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MEDIUM-SIZE NUCLEAR PLANTS

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By helping to save huge quantities of fossil fuel resources which can be devoted to other vital uses, nuclear energy is bound to play a part of prime importance in world industrial development. Up to now, its use has generally been limited to electrical power production in high consumption countries : the costs of large nuclear power plants, operated as base load plants, make them appear very attractive compared to alternatives. However, this pattern of nuclear energy use is indeed not the only one available, and small power reactors of the CAS PWR type can serve smaller communities in competitive economic conditions.

Power plants equipped with CAS Nuclear Steam Supply Systems built under CEA-TECHNICATOME licence are offered by ALSTHOM-ATLANTIQUE for sea and land applications.

Two NSSSs are presently marketed, under the names CAS 2 G and CAS 3 G for the number of their steam generators. They are respectively capable of 250 and 420 MW(th). Typically, a nuclear power plant equipped with a CAS 3 G produces 125 MW(e) net.

1. APPLICATIONS

The adaptable characteristics of CAS NSSSs allow to use them for a variety of sea and land applications, such as ship propulsion, electrical power generation, heat generation or combined power and heat generation.

	CAS 2 G	CAS 3 G
SHIP PROPULSION		
Net power	90000 SHP	
Design load factor	0.85	
ELECTRICAL POWER GENERATION		
Net production		125 MW(e)
Design load factor		0.80
HEAT GENERATION		
. District central heating		
Net production (19.5 bars, 225° steam)		680 t/h
Design load factor		0.72
. Process steam supply		
Net production (30.5 bars, 245° steam)		540 t/h
Design load factor		0.85

	CAS 2 G	CAS 3 G
COMBINED POWER AND HEAT GENERATION		
. Desalination of sea-water with heat supplied by :		
1. Steam bled from HP turbine exhaust		
Net production		106 MW(e) and 22000 m3/d
Design load factor		0.85
2. Back pressure turbine exhaust steam		
Net production		50 MW(e) and 150000 m3/d
Design load factor		0.85
. Process steam supply		
Net production (10 bars, 190° steam)		44 MW(e) and 380 t/h
Design load factor		0.85

Among these applications, we shall consider in more detail electrical power generation, combined or not with fresh water production.

1.1. Electrical power generation

A number of countries plan to commission power plants of medium size (under 300 MW(e)) in the years 1981-1990. These are either countries with grids which do not require larger units for optimum performance or countries where remote regions cannot be conveniently connected to the main grid and where it is economical to provide local generation capacity.

Under these conditions, primary requirements for new generating units are that :

- they are easy to transport and install on site,
- they can operate flexibly and remain reliable under extreme load transients,
- they are safe and simple to operate and maintain.

The CAS reactors were developed along these general lines :

- their compact design makes it possible to perform a maximum amount of prefabrication and testing in the workshop. The reactors can then be shipped in one piece or installed on platforms for easy access to site and quick commissioning,

- from their origin, the reactors have kept the ability to sustain fast load variations, as required for ship propulsion. This is made possible by the strength of their plate fuel and by the use of moving rods to control core reactivity ;
- they are safe and simple to operate and maintain, mainly because of their low primary coolant activity and radwaste production, which also leads to an outstanding availability.

1.2. Combined power and fresh water production

There is also a growing demand for fresh water (fig. 1), particularly in Middle East countries, which can be met in attractive economic conditions by combined plants which make the best use of reactor thermal energy, for low temperature energy is partly used for desalination whereas high temperature energy is used for power generation.

The two conventional plant designs which are currently available with CAS NSSSs allow to cover a wide production range with great flexibility.

1.3. Personnel training

In all their applications, CAS NSSSs are similar to large PWRs in many respects, and they can be used as representative training reactors by countries wishing to limit their investment plans before undertaking a wider nuclear program.

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The variety of applications is matched by a variety of installations to suit each specific site. This point will be best illustrated by considering in more detail the features of platform installed power plants and of land based combined plants.

2. PLATFORM INSTALLED POWER PLANTS

These power plants have the usual advantages of platform installed plants. They are entirely built in a shipyard before being towed to coastal sites, left afloat in their basin or landed. Hazards of building in remote places are thus eliminated and total building time is shorter.

Each platform (fig. 2) includes, from bow to stern :

- fore sea-water ballasts and fresh water fire tank,
- a power generating plant with its condensation turbine

and generator, condenser and feedwater plant.

- a nuclear island with its CAS 3 G PWR, auxiliary and safety systems, refuelling and radwaste processing equipment and shielding
- staff quarters
- aft sea-water ballasts and fresh water fire tank.

2.1. CAS 3 G Nuclear Steam Supply System

Saturated steam is produced in steam generators, by heat exchange across a tube bundle, inside which the primary water circulates. This water driven by pumps, is used both for transfer of energy from the core to the steam generators and as a moderator for the neutrons in the core.

Reactor coolant system (table 1) & fig.3

The reactor coolant system consists mainly of the pressure vessel containing the reactor core and internal support structures, the steam generators, the primary pumps and the pressurizer.

The pressure vessel is made of low alloy Mn - Mo - Ni steel, internally clad with stainless steel.

The steam generators are attached to the reactor vessel by means of short flanged or welded nozzles. Their vertical U-tubes are made of Alloy 800. The secondary side is designed for high water circulation and steam separation is very effective.

The primary pumps, of the helicocentrifugal, canned, glandless type are secured by studs to the bottoms of the steam generator water boxes. Suction is through a central stainless steel duct and delivery is directed towards the annular passage to the reactor vessel. Each pump is powered through a motor alternator unit, the inertia of which is used to increase slow-down time, in case of electric power failure. If all pumps were stopped, natural circulation in the reactor coolant system would be high enough to transfer core residual heat to the secondary cooling systems.

The pressurizer maintains primary pressure at a constant value and compensates for positive and negative variations of the primary water volume during reactor operation transients. It is a pressure vessel also made of low alloy Mn - Mo - Ni steel and equipped with electric heaters. A buffer tank is incorporated to minimize cyclic thermal stresses. The pressurizer is connected to the reactor coolant system by a small diameter pipe ($<$ 90 mm).

Reactor core and fuel assemblies (table 1) & fig. 4

The core, through which cooling water circulates from bottom to top, consists of rectangular fuel plate assemblies housed in pairs in square Zircalloy cans. Each fuel plate, made of Zircalloy, has a large number of chambers, each of which holds a thin rectangular uranium oxide platelet (approximate size 20 x 20 x 4 mm). Each chamber is sealed individually by a special welding process. Temperature at the hottest point of the uranium oxide is much lower than that of commonly used cylindrical pellet fuels.

The design of a low temperature and compartmented fuel is an essential feature of CAS NSSSs. It contributes greatly to their load following ability, safety and ease of maintenance, as explained further.

Nuclear fuel is supplied by an industrial subsidiary of CEA, COGEMA, whose activities cover the whole fuel cycle.

Core reactivity control system (table 1)

Reactivity control is ensured by :

- a soluble poison (boric acid in the reactor coolant)
- fixed burnable poisons
- cruciform control rods guided to move vertically in spaces between fuel cans.

Control rods are moved upward and downward by electromagnetic drive mechanisms of the screw-nut type mounted on sleeves running through the reactor vessel head.

Containment (table 1 & fig. 3)

The containment is a pressure resistant and leakproof steel vessel, cylindrical with hemispherical ends, which ensures radio-active product retention in the event of a coolant accident. It houses the reactor coolant system, its shielding and support structures, the fuel unloading and handling equipment and several auxiliary fluid systems. But the compact design of CAS systems makes it possible to limit the containment size, for a design pressure of less than 10 bars.

Auxiliary fluid systems

As on all pressurized water reactors, the main auxiliary fluid systems assure :

- In operation :
  . nuclear steam supply and return of feedwater to steam generators
  . primary coolant purification, chemical and volumetric control
  . intermediate and raw water cooling of operating auxiliaries.
- During shutdown :
  . residual heat removal
  . fuel pools cooling.
- In case of accident :
  . emergency core cooling
  . containment isolation and spraying
  . emergency core poising
  . intermediate and raw water cooling of operating auxiliaries.

However, the compactness of the CAS NSSS and the characteristics of its fuel allowed to design comparatively simple auxiliaries.

Radwaste processing, fire protection and ventilation systems are also provided.

Instrumentation and control

Instrumentation and control are designed so that process and safety equipment are separate. Whereas process equipment is, to some extent, tailored to suit each particular application, safety equipment, which is the same for all CAS reactors features mainly fixed logics and does not involve any computer.

The plant is normally operated from its main control room ; but an emergency control room is provided to stop the plant safely in case of unavailability of the main control room.

2.2. Power generating plant

The power generating plant operates on a conventional reheat condensation cycle with several feedwater heating stages (fig.5).

The turbine, through which the saturated steam is expanded, consists of a HP cylinder and a LP cylinder with an intermediate dryer-reheater. The exhaust steam is discharged in a condenser. The feedwater system receives the condensate which is deaerated and heated before being returned to the steam generators by the feedwater pumps.

The generator is hydrogen cooled. Power is delivered to the grid through the main transformer, and, during normal operation, an auxiliary transformer supplies all electrical auxiliaries in the plant.

2.3. Platform

The main dimensions are approximately as follows :

- length .... 125 m
- breadth .... 40 m
- depth .... 10 m
- draught .... 5 m
- displacement .... 25.000 t
- the bow and stern shapes of the platform are determined by a basin model test, in order to obtain a reduced resistance and a satisfactory directional stability during the towage to the site.
- The structures are built in welded steel, quality A41/50 and comply with shipbuilding standards.
- For protection against collisions, the platform has a double bottom of about 2.5 m on the whole length and a double hull over the whole lateral area of about 2.5 m.
- Transverse watertight bulkheads are arranged on the length to provide safe buoyancy in case of damage.
- The protection of the metallic structures is obtained as follows :
  . extra thickness compared to that strictly required by the strength ;
  . epoxy resin coatings ;
  . cathodic protection by imposed current.
- If needed, the maintenance of the water-line zone can be realized afloat by trimming the platforms with the ballasting system.

2.4. Site preparation

The setting of the platform must be studied for each particular case in order to obtain adequate protection.

In the case of a floating platform, adequate protection can be obtained, either by creating an artificial site, off-shore or coastal, or by using a natural site, coastal or fluvial, which is work-saving.

As an example the following design basis can be retained for an artificial site :

- the platforms are protected by a breakwater reducing the motion of the sea and avoiding the collision by ships liable to come around ;
- this breakwater allows the access of service ships ;
- the water depth at platform location can be as low as

10 or 15 m at low tide ;

- the suction of cooling water is inside the break-water, the discharge outside, in order to avoid the recycling or reheated water and to secure a fast thermic dilution.

If the platform is to be landed, her berth must be excavated and slabs must be prepared upon which she will bear.

3. LAND BASED COMBINED PLANTS

. CAS NSSSs can be installed on land while keeping most of the advantages resulting from the high amount of prefabrication. For, site access conditions permitting, the containment vessel and its content can be shipped in one piece and introduced into place, once the civil works have been completed, through an open side left in the reactor building. Civil works do not present any specific difficulty.

. To combine fresh water and power production, two conventional plant designs are available. In the two cases, CAS NSSS equipment remains unchanged.

The desalination technology is also the same : low pressure steam is used to heat brine which subsequently flashes when passing through multistage evaporators. The required sea-water flow is minimized by recycling the brine. Heat is removed by cold water circulation in the last stages of the evaporators.

The desalting plants are supplied by SIDEM, a specialized subsidiary of Compagnie Electro-Mécanique and Saint-Gobain, Pont-à-Mousson, which supplied many plants to various countries in the last ten years.

When the demand for water is marginal (say, 22000 m3/day, which is already a high figure on the desalination market), a bleeding point at the HP turbine exhaust supplies a LP steam generator which, in turn, is connected to the brine heaters (fig. 6). An intermediate heating system is thus provided, which ensures complete separation of the NSSS steam-water system from the desalting plant.

The heat rate is about 60 kcal/kg of product water. Maximum brine temperature is 91°C. The 22000 m3/day production is assured by two evaporator units. The recirculating brine flow rate is 5270 t/h and the total cold sea-water flow rate is 4050 t/min in each unit.

With the two desalting units operating, a gross power output of 117 MW(e) can be produced with a conventional turbine generator such as described previously, for a cooling water temperature of 28°C. Net power output can actually be varied with great flexibility between 45 and 106 MW(e).

The same plant arrangement can be used with minor alterations of the turbine to extend water production up to 50000 m3/day leaving a power production of 95 MW(e) gross.

Brine temperature is limited to avoid scaling in the evaporators. Low steam pressure at around 3 bars abs. is therefore sufficient for brine heating. When water production is comparatively low, it is practical to use 6 bars steam bled from the HP turbine exhaust for brine heating. But, larger productions of, say, 128000 m3/day impose a new arrangement for the conventional plant. A back-pressure turbine operating at the right pressure for brine heating (about 3 bars abs.) is then provided.

The nuclear steam is expanded through the turbine and exhaust steam is condensed in the heaters of an intermediate pressurized water system which transfers heat to the brine. As also shown by fig. 7, a turbine by-pass system allows to keep the desalting plant fully operating when the turbogenerator is shut down.

And, an auxiliary condenser is used as a dump for start up and for transient operating conditions.

The fresh water output is produced in five desalting units. Heat rate is about 50 kcal/kg of product water. Fresh water can be produced flexibly, for each unit can be operated between about 70 % and 100 % of its rated capacity.

A wide range of water to power production ratios can therefore be covered with the two designs to suit a variety of needs. But the economical advantages of CAS NSSSs remain the same.

4. ECONOMICAL ADVANTAGES

- Shorter delivery times mean less interests during construction and reduced escalation costs. They also mean that power and heat generation will start sooner, yielding revenues sooner.
- Prefabrication work in the shop costs less than the same construction work on the site.
- Financing is comparatively easier for CAS NSSSs, due to the high amount of prefabrication in France and to the smaller size of the plants.

These facts combine to assure the competitiveness of nuclear projects, in terms of cost of produced energy. Cost analysis which lead to this conclusion have been performed in several practical cases, taking into account various local conditions and production patterns.

Also, the medium size of CAS nuclear plants appears to be well adapted to the needs of many communities for which the purchase of larger plants would result in over investment.

TABLE I - MAIN CHARACTERISTICS OF CAS 3 G

PLANT		
Nominal thermal power (Wn)	420	MW(th)
Number of steam generators	3	
Steam pressure at generator outlet	47.4	bar
Steam temperature (at Wn)	261	°C
Steam flow (at Wn)	747	t/h
Feedwater temperature (at Wn)	180	°C
Primary operating pressure	140	bar
Core inlet temperature (average at Wn)	270	°C
Core outlet temperature (average at Wn)	299.5	°C
Total coolant flow	2700	kg/s
Average power density per core liter (at Wn)	69.9	kW/1
Primary design pressure	160	bar
Primary design temperature	320	°C
Secondary design pressure	78	bar
Secondary design temperature	295	°C
FUEL		
Refuelling cycle	1/3 every	year
Uranium mass	12.96	t
Average reload burn up (at equilibrium)	30000	MWD/t
Average enrichment (of reloads at equilibrium)	3.9	%
Number of fuel assemblies	144	
Assembly weight	142	kg
Assembly height	2	m
Active height	1.80	m
Number of fuel plates per assembly	17	
Lattice pitch	215	mm
Core equivalent diameter	2.02	m
REACTIVITY CONTROL		
Number of mechanisms	32	
Drop time	1.5	s
Control rod active height	1.80	m
CONTAINMENT		
Containment diameter	16	m
Containment height	22.5	m
eight	3000	t

FIGURE LIST

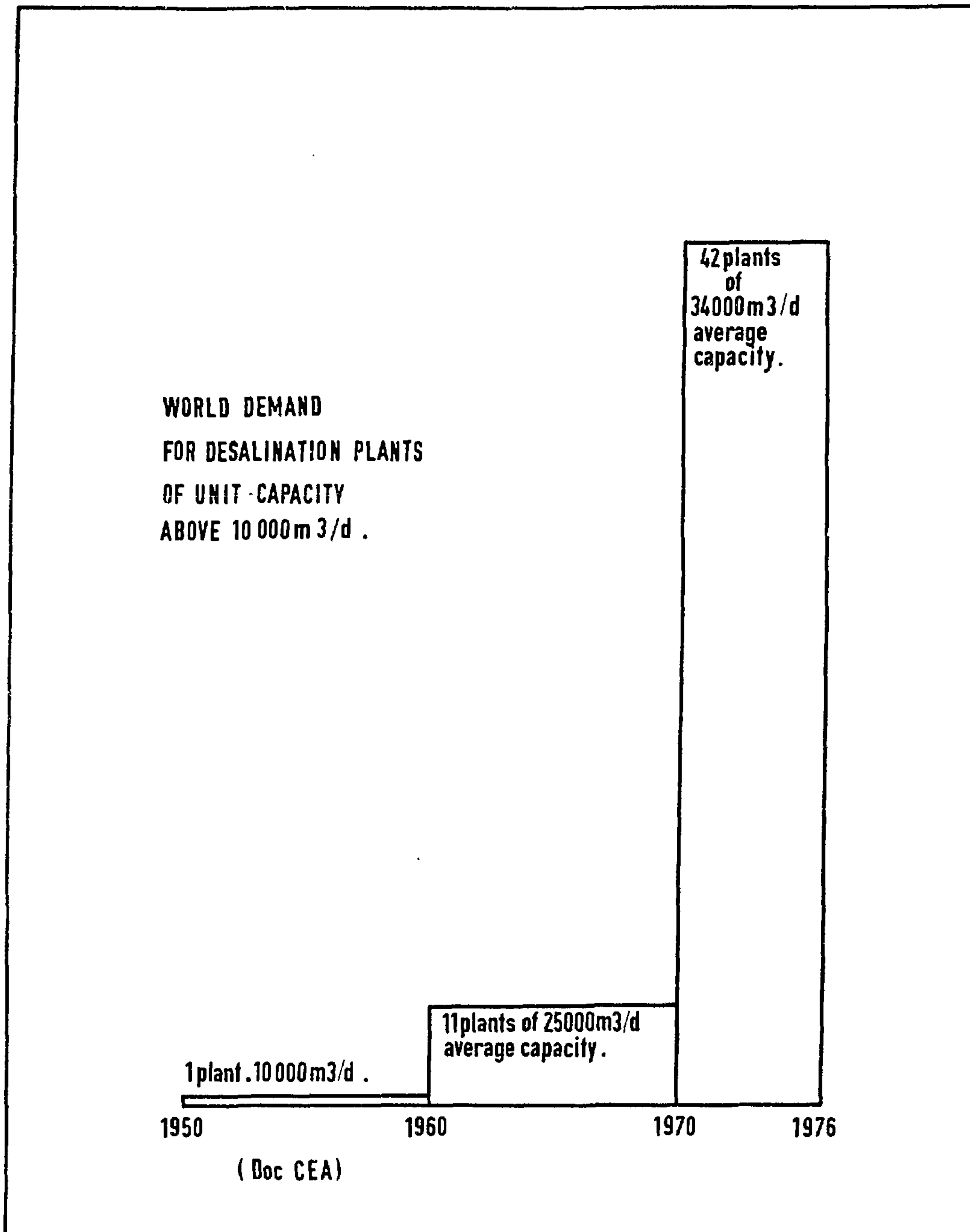
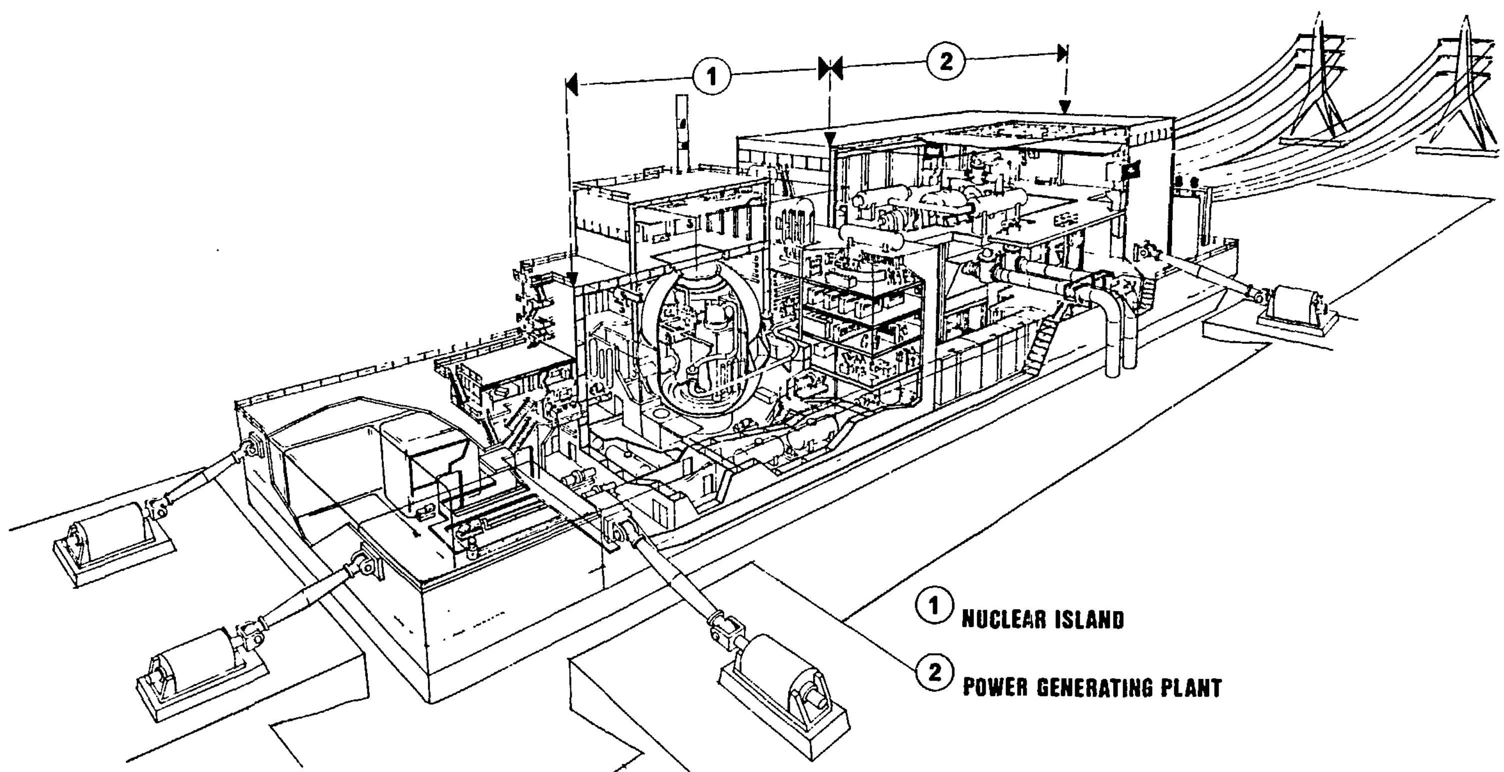
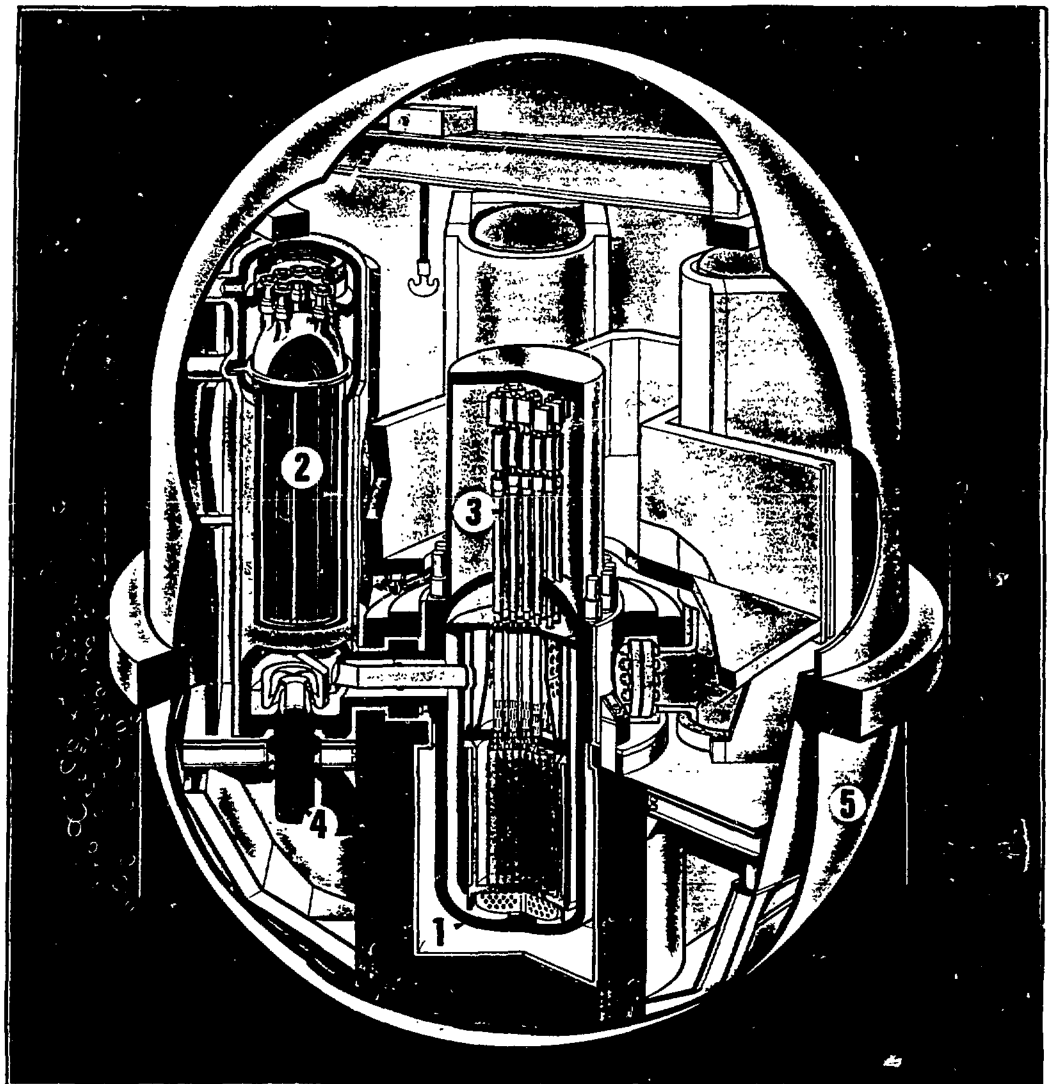

WORLD DEMAND
FOR DESALINATION PLANTS
OF UNIT-CAPACITY
ABOVE 10 000m 3/d .
42 plants of 34000m 3/d average capacity.
11plants of 25000m3/d average capacity.
1 plant . 10 000 m3/d .
1950
1960
1970
1976
(Doc CEA)

Fig.1



BARGE NUCLEAIRE CAS 3 G.
NUCLEAR FLOATING PLANT .

Fig. 2



CONTAINMENT VESSEL

1 REACTOR VESSEL

2 STEAM GENERATOR

3 CONTROL ABSORBER DRIVES

4 PRIMARY PUMP

5 CONTAINMENT

Fig.3

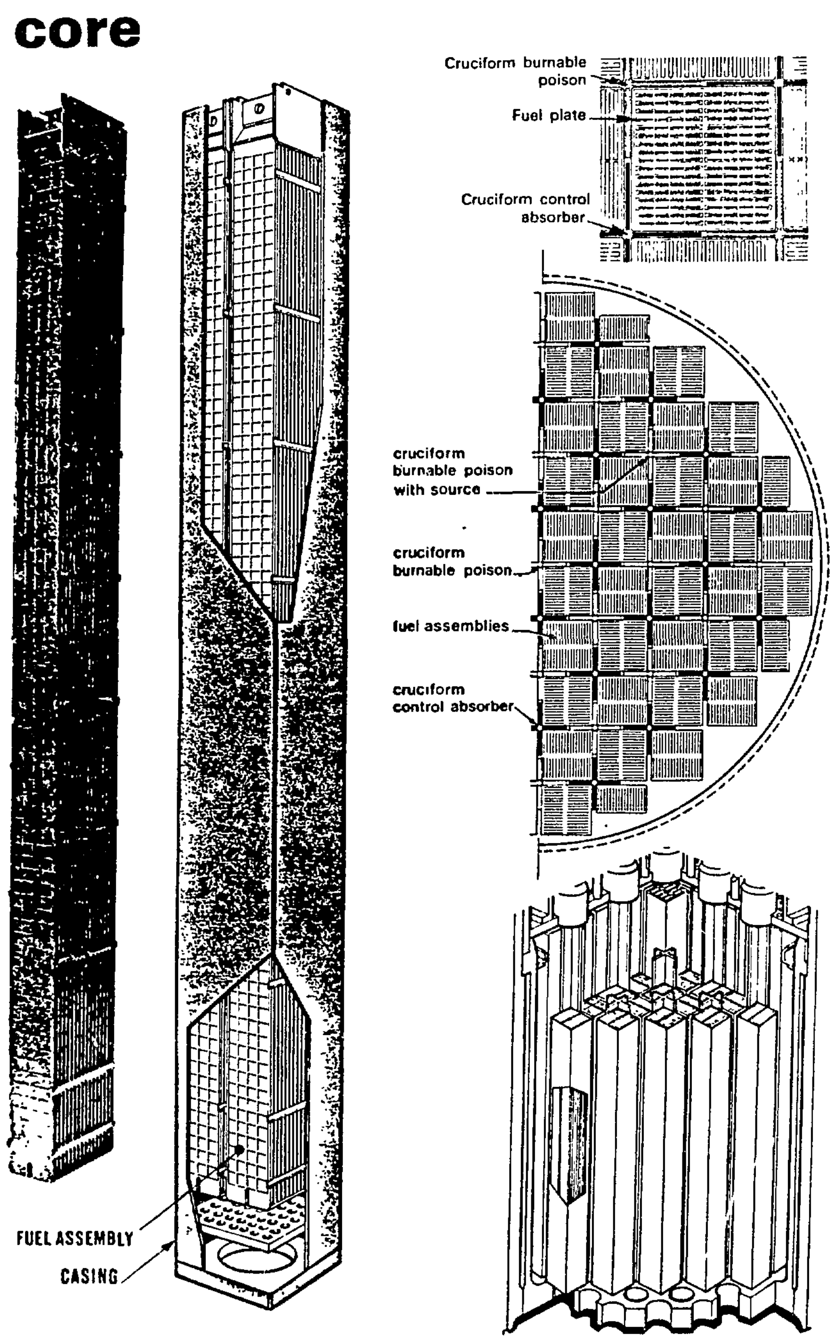

core
Cruciform burnable poison
Fuel plate
Cruciform control absorber
cruciform burnable poison with source
cruciform burnable poison
fuel assemblies
cruciform control absorber
FUEL ASSEMBLY
CASING

Fig.4

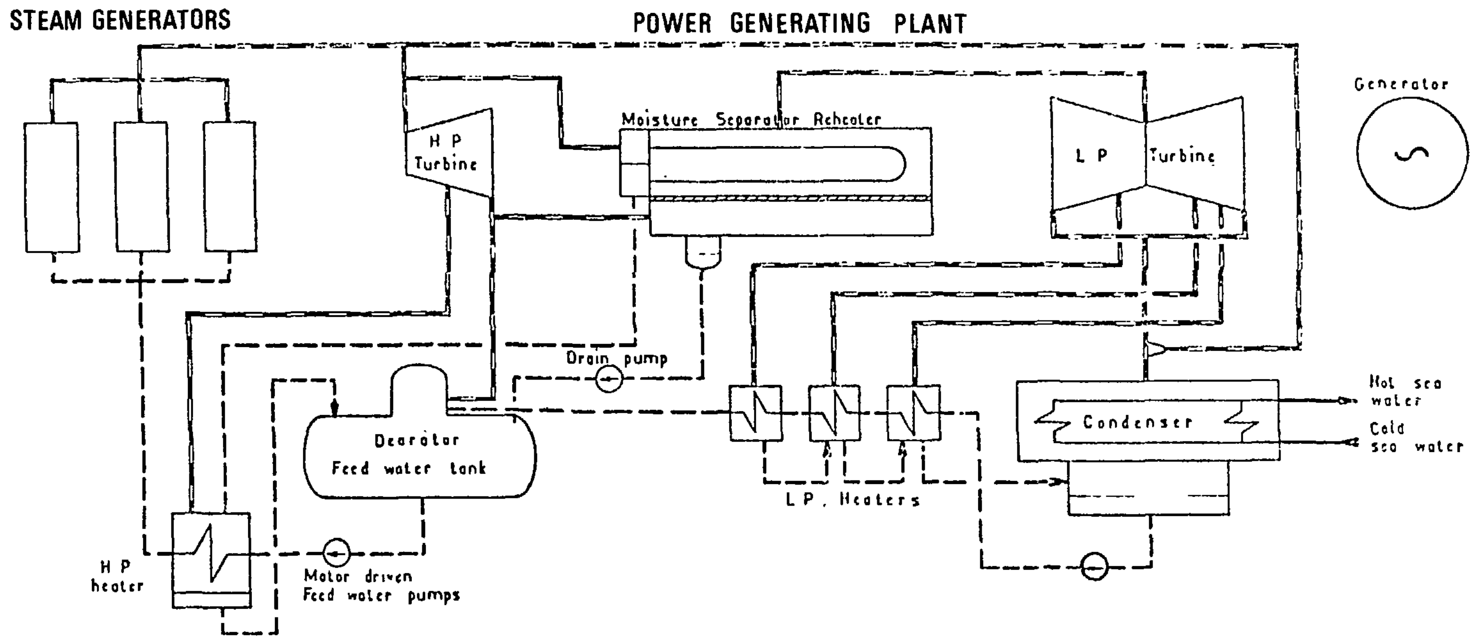


Fig 5 POWER PLANT – STEAM-WATER CYCLE

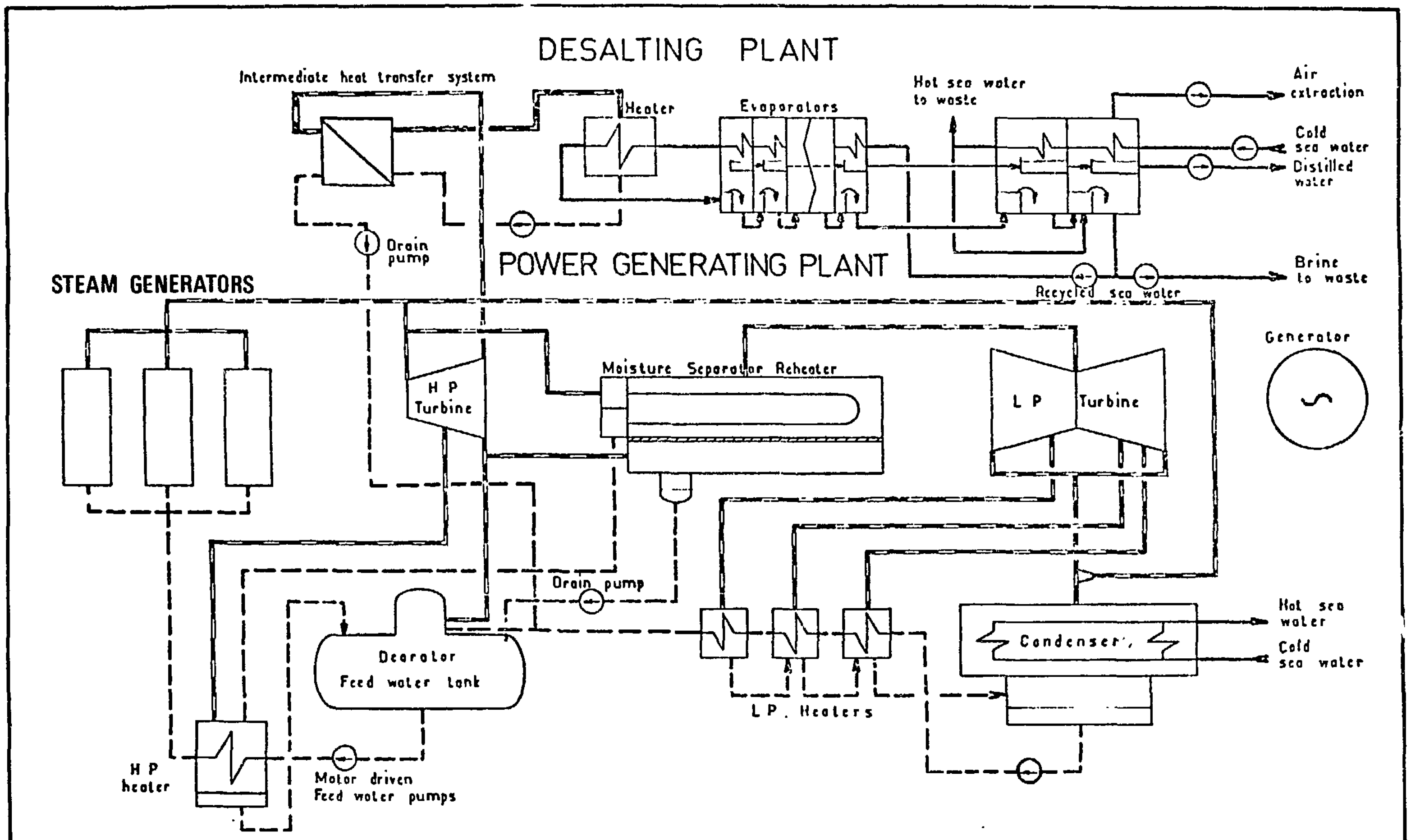


Fig.6 COMBINED PLANT _ STEAM-WATER CYCLE 1

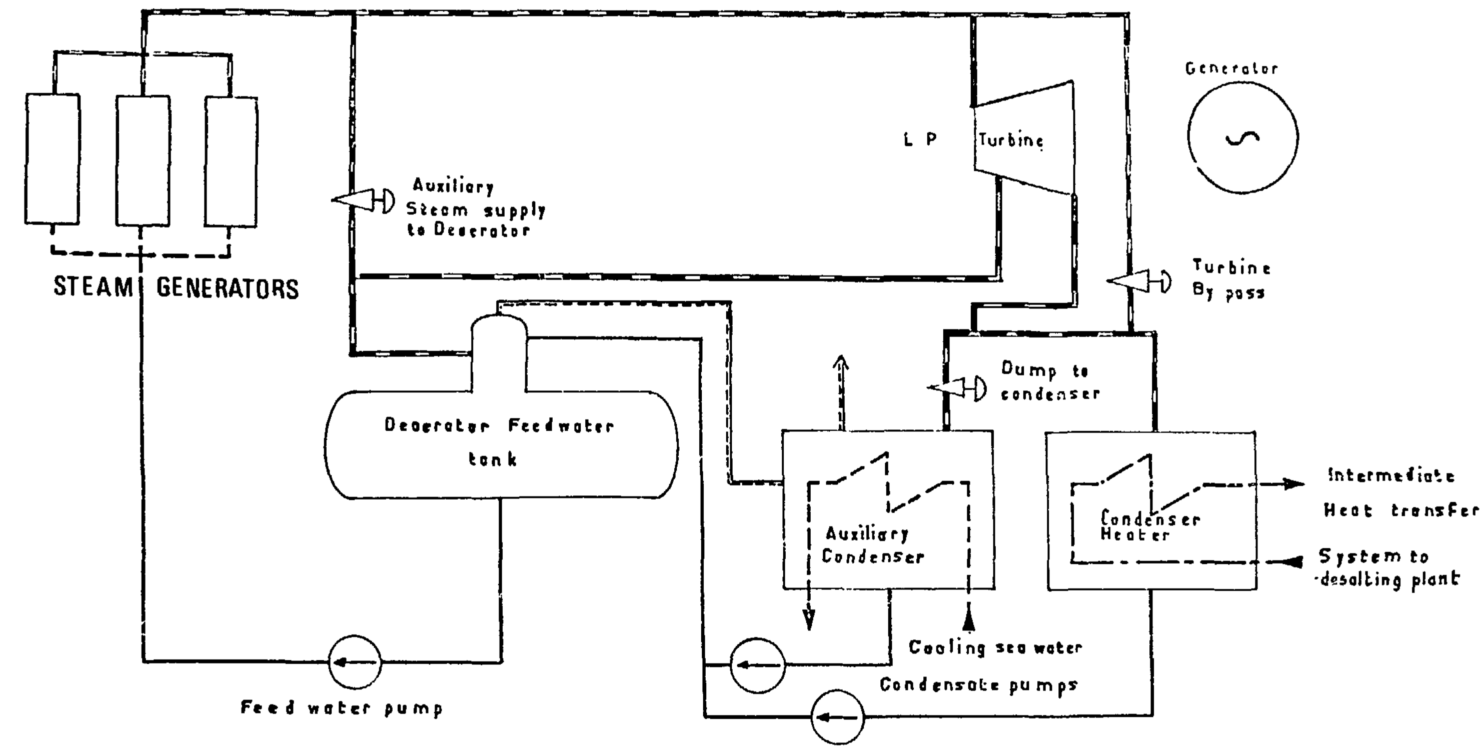


Fig.7

COMBINED PLANT _ STEAM-WATER CYCLE 2