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Abstract

The paper describes a partly integrated cooling system for liquid metal cooled reactors. The proposed system combines to a remarkable extent the advantages of the pool and loop systems generally discussed.

In the new design only the reactor core and eventually an emergency cooling system is located in the reactor pool. The components of the primary circuit are installed in one or several stationary component pools which are connected with the reactor pool via straight coaxial conduits. To accommodate thermal expansion effects bellows and sliding sleeve-joints were used. However, these parts are arranged in such a way that they might be easily replaced and any possible leak will not result in a coolant leakage.

Some design variants of the new partly integrated cooling system are discussed and a possible layout for a 1600 MWe plant is given.

Zusammenfassung

In dem Bericht wird ein teilweise integriertes Kühlsystem für flüssigmetallgekühlte Reaktoren beschrieben. Dieses System vereinigt in einem bemerkenswerten Umfang die Vorteile der bisher fast ausschließlich betrachteten Pool- und Loop-Bauweise.

Bei dem neuen System ist nur der Reaktorkern, gegebenenfalls zusammen mit einem Notkühlsystem, im Reaktorbehälter untergebracht. Die Komponenten der Primärkreise sind hingegen in einem oder mehreren, ortsfest angeordneten Komponentenbehältern angeordnet, die über gerade, koaxiale Rohrleitungen an den Reaktorbehälter angeschlossen sind. Für die Aufnahme von Wärmeausdehnungen werden Wellrohrkompensatoren und Schiebemuffen verwendet. Diese Teile sind so angeordnet, daß sie leicht ausgewechselt werden können und eine mögliche Undichtigkeit zu keinem Kühlmittelverlust führt.

Einige Entwurfsvarianten des neuen teilweise integrierten Kühlsystems werden diskutiert, und eine mögliche räumliche Anordnung für eine 1600 MWe-Anlage wird gezeigt.

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A PARTLY INTEGRATED COOLING SYSTEM FOR LIQUID METAL COOLED REACTORS

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The paper describes a partly integrated cooling system for liquid metal cooled reactors. The proposed system combines to a remarkable extent the advantages of the two opposite designs generally discussed and termed:

the pot-, pool- or integral system, in which all the major principal components are located in a single reactor tank configuration, and

the loop- or spread-out design, in which all the major principal components are separated by a piping system.

Both types were also described in detail in the American LMFBR Follow-on Studies /¯1_7; therefore, only a brief comparison will be given here.

1. Main Features of the Pool and the Loop System

1.1 Loss of Coolant

In the pool design the pressurized section of the primary circuit is completely contained within the low pressure coolant, and, consequently, the outer coolant vessel has to withstand only the low pressure of the coolant and the cover gas. Therefore, small leaks in the pressurized section can be tolerated and the discharge of coolant from the system by running pumps is impossible. Moreover, any leakage from the pool vessel would be stopped by a close-fitting containment jacket, so that the tank cannot be drained to an unsafe level. In addition, the probability of leaks is very small in such a low-pressure tank which is free of penetrations and extensions.

The loop design would offer comparable positive features only if a double wall design, at least for the pressurized section, is applied. However, this solution is not considered as a sound principle because of difficulties in design and construction. Therefore, any leak in the pressurized section of the circuit would require a pump trip or the fast closing of blocking valves, in addition to the reactor scram, to avoid excessive loss of coolant.

1.2 Decay Heat Removal

With this respect, the two systems should be nearly identical, provided that an undue loss of coolant can be prevented. However, the transition from full power to emergency cooling, particularly in the case of a major leak, can be managed much easier with the pool because the main pumps keep operating and the large sodium capacity alleviates thermal shocks. Moreover, a smaller capacity of the emergency cooling system will be sufficient here, since excessive decay heat released during a first period after the scram can be stored temporarily in the sodium pool.

1.3 Operational Performance

A satisfactory control of the primary and secondary coolant circuits as it is required by changes in load of the plant is possible with both concepts. However, the large heat capacity of the pool is generally considered to have certain advantages.

1.4 Design Restrictions of Adjacent Parts

The installations above the reactor cover, in particular the refueling equipment, are practically not impaired by the loop concept, since the components of the primary circuits can be installed at a sufficient distance from the reactor core. In contrary, a pool system will considerably affect these parts, especially, if a hot cell will be used for refueling.

1.5 Technical Risks

In this respect, the loop is undoubtedly superior to the pool, because it rises much less new problems than the latter. Problems generally discussed in connection with the pool are: field-fabricated pool vessel, large diameter shielded vessel closure, heat insulations, neutron shield contacted by sodium, sliding sleeve-joints, instrumentation etc. In addition, the loop allows better timing of construction work at site, since the prefabricated equipment can be installed after the termination of civil engineering work under relatively clean conditions.

1.6 Maintainability

Here the loop is also superior to the pool, since all components are easier accessible. Besides, the coolant activity in a separated loop can decay even during operation at reduced power and individual loops can be drained when repair work becomes necessary. This is not possible with the pool. In addition, the pool contains a number of components, e.g. the mobile joints, which are hardly accessible.

1.7 Availability

At the time being, nothing can be said on the availability of the two systems, since opposing effects are encountered here. On the one hand, the maintainability is higher for the loop so that the periods of shutdown will be shorter for one repair work; however, on the other hand, a loop including its auxiliaries is made of a greater number of components so that more disturbances may occur, mainly during the initial period of operation.

1.8 Capital Costs

A clear difference between the two concepts cannot be indicated yet. This is attributed to the fact that the costs of essential components, such as pumps, intermediate heat exchangers, reactor internals, refueling equipment etc. do not depend strongly on the design of the cooling system. This applies also to the partly integrated system described in this paper with the conclusion that the capital costs of this design will amount to a similar value.

As shown by these comparisons, quite a number of reasons are in favor of the loop design. However, the pool offers decisive advantages with respect to the vital question of leak-proofness, because no fast acting engineered safeguards are required. Consequently, this decisive advantage should be retained at any rate in a partly integrated system and combined with the greatest possible number of positive loop properties. Especially, the good maintainability and the lower technical risks of the loop should be included. Thus, it will not be sufficient to combine the circulating pumps and the intermediate heat exchangers into one unit as has been repeatedly proposed, e.g. in the Italian PEC-reactor /‾2_7. Such a design would not eliminate the coolant pressure from the outer vessel wall. It would rather be necessary to provide for a coaxial piping system with the inner line pressurized. This is reasonably done only with a simple pipe layout, preferably a single straight coaxial pipe. In this case, bellows have to be used to allow thermal expansion effects. For the new partly integrated coolant system this solution has been chosen. However, the bellows are arranged and located in such a way that they might be easily replaced and any possible leak will not result in a coolant leakage. Under these specific conditions the use of bellows is acceptable.

2. The Partly Integrated Cooling System

The basic principle of the new design is shown in Fig. 1. The core (1) is located in the lower portion of the reactor pool (RP). Via a coaxial conduit one or several stationary component pools (CP) are connected with the reactor pool. Each component pool accommodates the components of one primary subsystem, above all the intermediate heat exchangers (IHX) and the circulating pump (2). In Fig. 1 only one component pool is shown. The IHX and the circulating pump are installed as stationary components in the upper shielding cover. On the suction side the pump is equipped with a check valve (3). The pump sucks in the coolant from the component pool and circulates it through a pressure pipe (4), fitted with linked belows (5), to the reactor inlet. This pipe constitutes the central channel of the coaxial line. It is provided with a heat insulation in this region and in the reactor pool, not shown on Fig. 1. The coolant heated in the reactor flows back into the component pool by gravity through the annular channel (6) of the coaxial pipe. Passing a cross channel (7) and on overflow edge (8) it enters the shell of the IHX. The cooled coolant leaving the IHX flows downward into the main body of the component pool.

The thermal expansion occurring in the pressure line between the pump and the entrance plenum of the reactor is compensated by the above mentioned linked bellows. The outer shell of the coaxial piping is only guided in the wall of the component pool. Tightening is achieved here by an axial bellows (9). This design allows free thermal expansion of the pool tanks and the connecting pipe. To accommodate thermal expansion within the component pool sliding sleeve-joints (10) are provided at some points in the low-pressure system, e.g. at the entry of the pressure pipe into the coaxial conduit, in the outer wall of this coaxial conduit and in the cross channel to the IHX. Complete tightness is not required at these points.

As shown in Fig. 1, the axial bellows at the penetration of the coaxial pipe through the wall of the component pool is located in the cover gas space, the sodium is maintained at a lower level. Consequently, thermal stresses in this bellows and its adjoining parts will be kept low. The coolant level in the IHX-shell (∇IHX) corresponds almost to the level in the reactor pool (∇RP). Only the small pressure drop (Δh_1) between the reactor pool and the IHX-shell causes a small difference. These level characteristics are due to a somewhat higher cover gas pressure (Δh_3) in the component pool. For this reason, the cover gas system comprises a pressure step-up means (11) in addition to the usual surge pipe (12) which connects the reactor pool with the IHX-shell. However, the higher gas pressure in the component pool could be maintained also by a special pressure control device which is part of the cover gas storage or purification system.

The level conditions are determined by the following relations:

$$\nabla RP - \nabla IHX = \Delta h_1$$
$$\nabla IHX - \nabla CP = \Delta h_2 + \Delta h_3$$
$$\nabla RP - \nabla CP = \Delta h_1 + \Delta h_2 + \Delta h_3$$

with Δh_2 = pressure drop in IHX

This system is self-regulating. If the coolant flow rate is increased by the pump, ∇CP is decreased and ∇RP is increased. Consequently, if Δh_3 remains constant, the flow rate from the reactor pool to the component pool is increased until the pressure drop $\Delta h_1 + \Delta h_2$ satiesfies the above relations. If the pump is stopped, ∇CP increases, ∇RP and ∇IHX decreases until the level difference corresponds to Δh_3. Simultaneously, the flow rate and $\Delta h_1 + \Delta h_2$ decrease to zero. However, to limit the level variations to an acceptable value with Δh_3 remaining constant a comparably small value must be chosen for Δh_1 and Δh_2, as it is the case with all pool designs.

The IHX shell and the pump casing are interconnected by a coolant as well as a cover gas surge pipe (12). Therefore, the coolant level in the pump corresponds to the level in the IHX and the pump shaft seal (13) operates under conditions of low pressure.

The reactor pool and the component pool are located in individual shielded vaults (14). A close-fitting containment jacket (15) surrounds the pool vessels and the coaxial pipes. The containment jacket is heat insulated and cooled by inert gas on the outer surface. Support of the containment jacket is provided by special tie bars so that thermal differential growth is accommodated, while the horizontal pipe section acts as a compression/tension member.

2.1 Incidents

Single Pump Stop

This event results in a level change accompanied by a decrease of flow rate in the disturbed primary subsystem, as described above. The check-valve at the pump inlet is closed by the coolant pressure generated in the running pumps of the other subsystems. Continued operation of the plant at reduced load is possible.

Failure of one Secondary Circuit

In this case the coolant temperature in the component pool of the disturbed subsystem increases. However, the resulting thermal shock will be acceptably low, because of the relatively big coolant volume. The respective primary pump is switched off.

Loss of Pressure Difference Δh_3

∇CP increases and ∇RP decreases, until the level difference corresponds to $\Delta h_1 + \Delta h_2$. Under this condition the axial bellows is contacted by sodium.

Leak in the Pressure Pipe

Small leaks can be tolerated. Considerable leaks, e.g. a complete pipe rupture, call for a reactor scram.

Leak in the Outer Coolant Boundary

Contacted by the Coolant

Leaking coolant fills the annulus between the pool wall and the containment jacket up to a level determined by the pressure difference between the cover gas in the reactor pool vessel and the inert gas in the shielded vault. The resulting level decrease in the coolant system can be tolerated.

Leak in the Component Pool Boundary

Contacted by the Pressurized Cover Gas

Any leak rate of the axial bellows is limited by the sliding guide in the wall of the component pool, which provides a backup seal in this case. The design capacity of the cover gas system is adequate to maintain the pressure difference Δh_3 under these circumstances. Higher leak rates in the component pool wall are not considered as credible. Cover gas leakage can be terminated by the following sequence of operations applied to the disturbed subsystem:

- the pump is switched off
- the cover gas pressure in the IHX is increased to such a value, that the coolant level in the cross channel between the outer line of the coaxial pipe and the IHX shell drops below the overflow edge
- the cover gas space in the component pool is depressurized and balanced with the inert gas pressure in the shielded vault.

Coolant leaking into the idle component pool via the sliding sleeve joints and the closed check valve is drained at reasonable time intervals to maintain the coolant level at the specified value.

In every case discussed above, decay heat removal is assured in the remaining subsystems with low pump speed. However, it is also possible to install a separate emergency cooling system (16) in the reactor pool, as shown by dotted lines in Fig. 1. Such a system could operate with natural convection at the primary and secondary side and assure adequate cooling even with complete pump failure in all circuits. Thus, both coolant redundancy and diversity are assured. During normal operation, a check valve (3) in the primary circuit of the emergency cooling system will be held closed by the pump pressure, which is indicated as a ball type check valve in Fig. 1.

2.2 Alternative Designs

The increased cover gas pressure in the component pool offers distinct advantages:

- a closed coolant circuit after pump stop, so that natural convection is obtained
- an undisturbed coolant surface in the IHX shell, minimizing gas entrainment
- better NPSH condition for the main pumps

If the natural convection of the main primary circuit is no prerequisite and the other two features are obtained by design, e.g. with guide baffles for the coolant above the IHX tube-bundle and a low speed pump, then the increased cover gas pressure is not necessary. In this case, the level difference ∇IHX-∇CP corresponds to Δh_2 and the coolant would drop or, if baffles are installed, flow down from the overflow edge to the coolant surface in the IHX shell. If more than one component pool is connected to the reactor pool, individual control of the flow rates is not possible with fixed overflow edges, however. Such control would require additional devices, e.g. adjustable overflow edges, throttling valves in the coolant channels leading to the overflow edges, or a system, with which the cover gas pressure could be independently adjusted in each IHX.

2.3 Layout of a 1600 MWe Plant

Fig. 2 shows an appropriate layout of a 1600 MWe plant. There are three component pools connected to the central reactor pool. Each component pool contains two IHXs and one circulating pump. One component pool, which is partly sectioned, shows details of the installation of the axial bellows and the arrangement of the coolant lines, especially the two cross channels. The pump and IHX internals are not shown. In addition to the penetrations for the two IHXs and the pump in the top shield structure of the component pool a hatch (17), closed by a special removable shield plug, is provided which allows easy access to the internals. A hot cell (18) for the refueling procedure and all maintenance operations in the reactor pool can easily be installed without interference with the component pools, as shown on the drawing, if this system should be selected for these duties. The whole primary system is contained in a reactor building (20) of appr. 40 m diameter.

3. Concluding Remarks

It has been shown that the new partly integrated cooling system, which can also be termed "multi-pool system", represents an optimum design for liquid metal cooled reactors. This gets clear in particular when summarizing its main advantages:

- safety against leaks comparable to the pool design
- compact arrangement
- favorable primary coolant inventory mainly split up into two volumes, thus alleviating thermal shocks
- possibility of draining individual primary subsystems
- easy inspection, replacement and repair of components in the primary circuit
- simple preheating system
- less complicated instrumentation as compared to the pool design
- sufficient distance between the assembly of devices located above the reactor plug and the components of the primary circuit so that the design of the refueling equipment (e.g. hot cell) is not impaired by the location of pumps and IHXs.

Moreover, a neutron shielding located in the coolant, as it is the case with pool systems, will be avoided. By contrast, a thermal insulation in the coolant and sliding sleeve-joints are still required in the new system.

The paper does not take into account the possible effects of severe core-disassembly accidents, usually caused by meltdown or possibly also by sodium voiding in some core regions, because it appears likely that, by extensive and explicit use of probability analysis, one could ensure by design that severe core-disassembly accidents have such low probability that containment need not be provided for them. However, if such accidents were to be considered, the shock-, blast- and water hammer effects caused by the nuclear excursion and the sodium vapor explosion as well as the cooling conditions of the destroyed core would have to be investigated. The latter condition could call for an additional emergency coolant supply tank to be connected permanently to the cooling system and which would be sufficient to fill the reactor cavity to the appropriate level to ensure adequate emergency cooling. However, it is expected that all additional requirements with respect to severe core-disassembly accidents will not be more challenging and expensive in the new partly integrated system than in the loop and pool systems, respectively.

R E F E R E N C E S

/¯1_7 1000 MWe LMFBR Liquid Metal Fast Breeder Reactor FOLLOW-ON STUDY

ATOMICS INTERNATIONAL, USAEC Rep. AI-AEC-12765 (Vol. 1 and 2)

BABCOCK and WILCOX, USAEC Rep. BAW-1316 (Vol. 1 to 5)
BAW-1328 (Vol. 1 to 5)
BAW-1331 (Vol. 1 and 2)

COMBUSTION ENGINEERING, USAEC Rep. CEND-322
CEND-337 (Vol. 1 to 3)
CEND-346

GENERAL ELECTRIC, USAEC Rep. GEAP-5618
GEAP-5678
GEAP-5769
GEAP-5710

WESTINGHOUSE ELECTRIC, USAEC Rep. WARD-2000-33
WARD-2000-96
WARD-2000-97
WARD-2000-90

/¯2_7 AIELLO, P., FOGAGNOLO, G., PIERANTONI, F. and ZONA, R., PEC: Status of the Design before Construction, USAEC Rep. ANL-7520, Part II

Legend to Fig. 1 and Fig. 2

1	core
2	circulating pump
3	check valve
4	pressure pipe
5	linked bellows
6	annular channel
7	cross channel
8	overflow edge
9	axial bellows
10	sliding sleeve-joint
11	pressure step-up means
12	surge pipe
13	pump shaft seal
14	shielded vault
15	containment jacket
16	emergency cooling system
17	access hatch
18	hot cell
20	reactor building
RP	reactor pool
CP	component pool
IHX	intermediate heat exchanger
∇IHX	coolant level in the intermediate heat exchanger
∇RP	coolant level in the reactor pool
∇CP	coolant level in the component pool

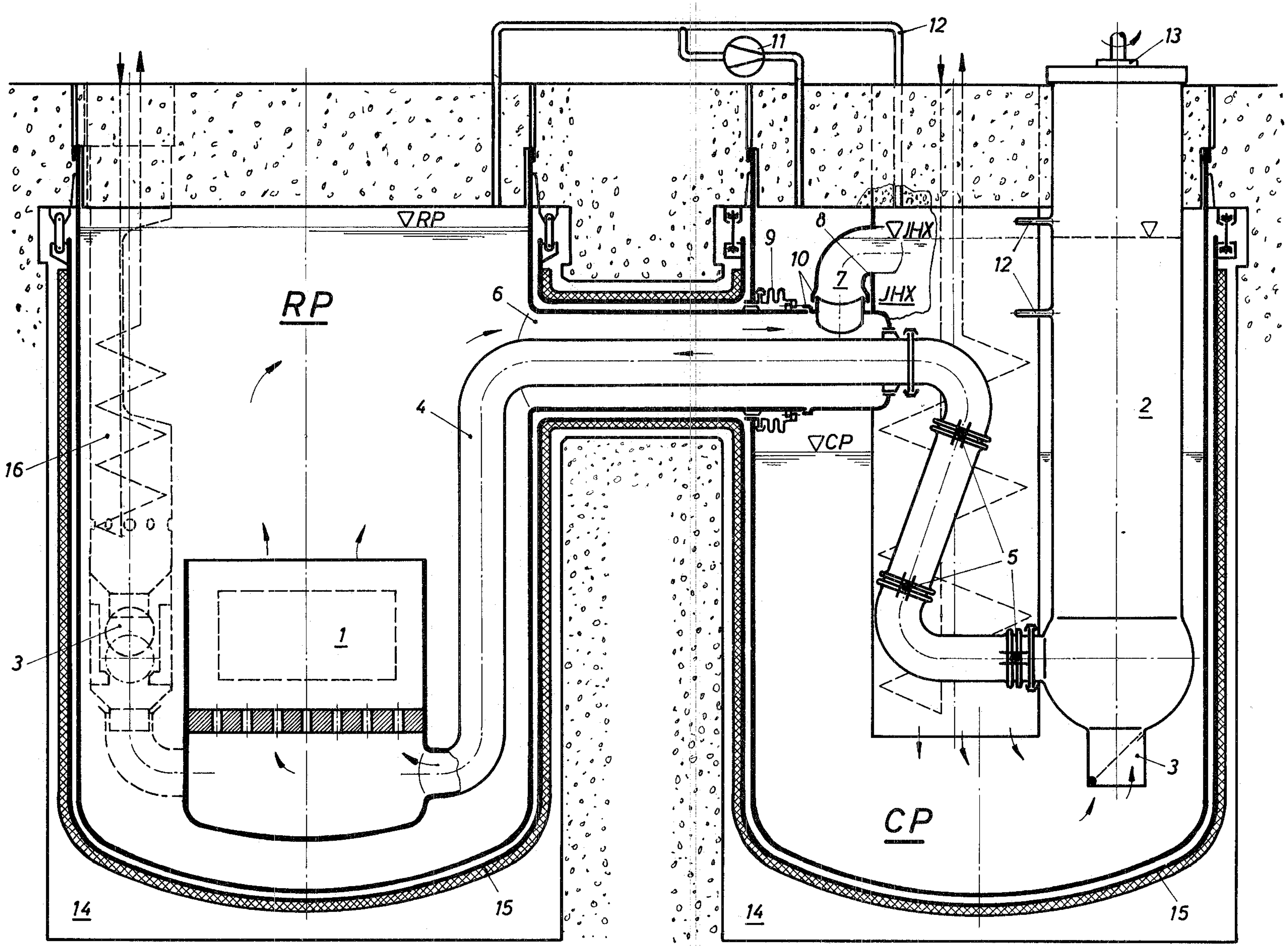
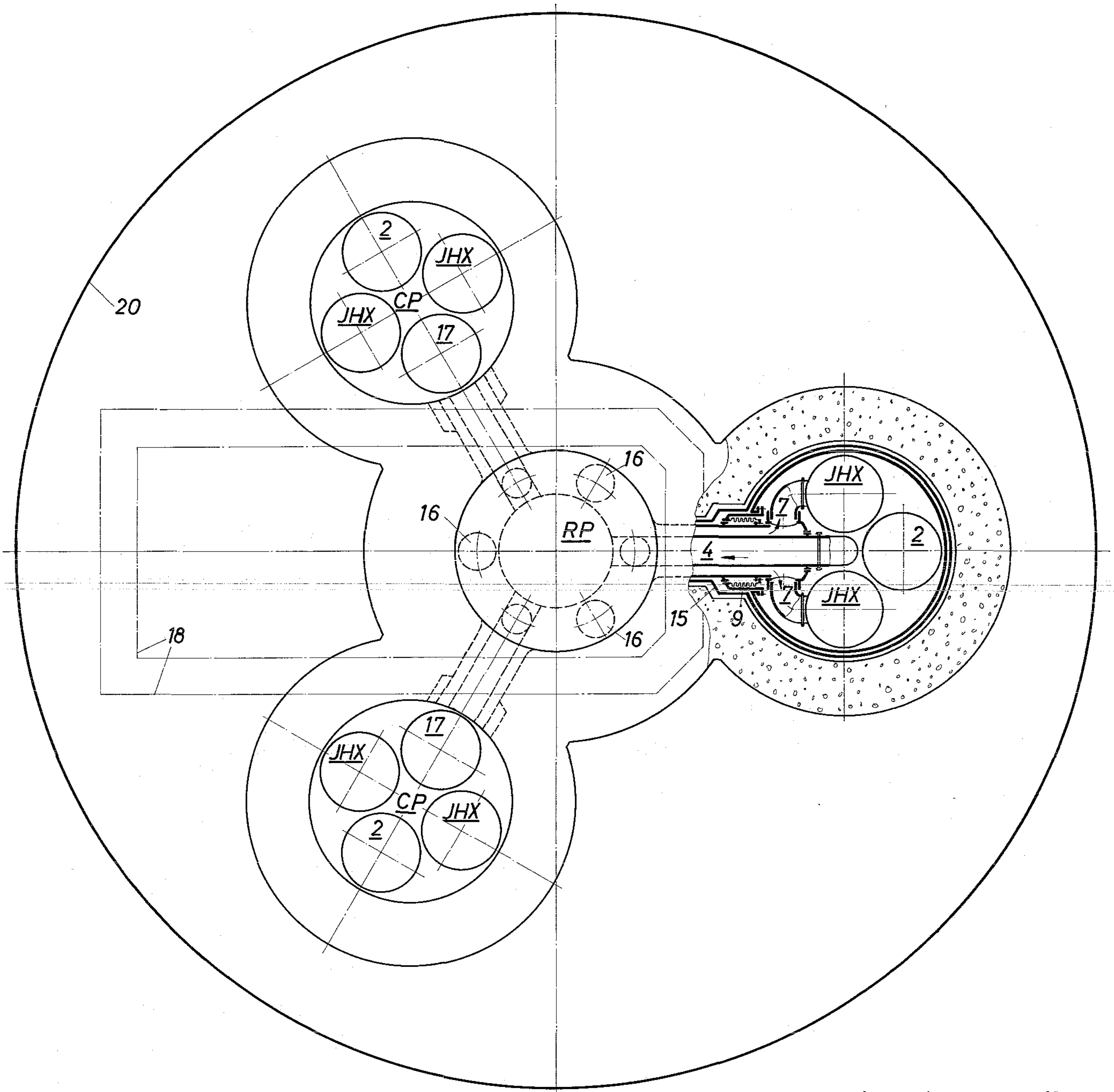


Fig. 1 Basic Principle of the Partly Integrated Cooling System

Legend see page 10



Legend see page 10

Fig. 2 Layout of a 1600 MWe Plant