproof measurements, performed and recorded automatically during the inspector's absence
- Spent fuel surveying (calculation and measurement)

The aim of this safeguards system is to determine whether diversion of fissionable material has occured from the plant, and also the quantity of such materials held at the site. In accordance with these aims, the tamperproof measurements and the spent fuel surveying refer to both fuel element movement in the plant and determination of burn-up.

The safeguards system presented in the present report aims at detection of a diversion of fissile material more than at an exact knowledge of the quantity and quality of this material at the plant. The latter is justified by the fact, that a determination of the quantity of fissile material produced in a nuclear reactor can only be determined with a reasonable accuracy (1-2 % standard deviation) by measurement in the accountability tank in a reprocessing plant. This measurement will be carried out in any case, if interesting amounts of fissile material are produced.

So the safeguards system proposed in the present paper avoids burn-up calculations and measurements. The detection of a diversion of fissile material is guaranteed by the proposed identification system and the instrumentation. The amount of fissile material detected to be withdrawn can be estimated by the known history of the fuel element (or pin) which has disappeared and the reactor power rate, known to the inspector by the operator's reports.

It should be noted that an identification system as it has been proposed in this paper is restricted to reactors with a relatively small number of fuel elements ($<$ 1000).

6. Detailed Description of Safeguards Measures and Instruments

6.1 Fuel Element Identification

The identification marks may either be attached to every fuel pin or just to every fuel element. In the latter case a sealing procedure has to render it forbiddingly difficult to remove or to exchange a fuel pin in a manner as not to leave any damage to a seal.

6.1.1 Sealing of the Atucha Fuel Element+)

Each fuel pin carries a screw thread at one end piece. This end will pass through an opening in the fuel element support plate (see Fig. 11). As the diameter of the end piece is slightly smaller than the diameter of the pin, a lock nut will serve to fix the fuel pin within the support plate. This lock nut has a short cylindrical sleeve attached to it that will be squeezed together around the roof shaped end of the fuel pin to lock it against accidental loosening. (If a pin is removed on purpose, the sleeve part of the lock nut has to be

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+)The sealing methods described in [2], [3] seem not to be applicable to the sealing of fuel elements.

[2] C. Sastre, The Use of Seals as a Safeguards Tool, BNL 13480,March 1969

[3] G.C. Fulner, Tamper Indicating Safeguards System. RL-REA-2228

pressed open again and it will be possible to design the lock nut in a way as to prevent it from being used twice. As applies to all seals of this type, however, this will serve as a tamperresistant measure only in case there are no spare lock nuts available to the reactor operator. This then would require for lock nuts that carry a certain tamperresistant identification.)

Six of the peripheral fuel pins are not fixed by lock nuts but carry a zirconium tube each. These six tubes provide the connection between the fuel element proper and its coupling piece.

The sealing of the fuel element will be achieved by means of a guard plate (see X in Fig. 11) that is welded to the six tubes just mentioned. The plate will be close enough to the lock nuts and can be shaped in a way as to prevent the use of a wrench that is necessary to fix a fuel pin that has been exchanged with another one. The problem of sealing the fuel pins within the fuel element can then be reduced to the inspection of a welding seam. This asks for an investigation of the problem: How can a welding seam be fingerprinted?

6.1.2 Identification of the Atucha Fuel Element

While it is desirable to have an identification mark that can be read easily and is also tamperresistant, it appears to be more practical to split up this twofold requirement, into two single ones: to have one mark that can be easily read (e.g. a number) and another one that is tamperresistant.

The automatic camera would primarily serve to register the first mark, while an inspector may check the correspondence of the two marks for all fuel elements that are in the storage bay or for part of them on occasion of a routine inspection visit. As the welding seams have to be made tamperresistant anyhow, to check the integrity of the sealing, it appears practical to use them as tamperresistant identification marks also. In case it turns out, that the photographic registration of a welding seam (that has been made to lock somewhat"individually" on purpose or that has been fingerprinted in one way or other is sufficiently tamperresistant, the camera will be able to provide the information for the control of both the registration marks with one shot. For a quick check, an inspector may satisfy himself by checking the number of the elements, while for a more careful check (to be done later, if practical) he may check some or all of the welding seams. The non-tamperresistant numbers will be attached three-fold around the periphery of the support plate. In this manner, one of them will be seen by the camera, regardless of the accidental azimuthal position of the element when it leaves or enters the transfer tube. As there are six welding seams per fuel element, at least two of them will appear on each photograph.

6.1.3 Identification of Individual Fuel Pins

For the sake of completeness, it shall be noted that an identification of fuel pins is possible at the lower end of the pins (i.e. opposite to the end that carries the thread for the lock nut). The end caps are flat and provide a circular area of 8 mm diameter for the attachment or for the engraving of random or fingerprint patterns. However it does not appear to be necessary.

6.2 Instruments

6.2.1 Automatic Identification

In routine operation fuel elements enter and leave the reactor through the fuel element transfer tube. For their automatic identification an under water operating camera will be installed as indicated in Fig. 10a. The head of a fuel element entering or leaving the reactor will be photographed. The outside end of the fuel element transfer tube has to be constructed so that the support plate of the fuel element, carrying the identification mark is visible for the camera. Attention has to be paid to the fact that the camera should take photographs only in its nominal position indicated in Fig. 10a. This can be achieved for example by sealing the camera in its position or by monitoring its movement in a suitable way. The camera is accessible to the inspector at any time.

For reasons of reactor operation such cameras have already been installed for the surveying of fuel elements. A periscope equipped with a camera can also be considered.

In addition, two radiation monitors (A and B in Fig. 10a) indicate the direction of motion of an irradiated fuel element. These monitors are mounted in the fuel element transfer tube, which is accessible during reactor operation from the annular space between the reactor building and the storage hall.

A direct inspection of the identification mark of the fuel elements stored in the storage pond is possible with the help of a periscope (J in Fig. 10a).

6.2.2 Recorders for the Movement of the Fuelling Machine and Heavy Cranes

The fuel element movements inside the reactor hall are recorded by two different equipments:

a) Tamperresistant sensors

By means of a set of three sensors, fixed in the positions D, E and F in Fig. 10b, the movement of the fuelling machine from the tilter position either to the reactor vessel or to the test position is recorded. These sensors can be checked by an inspector during reactor operation from outside the concrete roof of the reactor room. These relatively simple devices should be layed out as tamperresistant as possible.

b) Distance-load recorders

Distance-load recorders are routine equipment in many reactors. For safeguards purposes their records are used as redundant information to complement the information obtained by the sensors.

The same equipment - fixed tamperresistant position indicators and distance-load recorders - has to be installed for the main cranes in the reactor building and the storage hall (K, L, M and N in Fig. 10a and 10b). In order to avoid exess information, these devices are recorded on printers only when the cranes carry loads greater than a minimum weight - for example 4 to.

6.2.3 Radiation Monitors

For the detection of unauthorized movements of irradiated fuel elements without shielding, gamma radiation monitors (P, Q and R in Fig. 10a and 10b) are mounted in different positions in the reactor building and the storage hall. The location of these monitors has to be choosen in such a way that they cannot be masked by shielding walls.

7. Description of an Inspection Visit

In this section all measures to be taken by an inspector during a routine inspection visit to the reactor will be described. (The measures to be taken during a non-routine inspection will depend on the event, which has caused the visit, so that no general recommendations can be given.)

Before the inspector goes to the reactor plant, he determines the nominal inventory of the cold and hot storage and the reactor vessel from the plant operator's reports. These inventory lists contain the fuel element identification marks and the corresponding sealing marks, so that the inspector can check the identity and integrity of each fuel element.

7.1 Inspection of the Hot and Cold Storage Area

The actual fuel element inventory of the hot and cold storage area can be verified directly. The fuel elements in the cold storage can be checked visually and their identification and sealing marks be compared directly to the nominal marks in the inspectors lists. In order to avoid repeated checks of the same fuel element in subsequent inspection visits, the sealing of fuel elements, which are stored for a longer time period, in cages may be very helpful.

The inventory of the hot storage is verified by testing the seals of the cages with burnt up fuel elements, identified during former inspection visits and by identifying fuel elements, discharged in the meantime with the help of the periscope. The latter operation is very important because in this way the identity and integrity can be made sure in a tamperresistant manner. (The integrity of a fuel element is not checked by the automatic instrumentation). After a thorough check of their identity and integrity these fuel elements will be transfered into a cage which will be sealed. The integrity of the cages has also to be tested by visual inspection and with the help of the periscope.

A direct verification of the fuel element inventory of the reactor vessel is not possible. So the activity of the inspector is directed to verify the operator's reports about fuel element movements by means of the tamperresistant instrumentation.

This verification will not take place at the site, because of the equipment needed for data preparation and data evaluation (development of films etc.). This work will be carried out in the inspection center, where the equipment, computers, etc. will be available.

All plans, where the printouts of the instrumentation are stored and sealed, are accessible during reactor operation. The camera (Fig. 10a) is located in the fuel element storage hall, so that its film can be taken without difficulty. The printout of the two radiation monitors in the fuel element transfer tube (A and B in Fig. 10a) are accessible from the annular space between reactor and storage building. The signals of the tamperresistant sensors and the distance load recorders - so far as they have been installed on the inspector's demand - can on principle be transferred to the fuel element storage hall. But for the reason of tamperresistance long conduction wires should be avoided. So it is recommended to print out these informations at the place,where the instruments have been installed. In picking up the print outs the inspector can so check at the same time the integrity of his seals and of the total instrumentation. The proper inspection procedures, to be carried out by the inspector have been presented in table 4.

Table 4: Inspector's Activities during a Routine Visit

Activity	Instrument	Location
Verification of the cold storage-fuel element inventory (and sealing)	Visual	Fuel element storage hall
Verification of the hot storage-fuel element inventory and sealing	Visual and periscope	Fuel element storage hall
Indirect verification of the reactor vessel fuel element inventory (and sealing):		
a) Collecting information for the verification of reports about fuel element movements	Camera	Fuel element storage hall
	Tamperresistant radiation monitors	Annular space between reactor and storage hall
	Distance load recorders+ position sensors of the fuelling machine	Roof of the reactor room
b) Collecting information about non-declared movements	Distance load recorders+ position sensors of the heavy cranes	Reactor hall Storage hall

The collected data are evaluated and analysed by the inspector after his return from the inspection visit. For the data evaluation, automatic data processing is recommended. In case of contradictions of the operator's reports and the results of the tamperresistant measurements, investigations have to be started in a second action level.

8. Cost Implications

The costs of sealing and marking the fuel elements are anticipated to be close to negligible (under the assumption that the welding seams can be used for identification).

Costs will arise, however, through the necessity to install the following equipment, that is not needed for normal operation:

1. Under-water camera and associated equipment to control camera action.
2. Radiation counters plus associated equipment for monitoring the transfer tube and the reactor bay area.
3. Distance-load recording equipment for those cranes that would not routinally be equipped with such, i.e. the service cranes in the reactor building and in the storage area.
4. Sensors to monitor the movement of the loading machine.
5. Tamperproof installation of the equipment mentioned under 1 to 4.

The total costs for this additional instrumentation are not expected to exceed \$ $1.1 - 1.3 \cdot 10^5$. They are low compared to the shutdown costs/day of about \$ $5.5 \cdot 10^4$ for the Atucha type reactor.

9. General Conclusions and Recommendations for Further Work

The method proposed in this report, i.e. safeguarding of fuel elements, depends on the ability to fingerprint the welding seams attached to the guard plate of the fuel element. Therefore, highest priority should be given to a feasibility study concerning this problem. One should keep in mind, that the problem of checking the fingerprint in a reasonably convenient manner is of equal importance. It is highly desirable to do this check by means of the picture taken by the under-water camera that is provided anyhow.

Furthermore, an actual field test of the equipment proposed is recommended. This refers in particular to the reading of identification marks of fuel elements that have been in a reactor, to the photographic registration of these marks during fuel element transfer into and out of the reactor and to the reliability and sensitivity of the radiation monitors and position sensors.

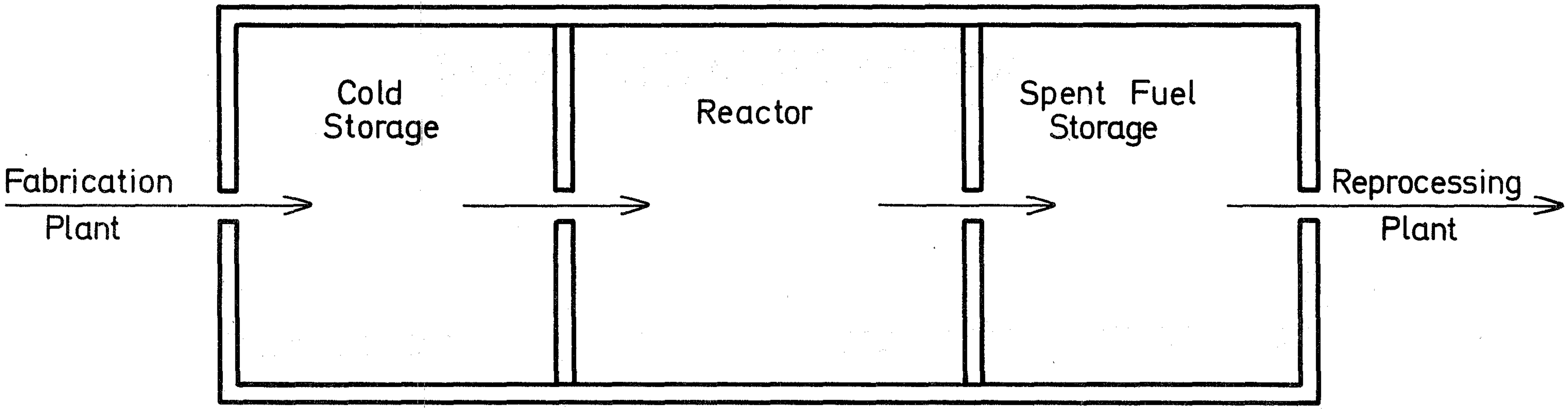
The testing time is estimated to be 18 months with the total costs not exceeding $\$\,1.5 \cdot 10^{5}$.

Acknowledgement

The authors would like to express their thanks to the firm Siemens A.G., Erlangen, FRG., the manufacturer of the Atucha reactor for their co-operation and particularly to Mr. Schabert of this firm for valuable suggestions and discussions through out this work.

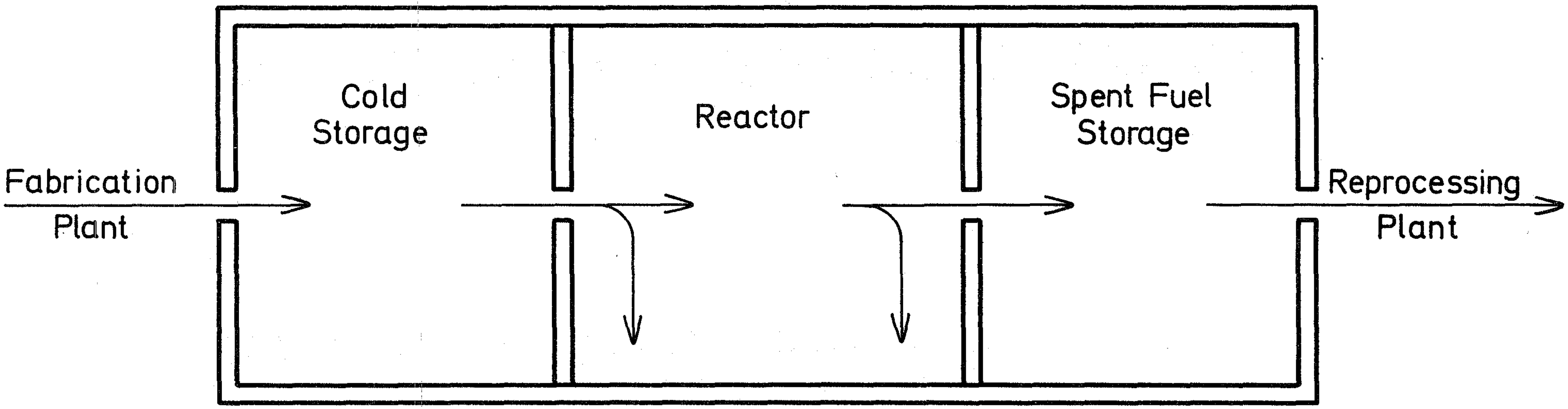
Literature

KFK 803 Gupta, D., et al.
"Safeguarding Fissile Material Flow at Strategic Points in Power Reactors."



Normal Fuel Element Flow through a Reactor

Fig. 1



Internal Diversion of Fuel

Fig. 2

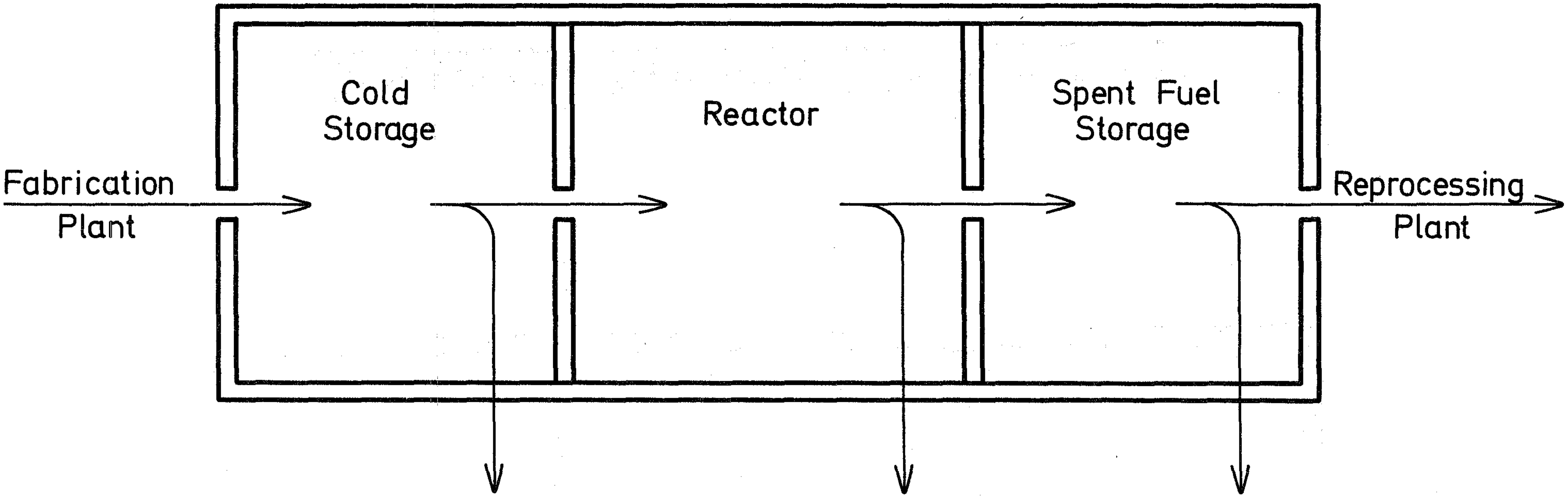
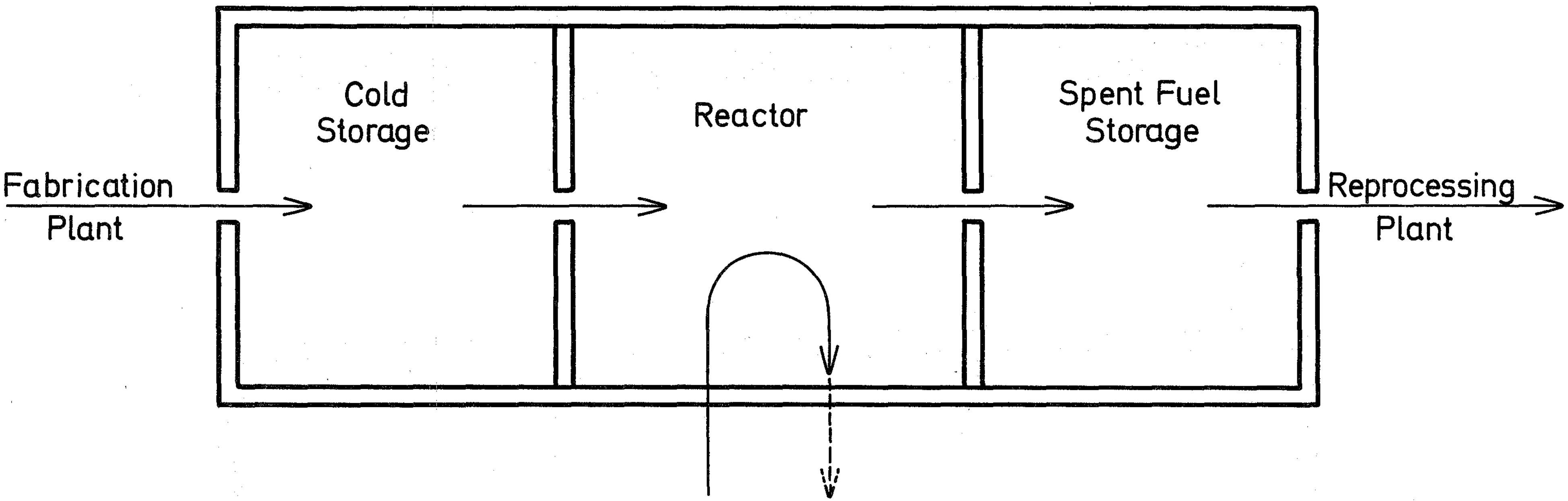


Fig. 3 Illegal Removal of Fuel from the Reactor and the Storage Areas



"Diversion of Neutrons" in a Reactor

Fig. 4

1	Reactor pressure vessel
2	Steam generator
3	Main coolant pumps
4	Pressurizer
5	Control rod drive
6	Fuelling machine
7	Tilting flask
8	Fuel transfer tube
9	Moderator cooler
10	H_2O supply
11	Storage bay for separation tubes
12	Fuelling machine repair room
13	Fuelling machine maintenance room
14	Valve room - Moderator circuit
15	Reactor bay crane
16	Steel shell
17	Secondary shielding
18	Pressurizer, blow off-tank
20	Service alley
21	Safety fuel pump
22	Pipe ducts
23	Cable ducts
24	D_2O storage tanks
25	Ion exchangers
26	Filters
27	Storage bay coolant circuit
28	Oil supply for main coolant pumps
29	D_2O drain
30	Container for fuel element transport
31	Fuel element lifting tool
32	Gantry
33	Storage bay crane

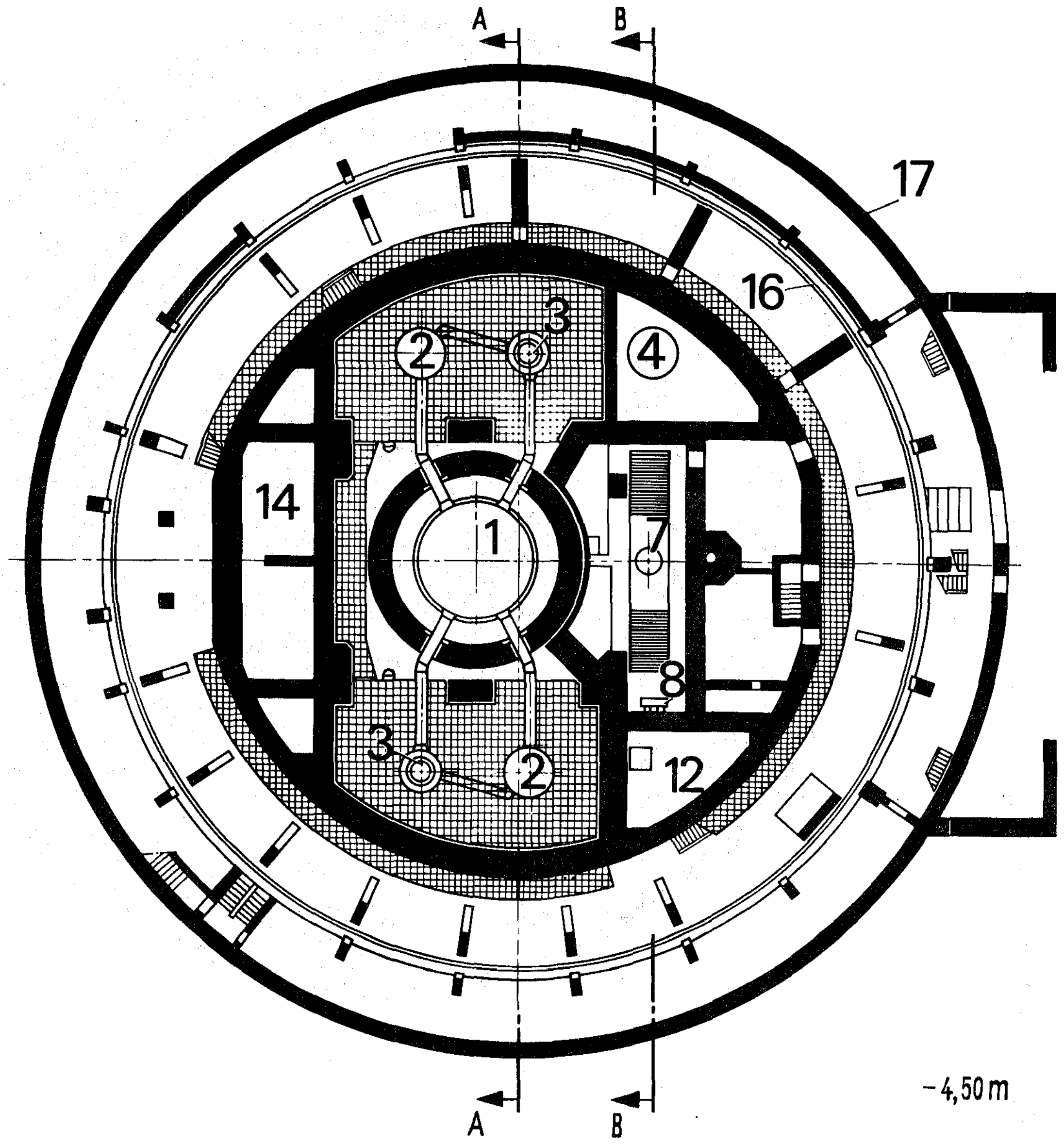
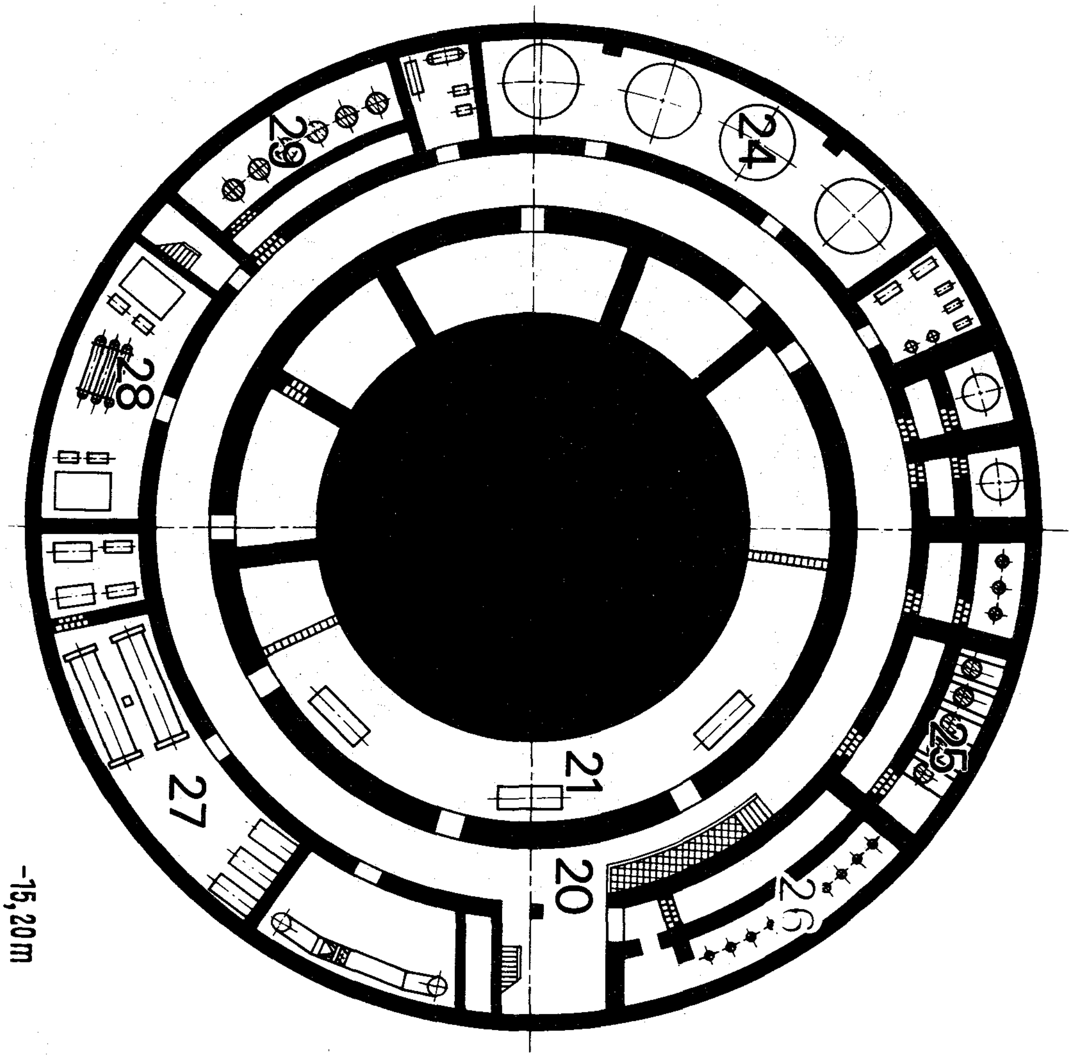


Fig. 5

Horizontal Cut Through Reactor Building at Level -4,50 m.

Fig. 6

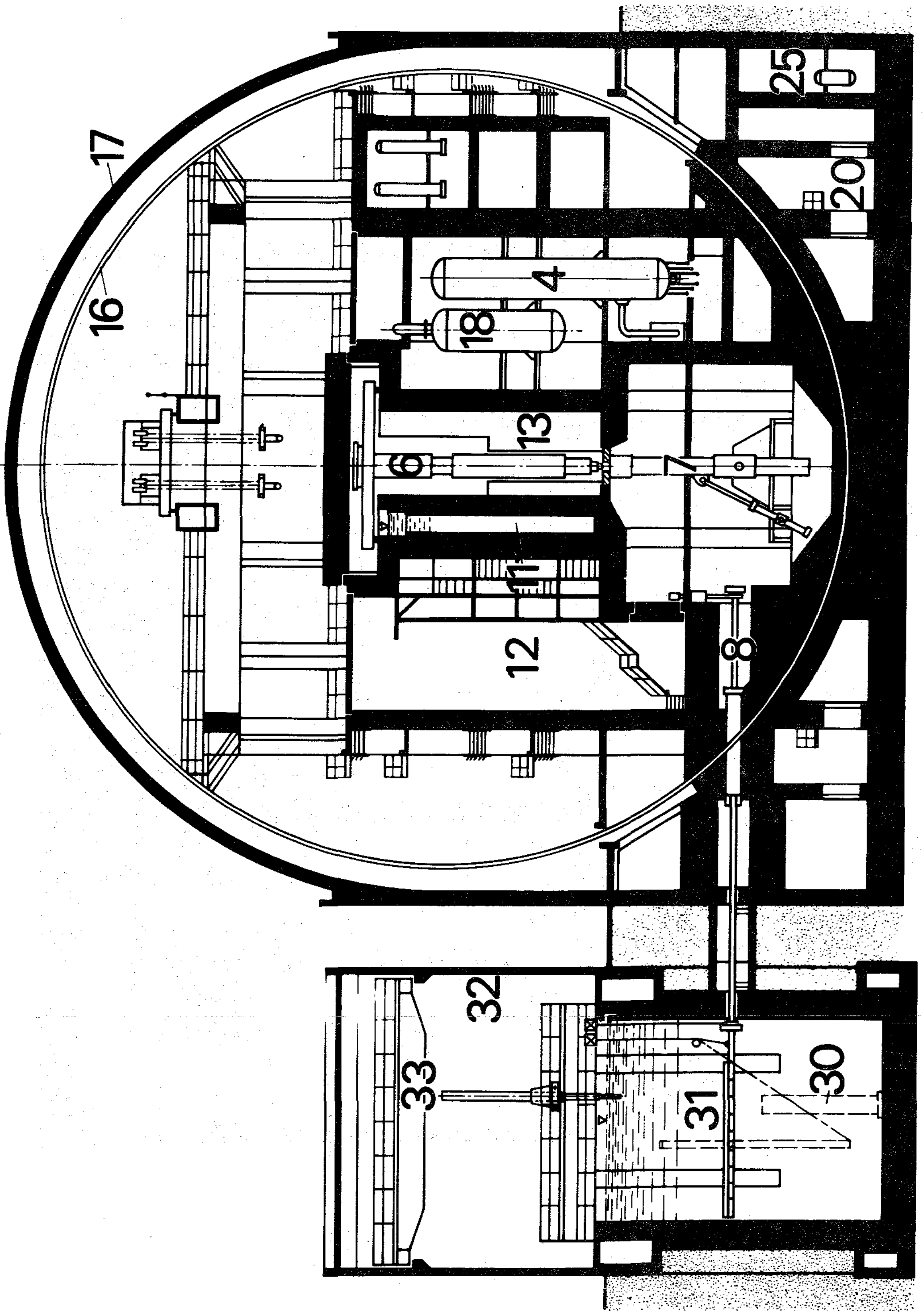
Horizontal Cut Through Reactor Building at Level -15,20 m.



For meaning of numbers see Fig. 5.

Fig. 7

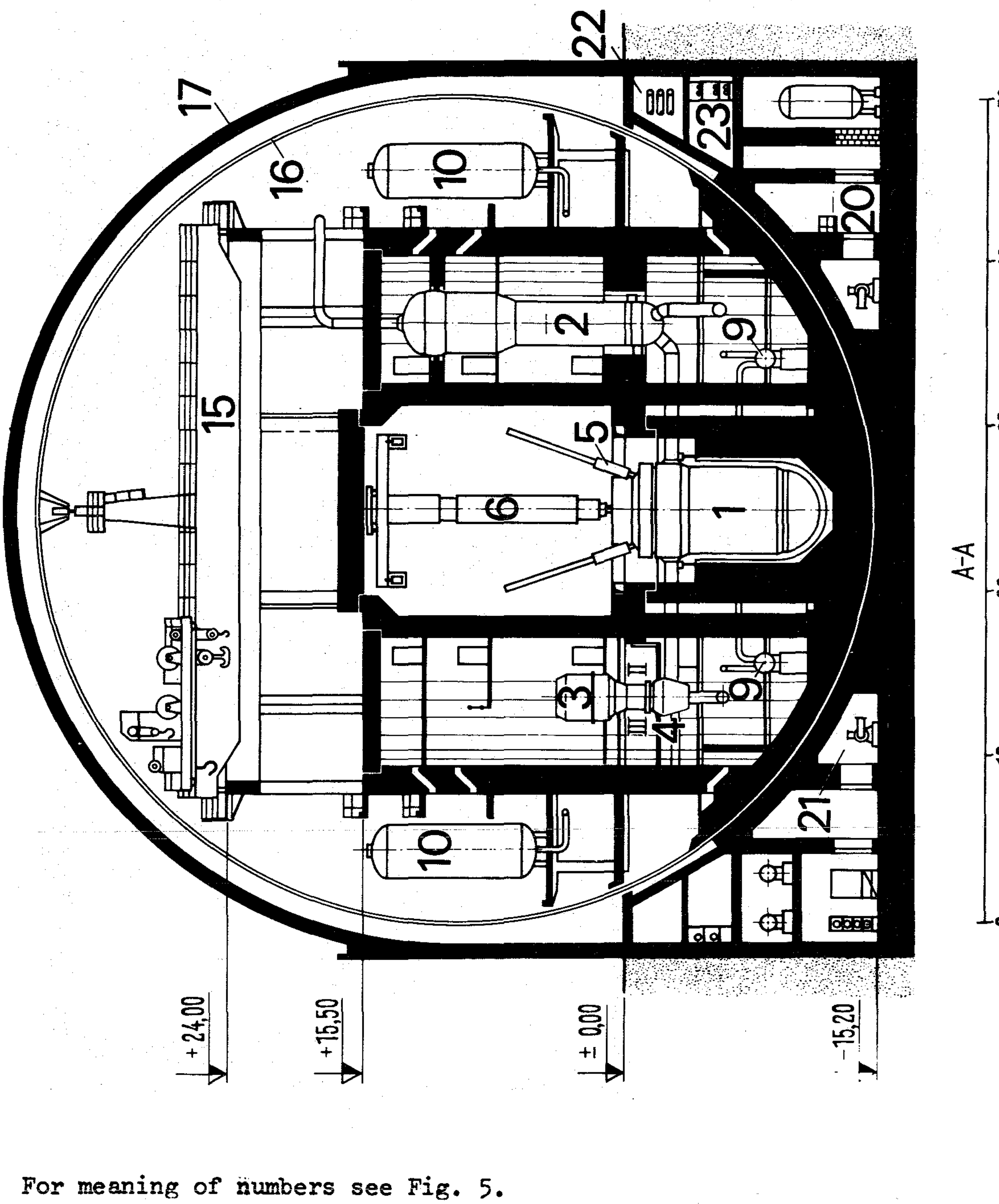
Vertical Cut Through Reactor Building and Fuel Element Storage Bay



For meaning of numbers see Fig. 5.

Fig. 8

Vertical Cut Through Reactor Building



For meaning of numbers see Fig. 5.

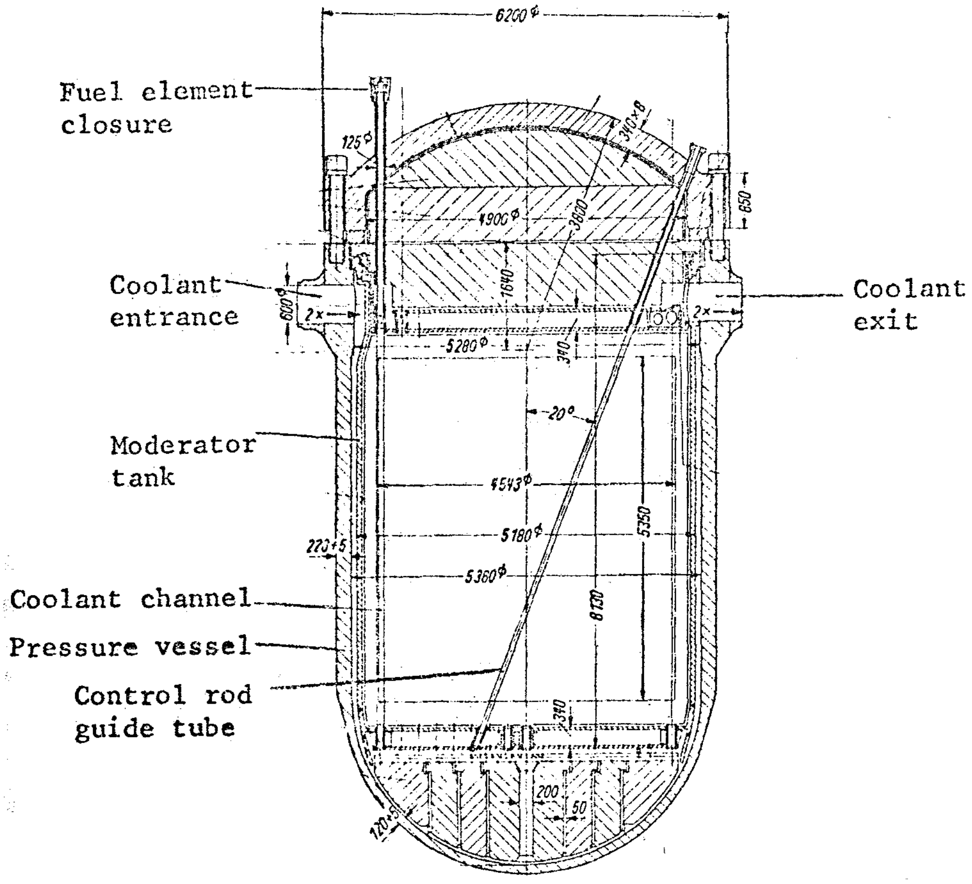
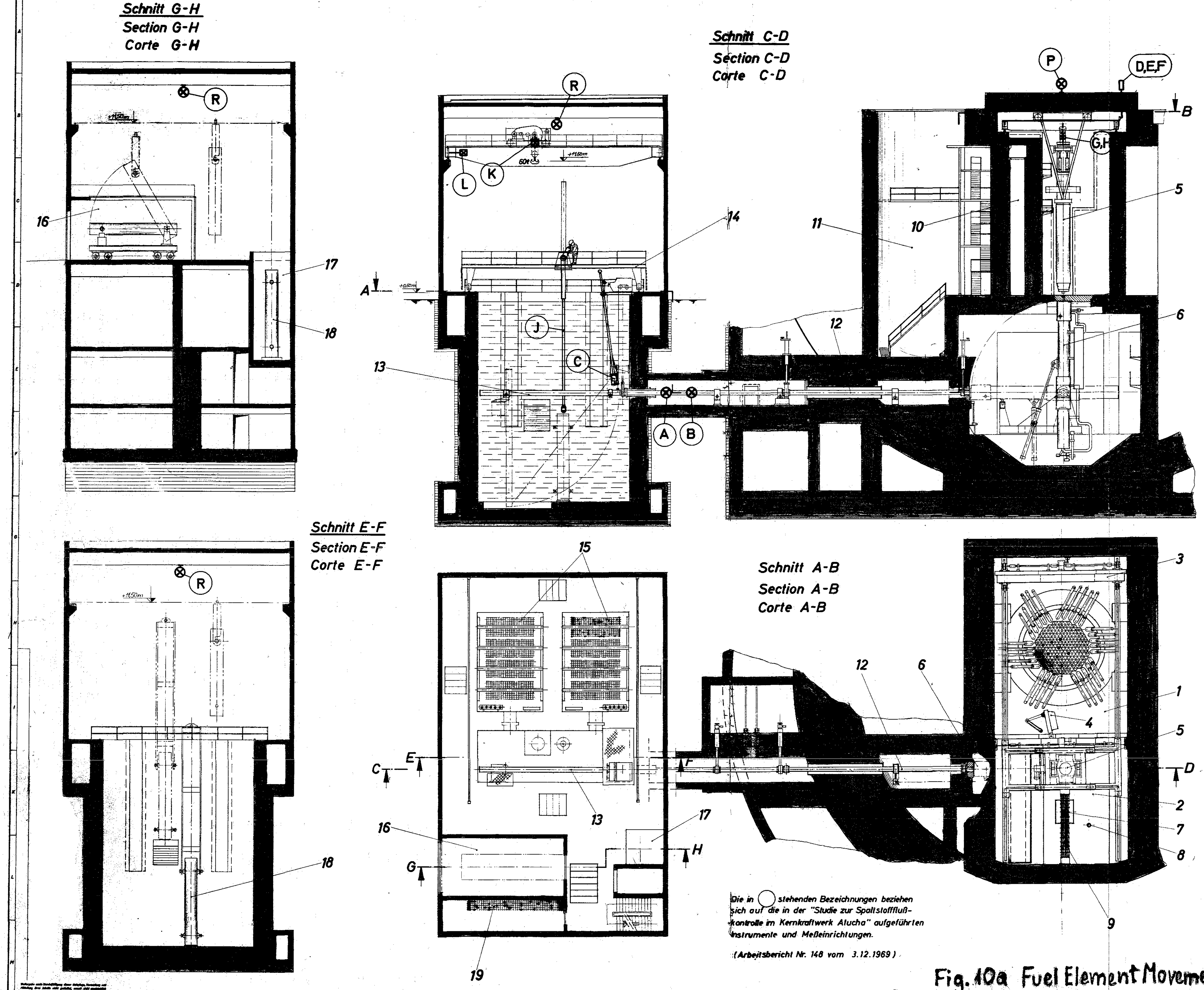


Fig. 9

Reactor Vessel



Die in ○ stehenden Bezeichnungen beziehen sich auf die in der "Studie zur Spaltstoffflußkontrolle im Kernkraftwerk Atucha" aufgeführten Instrumente und Meßeinrichtungen.

(Arbeitsbericht Nr. 148 vom 3.12.1969)

1 Reaktorraum
2 Lademaschinen-Wartungsraum
3 Verfahrbarer Riegel
4 Abschirmtür
5 Lademaschine
6 Schwenkflasche
7 Lademaschinen-Prüfposition
8 Dichtungswechsel-Position
9 Verschlußwechsel-Station
10 Trennrohrlagerbecken
11 Lademaschinen-Montageraum
12 Brennelementschleuse
13 Aufstellvorrichtung
14 Manipulierbrücke
15 Lagergestelle für verbrauchte BE
16 Beckenhauseinfahrt
17 Dekontstation
18 Transportbehälter für verbrauchte BE
19 Lager für neue BE

1 Reactor vault
2 Fuelling machine maintenance room
3 Movable shielding door
4 Rotating shielding door
5 Fuelling machine
6 Tilter
7 Fuelling machine test position
8 Seat-on.seal exchange position
9 Station for exchange of endclosure plugs
10 Calandria tube pit
11 Fuelling machine mounting compartment
12 Fuel transfer tube
13 Tilting device
14 Manipulating brigde
15 Spent fuel storage racks
16 Inlet port for fuel pit building
17 Decontamination pit
18 Spent fuel container
19 New fuel storage site

1 Recinto del reactor
2 Recinto de mantenimiento de la máquina de recambio
3 Puerta blindada móvil
4 Puerta blindada giratoria
5 Máquina de recambio
6 Basculante
7 Posición de prueba de la máquina
8 Posición de recambio del sello de asiento
9 Estación de intercambio de cabezales del combustible
10 Cámara de almacenaje de tubos de calandria
11 Sala de montaje de la máquina
12 Tubo de transferencia del combustible
13 Basculante exterior
14 Puente de maniobra
15 Marco de almacenaje de e.c.
16 Puerto del edificio de piletas
17 Estación decontaminadora
18 Recipiente para e.c. quemados
19 Emplazamiento para e.c. nuevos

Fig. 10a Fuel Element Movement

1969	Tag	Name	Entwurf:	Maßstab
Bearb.	29.7.	Lauren	BE Transport (normaler Ablauf) Fuel Handling (normal operation) Recambio de combustible (operación normal) CNA	1:100
Gepr.				
Norm				

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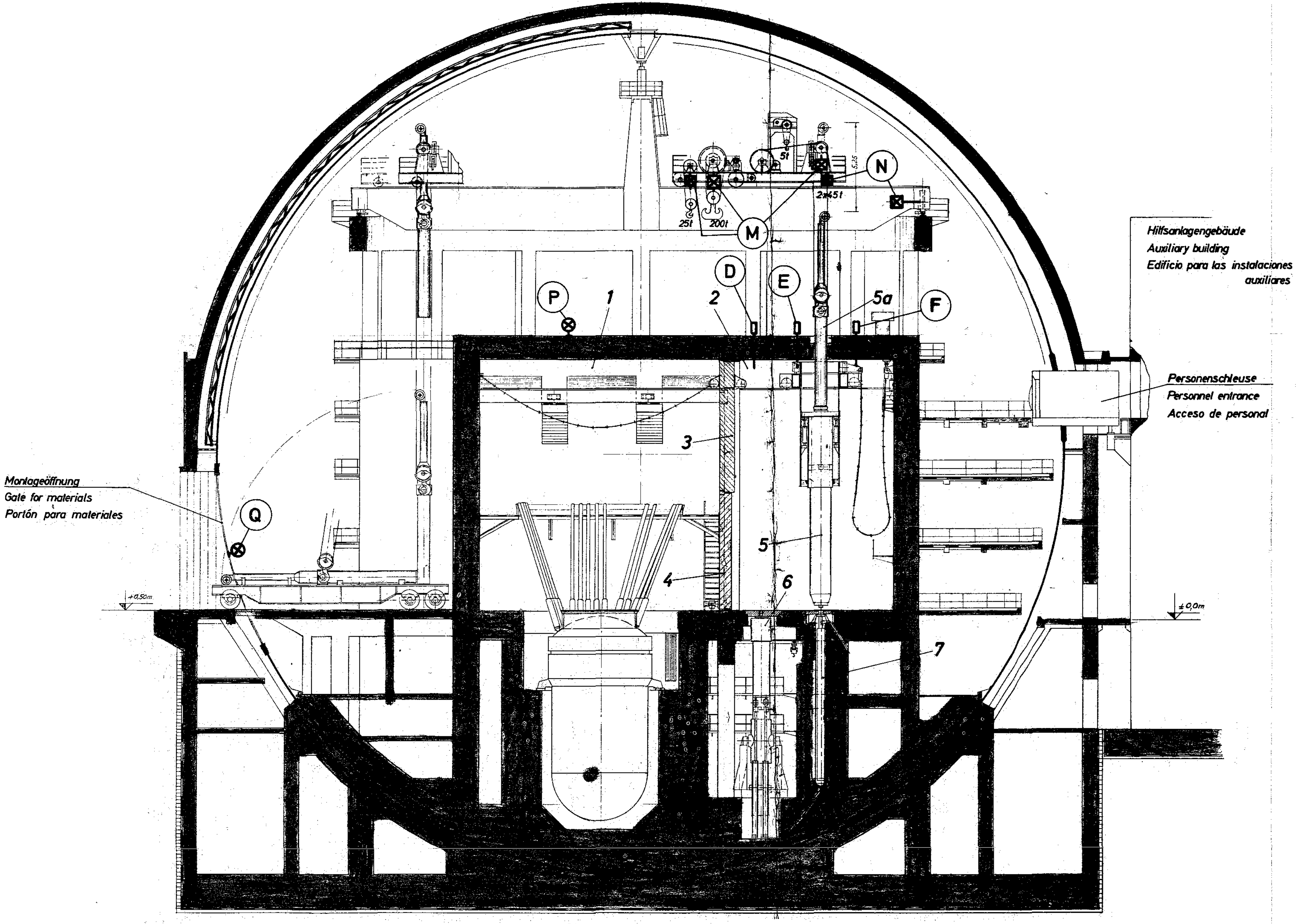
Ersatz f.
Ersetzt d.



1 Reaktorraum
2 Lademaschinen - Wartungsraum
3 Verfahrbarer Riegel
4 Abschirmtür
5 Lademaschine
5a Transferflasche (für Notausbau)
6 Schwenkflasche
7 Lademaschinen - Prüfposition

1 Reactor vault
2 Fuelling machine maintenance room
3 Movable shielding door
4 Rotating shielding door
5 Fuelling machine
5a Shielded tube for emergency withdrawal
6 Tilter
7 Fuelling machine test position

1 Recinto del reactor
2 Recinto de mantenimiento de la máquina de recambio
3 Puerta blindada móvil
4 Puerta blindada giratoria
5 Máquina de recambio
5a Recipiente blindado para emergencias
6 Basculante
7 Posición de prueba de la máquina

Die in ○ stehenden Bezeichnungen beziehen sich auf die in der "Studie zur Spaltstofffluß-kontrolle im Kernkraftwerk Atucha" aufgeführten Instrumente und Meßeinrichtungen.

(Arbeitsbericht Nr. 148 vom 3.12.1969)

Fig. 10b Fuel Element Movement

Freimaßtoleranzen	Änderungen			
1969	Tag	Name		Entwurf: BE - Transport (Notausbau) Fuel handling (emergency) Recambio de e.c. (emergencia) für CNA	Maßstab 1:100
Bearb.	14.7.	Laurer			
Gepr.					
Norm					

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Ersatz f. Ersetzt d.

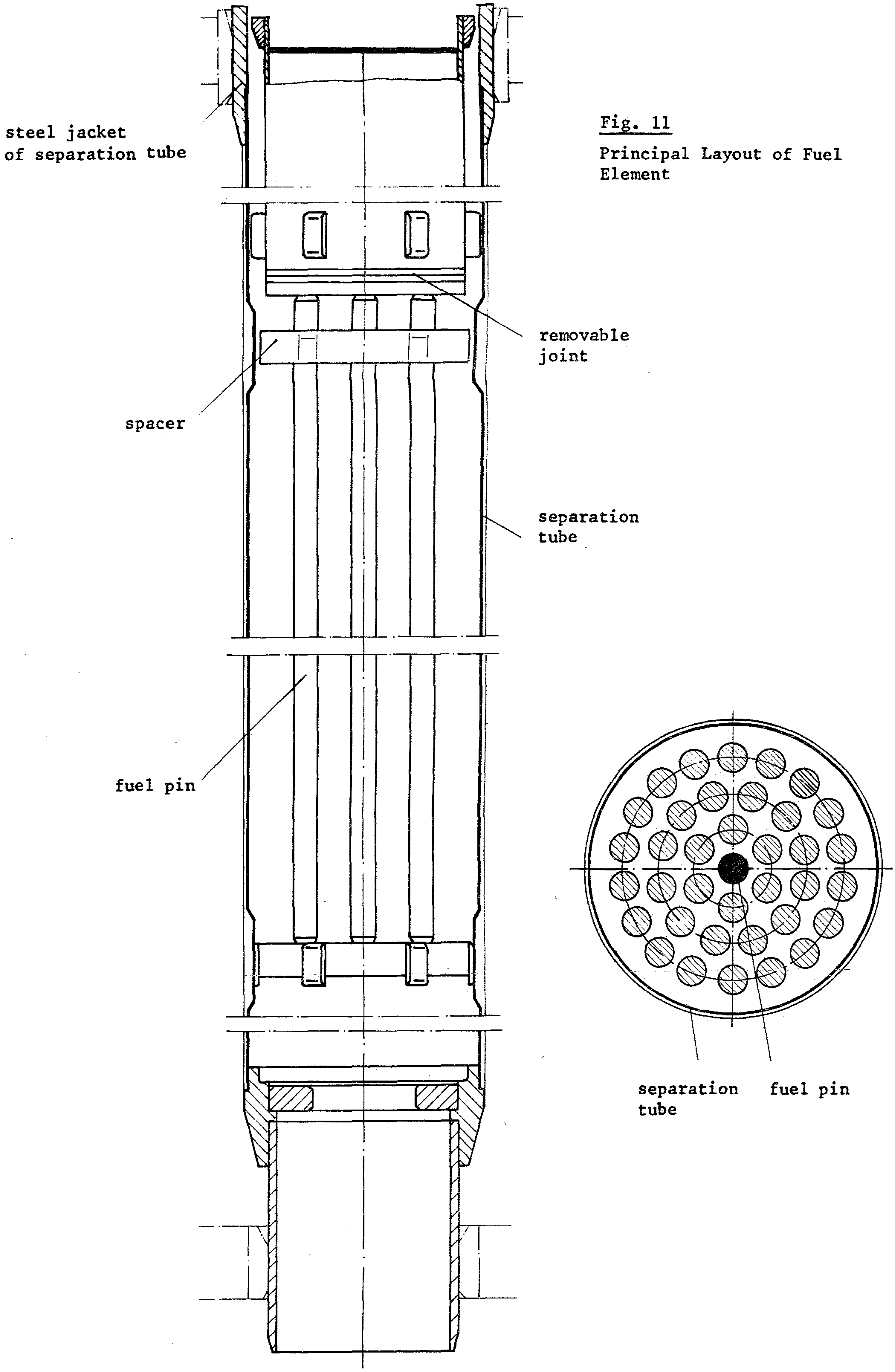

Fig. 11

Principal Layout of Fuel Element