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ARGUMENTS FOR THE INSTALLATION OF SMALL LWR-NUCLEAR POWER PLANTS IN DEVELOPING COUNTRIES

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R E F E R E N C E S

(1) DEUTSCHE VERBUNDGESELLSCHAFT e.V. (DVG), Heidelberg "Die Sicherheit der Stromversorgung" April 1973

(2) IAEA: Inter-Regional training course on "Nuclear Power Plant Construction and Operation Management" 7. Sept. to 17. Dec. 1976
item 2.4.3 turnkey contracting
Preparation of Bid Specification
(Dr. K. Weinlich and B. Lezenik)
item 2.4.7 turnkey contracting
Technical/Commercial Terms and Conditions
(Dr. K. Weinlich and B. Lezenik)

(3) W. Aleite "1300 MW-Kernkraftwerke im Lastfolgebetrieb" VGB Kraftwerkstechnik, Heft 2, Febr. 1976

Introduction

In the past, extensive investigations and studies prepared by several parties have referred to the need of smaller reactors and to their economic application. Supplementary to those findings, the following statements shall serve to explain that the technical aspects and arguments, such as grid integration, control behavior, proven technology and the short-time guaranteed implementation are equally in favour of these nuclear power plants.

The growing demand for energy of industrial countries with widely developed power distributing networks continuously led to even larger units in order to generate nuclear power more economically in comparison to fossil fuels. Such economical advantages and the desire to arrive at a longterm and reliable power supply are confronted with the fact that, for one thing, such large units require extensive capital expenditures, and secondly, have to comply with the demand of the electric utility companies for reliable grid operation in case of failure of such large units. Furthermore, in particular a developing country is dependant upon importing a proven and reliable technology.

Accordingly, each electric utility company is compelled to evaluate on an individual basic all manipulable parameters and to determine in each case the optimum aspects.

Grid Integration and Controllability

Apart from the economical aspects to be determined, the question concerning the maximum required demand of standby is of basic importance. In order to properly assess this standby demand, comprehensive calculations (computer) based on probability theories and mathematical concepts of the grid in question are required.

Unforeseeable rate of probabilities of the occurrence of malfunctions, failures etc. has to be taken into account as well as definitely scheduled unavailabilities of power plants (such as inspections, repairs and the like). Essential influences resulting from the parameters affecting each other are:

Size of Units and Number of Units

Many small power plants (especially if they have small probability of failures) are faced with a large unit power output. Available hydroelectric power plants support the stability because of their actually low rate of failures.

A decisive factor in selecting the unit size is, however, the risk of failure an operator has to be prepared to accept as this determines the additionally required standby demand. The resulting additionally expenditures needed are taken into account in the calculation of profitability.

Types of Power Plants and Design of Power Plants

The standby demand is reduced by low shutdown factors prevailing for hydroelectric power plants with a guaranteed water supply, or for thermal power plants which not only have passed the commissioning period but moreover will not be loaded at the upper permissible limit. High quality of components and due maintenance - both of which, of course, have to be purchased - equally lead to a smaller standby demand.

The value of reliable quality realized by promoted manufacturers and subsuppliers as well as profound training of the personnel have a strong bearing on the above.

Inspections and Released Load

The long running periods of nuclear power plants are due to the optimum fuel burn-up. As far as initial plants or grids being fed by but a few nuclear power plants are concerned, it is possible to arrange the refuellings to be performed during lowload periods. This procedure does not require the entire unit output during inspection-time but only that portion of unit output reduced by the seasonally released output.

Grid Load and Cyclical as well as Structural Effects

Investment plans depend to a great extent on forecasts of annual peak loads. For this purpose analyses of the slowly changing consumption periods are available which contain findings on the growth of output over an extended period of time.

The more detailed such overall economical (power consuming) investment plans are defined and fixed, the more reliable a forecast will be.

Interference factors underlying these considerations are mainly demand loads such, for instance, as they occur in Germany when very interesting football games are broadcasted on television.

Coverage of the supplementary demand is to be regarded as a static consideration which may be illustrated as a function of the added up occurrence probability. Based on this factor, it has to be investigated in a dynamic analysis during which period and for how long a time there is supplementary demand. From the thereby resulting supplementary supply conclusions may be drawn for analogous requirements in developing countries.

According to the Deutsche Verbund Gesellschaft (DVG)-Committee, in the interconnected grid system of the Federal Republic of Germany the periods of access to the supplementary supply are broken down into three groups:

Supplementary Supply within Seconds

Availability of potentially all operating thermal and hydroelectric power plants, whereby the power control has to be performed by frequency control. According to the DVG, a turbine designed for a load gradient of ± 5 % of the rated power is considered to be reasonable. In such a case it would be possible to also take temporary advantage of the permitted overload of fossil fired plants until same is taken over by the arising supplementary "supply within minutes". In difficult cases, the remaining grid should be stabilized by means of a step-wise load rejection (effected automatically, but with prior general agreement).

As far as the European interconnected grid system is concerned, a five-stage plan is applied for the following activities:

In the event of frequency dropping to 49.4 Hz (step I), the personnel is alerted and standby units are started. At 49.4 Hz (step II), large loads (industry) are cut-off. Sectionalization of systems is effected at 48.6 Hz (sept III), and emergency cut-off of loads in section at 48.4 Hz (step IV). At 47.6 Hz (step V), the power plants change to auxiliary power operation in order to feed the grid as soon as possible following remedy of the accident.

Supplementary Supply within Minutes

Following accommodation of a "failure within seconds", storage units or gas turbines may be run up within a few minutes, and units running at partial load may be further loaded in accordance with permissible gradients.

"Long-Term" Supplementary Supplies

These can be mobilized within hours, days or even weeks by means of start-up of cold thermal plants, commissioning of conserved plants or by the shortening of repair and inspection periods.

A decisive contribution to grid stability is provided by the "supplementary supply within seconds", that means mainly by the controllability and the load-follow behavior of the operating power plants. Accordningly, a positive argument in favour of the application of nuclear power plants is to be seen in their capability to substantially contribute to the frequency control.

The flexibility of a PWR-nuclear power plant may be demonstrated with the power-change data of the Kraftwerk Union AG (KWU) nuclear power plants. All components of a power plant are dimensioned in such a way so that they are suitable for the following power changes during the life-time of the nuclear power plant:

Ramp Power Changes

Starting from the steady-state operating condition between 20 and 100 % approx. ± 10 %/min of generator rated active output (measured at the generate terminals) within 30 to 60 minutes.

Step-Power Change

(1 %/s) positive as well as negative

Between 20 and 100 % up to 2 % of the generator rated active output without limitation of waiting time and load point.

Single step power changes of 10 % of the generator rated active output, provided a waiting time of two to five minutes is adhered to between two equal step power changes.

In addition, in the event of load rejection, the power plant unit has to be accommodated independently by the control system and subsequently operated with auxiliary power.

Looking for instance at the nuclear power plant Borssele, a 450 MW-PWR, due to the prevailing grid conditions (excess power during first time after commissioning), this plant had to be adjusted to the steadily changing power requirements and has well proved. Graph No. 1 shows an except from the operation diagram of this power plant.

Since its delivery in October 1973, the nuclear power plant Borssele generated almost 10 000 GWh until early 1977 and throughout the entire period reached an availability of close to 80 %.

The technical concept of the control systems applied at Borssele is basically still being realized today for the large standard 1300 MW plants. Graph No. 2 shows the simplified unit system plan of the output control systems used at Borssele:

> During power operation, each load change of the power plant is conducted into the turbine. The reactor output is adjusted to the respective steam requirement of the turbine. The reference values for the generator output control system are given separately from the grid frequency via the static characteristics. Output signals of the generator output controller are led to the turbine valve controller which controls the turbine valve opening. In order to avoid inadmissible rates of load change, the reference values of the output are conducted via a programmed set-point limiter and the reactor power limiter. Material stresses arising in the area of the h.p. cylinder of the turbine in case of power changes are limited by the wall stress computer.

Limit pressure controls (22) (23) prevent critical operating conditions resulting from deviations of the main-steam pressure from the reference values. In the event of falling short of the permissible main-steam limit pressure, the turbine output is either repositioned or maintained through main-steam minimum pressure controller until such time when the reactor output has been readjusted to the steam requirement. In case the upper limit of the main-steam pressure is exceeded, the excess steam, being controlled by the main-steam maximum pressure controller, is blown through the bypass valve into the condenser.

The reactor control system serves to adjust the reactor output to the output requirements of the turbine-generator. In connection therewith the main controlled variable is represented by the average value of the coolant temperature which is to be kept constant, whereby optimum use is made of the favourable controlling behavior of the reactor resulting from the negative reactivity coefficient (minor control rod movements). Furthermore, minimum volume changes in the coolant loop and least possible stresses at components are achieved.

The positioning element of the coolant temperature control system (2) is the L-control rod bank (3) (output repositioning bank). For the fine control in case of slow load changes, the D-control rod bank (Doppler-repercussion compensating bank) is additionally applied. The L-control rod bank also serves as positioning element for the power distribution control system which is applied for the damping of axial power distribution vibrations (vibration damper). Reactivity changes due to burn-up, xenon poisoning, and larger temperature changes of the coolant (during start-up and shutdown) are compensated by changing the boron concentration. For this purpose, the D-rod bank position control system is applied with its positioning elements boric-acid injection and demineralized-water injection.

In order to avoid reactor scrams in the event of specific anamalous operating conditions, a reactor power limiter (24) is provided which exercizes influence on the control rod control and on the generator output control.

Proven Technology also for Small Reactors

At KWU, the development of the PWR technology is based on a know-how license taken over from the US-technology back in 1955. Due to the specific and stringent design requirements in the Federal Republic of Germany, in particular in the field of PWR's, the US-technology had to be further developed. The first components resulting from this further developed technology were already apllied for Obrigheim, the first nuclear power plant built in accordance with an own concept and under full German responsibility. Because of their proven reliability, most components installed at Obrigheim are still being applied for the modern 1300 MW types of reactors. KWU has steadily built up and substantiated its development stages from Obrigheim (250 MW - commissioning in 1969) via Stade (660 MW - commissioning in 1972), Biblis A (1200 MW - commissioning in 1974) up to the consolidating phase of the standard 1300 MW types based on experience gained with components of previous plants.

From the experience obtained from the design, building as well as from the feedback of commissioning and operation, the smaller power units have actually been derived "backward". By decreasing the number of loops, and with the proven systems and components largely remaining unchanged, it has been possible to standardize the following power ranges for the overall plants:

4 loop for 1 300 MW
3 loop for 900 MW
2 loop for 600 MW

The 450 MW reactor may be regarded as a specific alternative of the 2-loop-type, where the essential deviation from the 600 MW unit lies in the decrease of the steam generator heating surface.

Thus it has been possible to build smaller reactors which are in compliance with the demands of the electric utilities calling for proven technologies and licensability.

Graph No. 3 shows a few substantial characteristics which habe proved their reliability up to the 1300 MW standard unit, and which equally may be applied for the smaller power plants derived from the standard plant. These are:

Fuel Assemblies

"open" design with rod cluster control elements. UO_2 pellets in pre-pressurized Zry-4-tubes; same number of fuel rods assembly, only two different active lengths of pellet stack for all three unit sizes.

Reactivity Control

mechanical control with rod cluster control element, chemical control by means of boric acid together with boron recovery.

Control Rod Drive

latch type for all sizes

Core Instrumentation

with areoball system for discontinuous and with stationary (n, β)-detectors for continuous measurements

Steam Generator

vertical U-tube with incoloy 800 tube material since Stade; preheating-zone introduced with Grafenrheinfeld plant (start construction 1973)

Main Coolant Circulating Pump

semi-axial impeller, controlled leakage type seal

Reactor Pressure Vessel

constructed from seamless forged rings in order to avoid longitudinal welds; shorter accumulated length of welds, shorter inspection time needed; better material properties throughout the whole wall thickness.

Reactor Building Cóncept

spherical full-pressure double containment with integrated spent fuel pit accessible during operation.

There are analogous advantages for thc non-nuclear parts of the nuclear power plants. At this point it should be mentioned that, for instance, the low pressure element of the turbine designed for the 600 MW Stade plant (however, of 4-flow-design) is still being applied today for the standard 6-flow 1300 MW power plants.

Guaranteed Implementation of Construction also for <u>Electric Utilities not Versed in the Nuclear Field</u>

Experience gained during the design of standard components is substantially supplemented by the building and commissioning of nuclear power plants. In this respect the turn-key contract, preferred by KWU and its customers, plays a decisive role in view cf the fact that the strictly coordinated responsibility lies in one hand. By this approach the information feedback is greatly intensified. More effectively directed actions lead to a number of advantages for the customer.

In the Federal Republic of Germany, the turnkey-job is given preference because - among other things - the cost savings realized in case of component-wise awarding do not justify the increased risks (according to a Rheinisch-Westfälisches Elektrizitätswerk AG (RWE)-study only approx. 4 %). Possible risks which may occur due to the following are more than difficult to calculate:

- Change of exchange rates, interests, taxes and fees
- increase of suppliers prices
- delays of licensing and acceptance test
- change of standards, rules and regulations
- effects from parts of supply on the total plant, concerning

  delivery and erection time
  output and efficiency
  data and properties
  gaps, faults and failures
  quality and reliability
  transport and erection damage
  warranties
  liability

In the event of the occurrence of any of such risks they can be coped with more effectively by a coordinating turn-key contractor, and consequently kept to a smallest possible value. The electric utility is not approached in case of any disputes over competences and responsibilities as well as concerning causes of possible interferences. It is up to the main contractor to locate the source of problems and to clarify these with his subsuppliers.

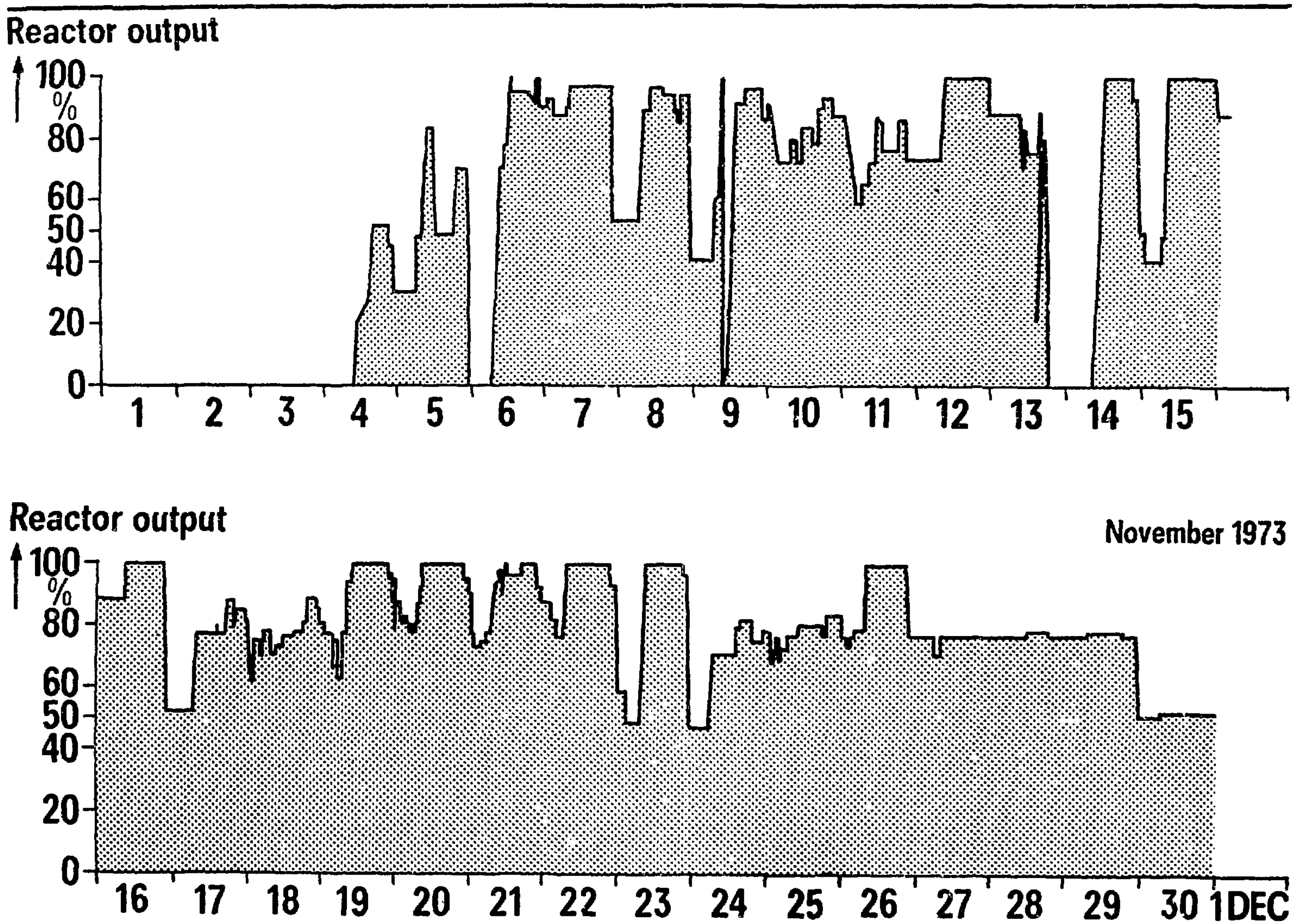
In particular, when nuclear technology is introduced in a country which hitherto has been little or not at all familar with this technology, a turn-key contract is the best and safest way of ensuring an adequate and efficient know-how transfer.

Based on the cooperation on the domestic personnel (personnel of both the electric utility and the engineering company) with the turn-key contractor, the know-how, which is transferred during on-the-job training, is down-to-earth and most up to date. In addition to gaining an insight into the design and activities of the project management, the learning partner is in a position to also witness "emergency actions". Such actions demonstrate the handling of sudden problems within the everyday organizational activities. The "instruments" required to cope with such problems are recognized - a training process which normally is not included or taught in any other training program.

The training and know-how transfer process within the subsupplying industry represents another important basic for an efficient participation of the national industry. As a result of the cooperation between the qualified subsupplying industry and the national companies as well as of the granting of licenses or the forming of joint ventures close relationships are created on the production level.

Such an approach leads to a know-how transfer on a level which will form (on a long-term basic) the foundation for the build-up of the nuclear industry. In view of the frequently long intervals between the realization of the first nuclear power plant and the subsequent ones, it is, however, of imminent importance to ensure that the industrial companies involved dispose of an adequate employment basic - for instance by means of alleviating measures on the part of the government. Moreover, a uniform and continuous work load may enhance the desire of qualified foreign companies to cooperate which in turn would provide an incentive for economic growth. Related therewith is the procurement of work places which exercise a stabilizing effect on the overall economy. (According to a study prepared by the Deutsches Institut für Wirtschaftsforschung (DIW), in the Federal Republic of Germany the implementation of one nuclear power plant provides employment for 39 000 man-years.

The present know-how transfer to Brazil and the Iran is a representative proof of how knowledge may be effectively transferred from the supplier country. Under the "umbrella" of government agreements, authorities, institutes, experts as well as the nuclear industry, the supplier industry and the electric utilities participate in the exchange and transfer procedure. The broad and comprehensive basic for the build-up of the nuclear technology offers a starting position which, due to the realization of specific building projects, is contractually guaranteed within defined periods. The simple import of a nuclear power plant has thus led to the import of an entire technology which in addition to power generation comprises political and economical significance of great bearing for the future.



Load Cycle Operation of the 450 MW Nuclear Power Plant Borssele with KWU-PWR

Graph 1

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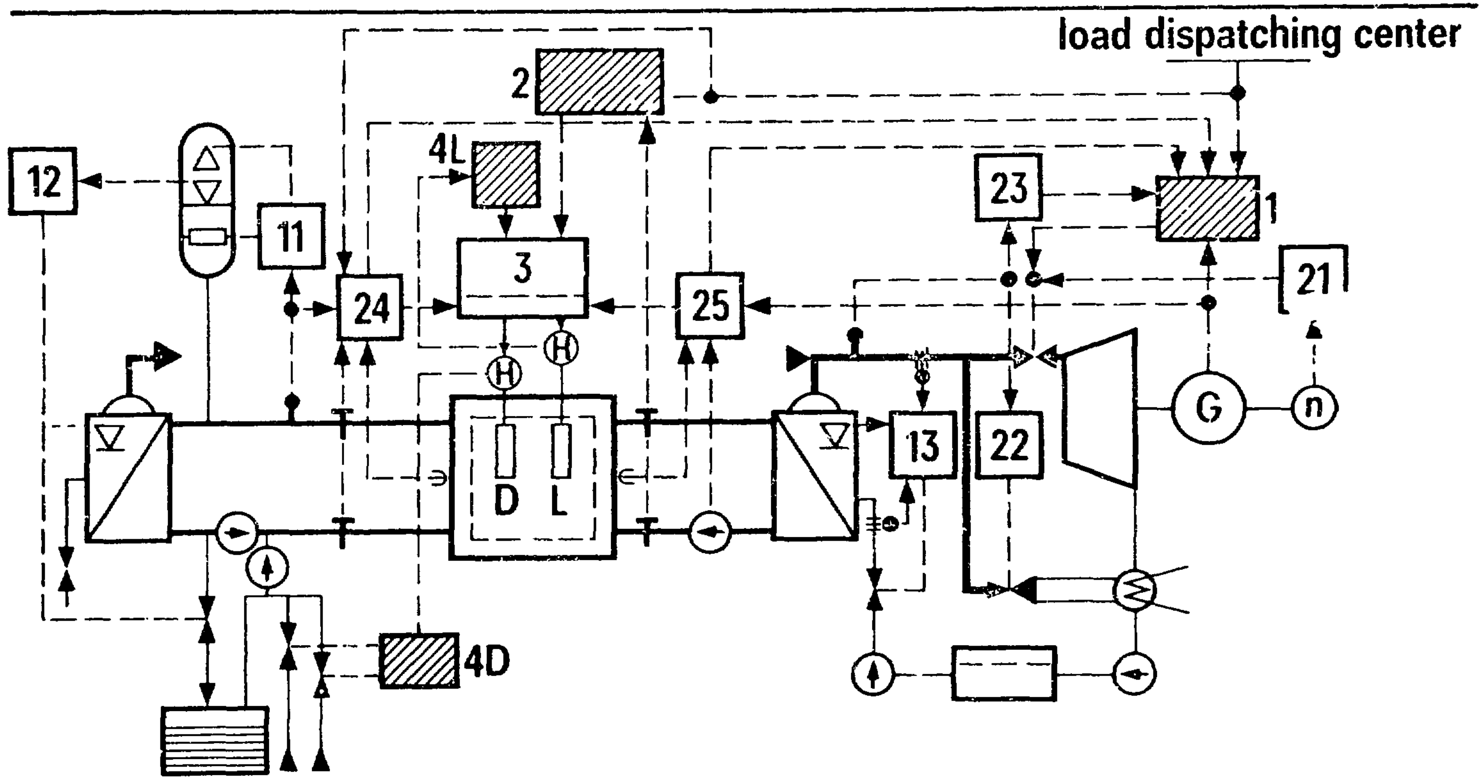
Kraftwerk Union



1 Generator output
2 Coolant temperature
3 Control rod control
4 Control rod bank position for Power-, Doppler-bank
11 Coolant pressure
12 Pressurizer water level
13 Steam generator water level
21 Turbine generator maximum speed
22 Main steam maximum pressure
23 Main steam minimum pressure
24 Reactor power DNB
25 Control rod insertion

Control Equipment of a Nuclear Power Plant with Pressurized Water Reactor

Graph 2

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Kraftwerk Union

		Obrigheim	Stade	Gösgen	Standard
Net output	MW_{el}	330	630	930	1200
Primary coolant loops		2	(4)	3	4
Type of fuel element	Open	→	→	→	→
Fuel canning	UO_2/Zry-4	→	→	→	→
Pre-pressure			→	→	→
Reactivity control, mech.	Finger type	→	→	→	→
chem.	Boric acid	→	→	→	→
Boric acid regeneration			→	→	→
Control rod drive	Latch type	→	→	→	→
Core instrumentation, discont.	Aeroball system	→	→	→	→
cont.	Stat.(n,ß)-detectors		→	→	→
Steam generator	Vertical U-tube	→	→	→	→
with preheat-zone				- - - -	→
Tube material		Inconel 600	Incoloy 800 →	→	→
Live steam pressure	bar	54	54	68	68
Primary coolant pump — type	Semi-axial	→	→	→	→
seal	Non-contact	→	→	→	→
Safety shell	Full pressure steel	→	→	→	→
Fuel pool location	within safety shell	→	→	→	→
Missile protection shield			→	→	→
Core internals storage pool				→	→

Essential Characteristics in the PWR-Development

Graph 3

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