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FRAMATOME PWR TECHNOLOGICAL DEVELOPMENT.

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Framatome PWR technological development

Framatome's export model pressurized water reactor (PWR) reflects 25 years of experience in the nuclear field. To fully appreciate the positive impact of this experience on PWR design, it is first necessary to review Framatome's position as a reactor vendor, the development of its PWR technology, and its current product.

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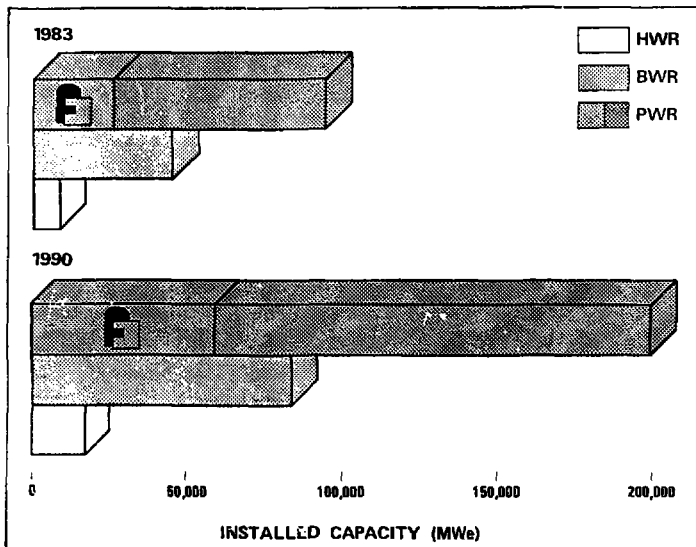
Framatome and the world reactor market

With 25 years of experience in the nuclear field, Framatome is now the world's second largest supplier of pressurized water reactors (PWRs).

Framatome chose the PWR because of its many advantages, including enhanced safety provided by separation of the primary and secondary systems, high reliability and ease of maintenance.

In 1975, Electricité de France (EDF), the French national electric utility, decided to base France's nuclear program exclusively on PWRs. To date, more experience has been accumulated worldwide with PWRs than with any other type of reactor.

On December 31, 1983, the installed nuclear capacity of the main types of commercial reactors in the Western world was 95,000 MWe for PWRs (Framatome reactors supplied 26,000 MWe), 46,000 MWe for boiling water reactors (BWRs), and 9,000 MWe for heavy water reactors (HWRs).



In 1990, based on the order books of world's leading reactor vendors, the breakdown will be 200,000 MWe for PWRs (Framatome reactors will supply 60,000 MWe), 85,000 MWe for BWRs and 20,000 MWe for HWRs. In other words, by the end of this decade, PWRs will produce twice as much power as the other two main reactor systems combined.

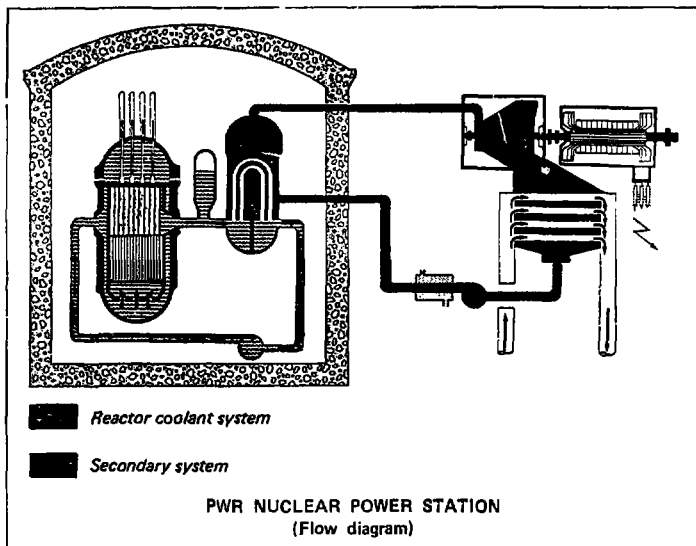
By 1990, with its French industrial partners, Framatome will be one of the largest constructor/designers of standardized nuclear power plants with 41 three-loop units producing a total of 37,000 MWe and 18 four-loop units producing a total of 23,000 MWe.

Framatome PWP development

Framatome's current PWR design incorporates the same basic concept as that adopted in 1961 for Chooz, the first PWR built in France, namely :

- a reactor coolant system in which light water is heated but prevented from boiling by a pressurizer which maintains the necessary pressure level,
- a secondary system, connected to the steam generators, which produces steam by extracting heat from the reactor coolant and then routes the steam to the turbine generator to produce electricity.

The reactor coolant system is housed entirely inside a leaktight containment which prevents release of radioactivity to the environment.



Since the first PWR built in France, a four-loop 300 MWe unit at Chooz, Framatome PWR design has evolved progressively. The step-by-step approach used has constantly aimed at fulfilling the same objective: increasing PWR performance and reliability while enhancing safety.

Two factors have made it possible to achieve this goal: extensive research and development (R & D) and reactor operating experience, which is all the more significant due to the standardization of Framatome systems and components.

Framatome has never introduced PWR design changes without full justification based on prior experience or an R & D program. Some of the areas in which major changes have been introduced are briefly described below.

After Tihange 1 which, compared to Chooz, had undergone considerable changes (3 loops instead of 4, increased reactor power and component size), modifications have been limited to the following areas:

- the Fessenheim fuel assemblies,
- the 51M steam generators for EDF's first standardized 900 MWe plant series,
- the 51B steam generators for EDF's second standardized 900 MWe plant series in France.

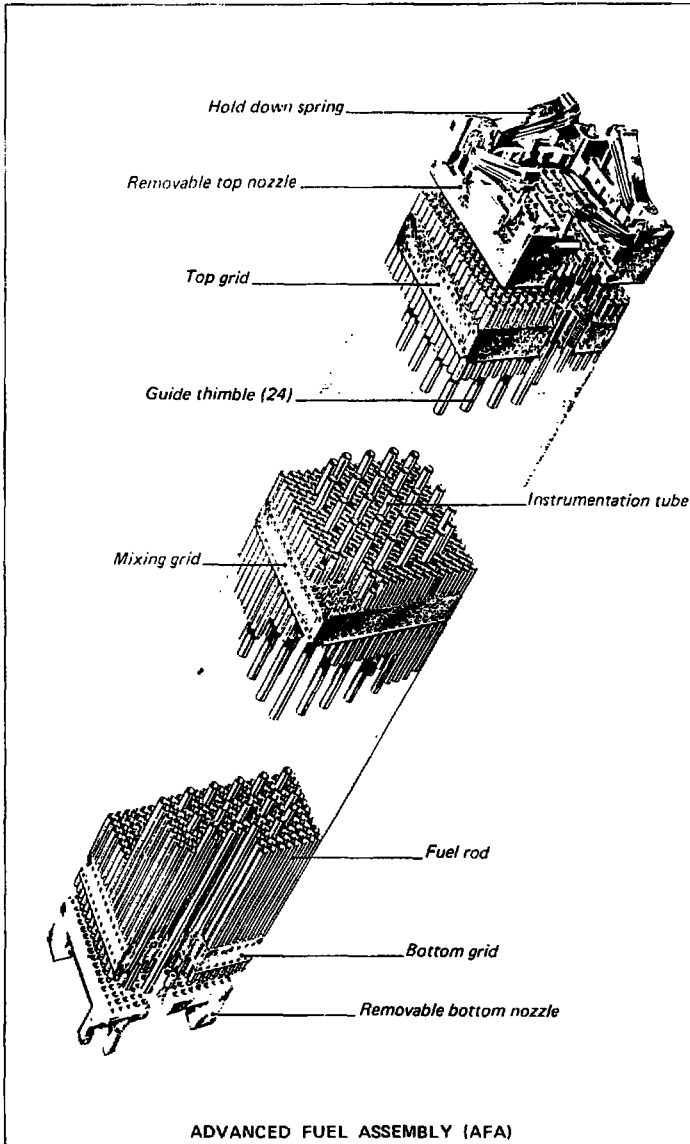
	Design year	Number of loops	Fuel	Reactor coolant pump	Steam generator	Upper internals
Chooz	1961	4	14 x 14			
Tihange 1	1969	3	15 x 15	93 D	51 A	Honeycomb configuration
Fessenheim Bugey	1970	3	17 x 17	93 D	51 A	Honeycomb configuration
French 900 MWe program (CP1)	1974	3	17 x 17	93 D	51 M	Honeycomb configuration
French 900 MWe program (CP2)	1975	3	17 x 17	93 D	51 B	Honeycomb configuration
Doel 3 Tihange 2	1975	3	17 x 17	93 D	51 B	Inverted hat configuration
French 1300 MWe program	1976	4	17 x 17 (14')	100	68/19	Inverted hat configuration
M 31 Model	1983	3	17 x 17 AFA	100	55/19	Inverted hat configuration

The 1,000 MWe-range three-loop model currently offered by Framatome features all of the above design improvements in addition to most of those incorporated in EDF's standardized four-loop 1300 MWe plant series.

FUEL ASSEMBLY DESIGN IMPROVEMENTS

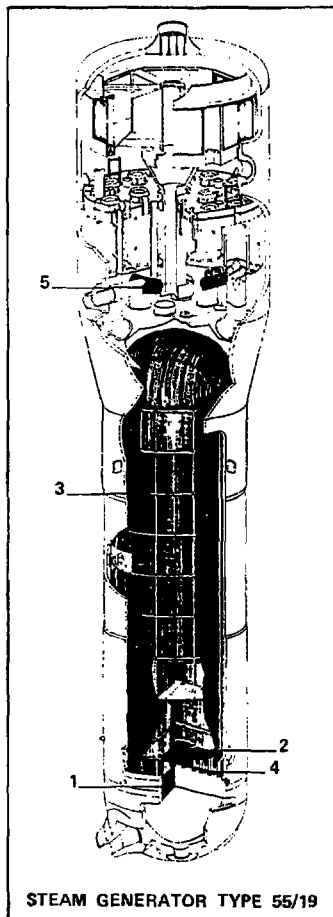
The fuel assembly design used at Chooz, which features a 14 x 14 array, was subsequently modified for later units (15 x 15 design for Tihange 1 and 17 x 17 design at Fessenheim). This allowed fuel rod linear power density to be reduced without affecting the overall power for each fuel assembly, thereby increasing resistance of the assembly to a loss of coolant accident (LOCA).

The advanced fuel assembly (AFA) which Framatome currently offers benefits from all the experience acquired with the standard 17 x 17 fuel assembly. The AFA uses the same array and exactly the same fuel rods. It nevertheless enhances fuel performance by means of a Zircaloy and Inconel mixing vane grid that reduces neutron absorption. The AFA also improves plant operation through the use of removable top and bottom nozzles, enabling failed fuel rods to be replaced. Extensive tests were conducted to verify the design of the mixing grid and nozzles before deciding to use the new assembly commercially.



STEAM GENERATOR DESIGN IMPROVEMENT

The steam generator is a typical example of a sensitive component whose design Framatome has gradually refined, taking advantage of operating experience. At the same time, Framatome has never deviated from the initial concept in order to avoid any incidents during reactor operation.



Numerous problems were observed in other countries between 1970 and 1974 on many steam generators similar to those at Fessenheim. To forestall such occurrences, Framatome has implemented five design improvements for the steam generators of France's first standardized 900 MWe plant series:

- full-depth (instead of partial) tube rolling (1),
- addition of a flow distribution baffle above the tubesheet (2),
- lengthening of the tube bundle wrapper (3),
- new blowdown line geometry (4),
- changes in feedwater distribution (5).

The first four modifications were aimed at reducing the risk of tube corrosion above the tubesheet; the fifth eliminates the risk of steam hammering in the piping.

These five measures implemented for the first standardized 900 MWe plant series in France were followed by three additional measures in the second standardized 900 MWe plant series to prevent tube corrosion at the tube support plates:

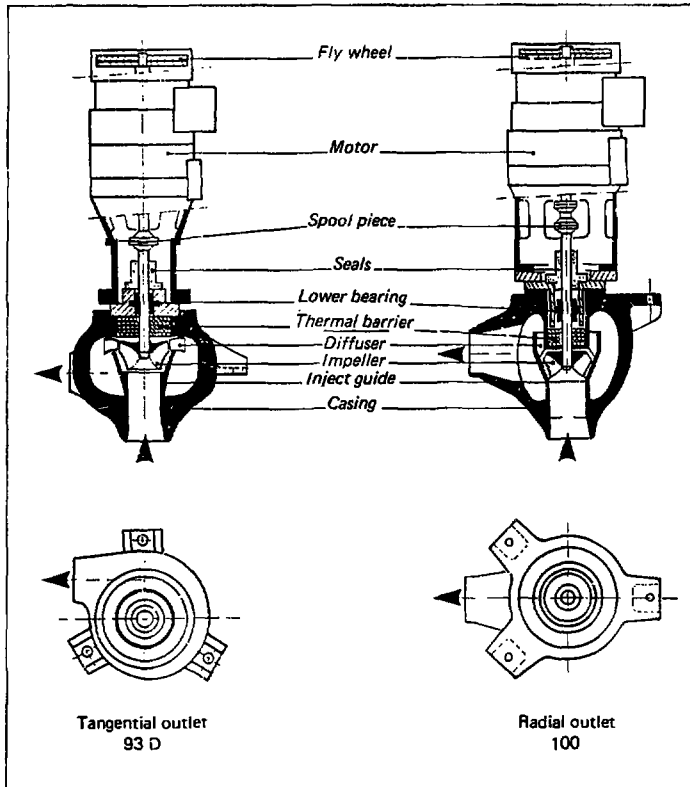
- modification of feedwater specifications,
- use of stainless steel tube support plates,
- improvement of water circulation through the annular gaps at the tube support plate intersections by adopting a new geometry with broached quatrefoil holes.

All of these improvements were developed from operating experience with similar steam generator models and were validated by intensive test programs. These modifications have of course been incorporated in Framatome's latest PWR model, the M31, whose steam generator differs from that of EDF's standardized 900 MWe plant series in that it uses technology from the 1300 MWe plant series, enabling the steam generator outlet pressure to be increased from 58 to 67 bars.

REACTOR COOLANT PUMP DESIGN IMPROVEMENTS

The reactor coolant pump was modified for the standardized 1300 MWe plant series in order to enhance hydraulic efficiency and permit all welds to be periodically inspected.

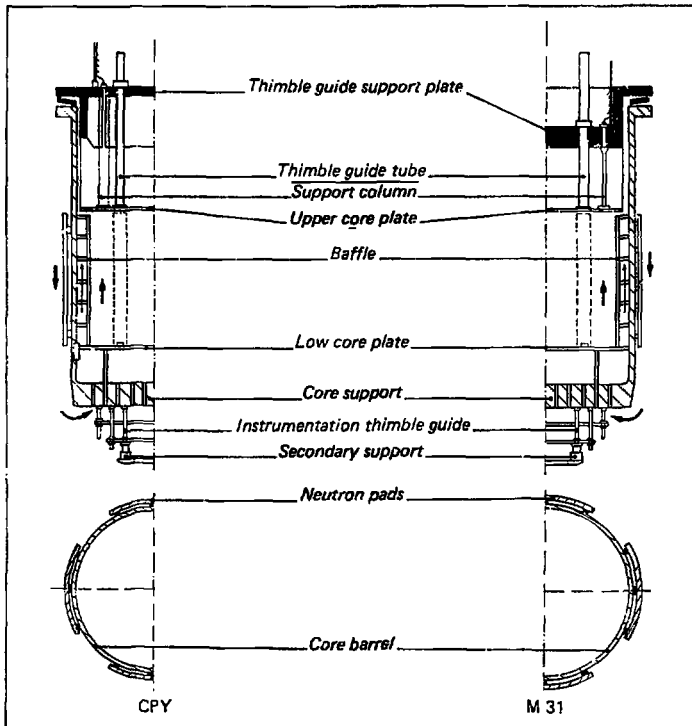
The most recent reactor coolant pump design, the model 100, now equips all of our 900 MWe export and 1300 MWe PWRs. It differs from the preceding model, 93D, in that the pump casing has a radial outlet.



REACTOR INTERNALS DESIGN IMPROVEMENT

The upper reactor internals were modified for the standardized 1300 MWe plant series in France, and for Doel 3 and Tihange 2 in Belgium.

The use of a simplified inverted hat configuration, seen in blue in the drawing, enables thorough stress analysis of this complex welded structure, used for the M31 model, to be performed.



The Framatome PWR today

The progressive approach to PWR development just outlined, plus the fact that each change is incorporated into a considerable number of standardized plants in France, has enabled Framatome to more accurately determine actual design limits. Framatome was thus able to gradually improve the performance of its PWRs while ensuring compliance with all applicable safety regulations and criteria.

	Design year	Number of loops	Thermal power (T.P.)	T.P. per loop	Steam pressure	Net electrical power
Chooz	1961	4	905	226	38	305
Tihange 1	1969	3	2660	887	58	870
Fessenheim	1970	3	2660	887	58	890
French 900 MWe program	1974	3	2785	928	58	920
M 31 Model	1983	3	2905	968	67	1000

The current M31 model, which produces 2905 MWth or 1000 MWe for a steam pressure of 67 bars, offers increased performance when compared to the standardized 900 MWe plants. Because the above-mentioned design limits were demonstrated on French standardized plants, increased thermal output is now possible. The French Safety Authorities have granted acceptance of this improved design.

The M31 is based on a set of design and construction rules, issued in a document called the RCC, which have been applied to all nuclear power plant projects in France.

Preparation of the RCC required a considerable technical effort involving the cooperation of EDF and Framatome in AFCEN, an organization specially created for the formulation of such rules. The RCC covers all technical aspects of PWR nuclear islands including systems design, mechanical, electrical and instrumentation and control equipment, fuel assemblies and civil works. The complete RCC comprises approximately 3000 pages.

Conclusion

Two fundamental principles have guided the development of succeeding generations of Framatome PWRs: technical continuity of the basic design and maximum use of the lessons drawn from operating experience. Application of these principles has been facilitated by the nature of France's nuclear power program, with its series of standardized power plants.

One further guiding principle is that all system and component modifications resulting from the application of the two fundamental principles must be thoroughly validated by testing, before being adopted as design changes.

This continuous but prudent advancing of PWR technology is the best possible guarantee for our customers of the reliability and top-notch operating performances of their Framatome PWR installations.

