INIS-XA-N--213

INVAP

CAREM PROJECT
15 to 150 MWe

INTRODUCTION

The main goal of the Carem Project is the introduction of a Inherent Safe Nuclear Power Reactor in the range of low power (15 to 150 MW_e).

For this low-power application, light-water and low enriched uranium was selected, since using those concepts permits to take full advantage of the special characteristics of low power reactors.

INVAP has been involved in the last years in the design and construction of a Carem Reactor, which could cover a range up to 150 MW_e, using a multiple-unit approach. It would furnished the 150 MW_e, using six Carem Reactors, of proper power, which would share most of the services.

INVAP is a reliable supplier of not only the nuclear reactor but also of the fuel.

1. PROJECT CRITERIA

1.1. OBJECTIVES OF THE PROJECT

The main objective of the CAREM project is to allow the use of nuclear energy in ranges of lower power than those used at present.

The average module, in the current nuclear industry, is of the order of 1000 MW_e. A 600 MW_e plant is considered medium, and a 300-400 MW_e, small.

The CAREM project is geared to the range of 15/150 MW_e. Such a power reactor could be used by any country and for different purposes, such as:

* Electric energy production

* Industrial steam production

* Water desalination

* Urban heating

Nuclear power has not been widely introduced in very low power applications for two reasons:

- The bigger the modules, the cheaper the nuclear energy.
- In order to use nuclear energy, a country requires a large number of highly qualified staff, which is in general only possible for large scale projects.

For these reasons the use of low power nuclear energy seems unlikely. The CAREM concept proposes a reversal of this view.

In the first stage of the project, we looked for design criteria that using the advantages of a very low power reactor might overcome the limitations mentioned above.

The answer which the CAREM concept proposes consists in making the simplest possible reactor, easy to operate and maintain, and satisfying all criteria of reactor safety.

This was accomplished by six design criteria, which make possible a simple reactor, easy to build, easy to operate and safe, namely:

A)Modular design

B)Minimization of on-site work construction work.

C)Built-in allowance for power increase by the addition of new modules

D)Easy transport of components

E)Self-controlled design

F)Passive emergency systems

1.2. DESIGN CRITERIA

1.2.1. Modular design

The present trend in nuclear engineering is towards standardization. Modern nuclear plants are built based on standard engineering, the licensing stages are standard and the big components are identical. Reactors differ from one another only in the modifications performed on the basic design to adapt them to the site.

A low power reactor is fit for a standardized design and licensing and through the use of modules enables the planning of a real serial production.

The CAREM design is modular, in a double sense:

A)Each reactor is made up of twelve parts, manufactured and tested independently, and then taken to the site of the reactor to be assembled as a complete unit and interconnected with the rest.

B)A plant may be made up of several reactors, which together, provide the required power.

The advantages of this criterion are:

- Lower engineering costs

- Lower quality assurance costs

- Lower licensing costs

- Lower interest rates while under construction

- Lower radioactive inventory and less hazards, hence, higher public acceptability

- Plants adjust to the real needs of the user, and to his financial possibilities, with, additionally:

* The possibility to add new modules in case of greater demand
* Lower power distribution loss due to shorter distances between plant and consumers
* Higher utilization rate of the installed power production capacity

- * Lower stock of necessary spare parts and hence, lower maintenance costs
- * Lower network interconnection costs due to more homogeneous power distribution

1.2.2. On-site works

Another advantage of a small power plant is that the on-site works can be minimized. Therefore, there is a reduction of dead times and costs of qualified personnel transport.

This reduction in the CAREM project has been achieved in two ways. On the one hand, modular design allows pre-assembly and testing of all the systems in the factory; once on the site they are only assembled and interconnected. On the other hand, civil works are drastically reduced using pre-assembled elements.

1.2.3. Growth of the plant

New reactors can be added to the plant, should this be required by the demand. All services which are in common are shared by the new modules and the existing ones. In particular,, only one control room for all reactors, only one effluent treatment plant and only one fuel elements storage room are required.

1.2.4. Components transport

Modular design implies the transport of finished parts, which are carried by regular means of transport along roads or rail.

If possible, parts can be tansported in containers; otherwise they should not exceed 60 ton weight, so that they can be carried by conventional means available in all countries.

This criterion reduces transport costs, and avoids limitations when choosing the site.

1.2.5. Self-control

The CAREM design must assures easy operation and simple control systems.

The power automatically adjusts to the demand, so that the reactor can work as base and semi-base plant and admit power cycling.

This criterion allows an easy and flexible reactor operation, so that it can be used in any power network.

1.2.6. Emergency system

Special emphasis was put upon the design of passive systems of shutdown and emergency cooling. Small power networks may not be very reliable. Therefore it is very important that the emergency systems do not need electric energy from external sources.

On the other hand, safe and reliable designs can be taken up because the power produced by CAREM is small.

Furthermore, if such designs are technically and economically sound, the licensing stages and acceptability of nearby residents will be simplified.

Reducing both the likeness and the possible consequences of an accident, results in a real reduction of the nuclear risk per MW_e installed.

2. THE CAREM MODULE

2.1. MAIN FEATURES

The nucleo-electric generation module CAREM-15 can be defined by its main features, namely:

- Light water and enriched uranium
- Integrated primary circuit
- Self-pressurized
- Natural convection cooling
- Passive emergency systems

a) Light water and enriched uranium:

Heavy water in a small power plant implies a complex design due to the need for water treatment, tritium production and on-line refueling.

Therefore the CAREM is a light-water enriched-uranium reactor. Enrichment varies, depending upon the selected fuel management modality, but it never exceeds 5% The CAREM-25 nucleoelectric module has 3.9% enrichment.

b) Integrated primary circuit:

This means that the steam generator is included within the pressure vessel. In this way, the whole primary circuit is contained in only one vessel. For comparison purposes, traditional primary systems consist of pressure vessel, two to four pumps and all the associated interconnecting piping.

c) Self-pressurized:

The reactor generates its own operating pressure, which is, therefore, the vapor pressure corresponding to the core outlet temperature. There is no direct pressure control. There is an indirect pressure control through the neutron power, so as to ensure that for steady-state use, the operating pressure is the same for any operating power. A vapor chamber, in the upper part of the pressure vessel, absorbs the pressure during transients.

d) Natural convection:

An integrated system has a very small pressure drop in the piping.

This fact allows cooling of the core by natural convection, so that the reactor does not need primary pumps. This results in a very simple reactor operation and in a reduction of costs. The coolant flow is induced by the different densities of the water in the riser and the down-comer and by the different levels of the core and steam generator.

Fixing an appropriate temperature gradient in the core and a height difference between core and steam generator, a coolant flow, sufficient for the core requirements, can be obtained.

e) Passive emergency systems:

The emergency systems are fundamental to ensure the safety of the PWR. In this type of reactors, the design of these systems has evolved through the years by adding new systems to previous designs, and improving those previous design, in order to achieve the highest safety standards. There is world-wide consensus in the nuclear industry that a new safety philosophy is possible as regards design of emergency systems.

This new philosophy must achieve two goals: inherently safe reactors and more reliable yet simpler safety systems.

This CAREM module is an inherently safe reactor: self-controlled, self-pressurized, integrated, cooled by natural convection and very simple to operate.

As regards the second goal, the CAREM module has passive emergency systems, that is: simple, highly reliable systems not depending on human intervention, or need of electricity for several days. In the CAREM, positive measures are not required before one week to ensure the safety of the plant. The CAREM module has passive emergency systems, which also prove simpler than the emergency systems of the present plants.

2.2. GENERAL DESCRIPTION

Fig. 1 shows a diagram of the pressure vessel, containing the core, the riser, the steam generator and the down-comer.

The coolant heats up in the core, goes up through the riser makes a 1800 turn, goes down the steam generator, where it cools, and returns to the core through the downcomer.

The difference in densities between the hot-leg (core plus riser) and the cold leg (steam generator plus downcomer) provides the driving force that ensures the establishment of a flow by natural convection.

The difference in levels between the core and the steam generator, permits the adjustment of the design to provide the needed flow to cool the core.

The steam generator are twelve shell and tube heat exchangers. The primary coolant passes through the tube side in a downward way, while the secondary water goes through the shell side, where is preheated, evaporated and superheated. Primary and secondary water flow in counter current.

3. CONCLUSION

The CAREM module introduces a new proposal into the nuclear energy market. Its outstanding characteristics as regards safety, ease of construction, assembly and operation are the result of an effort towards fulfilling the design criteria which ensure its competitively with other electric energy sources in the 15 to 150 MW_e range.

Maintaining all the advantages of the nuclear energy utilization, such as the substitution of fossil fuels and the access to high levels in technology, the use of the CAREM is feasible in countries having a smaller installed power capacity than is needed for the installation of a conventional nuclear power plant.

4. MAIN FEATURES

CORE

MAIN FEATURES

Net Electrical output: 25 MW_e
Fuel: 3.9% enriched uranium (equilibrium core)
Moderator and coolant: light water
Length of cycle: Minimum, 300 days at full power.
It can be adjusted for longer cycles.
Number of fuel elements: 61

MOST IMPORTANT FEATURES:

- Low power density
- Undermoderated core
- Soluble poisons are not used for reactivity control; burn-able poisons are used insted.

FUEL ROD

Cladding: Zry-4
Fuel Material: UO_2 (density: 10,15 gr/cm^3)
Pellet diameter: 7.58 mm
Active length: 1400 mm
Cladding I/O diameters: 7.71 mm/8.95 mm
Pitch between rods: 13.8 mm

FUEL ELEMENTS

Number of fuel rods per fuel element: 103
Number of position for control rods or burnable poisons/fuel element: 24
Fuel element configuration: hexagonal

CONTROL RODS

Control rod material: Ag-In-Cd
Type of control rod: clusters
Number of control rods: 25

BURNABLE POISONS

Material: Gd_2O_3-UO_2
Disposition: in solid rods, at certain positions in the fuel element or mixed with the fuel.

PRIMARY CIRCUIT

PRINCIPAL CHARACTERISTIC

Integrated.
Cooled by natural convection.
Self-pressurized.

OPERATING PARAMETERS

Inlet temperature: 283 °C
Outlet temperature: 326 °C
Pressure: 12.25 MPa
Coolant flow: 410 kg/sec

PRESSURE VESSEL

Material: SA-533B
Cladding: Stainless steel
Diameter: 3.08 m
Height: 11.2 m

STEAM GENERATOR

Type: Once-through, straight-tube type.
Number of Steam Generator: 12
Number of tubes per Steam Generator: 460
Tube material: Incoloy 800
I/O tube diameters: 13,8/15,8

SECONDARY CIRCUIT

OPERATING PARAMETERS

Turbine inlet pressure: 4,5 MPa
Cycle efficiency: 27,4%
Pre-heating stages: 2
Turbine: full expansion turbine

SAFETY SYSTEMS

CONTAINMENT

Type: pressure suppression
Design pressure: 600 kPa
Design temperature: 145 °C

ECCS

Type: water injection by gas pressurization.
Pressure of injection: 1.5 MPa
Volume of water injected: 70 m^3
Duration of injection: 1 week

RHRS

Type: a double natural convection system, which takes the heat from the core and send it to the atmosphere.

Assured operation without human-intervention: one week

PRESSURE VESSEL

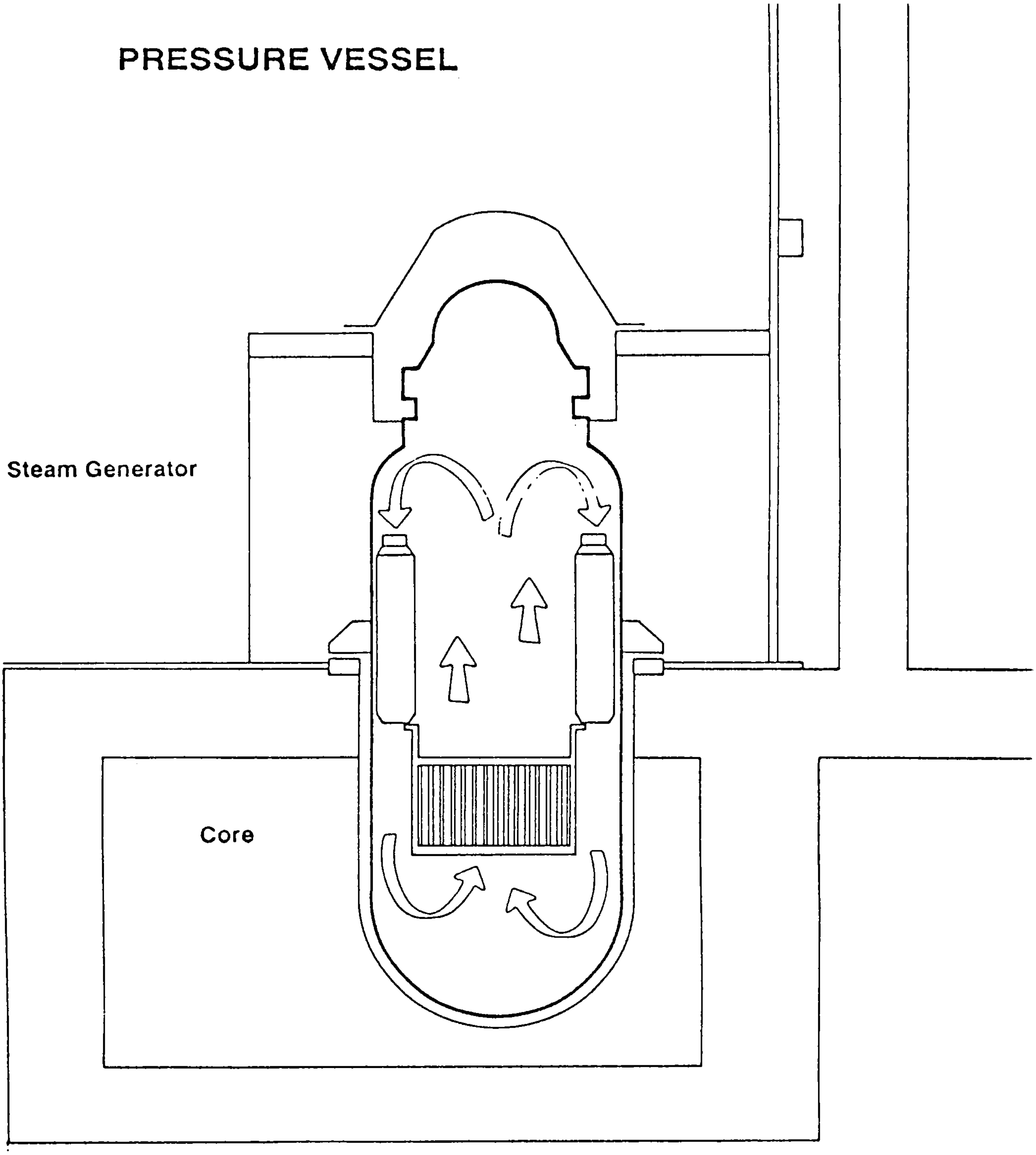
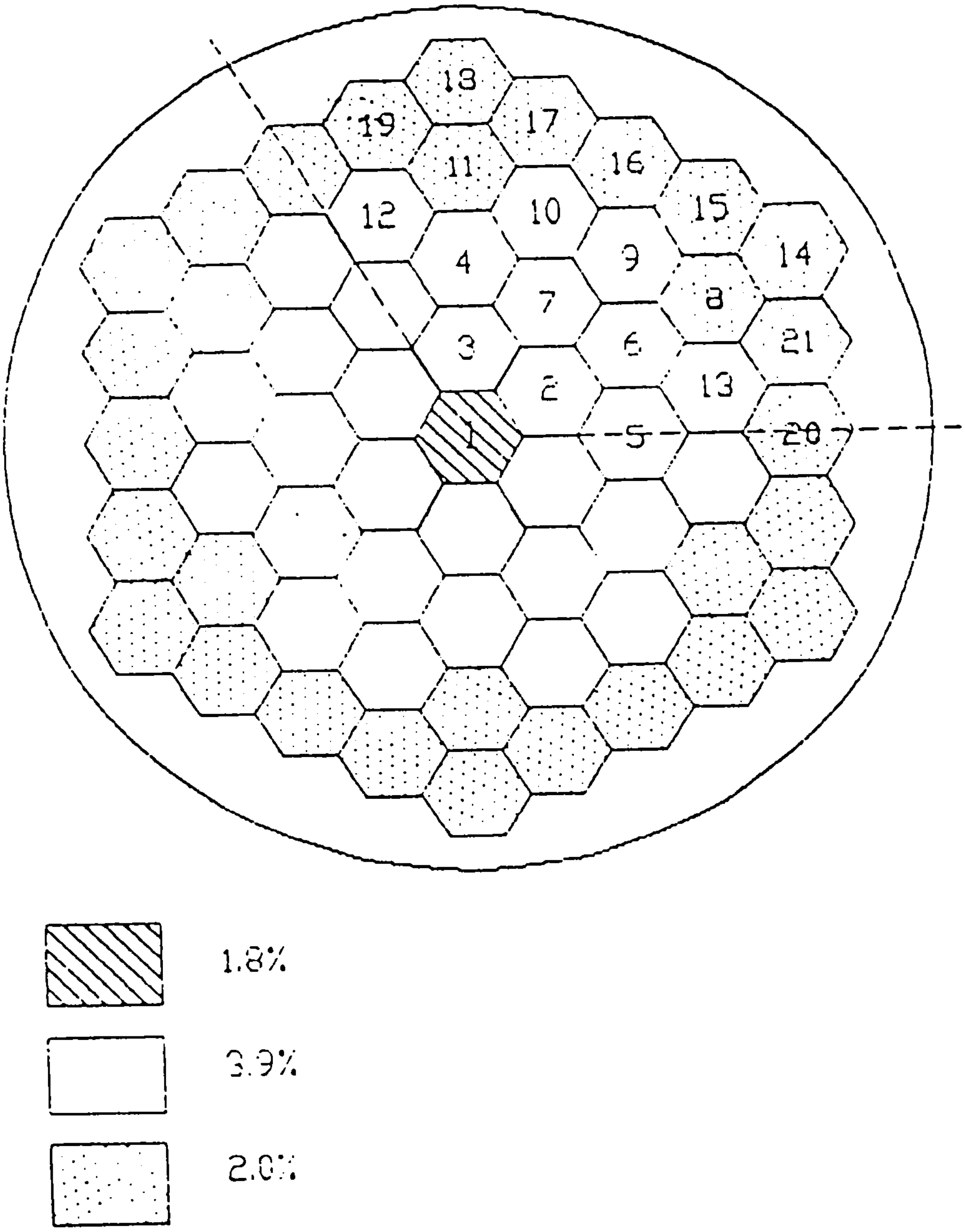
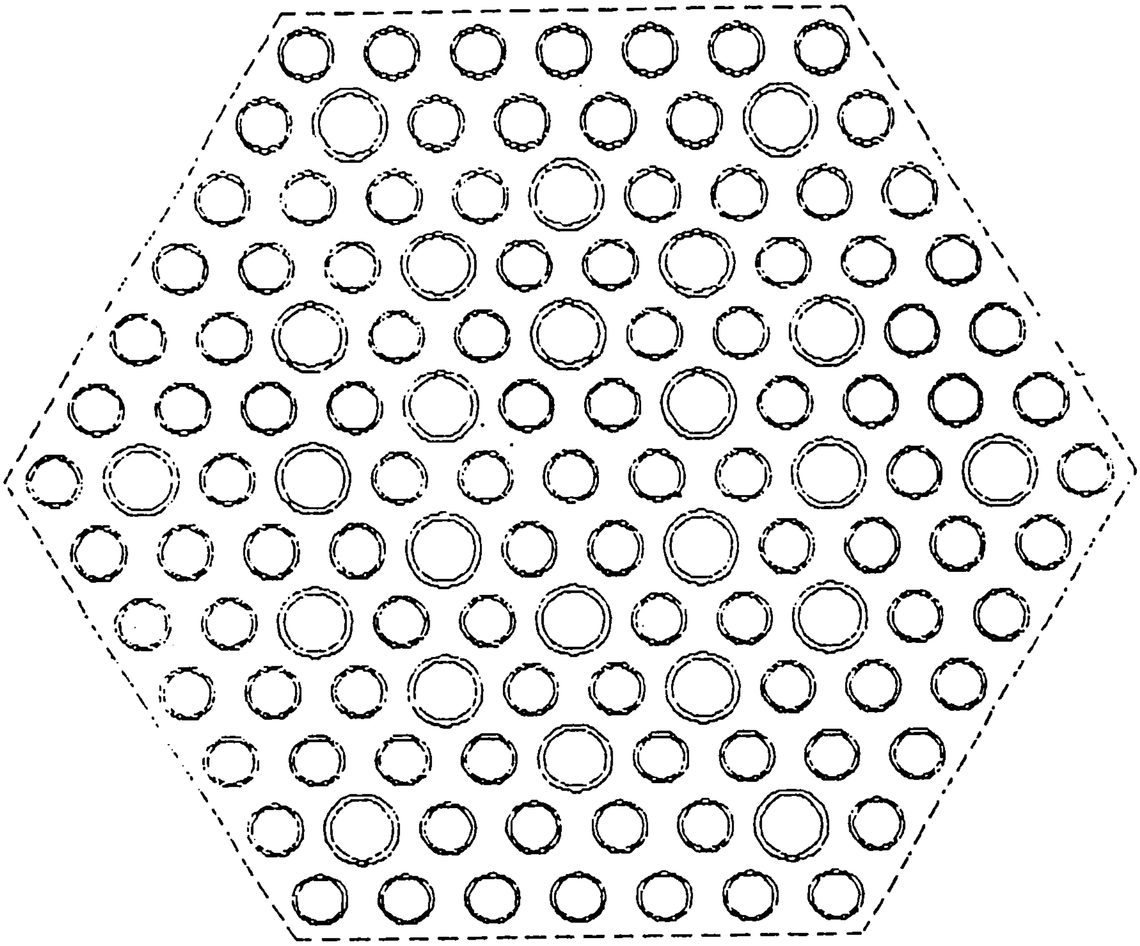


Fig. 2.1.1



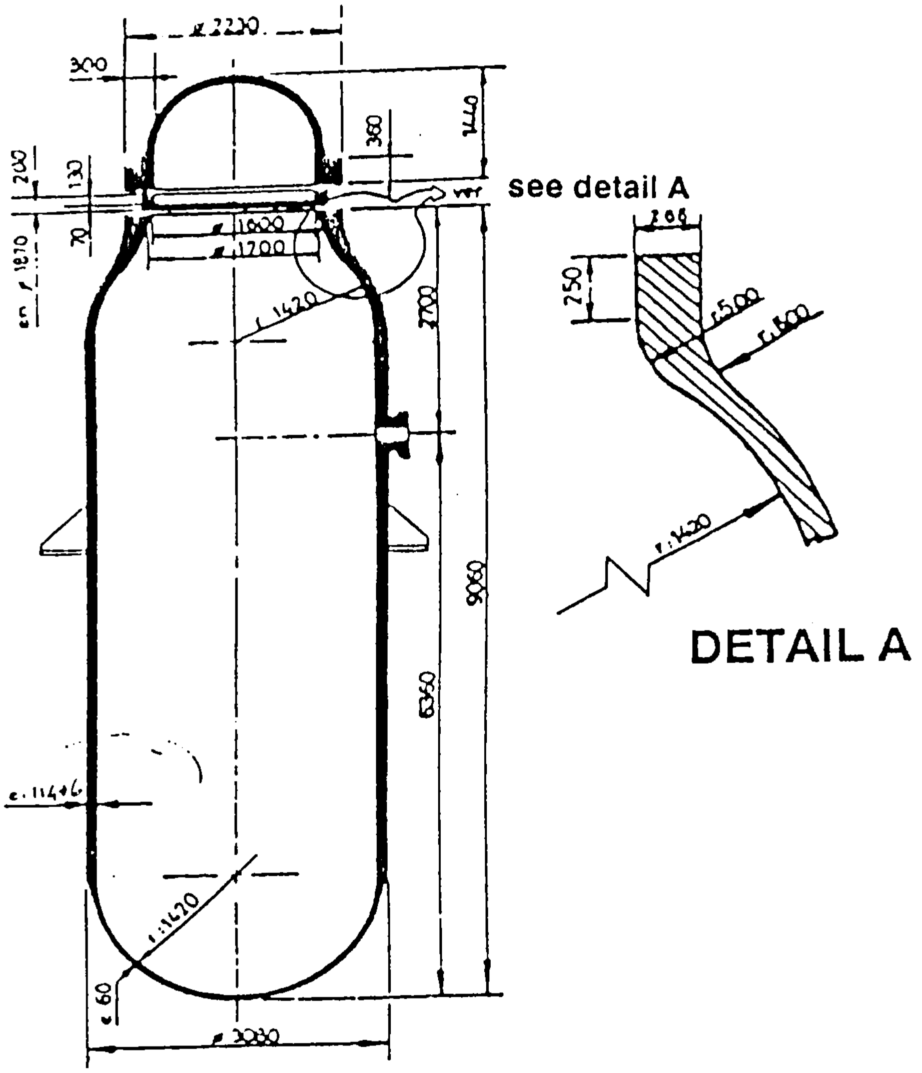
ENRICHMENT DISTRIBUTION

Fig. 2.2.1



CAREM FUEL ELEMENT

Fig. 2.2.2



PRESSURE VESSEL

Fig. 2.3.1

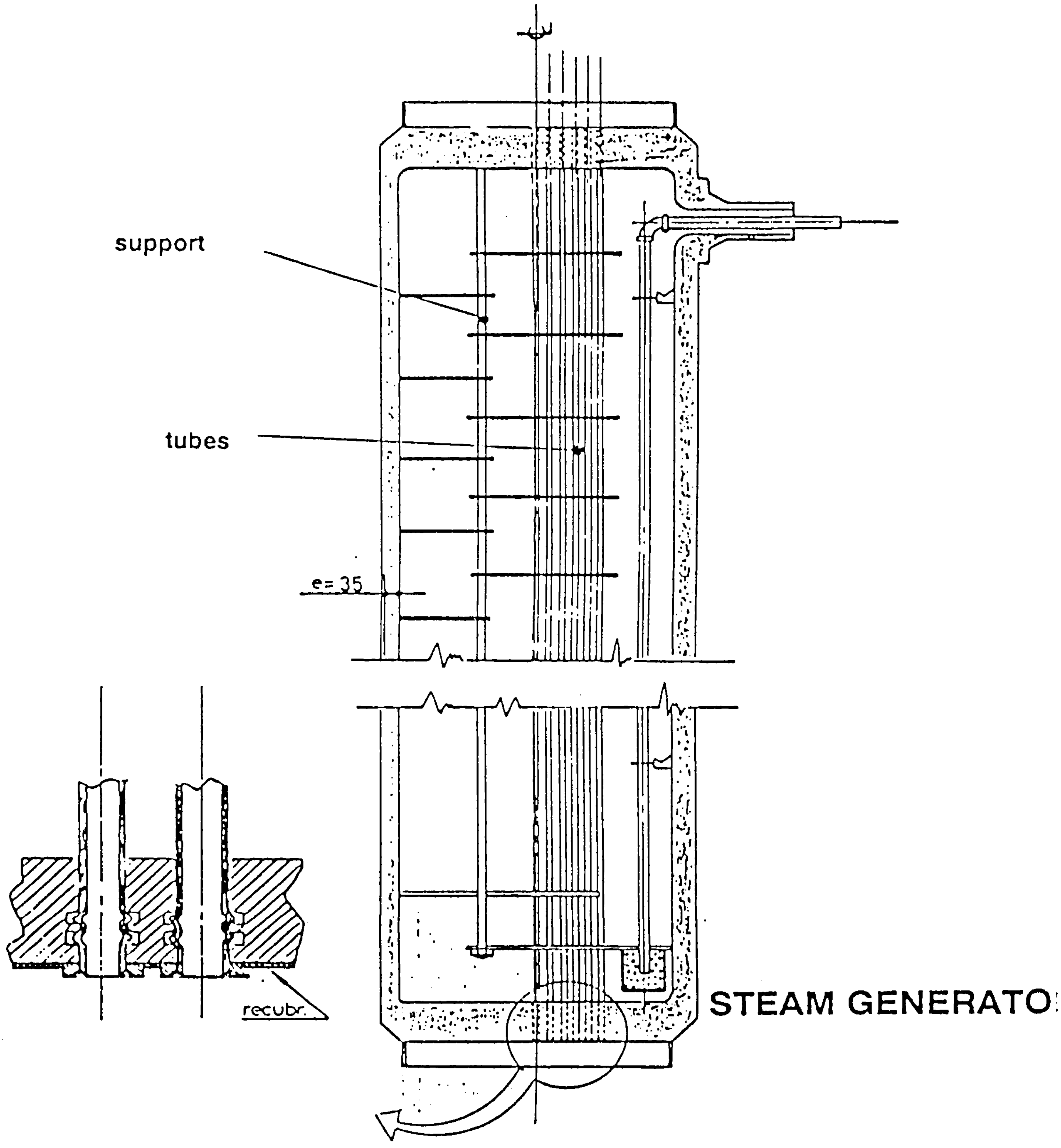
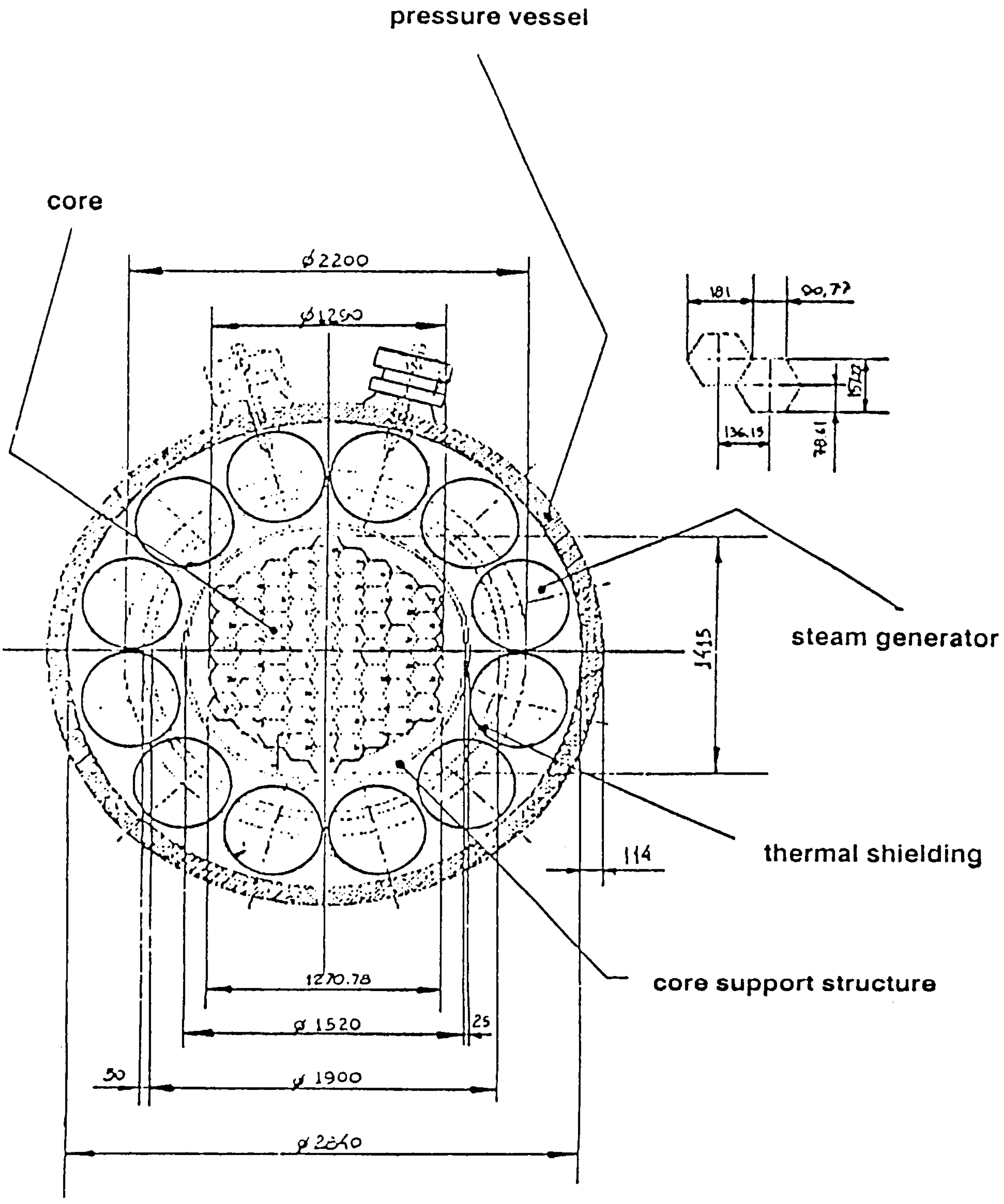


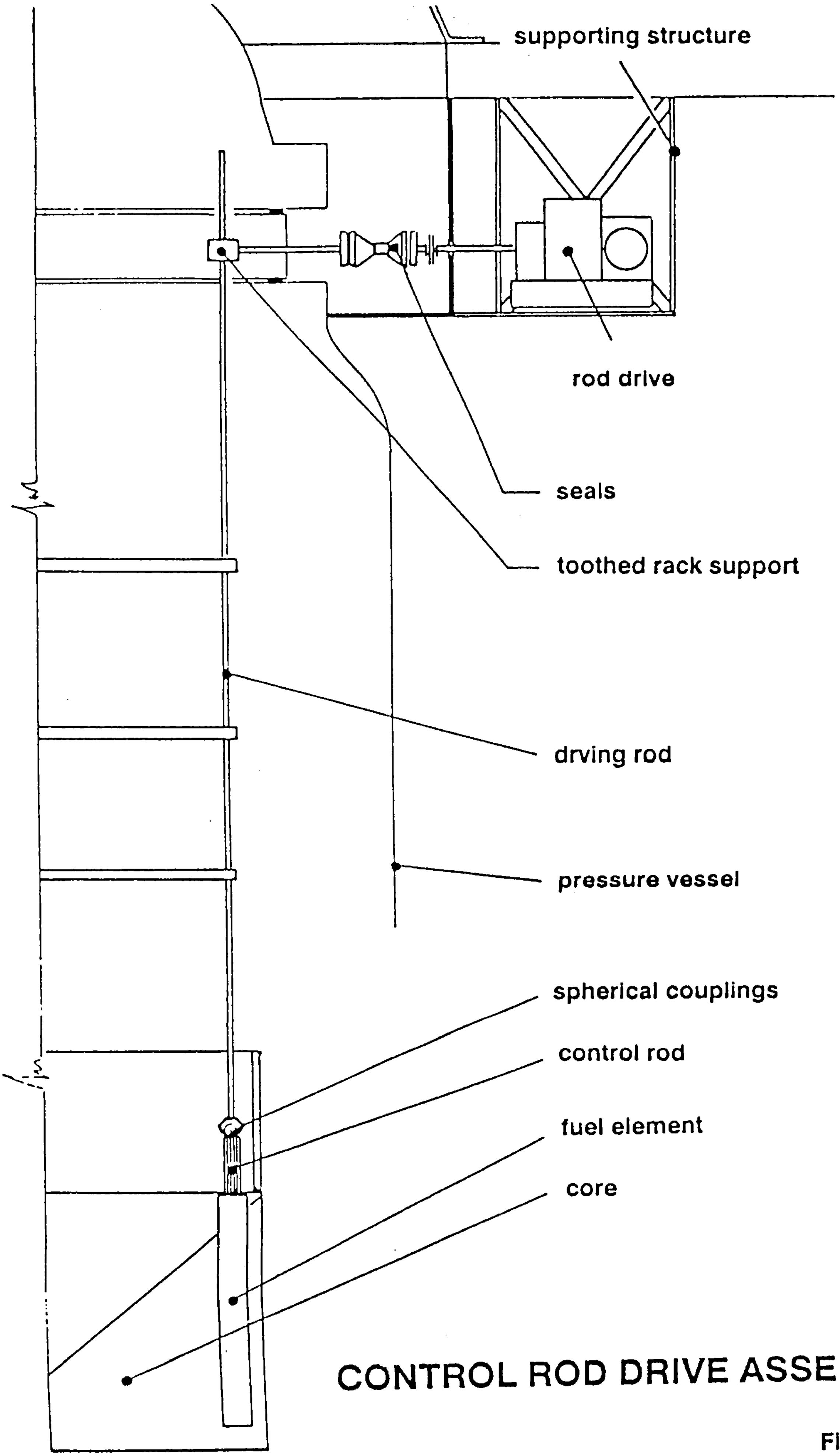
plate tube (detail)

Fig. 2.3.2



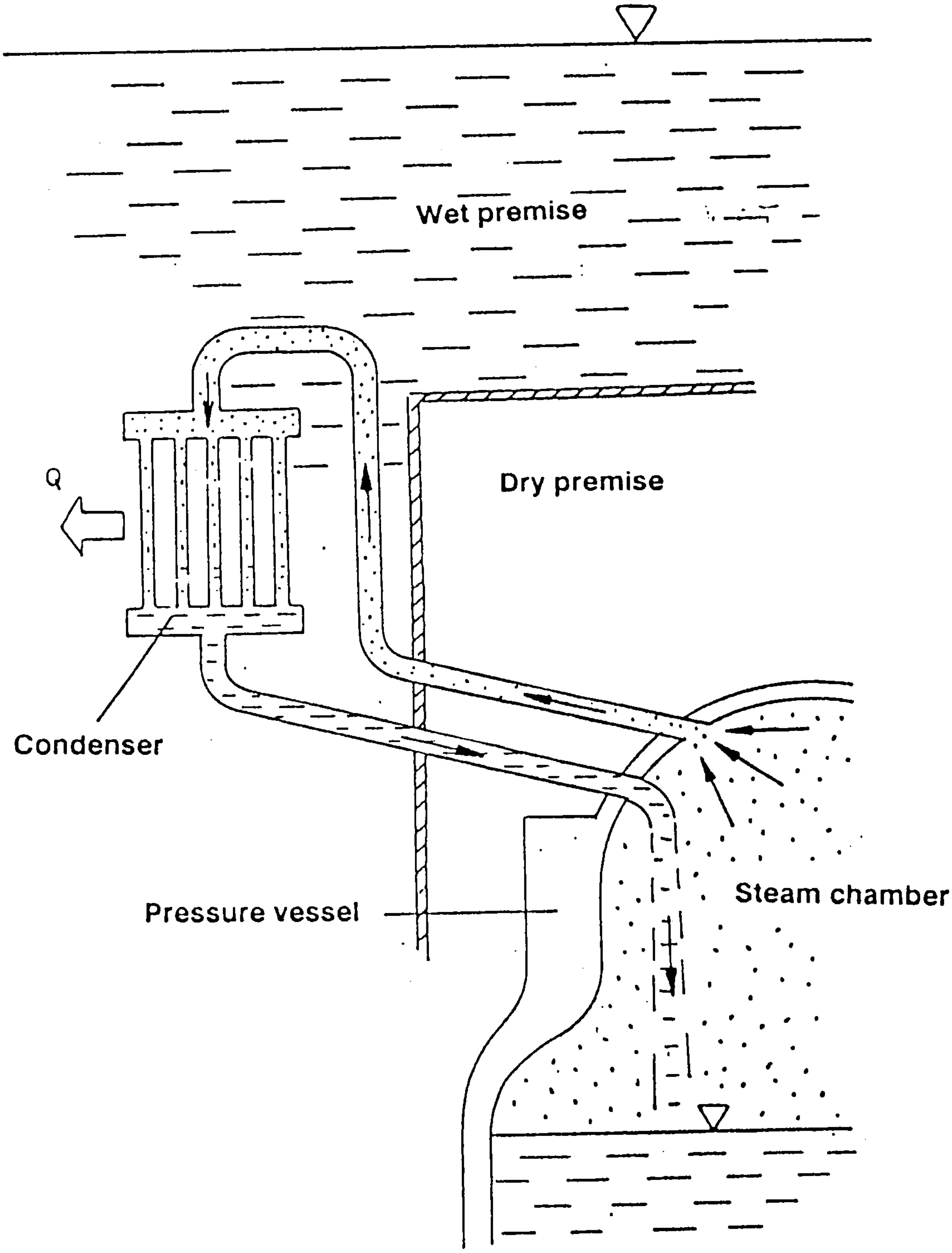
CROSS VIEW OF THE PRESSURE VESSEL

Fig. 2.3.3



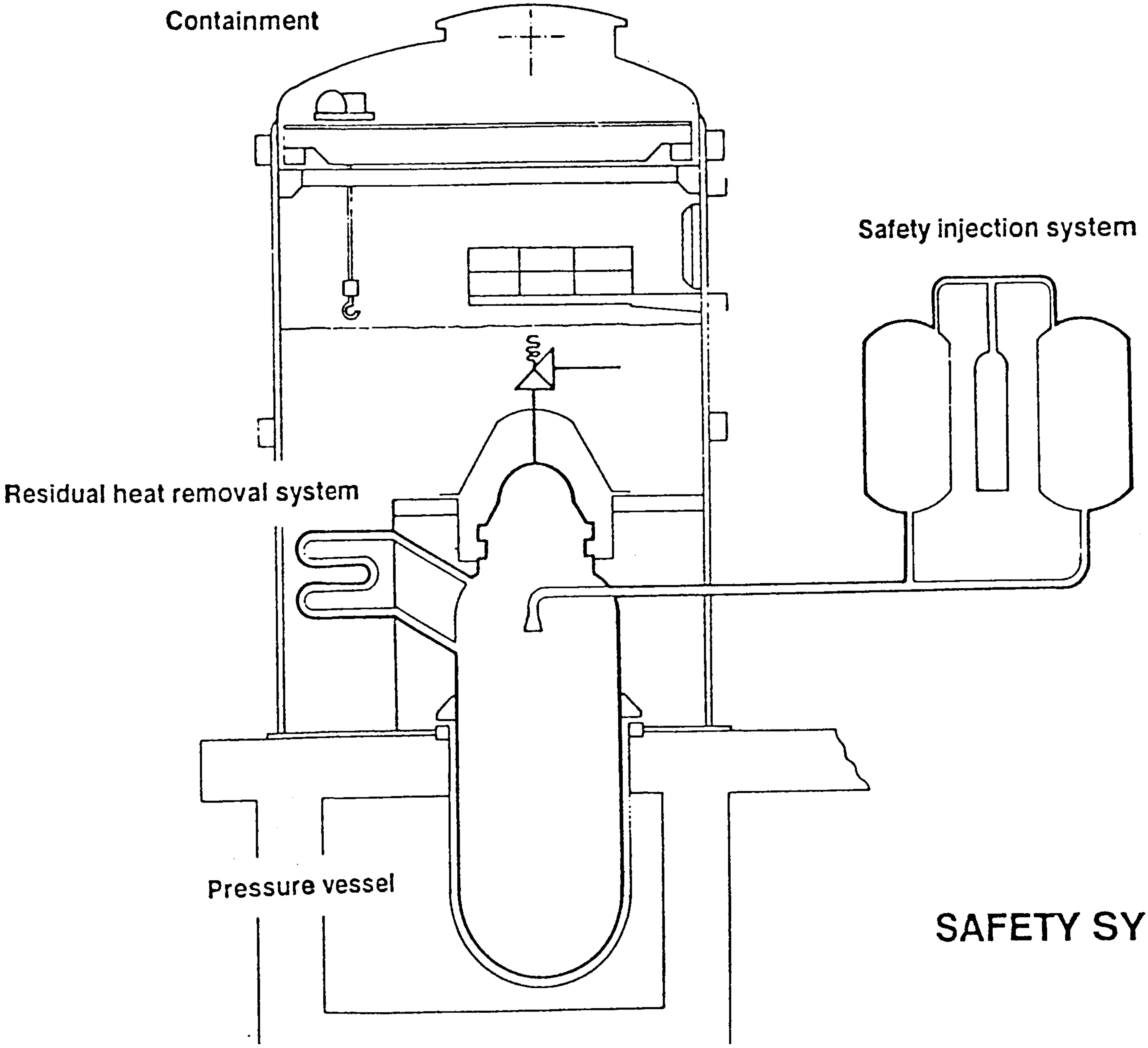
CONTROL ROD DRIVE ASSEMBLY

Fig. 2.4.1



PASSIVE COOLING SYSTEM

Fig. 2.4.2



SAFETY SYSTEMS

CONTAINMENT

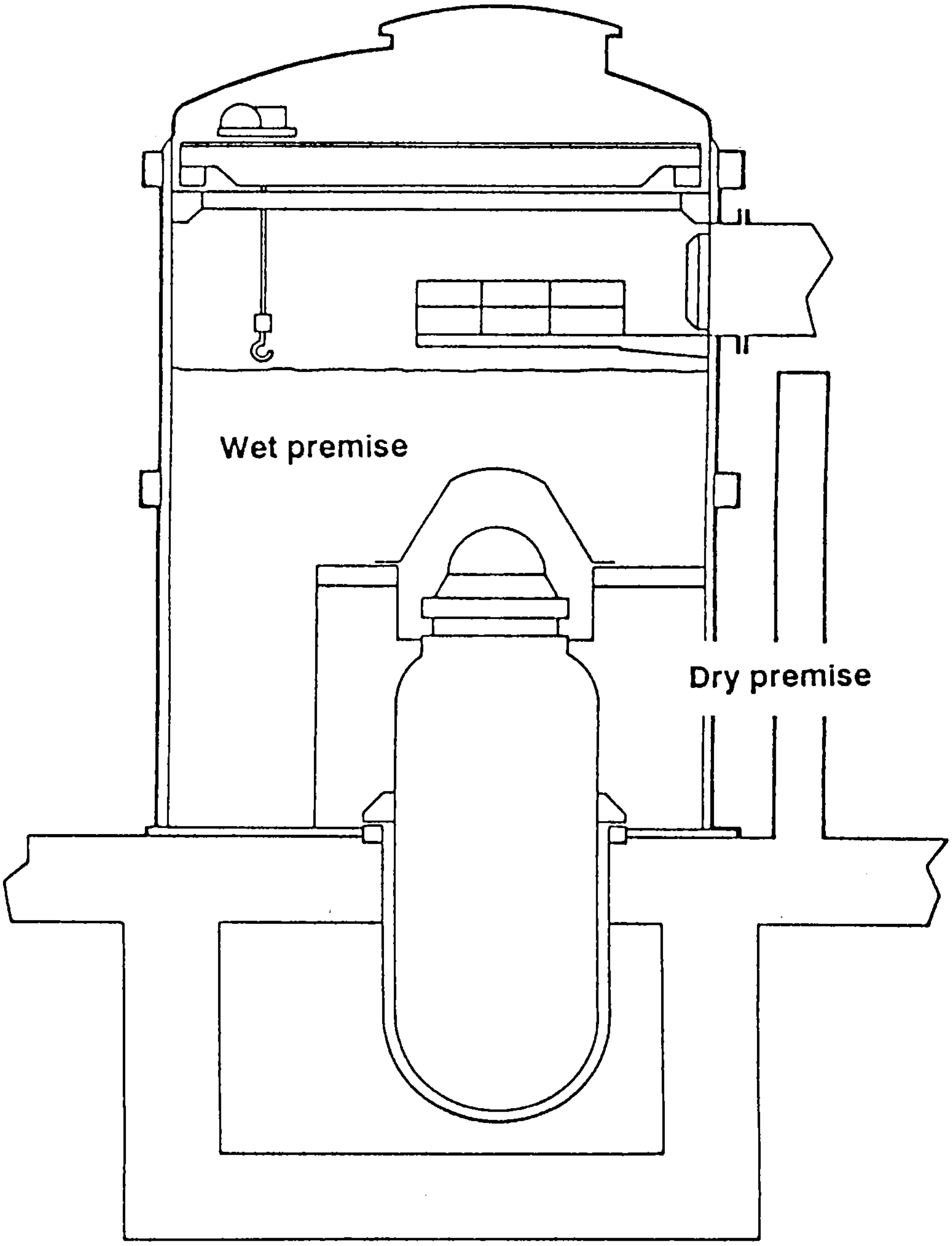


Fig. 2.4.4

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