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AVAILABILITY AND ITS CORRELATION WITH THE COST SITUATION OF NPPs AND AN ADVANCED REACTOR AS A POSSIBLE FUTURE SOLUTION

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Abstract

The availability depences from a lot of factors, especially from design approaches. The way for the development of design approaches for attaining the safety requirements with more redundancy and without diversity of the systems, especially of safety systems, in NPP's in the past is not acceptable for the future because of cost reasons. It is necessary to find new technical ways to achieve a better availability, reliability and safety by lower costs. The simplification of safety systems by using passive systems may be a solution in the future. The development of a new boiling water reactor BWR 1000 in Germany by Siemens which is sponsored by german utilities and supported by various European partners can be named as such example.

Introduction

Thank you, Mr. Chairman. Good afternoon, Ladies and Gentlemen. I am working for the german utility PreussenElektra in North-west of Germany. This company has the technical responsibility for four Nuclear Power Plants in Germany and it is a share holder of some other NPP's. Some slides in my presentation relate to the following PreussenElektra NPP's (Table I).

I am very pleased to have an opportunity to present our results of availaibility and to adress some facts of the correlation between availability and the cost-situation. The availability means in this case the technical development of the NPP's during the last time. I like to show, that an extensive development with more redundancy without diversity of the systems, especially of safety systems, in NPP's is not acceptable because of cost reasons. It is necessary to find new technical ways to achieve a better availability, realibility and safety by lower costs. The present task is to verificate if the the simplification of safety systems by using passive systems may be a solution in the future. The development of a new boiling water reactor BWR 1000 in Germany by Siemens which is sponsored by german utilities and supported by various European partners can be named as such example.

Table I PreussenElektra's Nuclear Power Plants

Unit	year of start up	typ	output power in MW
Stade	1972	PWR	640
Unterweser	1978	PWR	1230
Grohnde	1984	PWR	1300
Brokdorf	1986	PWR	1307

Availability

The availability of german nuclear power plants during the last 10 years is shown on Fig.1.

It is constantly higher than 80%. A certain reducement can be noticed from 1988 to 1991. Especially during the period 1990-1991 was done a great amount of work at the pressurizer safety valves because of safety requirements. In addition as a consequence of Chernobyl a high number of modernizations-measures in the field of accident management in order to cope with severe accidents were undertaken during this period. After this time we can watch a stable operation of NPP's.

The availability depences from a variety of factors, such as:
- Design approaches and technologies,
- Behaviour in terms of normal operation and transients
- Design for optimised outages
- Optimal conditions for preparation of outages (informations about the state of components)
- Level of education and training of operators
- Relationship with the authorities

Cost situation

An intensive development of design approaches, especially with the purpose to increase the safety, took place in the past. It was required because of following circumstances:
- Design of NPP's for external hazards (aircraft crash and earthquake),
- High expenses for nuclear specific components, also outside the primary circle
- Increase of redundancy, especially for safety systems in order to control the external hazard-events (for example, four <u>additional</u> emergency diesel generators and four <u>additional</u> trains emergency feedwater systems protect against extemal hazards)

The final result was a much more complicater but only a little bit safer plant. Especially the probability of severe accidents was not substantially reduced, because it is not determined by external hazards, but by common mode failures.
The noticed measures caused the extreme growth of costs for NPP's.

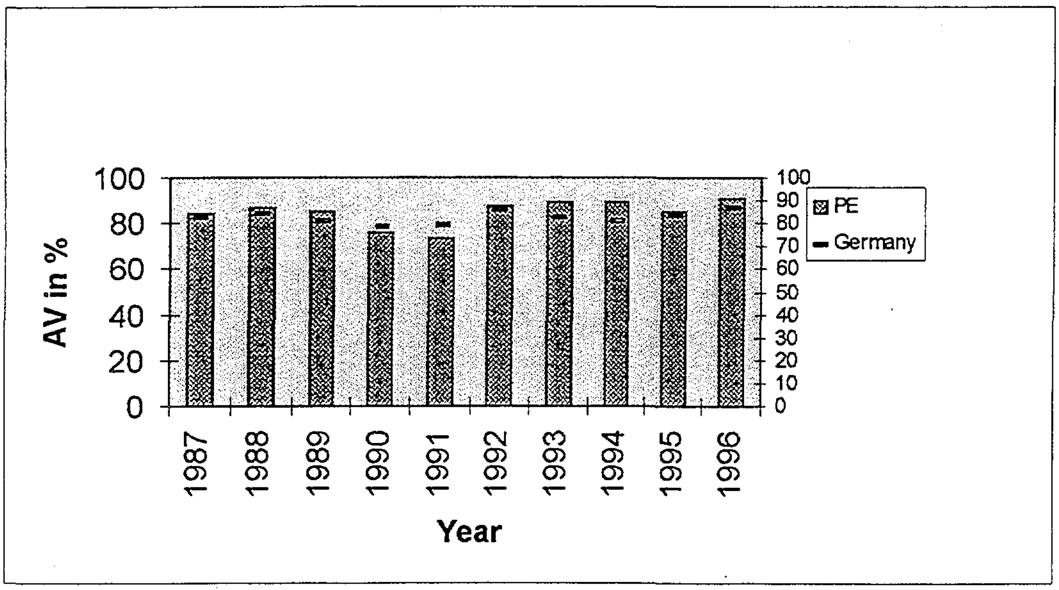

Figure 1 Availability German's NPP

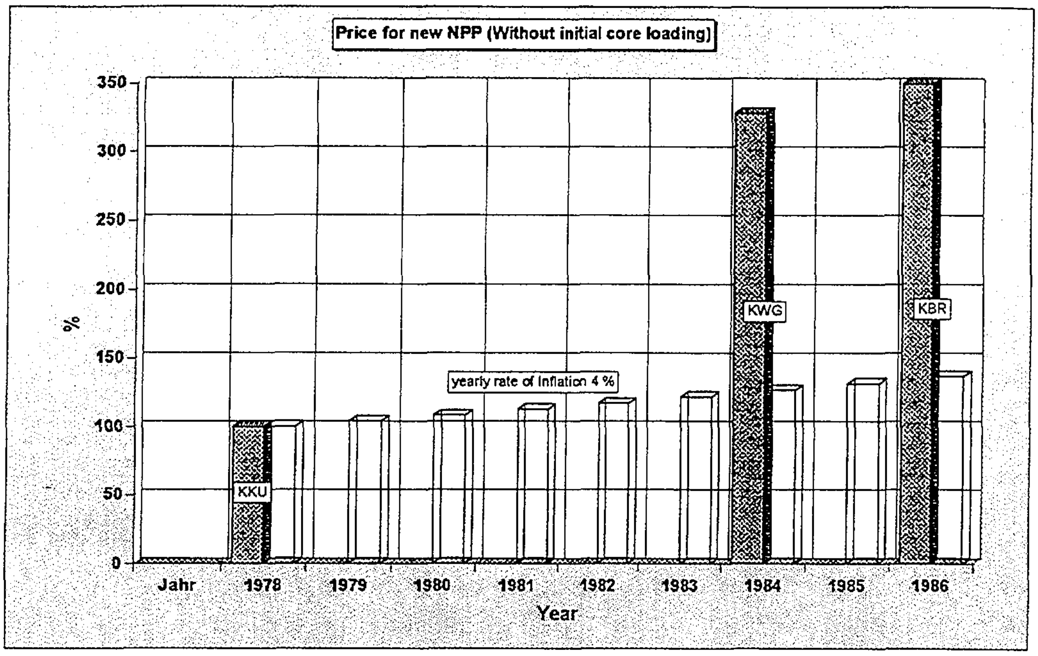

Figure 2 *Costs Compararision between three NPP of PreussenElectra Utility*

On Fig. 2 is shown a comparison between the investing costs for three NPP's of PreussenElektra.

The NPP KKU (Unterweser) was built in 1978. 6 years later the investing costs for NPP Grohnde (KWG) with approximately the same electrical output was more than three times higher. Taking the inflation-rate into account the investment costs by an equal design might have been increased only 1,3 times.

Not only the new NPP's were affected with such a growth of costs. Even the existing plants had to be additionaly improved. The Fig. 3 shows the costs, which were arisen by the additional improvements and repairs because of design lacks and material reasons.

Further expenditures for attaining of new safety regulatory requirements were generated (Fig. 4), which partly exceeded investment costs.

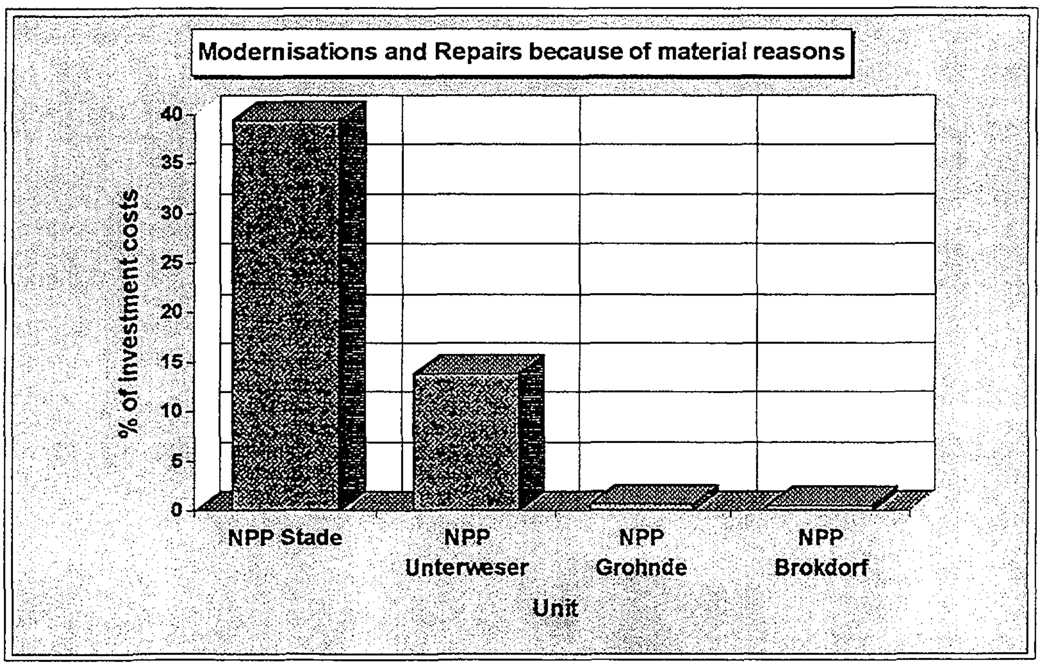

Figure 3 *Costs due to Modernisations and Repairs*

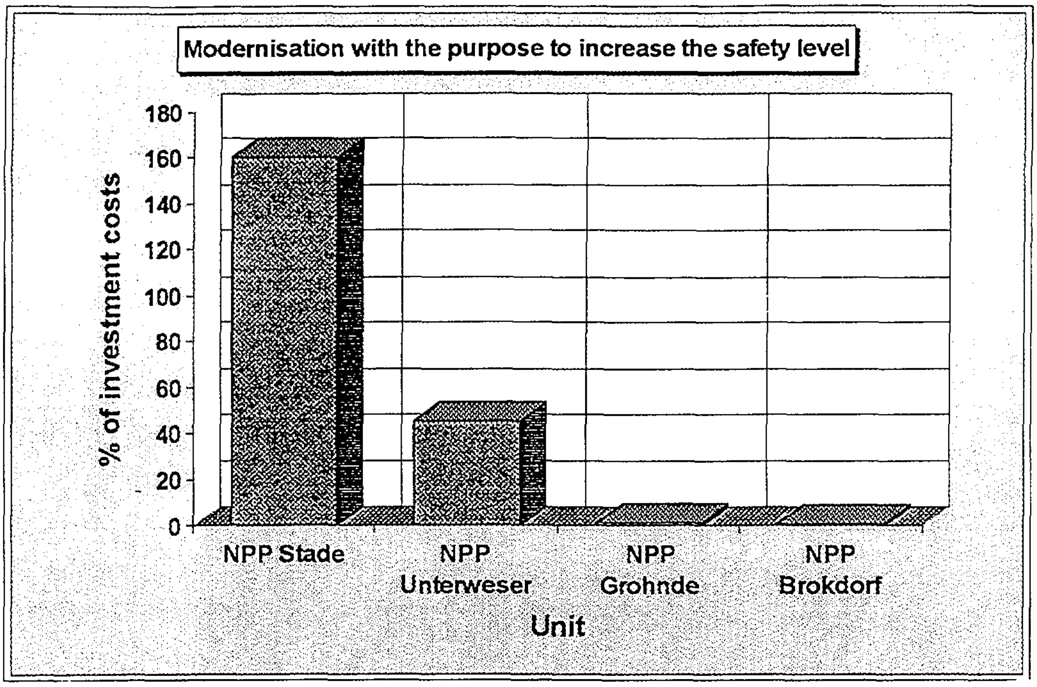

Figure 4 *Additional Costs due to the New Safety Regulatory Requirements*

Such an evolution and further cost-factors, especially in the waste management caused the situation, that nuclear energy today is not without hesitation the cheapest source of energy. The situation with the nuclear energy was additionally complicated with the fact, that the prices for coal and gas during the last years constantly decreased. Above it with the increasing of power efficiency also the investment costs for fossile-fired plants decreased. The fossile-fired technology has become more competitive with nuclear power.

On the other hand we know about the existance of some issues, which shows the advantages of nuclear energy. For example, a well operating plant produces no emissions harmful for the enviroment and the atmosphere, especially greenhouse gases.

Were is the way out?

In the present time we can watch an evolutionary and a revolutionary or innovative lines of development of nuclear plants. I think, that the optimum for the future should include the advantages of both development-lines in new projects. It means:

- For the production of energy (non safety grade systems) we should use proven technology with a high reliability. For such systems it has to be possible to use only one train without redundancy and to achieve in this case a good availability.
- The active safety systems for decay heat removal can be partly replaced and partly completed with passive features for safety. The passive systems should give the possibility for a substantial simplification for the whole system, I&C-systems and power supply.

In this case we can be sure, that we are noting an important technical requirement: Not too long development-strides from the existing technology. On the other hand, we are opening the door for a new generation of nuclear plants with a better competitive examination, higher safety level and I hope with an increased public acceptance.

Two types of NPP's are in development in Germany now. I prefer to speak about the development of the BWR 1000, because of a high number of publications about the European pressurized water reactor (EPR), which is being worked out in cooperation with France.

Development of a new BWR

As an example of a reactor, which connects the advantages of the evolutionary and a revolutionary lines, I like to present you the development of a new boiling water reactor BWR 1000 in Germany by

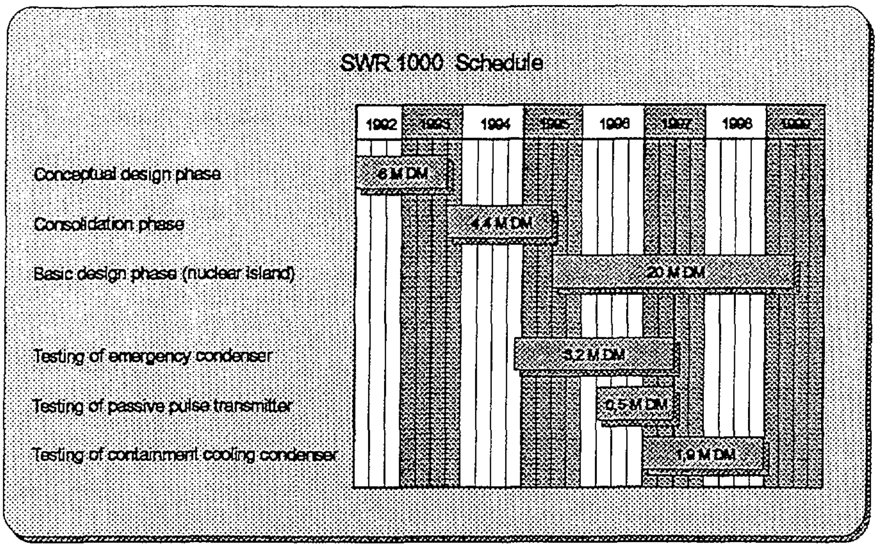

Figure 5 *Costs Resulting from Development of a New Boiling Water Reactor BWR 1000*

Siemens. The project is sponsored by German utilities and supported by various European partners. The work has been started in 1992 (Fig. 5), based on the following principal goals:
- To reduce the probability of a severe accident, especially of core melt,
- To control a core melt accident in such a way, that the consequences o f the accident remain restricted to the territory of the plant,
- To make the economy comparable with already existing large nuclear or coal-fired plants.

The following principal design-decisions were made for attaining the afore- mentioned goals:
- Low core power density will be combined with large water inventories in the reactor pressure vessel in order to achieve a good-natured behaviour in terms of normal operation, transients and accidents,
- Passive systems will be used in combination with a reduced number (combined to existing plants) of active systems. This diversity makes possible to exclude the probability of common mode failures in such safety systems and to reduce in this way the probability of severe accidents. On the other hand, the passive systems gave the possibility to simplify the technology of systems, I&C and power supply for attaining the economic goals.
- The water inventories for passive systems are calculated for a grace period of several days before manual intervention by operating personnel will become necessary. This design feature helps to control the plant after external hazards.
- The area around the reactor pressure vessel will be flooded in case of risk for a melting core, in order to ensure retention of the molten core inside the vessel and to achieve the removal of heat through cooling of the reactor pressure vessel exterior.
- Proven components and technologies with simplifications based on operating experiences in existing plants will be used in active safety systems and non safety grade systems, especially in the turbine area.

The main technical characteristics of the design concept are shown on the Table II in comparison with the parameters of the most modern existing BWR in Germany, Grundremmingen B and C.

The striking differences between existing BWR's and BWR 1000 are in the reactor internals (Fig. 6). The length of core is about one meter shorter and the average power density is probably 17 % lower. These issues in conjunction with a different fuel rod geometry decrease the average linear rod power to 44 This is the main factor contributing to the reactor's good behaviour during normal operation and transients, which also provides the basic prerequisite for achieving higher discharge burnups.

The feedwater and main steam nozzles as well are positioned higher. The diameter of the chimney above the core has been necked down in order to reduce the volume of the steam-water-mixture. All this features provide a water inventory above the core that enables the reactor to be depressurized without any feedwater make-up and without any risk of core uncovery.

Table II *Technical Characteristics of New BWR 1000*

	BWR 1000	Grundremmingen B/C		BWR 1000	Grundremmingen B/C
Plant			Reactore pressure vessel		
Thermal power	2778 MW	3840 MW	Inner height	22,7 m	22,35 m
Gross power output	1013 MW	1344 MW	Inner diameter	7,00 m	6,62 m
Net power output	977 MW	1284 MW	Design pressure	88 bar	87,3 bar
Reactor core			Number of internal recirculation pumps	6	8
Number of fuel assemblies	684 (12 x 12)	784 (9 x 9)	Containment		
Number of control rods	157	193	Inner diameter	34 m	29 m
Length of active fuel element	2,80 m	3,76 m	Inner height	28,7 m	32,5 m
Average power density	48 kW/l	56,8 kW/l	Turbine		
Average enrichment	5,3 %	3,14 %	Speed	25 s^{-1}	50 s^{-1}
Discharge burnup	65 GWd/t	35 GWd/t	Number of casings	1/3	1/3
Fuel cycle length	1 year	2 years			

The main innovations in the design concept has been achieved by introducing passive safety features which provide redundancy and diversity for a reduced number of active safety systems. As long as the reactor vessel is closed, the passive systems are capable to control an accident entirely by themselves for a period of several days without any need for manual intervention, even if there has been a complete loss of power. The following passive features are integrated into the concept:

- Emergency condencer for the heat removal from the reactor water,
- Gravity core flooding for core flooding depressurized reactor,
- Containment cooling condenser for heat removal from the containment atmosphere,
- Passive pressure pulse transmitter.

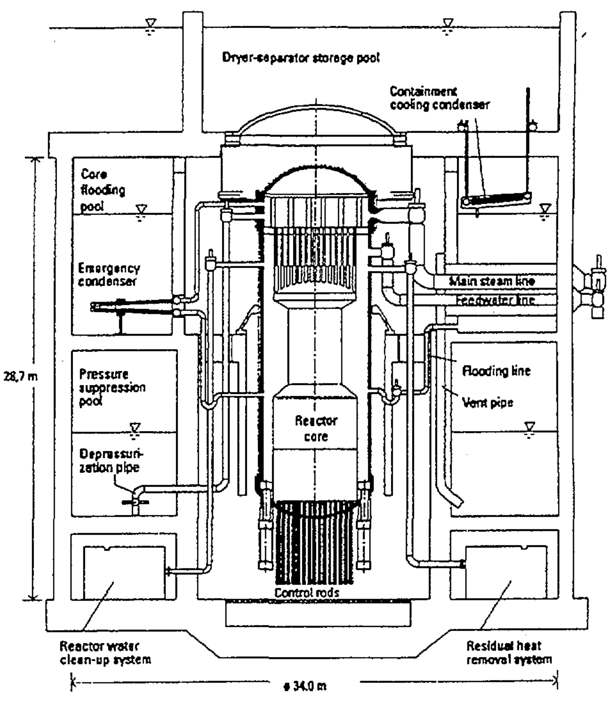

Figure 6 *Reactor Vessel of the New BWR 1000*

Emergency condencer:

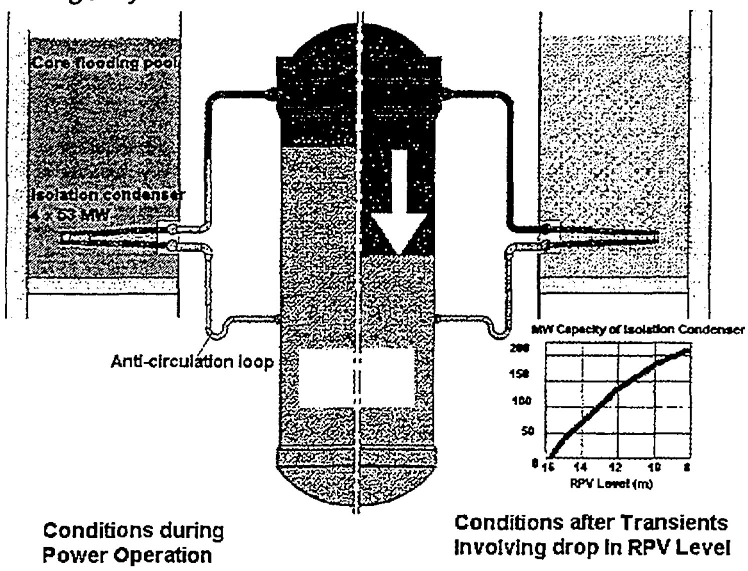

Figure 7 Passive Features of the New BWR 1000

The four emergency condencers are located in the core flooding pool and conected with the reactor pressure vessel by non-isolated steam discharge and condensate return lines (Fig. 7). Condensate lines contain an anti-circulation loop (termosiphon), so that practically no circulation of reactor water takes place through open lines by a normal water level in the reactor.

If the water level in the reactor is droping, the steam will enter the condensator and the condensate will return into the reactor vessel. The energy will transfer to the water of the core flooding pool, which will slowly raise its temperature. If the water will not be cooled, it begins to evaporate after 10 hours. The emergency condencer was tested in the Forschungszentrum Julich. The condenser showed no problems during all operation phases of the tests. Because of thermosiphon, as long as the primary water level remains higher than the heat exchanger pipes, is the convective heat transfer unpossible. The power rate depends from the water level and the pressure. It corresponds very well with the calculated rates.

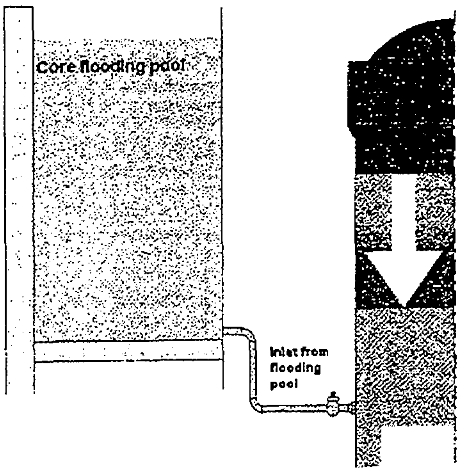

Figure 8 Gravity core flooding:

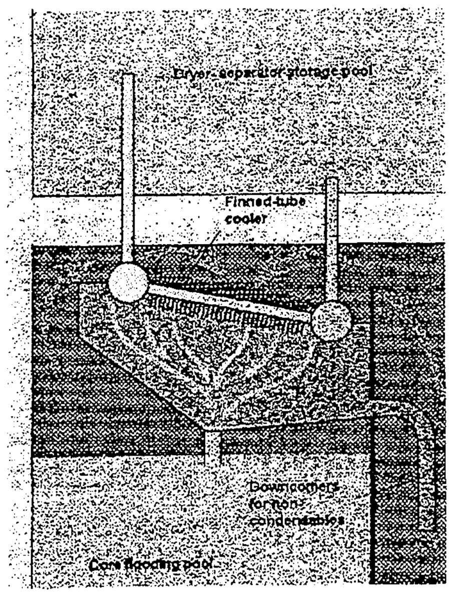

Figure 9 Containment cooling condenser.

In case of a loss-of-coolant accident (LOCA) or depressurisation of the reactor with the safety-relief valves, it is necessary to make up the water inventory in the reactor vessel. If the pressure in the vessel is lower than the geodetical pressure in the flooding pool, the water can go by gravity flow via six supply lines and self-actuated check valves into the reactor vessel (Fig. 8). The flooding pool contains a water inventory of 3600 m^3. This volume of water is sufficient to fill the reactor pressure vessel and the drywell of the containment up to a level, which is equal to that in the flooding pool. This level is higher than the emergency condenser. The flooding pool guarantees because of this issues, firstly-the existence of a water-cover over pipe breaks at lower elevations inside and outside of the reactor pressure vessel, secondly-an effective cooling of the reactor vessel exterior and thirdly-the heat transfer by the emergency condenser. Even in case of LOCA on the heat transfer pipes of the emergency condencer we don't expect problems. This situation is comparable with a small leak in a safety-relief valve.

By an accident control without the using of active heat removal systems and only with the help of passive systems, the energy is accumulated in the containment and the temperature rises up. The containment cooling condenser (Fig.9) realized the heat transfer from the inside of the containment to the outside, into the water inventory of the steam dryer and steam-water separator storage pool. The condensate from the containment condenser returns into the flooding pool. This system works also without any active components. There are no valves in the lines. The containment condenser can be in operation more than three days before it will be any need for external interference. After this period it will be necessary to make up the water inventory of the steam dryer and steam-water separator storage pool.

The existence of non condensable hydrogen and nitrogen in the containment atmosphere and aerosols during several accidents was also taken into account for the design.

The first tests of the containment cooling condenser are going on now at the PANDA test facility in Switzerland.

This switching device, which operates without any interactions with I&C systems, initiates safety functions. The transmitter (Fig.10) is like a small heat exchanger and works similar to the emergency condenser. When the water level in the reactor pressure vessel is normal, the tubes inside the transmitter are filled with cold water and don't transfer heat. If the water level drops, steam comes into the transmitter and condensates. The transferred heat during this process causes the pressure on the shell side of the heat exchanger. This pressure-signal can be used to activate pilot valves, which in turn initiate the safety functions of reactor scram, containment isolation and reactor vessel depressurization.

During the tests the transmitter works properly. The main task of the actual tests is to promote the design's optimization in order to achieve a shorter erection time.

The described passive safety systems on Figure 11 in combination.

This passive safety systems are in operation with a reduced number of trains of proven active safety systems. Table III shows how the both kinds of safety systems achieve safety functions.

It is difficult now to forsee all the peculiarities of the cost-situation. But because of the far-reaching simplifications in the basic design, we can be sure, that the BWR 1000 will achieve the sufficient level of competitivness with the other power producing technologies. Table IV shows the simplification of the most important systems in comparison with a modern standard BWR, which are in operation in Germany now.

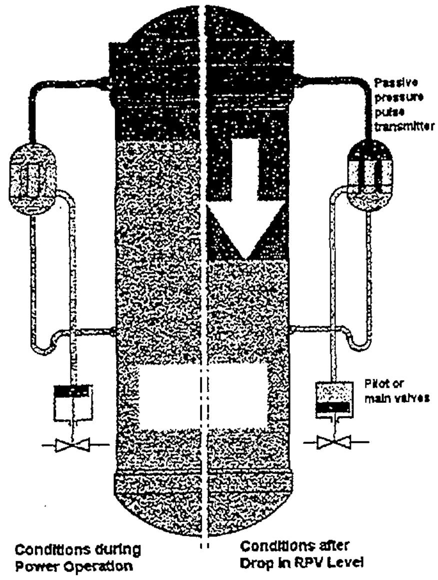

Figure 10 *Passive pressure pulse transmitter.*

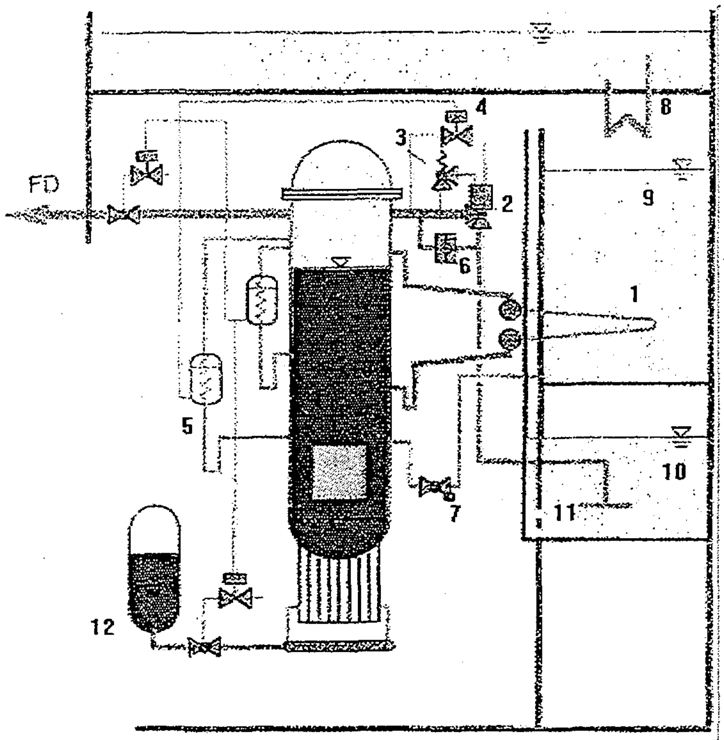

Figure 11 *Passive Safety System*

Table III *Safety Functions of the Active and Passive Safety System*

<table>
<tr><th>Safety functions</th><th colspan="2">Active safety systems</th><th colspan="2">Passive safety systems</th></tr>
<tr><td rowspan="4">Reactivity control</td><td colspan="4">2 scram tanks</td></tr>
<tr><td colspan="2">tripped by I&C</td><td colspan="2">tripped by passive pressure pulse transmitter</td></tr>
<tr><td colspan="2">high pressure boron injection by pumps tripped by I&C</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2">Motor-actuated CRD tripped by I&C</td></tr>
<tr><td rowspan="2">Containment isolation (main steam line)</td><td colspan="4">3 Main steam line isolation valves per line</td></tr>
<tr><td colspan="2">Solenoid pilot valves tripped by I&C</td><td colspan="2">Diaphragm pilot valves tripped by passive pressure pulse transmitter</td></tr>
<tr><td rowspan="2">Reactor pressure control</td><td colspan="3">8 Savety-relief valves</td><td rowspan="3">8 rupture disks</td></tr>
<tr><td>tripped by I&C</td><td rowspan="2">8 solenoid pilot valves</td><td>8 spring loaded pilot valves</td></tr>
<tr><td>Reactor depressurization</td><td>tripped by I&C</td><td>8 diaphr. pilot valves tripped by passive pressure pulse transmitter</td></tr>
<tr><td rowspan="2">Core cooling
- high pressure
- low pressure</td><td colspan="2"></td><td colspan="2">4 emergency condensers</td></tr>
<tr><td>low pressure core injection mode</td><td rowspan="2">2 residual heat removal systems</td><td colspan="2">6 flooding lines</td></tr>
<tr><td>Residual heat removal from containment</td><td>- low pressure core injection mode
- wet well cooling mode
- residual heat removal mode</td><td colspan="2">4 containment cooling condensers</td></tr>
</table>

Table IV *Comparison between the two BWR's Systems*

Systems	BWR today	BWR 1000
Heat removal system	3 trains for high pressure injection, 4 trains for low pressure injection and heat removal	2 trains for low pressure injection and heat removal, - Emergency condenser, - Containment cooling condenser, - Flooding pool
Cleaning systems	2 high pressure reactor water clean up systems, 2 trains for heat removal and water cleaning in the storage pools, 2 trains of gas exhausting systems	1 low pressure reactor water clean up system, 2 trains for heat removal in the storage pools, - mobil devices for water clean up in the storage pools, 1 train of gas exhausting system
Steam system	4 main steam lines, 1 auxiliary steam line, - steam lines for 2 preheater trains	3 main steam lines, - steam lines for 1 preheater train
Feedwater system	4/2 feedwater lines, 2 trains of preheaters, 3 x50% condensate- and feedwater pumps	2/1 feedwater lines, 1 train of preheaters, 2 x50% condensate- and feedwater pumps
Energy supply	6 emergency generators, - safety grade energy supply for 3 or more trains	2 emergency generators, - safety grade energy supply for 2 trains
Buildings		25 % lower volume

Conclusions

I have tried to show, how the passive and active systems together can be used for BWR 1000 and in what way it will be possible to achieve the appreciable simplification. These simplifications are visible not only in the systems themselves, but also have an impact towards the energy supply, I&C, auxiliary systems and the volume of buildings. In this way it will be possible to decrease enourmously the investment costs and the expenditure for maintenance in the whole.
The simplification is now urgent necessary from the point of high costs for the extensive development of safety systems in the NPP's, which are in operation today. From my point of view, provides BWR 1000 a interesting direction of development for increasing the safety level and probaly for decreasing the costs.

Reference

W. Brettschuh and K. Wagner, Germany's next generation of boiling water reactors. Kerntechnik 61 (1996) 5-6, p. 223-227