KRAFTWERK UNION AG

EXPERIENCE WITH LIGHT WATER REACTOR STANDARDIZATION

BY

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Experience with Light Water Reactor Standardization

As long as there was a multitude of reactor types, using various combinations of fuel, moderator and coolant, there was no real possibility for the standardization of nuclear power plants. However, when light water reactors demonstrated their commercial success, and allowed the development of 1300 MW plants out of the excellent experience gained from plants one fourth or half of this size, it was time to think of standardization as a means of building plants more economically, faster, and yet with improved safety. I would like to limit my remarks to the standardization of the pressurized water reactor, although we are currently in the process of standardizing also the boiling water reactor. The two 1300 MW BWRs we are currently constructing in Gundremmingen, Germany, will be the basis of our future series of boiling water reactors.

Today's state of standardization of KWU's PWR is represented by the 1300 MW nuclear power stations. These plants are the result of many years of development which started with a PHWR, the multi-purpose-research-reactor (MZFR) of 55 MWe in Karlsruhe; (commissioned in 1965, the time-availability since then is 59 percent). Since the MZFR is not a pressure tube type

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reactor but a PHWR with pressure vessel, it was possible to include several of its design principles in our first light-water reactor, the nuclear power station of Obrigheim (KWO, with 345 MWe). That station, commissioned in 1969, is already equipped with open fuel assemblies and finger control rods, possesses boric acid power control, and has main coolant pumps with controlled leakage seals. The integrated load factor in the 9 years since commissioning is 81 percent.

KWO is the first in the series of KWU PWRs with a spherical full pressure, dry steel containment, continued with the Stade nuclear power station, commissioned in 1972. The Stade station is the first one with Incoloy-800 steam generator tubes and austenitic tube spacers with spring characteristic. "Denting" is therefore an unknown appearance in our reactors. Already in the Stade planning phase we aimed at PWRs of the 1200 MW class, and therefore equipped the plant with a 1500 rpm turbo-generator. The two low-pressure cylinders are practically identical with those of the Biblis nuclear power station, and the generator is water-cooled, too. Although Stade is a prototype plant in many respects, its integrated overall load factor since commissioning is 85,3 percent. In 1977 Stade has achieved for the second time a load factor of 94 %. Picture

When Biblis A was handed over in 1975, after a construction time of 61 months, the risk, for us as well as for the Utility, was limited: We had used, as much as it was possible, design principles and components which already had proven their quality in operation. The Biblis A plant, the first one in the 1200 MW class, therefore has been and continues to be without major problems. When speaking today of standardization, we at first are thinking of this principle of "inner standardization". Of course it is easier for a turn-key supplier or general constructor to achieve such inner standardization, meaning similar and proven technology in the whole nuclear power station, and not just in the NSSS or in the nuclear island. We believe that the high load factors of these plants are, at least partially, the result of this kind of standardization: Since commissioning the load factors for Biblis A are 71 percent, and for Biblis B 68 percent.

The picture with PWR orders shows the history of PWR-development at KWU: The MZFR as starter, KWO and KKS as prototypes, Biblis A as demonstration plant, and Biblis B and KKU as "semi-standards". This is followed by 7 1300 MW standard plants in construction and a further 8 received as contract or LOI. Picture 2

It is not to be denied that standardization of nuclear power plants is more difficult than that of other plants. For one thing the ever increasing requirements of the licensing authorities are always reason for changes. On the other hand, technical development in certain areas (for example: materials, examination technology, and electronics), is so fast that a nuclear power station just completed, after 6 years of construction time, does not correspond to the latest state of the art any more. Therefore it would not be wise to standardize down to the last detail. One should restrict the efforts to essential things. Within a frame of standardization it should not be impossible to follow suit to new requirements of Authorities or to acceptable developments of the technology.

Kraftwerk Union, as supplier <u>and</u> architect enigneer of complete power plants, has standardized not only the nuclear steam supply system with its auxiliary systems, but also the arrangements of the buildings for the site-independent parts. This has been done together with German Utilities. The arrangement which resulted as the optimum solution can be seen in Picture 2. It should be mentioned here that standardization without co-operation of and contributions by potential customers is not possible. Only through previous consent with the Utilities can a standardized concept be successfully sold. Picture
I will mention later some of the reasons which led to this standard site plan. Here I would like to point out a speciality in the German standardized site plans:
You see the emergency diesel building (f) diametrically opposite from the emergency feedwater building (e). The reason is that the emergency feedwater building contains

an additional set of 4 diesels, and that in the case of an "external event" (e.g. airplane crash) the airplane would fall onto either of the two buildings, but not on both. The protection against external events has led to standardized system designs which permit the plant to run in a shutdown mode for at least 10 hours, without any human action necessary during this time.

We have maintained the spherical reactor building concept ever since the first reactor we built. We even use this same principle for our heavy water reactors. Of course the arrangement of components within the containment, as well as the components themselves are standardized. When we realized this concept for the first time in Obrigheim, we were guided by the thought that refueling actions and activities in the fuel pool should all take place within one closed containment, so that the fuel change can be performed in the minimum possible time. In the meantime this design has shown other essential advantages: Picture 4

1. The large working area available on the refueling level reduces the time necessary for preparation and execution of all refueling work and of inspection and repair activities;

2. The placing of equipment air lock and construction hatch on the refueling level, together with the inner polar crane and the outer gantry, permit to bring all heavy

components into the reactor building when the reactor building has already been finished. This is of particular importance for the erection scheduling of the NSSS and the required clean room conditions. It is even possible to take out heavy components for repair, without having to remove civil engineering structures.

3. The spherical full-pressure containment with a secondary concrete shield is a double containment whose annulus is ventilated separately through filters. Furthermore the ECCS is ideally located in the lower annulus.

In the interest of cost minimization it has been necessary to forsake the temptation of incorporating the technical optimum in all plant sizes. Instead, it has shown that using identical components for 2-, 3- and 4-loop plants is the only way which makes sense, both in commercial and technical aspects. For example, the main coolant pipes of all plant sizes have a diameter of 750 mm throughout, allowing the use of unchanged tools during the fabrication process.

Picture 5 shows the main data of the three plant sizes which we have standardized and which we are offering on the world market. Of particular importance is the fuel design. You see that we have maintained a 16x16 cross section throughout, for all plant sizes. The only difference is the fuel element length, which we have Picture restricted to two sizes. This is a success in standardization which is based on the good experience with our fuel. It has never been necessary to decrease the rod diameter, since there were no problems with collapsed fuel, high canning temperature, etc. The fuel element is shown in Picture 6. It permits the removal and replacement of individual rods if they should show leakages, so that a defect fuel element can be reused in the reactor. Picture 6

Standardized for all reactor sizes is also the concept of emergency core cooling. Based on countless experiments with single rods and bundles, we cool the core in the case of a loss-of-coolant accident from the bottom <u>and</u> from the top. As a consequence, all hot-leg reactor coolant pipes are equipped with injection nozzles, as shown in Picture 7, so that emergency coolant can be brought in against the normal flow direction. We have had to back-fit older plants with this type of emergency cooling equipment. It has proved highly efficient as a spray-condenser in the upper plenum against all kinds of steam-binding effects in case of a cold-leg break. It even quenches the core effectively from the top, reducing the fuel temperatures appreciably. Picture 7

An essential condition for successful standardization is a solid technical basis which does not require repeated changes. One example for this are steam gene- Picture 8 rators. Being the weak point in many of today's PWRs, they ought to be designed with the utmost care. We are installing steam generators of identical design (minor points excluded) in all plant sizes, so that the experience gained in a 4-loop plant is valid also for 2-loop plants. For all of our reactor plants, except the first demonstration plant (KWO), we have equipped the steam generators with Incoloy-800 tubes and have specified a low concentration phosphate water chemistry. The philosophy is to buffer only against such impurities through condenser leakage whose concentration is below the detection level. Waisting of tubes is negligible and obviously comes to a standstill at 5% waisting after 5 years. Tube spacers were made of austenitic steel. As a result, we have never had a leaking tube, and never any problems like denting, waistage-corrosion etc. Costly R+D efforts have in this case resulted in a highly successful technical solution, which then was a basis for thourogh standardization.

One aspect which usually remains unnoticed is the level on which standardization is pursued. A company like KWU, as supplier and single contractor for complete turn-key power stations, is in a better position to standardize with respect to overall plant optimization than other suppliers. If the supply of a power station is in one hand only, it is possible to create an overall standard concept without having to consider, for example, that there might be half a dozen possible turbogenerator suppliers, all with different technologies. Besides, having only to deal with a single contractor who is responsible for all subsuppliers and who carries all risks, is an advantage which is very much appreciated by our customers. This especially holds for the instrumentation and control technology which is uniform throughout the whole plant, helping to make operation and maintenance easier and safer.

As mentioned before, standardization to the extent that we have performed is not possible without utility co-operation. It has been a lengthy process, involving Picture 9
hundreds of meetings and thorough co-ordination within our company. As shown in Picture 9, initial steps towards standardization were taken in 1970, and detailed discussions with Utility working groups started in 1974. One of the accelerating factors towards standardization has been the 1973 oil crisis which made everybody aware that fossil fuel will become rare and expensive.

The 9 working groups, consisting of KWU and several German Utilities, are shown in Picture 10. All parts of the plant are covered, from primary system to licensing procedure. In this way the KWU 1300 MW PWR plant has become a well-known product, accepted by German and foreign Utilities. Picture 10

Picture 11 shows the organizational interconnections which were set up within KWU to make sure that all aspects of standardization decisions are recognized, including direct and indirect influences on other parts of the plant.

Pictur

As far as the arrangement of plant buildings is concerned, we believe to have found an optimum solution for all plant sizes, as shown in Picture 12. Of course, site-dependent structures like cooling water intakes can only be standardized to a relatively small extent. The arrangement we came up with is the result of an integral consideration of the following major requirements:

Pictur

- Possibility for independent construction and erection of the individual buildings and optimization of construction-site management and -tooling
- Concentration of those components and systems which are interconnected
- Use of short pipe and cable connections, under consideration of the separation of redundant channels
- Provisions for easy accessibility for maintenance purposes, with minimized radiation exposure to the personnel
- Unambignous definition of controlled-access areas
- Adequate shielding of all sources of radioactivity
- Protection from plant-internal and plant-external influences, like loss-of-coolant accidents or airplane crashes.

The reactor building itself, consisting of an inner spherical steel shell and an outer concrete shield (double containment), is the building which is standardized to the greatest detail. The annulus between the steel and concrete containments is used extensively to house safety-related equipment. For example, this is the space where we locate the 4 pairs of refueling water storage tanks, one for each emergency core cooling strand. The merits of the internal fuel pool have never been questioned by the German Utilities, and therefore the internal pool within the spherical containment may be regarded as an example in success of standardization. Picture 13 Picture 14

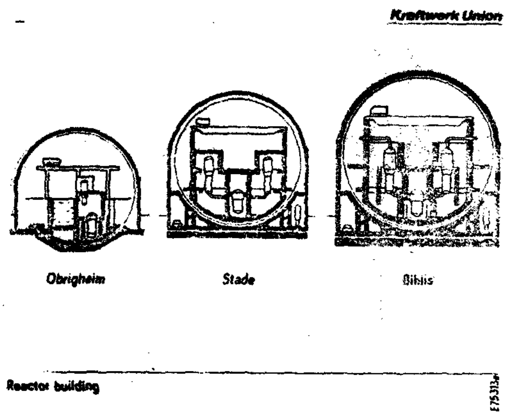
I would like to point out that even the possibility of extensive steam generator tube failures has been taken into account in building standardization: The equipment air lock, which can be seen on the left side of the picture, can be completely removed to open a construction hatch, allowing even the replacement of a steam generator in one piece in a relatively short time.

The unquestionable economic advantages of standardized equipment, systems and plant arrangement are complemented by the increased safety standard achieved by retaining well-proven concepts. The double-containment belongs to this category, but also the 4-fold redundancies of safety systems and the reactor protection system which is self-supervising by a pulse frequence of 1000 times each second. Increased dependability of quality control is one of the by-products of standardization, since well-known and proven equipment and inspection methods applied there-on can be repeatedly used for assuring the quality of systems and components.

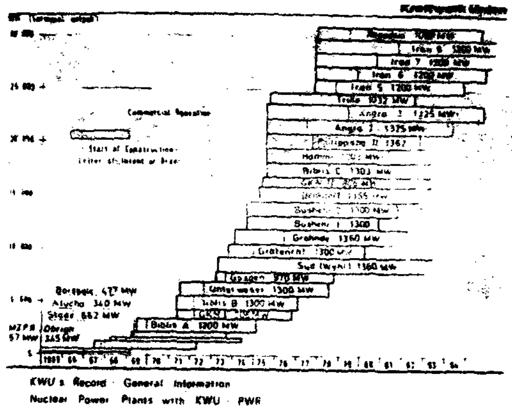
The uniformity of instrumentation and control technology in the whole plant has already been mentioned as essential element of inner standardization. In KWU's control rooms, for example, the same kind of equipment is found for the turbo-generator, reactor protection and control assembly control. In the amplifier rooms there is the same kind of equipment throughout. This uniformity in control technology makes any kind of balance of plant criteria unnecessary. The great advantage for reactor operation is simple servicing, one kind of spare parts only, and the possibility for the electricians to concentrate their knowledge on the one existing technology.

Conclusion

The progress made in standardizing nuclear power plants is to a large extent based on co-operation between the power station supplier and the Utilities. Utilities have important contributions to make, based on their operating experience and their profound knowledge of licensing requirements. A handicap which still exists for a worldwide supplier of power plants is the difference in safety requirements and licensing regulations in various countries. This runs of course counter to standardization efforts, and this is an area in which future standardization efforts would be worthwile.



Picture 1



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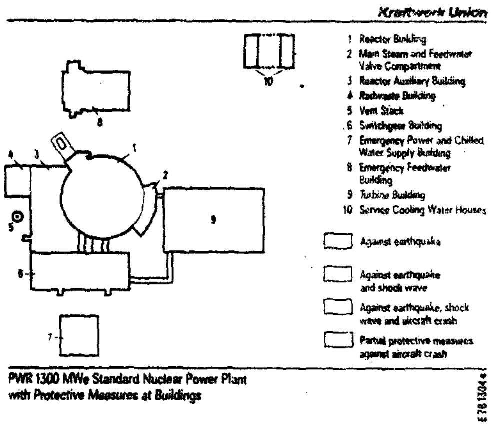

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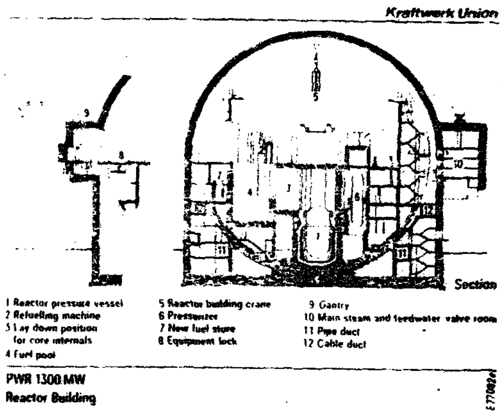

Picture 4

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	Standard 700 MW	Standard 1000 MW	Standard 1300 MW
Number of loops	2	3	4
NSSS thermal power	1990 MW	3027 MW	3782 MW
Power per loop	995 MW	1009 MW	945.5 MW
Number of fuel assemblies	157	177	193
Active core height	3400 MW	3400 mm	3900 mm
Fuel assembly matrix	16×16	16×16	16×16
Containment diameter	50 m	53 m	56 m

Main Parameters of Standard KWU Pressurized Water Reactor

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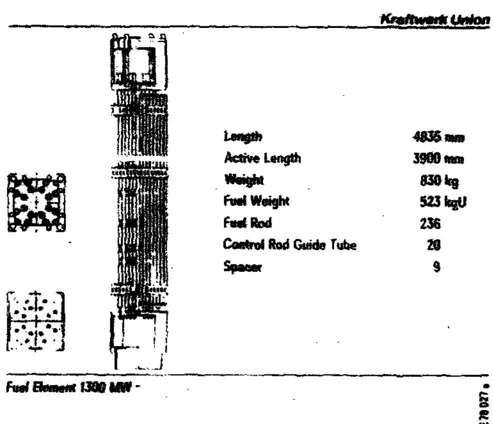
Picture 5



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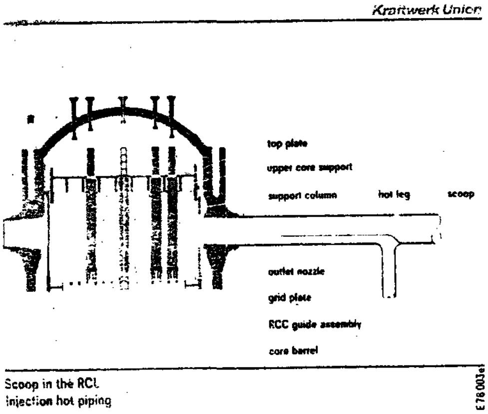

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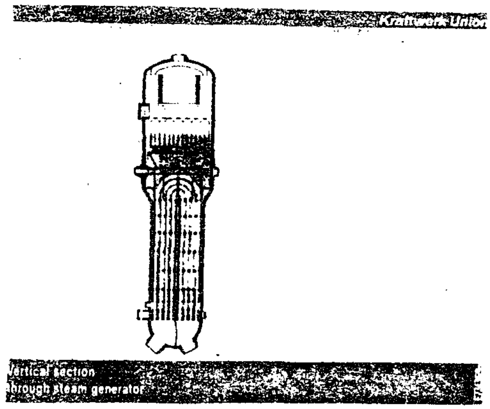

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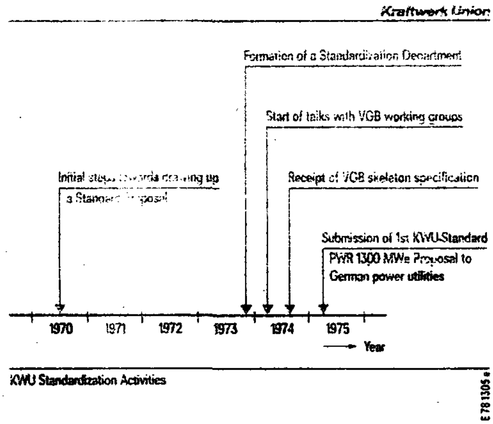
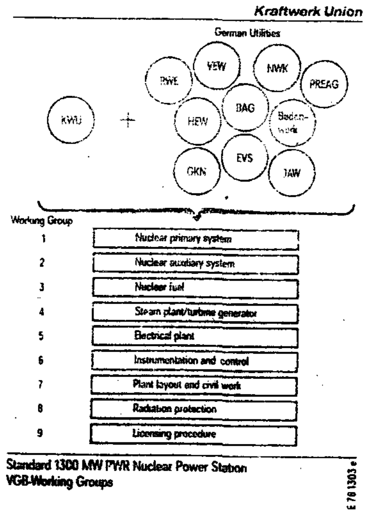
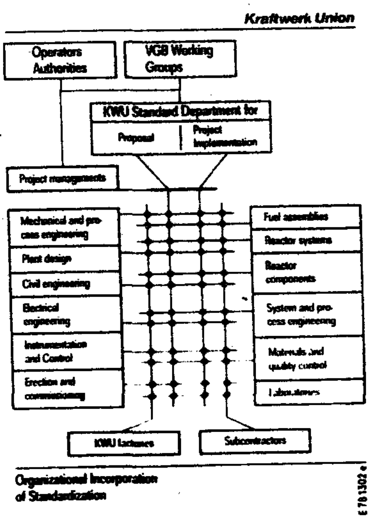


Picture 9



Picture 10



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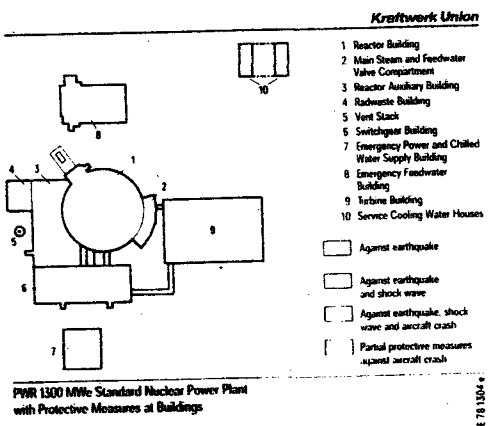
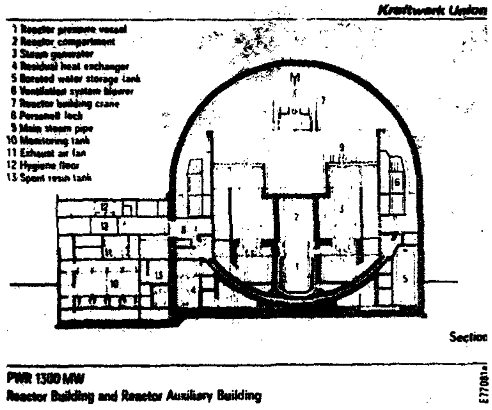
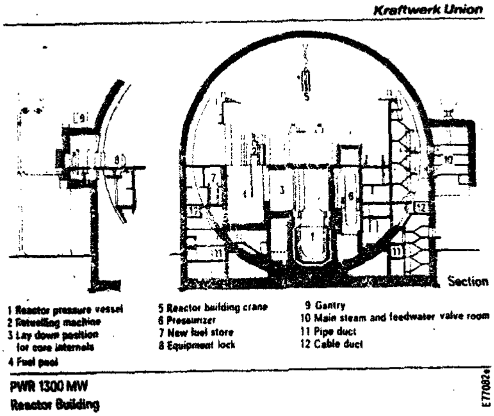


Picture 12



Picture 13



Picture 14