EPR DESIGN FOR MAINTENANCE

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Abstract

Preventive maintenance is very important in achieving high plant availability. For the European Pressurized Reactor (EPR) preventive maintenance has been carefully addressed in the design stage. This is particularly necessary because of the traditionally different maintenance strategies employed in France and Germany. This paper emphasizes the following features introduced in the EPR design to minimize the duration of the refueling outage: (1) containment accessibility during power operation; (2) overall plant layout to facilitate inspections and maintenances within the containment; and (3) safety system design for enabling preventive maintenance during power operation.

1. Introduction

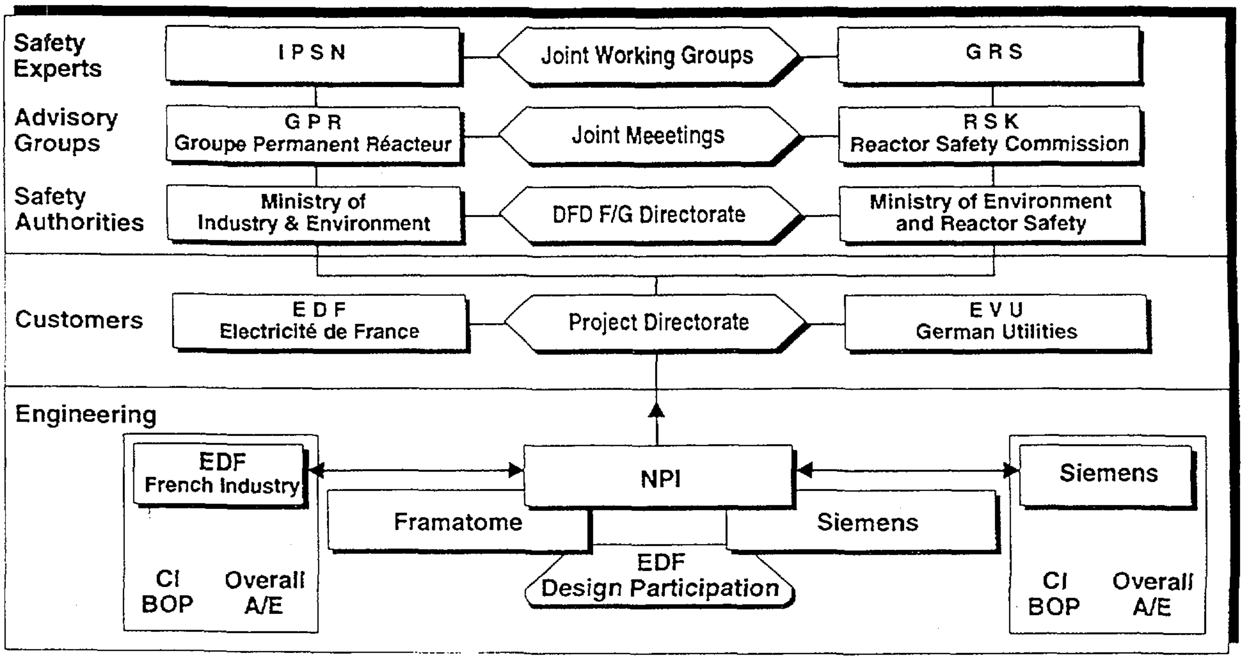
The economic objective of the EPR is competitivity with fossil power plants. This objective led beside others

- to the relatively high power output of 4250 MW_{th} which is presently again in discussion to be further increased
- to a design life of 60 years
- to the requirement of replaceability of the majority of components
- to a plant availability target of 87 % and, as a consequence
- to the objective to minimize the normal plant outage for refueling and revision works to less than 25 days.

It is obvious that these objectives can only be met if in an early design stage maintenance strategies are developed and translated into design. This is for the EPR even more important because traditionally in France and in Germany different maintenance strategies had been followed which needed to be harmonized.

For this purpose, the utilities in France and Germany have been involved since 1991 directly in the development of the EPR to ensure - beside others - that operational aspects and utility requirements in the field of maintenance enter immediately into design. Table 1 shows the partners involved in the EPR basic design.

TABLE I. EPR'S OVERALL ORGANIZATION



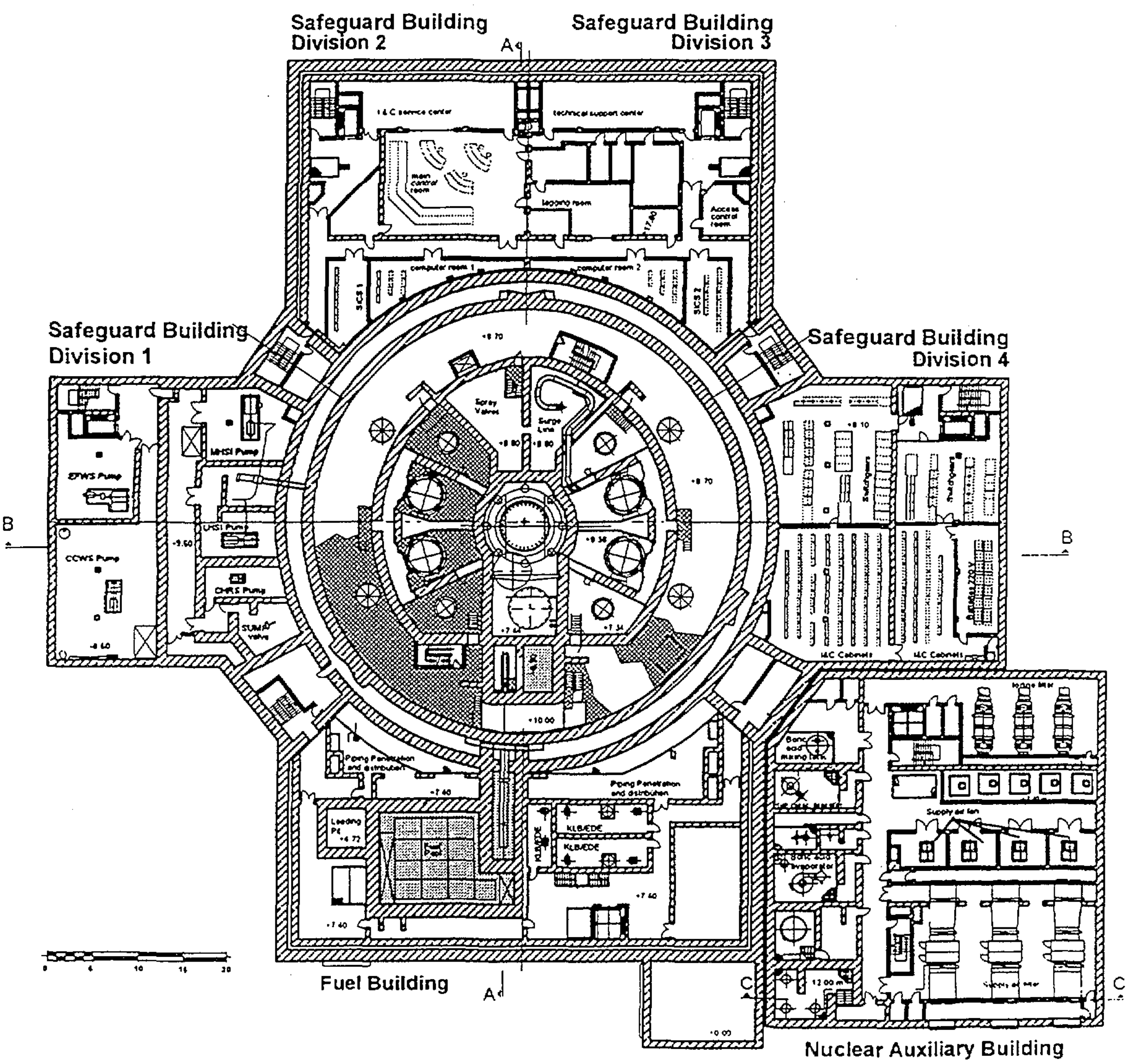


FIG. 1. EPR's Plant Layout, Nuclear Island and Plant View different Levels.

Before entering the subject of design for maintenance, let me shortly repeat some essential technical features of the EPR (Fig. 1): The EPR is an evolutionary 4 loop PWR developed on the basis of the French N4 and the German Konvoi designs. The 4-train-safeguard systems (mechanical, electrical and I&C) are allocated in 4 separated safeguard buildings. The reactor building has a double containment with a prestressed concrete inner containment without liner. Compared to existing plants containment free volume and design pressure are increased in order to cope with severe accidents. The fuel pool is allocated in a separate building outside the reactor building. The refueling water storage is allocated within the containment. The main control room is allocated on top of the safeguard buildings 2 and 3. The nuclear auxiliary systems are allocated in the Fuel Building and the Nuclear Auxiliary Building. The Diesel Buildings which belong also to the Nuclear Island, are not shown in Fig. 1.

In the following, I want to deal with some maintenance features introduced in the EPR design in order to minimize the duration of the refueling outage. The EPR standard refueling outage schedule is described in Fig. 2. Compared to the Basic Design objective mentioned in the beginning, it is furthermore shortened by roughly one week to 425 hours. With regard to this further reduction of the refueling outage duration, I want to highlight especially on

- the containment accessibility during power operation
- the overall plant layout in order to enable and improve revision works within the containment
- the safety system design for enabling preventive maintenance during power operation

2. Containment accessibility

An important improvement of the EPR compared to predecessor plants consists in an improvement of the confinement function.

This implies - as already mentioned - the consideration of severe accidents for containment design. Furthermore, a number of measures have been taken in order to improve the confinement function during normal operation.

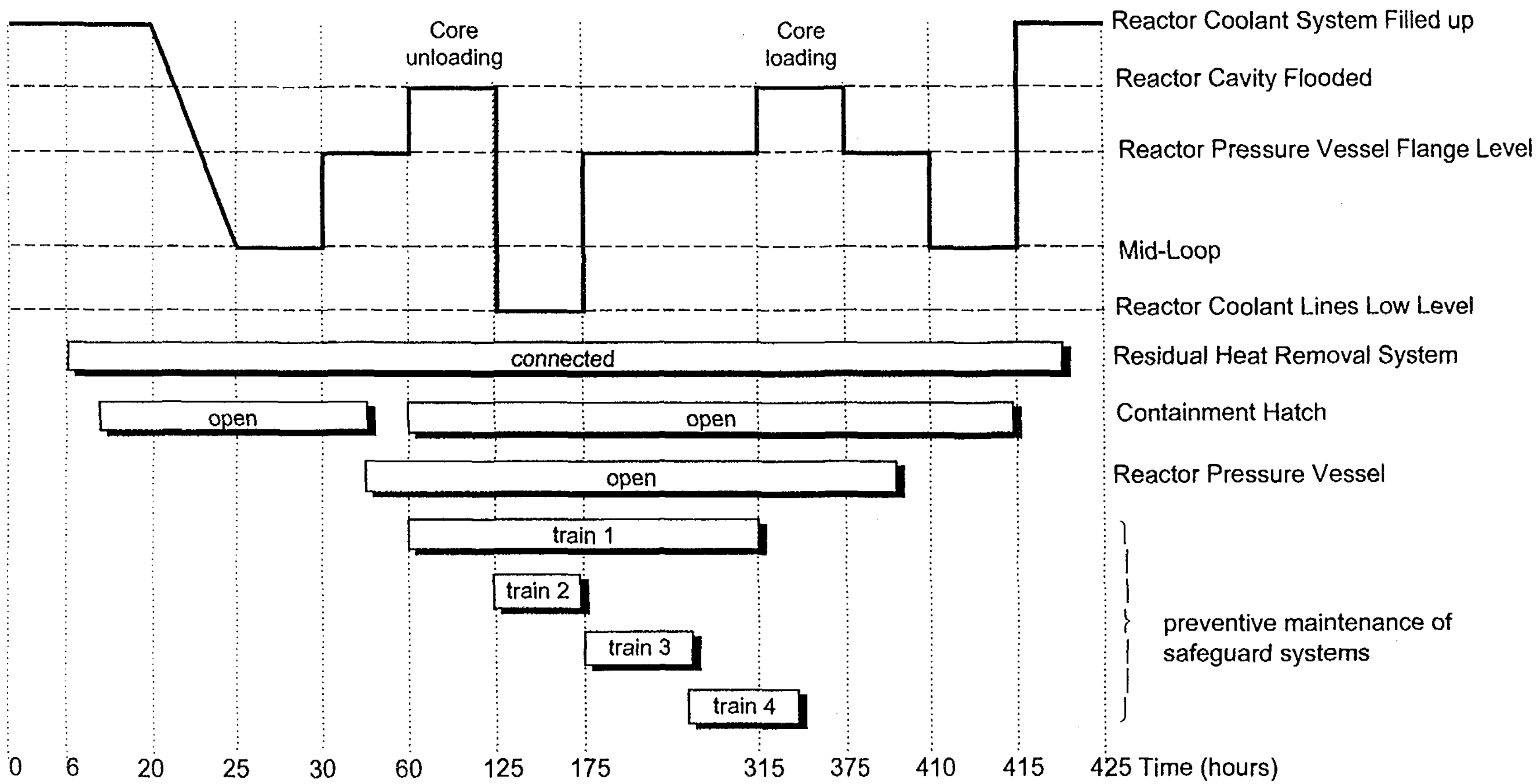


FIG. 2. EPR's Standard Refuelling Outage Schedule.

I want to mention in this context:

- The allocation of the residual heat removal system inside the reactor containment in order to reduce the containment bypass probability especially as long as the primary coolant is at temperatures above 100° C. For economical reasons, this feature is presently again under discussion.
- The closed ventilation system of the reactor containment during normal power operation.

Nevertheless, in order to relieve plant outage from preparatory functional and safety tests of lifting gears and other revision tools, as well as from final cleanup actions inside containment, the EPR containment shall be temporarily, especially about one week before and after refueling outage, accessible without need for heavy breathing apparatus. This is requested especially for the main service floor, as well as for the annular space between the missile shield cylinder and the inner containment wall (Fig. 3). It had to be investigated if for this purpose the heavy equipment compartments had to be equipped with a separated ventilation system, and had to be separated from the operating compartments, as it is the case for present German permanently accessible containments. Eventually, it turned out, that a one-room-containment is acceptable, provided sufficient containment purging capacity is available. This has advantages for accident and severe accident control with regard to equalization of pressure and homogenization of local hydrogen concentration.

3. Provision of sufficient service area on the operating floor

Because of the location of the fuel pool outside containment, there is no need for transportation of major pieces of equipment or material into or from the containment interior during power operation. However, after reactor shutdown for refueling, the multistud-tensioning device needs to be entered into the containment. It is stored immediately beside the equipment hatch in the fuel building in order to enable the common use for various units at one site (Fig. 4). For the purpose of transportation into the containment, the equipment hatch is opened at primary temperatures below 100° C (Fig. 2).

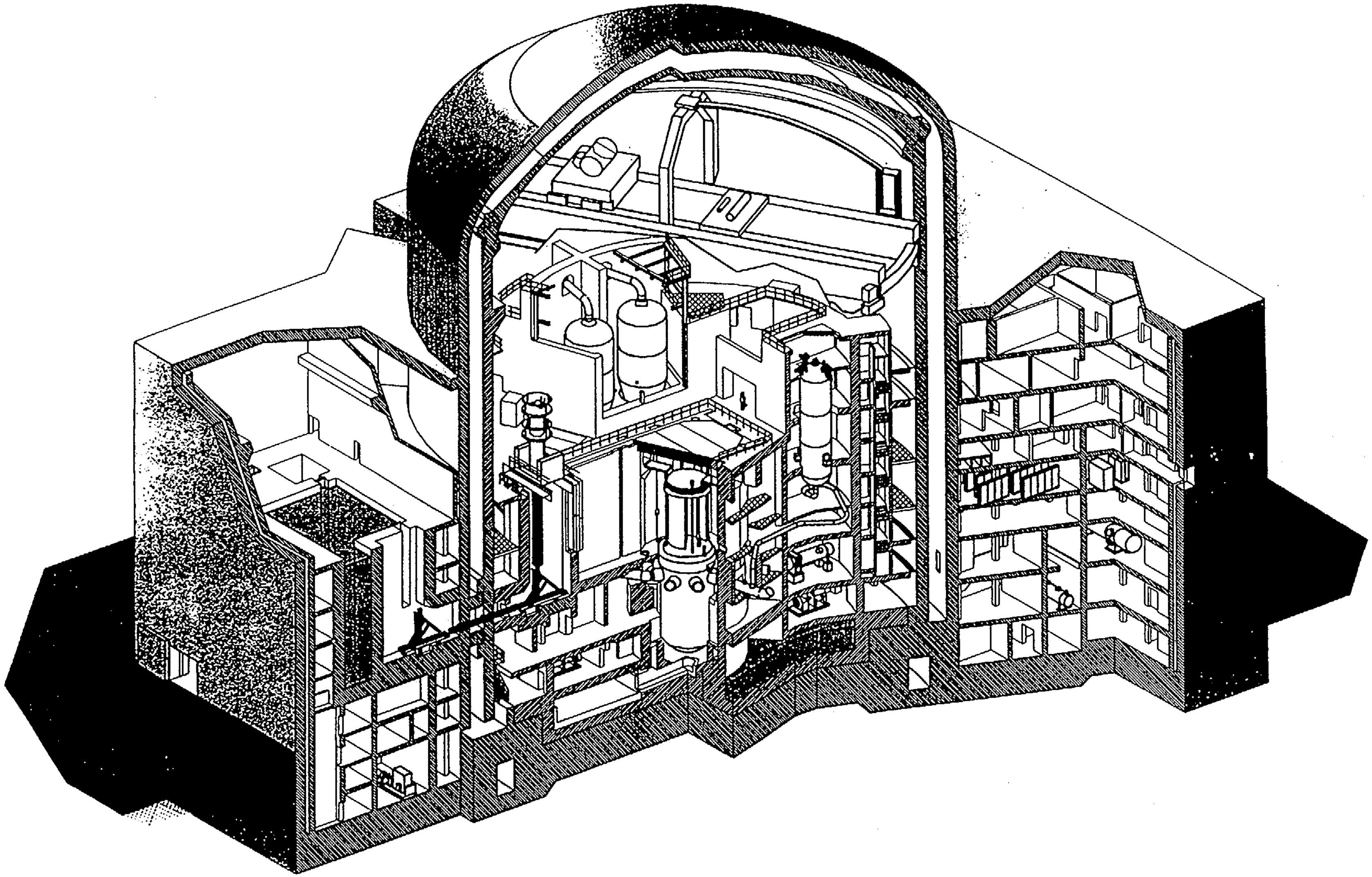
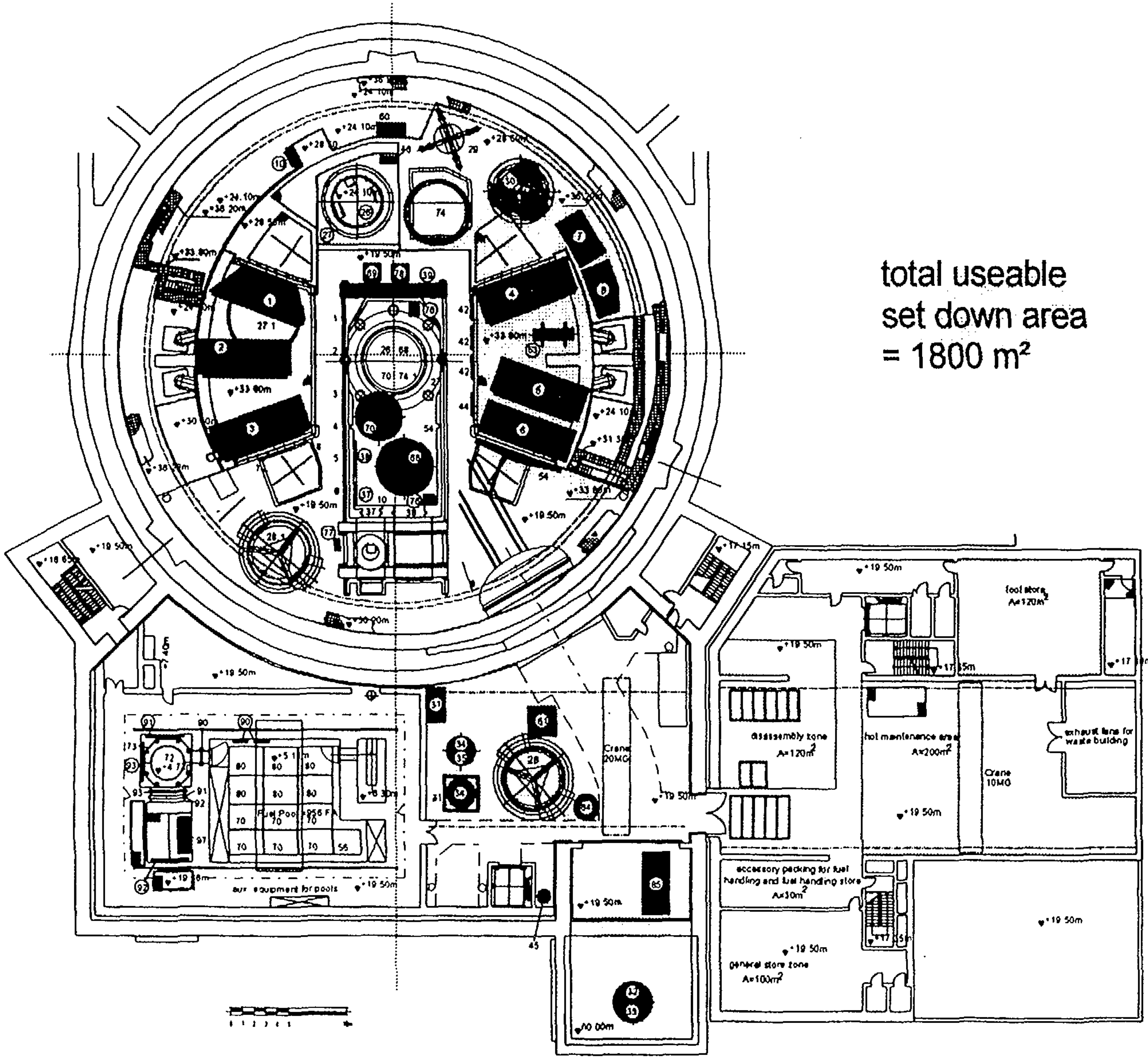


FIG. 3. EPR's Plant Layout, General Arrangement of Nuclear Island.



total useable
set down area
= 1800 m²

POS.COMPONETS AND PEACES
NR.
1 POOL SLABS
2 POOL SLABS
3 POOL SLABS
4 POOL SLABS
5 POOL SLABS
6 POOL SLABS
7 MCP SLABS
8 MCP SLABS
10 SHIELDING GATE (FOR THE TRANFER COMPARTMENT)
26 RPV CLOSURE HEAD WITH INSULATION
27 MOVING INSULATION COVER WITH ERECTION PLATFOM
27.1 TEMPORARY SET DOWN OF POS. 27
28 MULTISTUD TENSIONING DEVICE FOR RPV HEAD
28.1 TEMPORARY SET DOWN OF POS.28
29 LIFTING DIVICE FOR RPV HEAD
30 LIFTING UNIT FOR CORE INTERNALS
31 SLABS ABOVE DECONT. STATION OF MCP
32 MOTOR OF MAIN COOLANT PUMP
33 ERECTION RACK FOR MOTOR OF MCP
34 INTERNALS OF MAIN COOLANT PUMP
34.1 TEMPORARY SET DOWN OF POS. 34
35 ERECTION RACK FOR INTERNALS OF MCP
37 TRANSFER COMPARTMENT GATE
38 LANCES COMPARTMENT GATE
39 AUXILIARY PLATFORM
42 HANDLING TOOLS (FUEL,LANCES,DRIVE SHAFT)
44 TRANSPORT TOOL FOR INSULATION COVER
45 HYDRAULIC BOLT TENSIONING DEVICE FOR MAN HOLE
46 SLIDING ROD AND SPARE BOLTS FOR RPV HEAD
53 LIFTING UNITS FOR CONCRETE SLABS
54 REACTOR CAVITY GATE
60 LIFTING DEVICE FOR REACTOR CAVITY GATE
61 CLEANING UNIT FOR MSTD
68 CORE INTERNALS
69 SWITCHBOARD FOR RPV MULTISTUD TENSIONING DEVICE
70 HEAVY REFLECTOR
72 CASK CONTAMINATION PROTECTION SHIRT
73 CASK FILLING PLATFORM (LOADING HALL ±0.00m)
73.1 TEMPORARY SET DOWN FOR CASK FILLING PLATFORM
74 DUMMY RPV HEAD
74.1 TEMPORARY SET DOWN OF POS. 74
76 ELEVATOR PLATFORM
77 CONTROL DESK FOR TRANSFER
78 CONTROL DESK FOR REFUELING MACHINE
84 LIFTING DEVICE FOR MCP
85.1 MAINTENANCE AREA FOR ROTOR OF MCP MOTOR
90 SHIELDING GATE BETWEEN SFSP AND SFCP (TWO PARTS)
91 SHIELDING GATE FOR LOADING PIT (PART 1)
92 SHIELDING GATE FOR LOADING PIT (PART 2)
93 WATER GATE FOR LOADING PIT
97 LIFTING DEVICE FOR CASK

Example:
59 ERECTION PLACE
(69) SET DOWN AREA
27.1TEMPORARY SET DOWN
(7) SET DOWN AREA OF LOWER PART

POSSIBLE SET DOWN AREA

FIG. 4. EPR's Set Down Area during Outage.

At these operating conditions, the risk for fast pressure transients in the containment is relatively low, so that a continuous preservation of the containment function is not necessary, and there is no need for a material airlock.

However, because there remains a risk during reduced primary water level with open reactor pressure vessel, the equipment hatch is closed again provisionally before the reactor pressure vessel head is lifted (Fig. 2).

After flooding of the reactor cavity, the equipment hatch is kept continuously open in order to enlarge the service area at the operating floor by approximately 800 m^2 in the fuel and nuclear auxiliary buildings, e.g. for revision works like decontamination of the reactor coolant pump impeller or servicing of the reactor coolant pump motor.

During this period of time, a dynamic activity confinement is ensured in the enlarged service area. For transportation of major pieces of equipment into or from this area, e.g. of the reactor cavity concrete slabs, or of the multistud-tensioning device, the fuel building gantry is designed as an airlock.

4. Preventive maintenance of Safety Systems

It is the objective of the French and German utilities that preventive maintenance of the safety systems during refueling shutdown is not on the critical path (Fig. 2).

In one train, a full mechanical and electrical maintenance including subsequent re-qualification tests is foreseen, in the other trains, only partial mechanical and electrical inspections shall be performed. The outage of 1 safeguard system train is accepted during core loading and unloading, the outage of 2 trains is accepted with unloaded core. During this last period of time the only safety functions to be performed are fuel pool cooling by the 2-train fuel pool cooling system, and maintenance of the dynamic confinement function by the 2 train controlled area ventilation system.

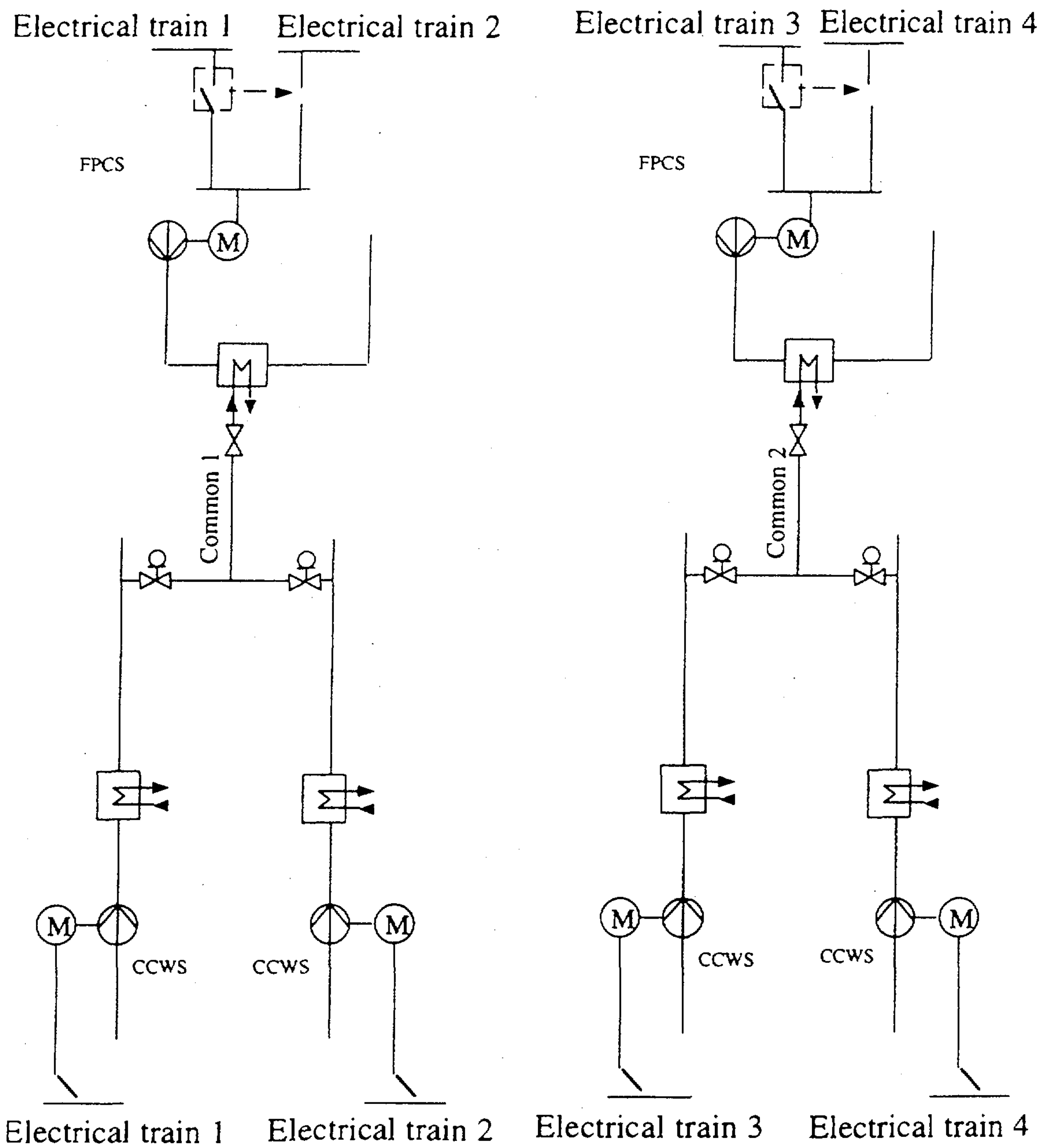


FIG. 5. Design of Fuel Pool Cooling System for Maintenance.

In order to be able to perform preventive maintenance during this period of time on 2 cooling chain and electrical trains, each fuel pool cooling train is connected via a header to 2 cooling chain trains, and via special switching elements to 2 electrical trains (Fig. 5). An equivalent cross-connection would be necessary for the electrical power supply of the controlled area ventilation.

TABLE II. EPR'S PREVENTIVE MAINTENANCE OF SAFETY SYSTEM DURING POWER OPERATION

System/Equipment	No. of trains	Preventive Maintenance Duration during Power Operation	Remarks
Safety Injection System	4	28 days/system 14 days/train	except accumulator injection
Fuel Pool Cooling System	2	28 days/system	
Component Cooling System Service Water System	4	28 days/system 14 days/train	Only for safety-classified portion; no preventive maintenance to be done for common headers except FPCS header
Emergency Feedwater System	4	28 days/system 14 days/train	
Emergency Diesel Generators	4	28 days/system 14 days/train	including support and cooling systems, as well as correlated electrical busbars

TABLE III. EPR'S UTILITY REQUIREMENTS FOR PREVENTIVE MAINTENANCE DURING POWER OPERATION

System/Equipment	No. of trains	Preventive Maintenance Duration during Power Operation	Remarks
Electrical switchboards 10 kV, 690 V, 380 V	4	coherent with systems maintenance	only interruptible power supply
Batteries	4	48 hours/train	discharge/reloading tests
Safety-classified Ventilation Systems (non-controlled area)	4	to be specified	including electrical divisions and chilled water system
Safety classified Ventilation Systems (controlled area)	2	to be specified	except annulus accident ventilation system

Behind this solution is the requirement raised by the French Group Permanent Réacteur and the German Reactor Safety Commission, that for safety systems required during all reactor states, including shutdown, scheduled maintenance has to be superposed with a single failure, taking into account the required capacity of the corresponding safety function during this maintenance.

In order to meet the requirement that the refueling schedule is not determined by safety system maintenance, the utilities requested the investigation of the possibility to do preventive maintenance during normal power operation to the extent specified in Tables II and III.

In addition the following requirements for this investigation were specified:

- the demonstration that the specified maintenance times are acceptable should be done either deterministically as above for the fuel pool cooling system, or probabilistically; preferably, major modifications as for example significant oversizing of pump flow rates or heat exchanger capacities which had been achieved on a n+1 basis, that means considering only 1 outage due to a single failure, should be avoided

- preventive maintenance on different components during plant power operation will only be performed within 1 train simultaneously

- preventive maintenance on 1 train shall not induce any reduction of the reliability and availability of remaining plant, and especially of the other safety trains

- preventive maintenance during plant power operation should not induce an unacceptable reduction of admissible repair times

Because for the EPR the majority of safety systems is designed as 4 train systems (except residual heat removal system, fuel pool cooling system and some ventilation systems) with strict train separation, the n+1 redundancy requirement determines essentially system dimensioning. In this context it has to be mentioned that beside deterministic safety requirements, availability or operational requirements have been considered for EPR safety system dimensioning.

An example is the emergency feedwater system, where for probabilistic reasons the system has been sized such that 1 train is sufficient for heat removal in case of loss of main feedwater (Fig. 6).

Another example is the medium head safety injection(Fig. 7). For operational reasons it is designed in such a way that for very small primary leaks (≤ DN 25) the water level in the reactor pressure vessel will not decrease below the main coolant line nozzles considering a single failure. This means implicitly that a (n+2)-redundancy is

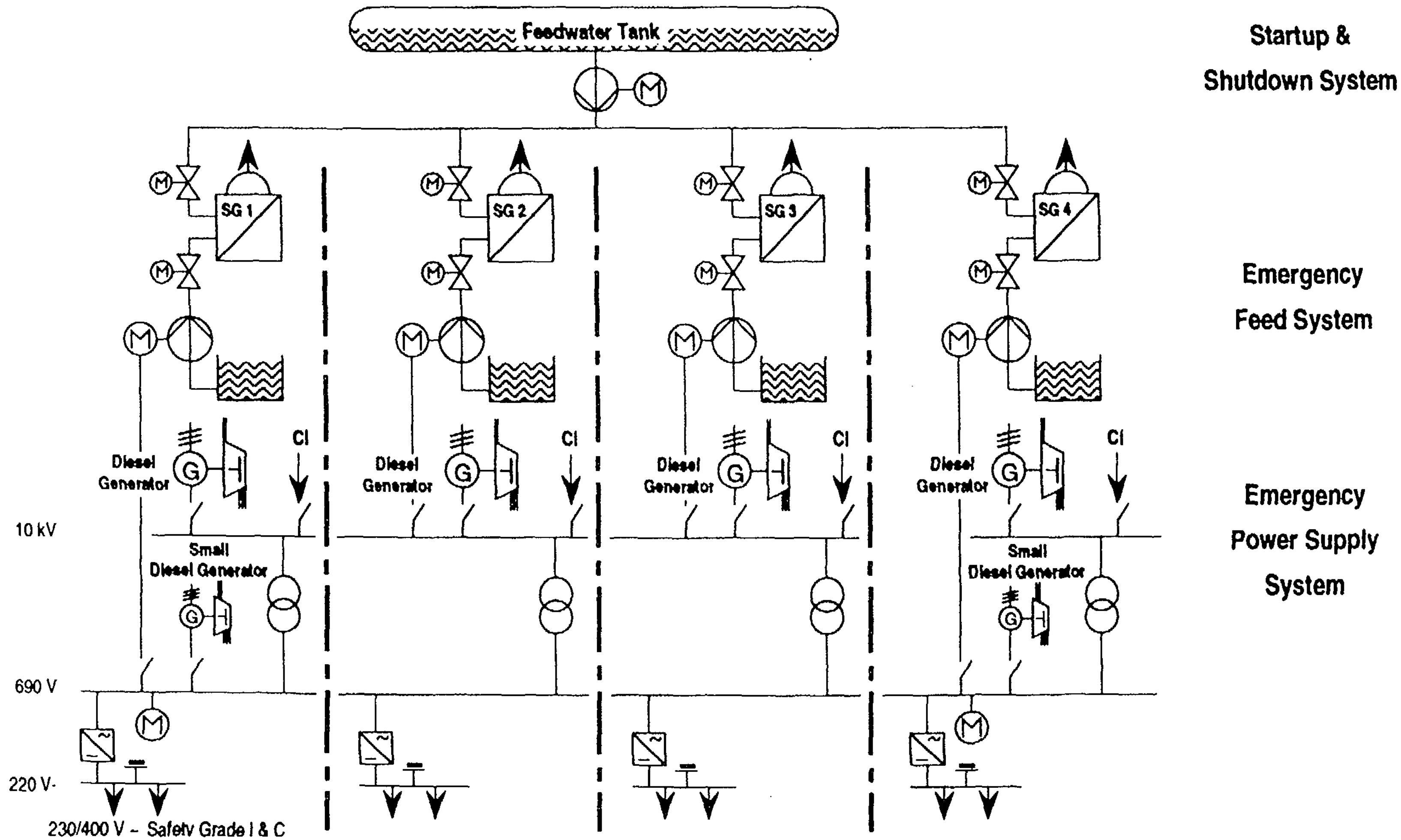


FIG. 6. EPR's Conceptual Arrangement of SG Feed Including Electrical Power Supply.

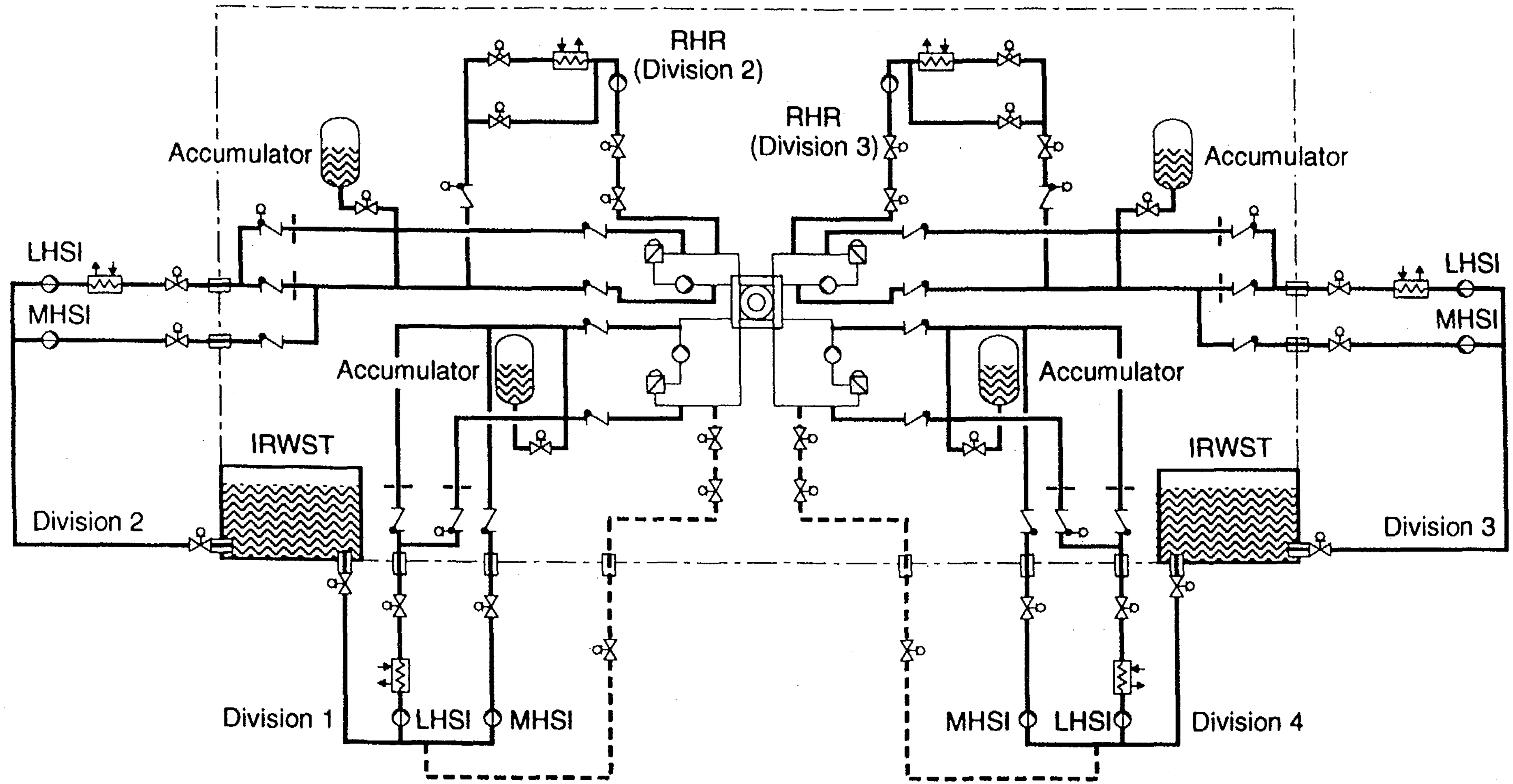


FIG. 7. EPR's Primary Side Safety Systems.

achieved for all primary leaks where the medium head safety injection is required with regard to the relevant safety criterion "limited core heat-up".

Furthermore, for a number of safety systems functionally diverse back-ups are provided which is de facto equivalent to a higher redundancy of the safety system function. An example is the 2 train residual heat removal system which can be backed-up by 2 trains of the low head safety injection system at primary temperatures below 100° C (Fig. 7).

TABLE IV. EPR'S PREVENTIVE MAINTENANCE OF SAFETY SYSTEM DURING POWER OPERATION

Maintenance has to be performed during Power Operation for:	Maintenance can be performed during Power Operation
• Fuel Pool Cooling System with the correlated Component Coolers headers • Controlled Area and Fuel Building Ventilation	• Safety Injection System • Residual Heat Removal System (although not intended) • Emergency Feedwater System • Component Cooling System (safety-classified part) and Service Water System • Non-controlled Area safety-classified HVAC Systems • Emergency Diesel and Parts of MV and LV switchgear and busbars • Main Control Room Ventilation • Safety-classified Chilled Water System

TABLE V. EPR'S PREVENTIVE MAINTENANCE OF SAFETY SYSTEM DURING POWER OPERATION

Maintenance cannot be performed during Power Operation

- RCS isolation
- Containment isolation
- SG isolation
- RCS hot leg letdown
- SG steam relief
- uninterruptable LV busbars and switchgear
- DC busbars
- Annulus ventilation

In consequence, there was already extra redundancy available in EPR safety system design which could be used for

- doing preventive maintenance by satisfying the licensing requirement of the French and German authorities to deterministically superpose outage due to preventive maintenance with an additional single failure, and thereby for
- relieving time pressure during revision outage due to safety system maintenance work which could be done in a more relaxed manner during normal power operation.

The results of the investigation are outlined in Table IV and V. They can be summarized as follows:

Maintenance of those 2 train systems which are functionally necessary during refueling outage has to be done during power operation. For their auxiliary functions cooling and electrical power supply train cross-connections are necessary as discussed above for the fuel pool cooling system (Fig. 5).

Maintenance of the majority of safety systems which are 4-train systems is possible during power operation without any need of resizing because of existing design margins.

Not possible is preventive maintenance especially for all those safety functions which are provided by valves, in general 2 valves in series, and their power supply which is provided by the uninterruptable LV and DC power supplies, unless additional measures for ensuring redundancy in case of maintenance are provided. This is presently not foreseen for the EPR because of reasons of train separation.

Conclusions

Preventive maintenance is an essential aspect with regard to plant availability. I have tried to outline for some examples that early consideration of maintenance needs in the design is necessary and contributes to improve the overall plant performance and to optimize especially the refueling outage.