Advanced light-water reactor: Russian approaches

A number of projects are under way for nuclear plants featuring new design concepts and approaches

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Severe accidents at the Three Mile Island and Chernobyl nuclear power plants have become the temporal milestones dividing the history of nuclear power into extremely different stages.

In the first stage, nuclear power development, on the whole, took place within the favourable background of public acceptance. In some countries, its development was even surrounded with an atmosphere of confidence and euphoria.

In the second stage, worldwide public opinion rapidly focused on nuclear plant safety, as powerful anti-nuclear movements arose, and nuclear's development strategy was critically reviewed.

This evolution, starting from the West, reached Eastern European countries after the Chernobyl accident. Consequently, by the turn of the century, the total nuclear power plant capacity in the Commonwealth of Independent States (CIS) will not be able to reach even one-third of the capacity level which was the objective of the Soviet nuclear program adopted in the early 1980s. On the whole, survey and construction activities were stopped at 39 nuclear sites having a total design capacity of 109 gigawatts (GW).

In Western countries as well, nuclear power's development has appeared frozen. In some of these countries, partial or complete moratoria on nuclear plants have been introduced.

Despite such conditions, deep economic and ecological motivations for developing a nuclear electricity component in the fuel-power balance have far from vanished. They are even growing with time. Systematic studies on the specific costs of coal- and nuclear-powered electricity production in countries of the Organisation for Economic Co-operation and Development (OECD) indicate a stable nuclear advantage over the period of the 1980s. Studies for the CIS confirm a similar tendency. The replacement of coal with oil or gas increases the economic competitiveness of nuclear power even more.

The period of the late 1980s also can be characterized as a time when the general public began to realize the ecological risk involved in the burning of organic fuels. Such growing concerns further gave rise to signs of nuclear power's revival.

Advanced reactor trends

Designs of advanced reactors capable of meeting the requirements of acceptable, or even ultimate, safety can be considered as a response to today's challenges by the physics community engaged in nuclear power development.

A strategic line now clearly emerging worldwide is the orientation of nuclear development to light-water reactors (LWRs) over the coming quarter of a century. Two basic tendencies have been identified in implementing this evolutionary development based on the experience of operating LWRs.

The first one is to integrate technologically proven solutions into new designs so as to eliminate the need for constructing a pilot plant. Such designs may pave the way for nuclear power development in the near future.

The ways of doing this essentially differ for large- and medium-sized advanced LWRs. For the large power plants, typical steps are the further improvement of measures for assuring safety, and this will lead to complication of designs to some extent.

For medium-sized advanced LWRs, the reactor power and specific core power are reduced, while the essential simplification of designs and

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the maximum possible utilization of passive safety means are achieved.

There are naturally projects trying to combine these two approaches. For example, additional passive safety features are being introduced in projects for large reactors, such as the Russian WWER-88 and WWER-92 projects.

The second identifiable tendency in the development of advanced nuclear plants concentrates on achieving the maximum possible level of self-protection for the reactor. To achieve this, inherent safety features are primarily used in combination with passive safety means.

It is natural that many of these features lack sufficient experimental verification. Some of them are at the stage of physical ideas. Therefore, if such innovative approaches are to be a success, their implementation should pass the stage of pilot prototype plants. As a result, the probable time of project implementation would be delayed to at least the turn of the century. It should be admitted that in terms of "physical simplicity" the innovative projects have greater chances of gaining the required level of public acceptance.

The plurality in approaches, however, is fraught with the threat of over-diversification and scattering of efforts. To keep diversification within reasonable limits seems a very important task. To solve it, continual analytical work is required to follow all levels of development, and to ensure experimental validation and reliability.

One may suppose that such an analysis, revealing advantageous features in individual projects, would make it easier to formulate requirements for a potential "East-West" advanced LWR project. It could incorporate technological achievements of the Western LWR and the Russian WWER (water-cooled, water-moderated energy reactor), and it could offer a good way for achieving international integration in the field of nuclear power.

This article presents a brief description of specific features for advanced LWRs now under development in Russia.

Large power plant projects

The attempts to design a new-generation, enhanced-safety nuclear power plant based on a WWER-1000 reactor were initiated a few years ago within the framework of the WWER-88 concept. *(See table).* To improve safety, the reactor unit was equipped with additional systems. They include a passive decay heat removal system with an air/heat exchanger mounted on the outside of the containment; a filtering system for relieving pressure in the containment under accident conditions going beyond the design basis; and additional accumulators for emergency core cooling.

In respect of these efforts, the Russian firm, Hydropress, started designing a new WWER-92 (V-410). *(See schematic.)* In contrast to the previous concept, this one suggests a radical simplification of the nuclear power plant (including active safety systems), improvement of passive system efficiency, and a potential reduction of core power.

The project envisages a four-loop arrangement of the primary circuit with vertical steam generators. A newly designed main circulation pump would be used. For emergency core cooling, additional water tanks are incorporated. The plant would have a passive system for rem-oval of decay heat that consists of four loops, one for each steam generator. The containment is double, with the inner one 42 metres in diameter and made of reinforced concrete.

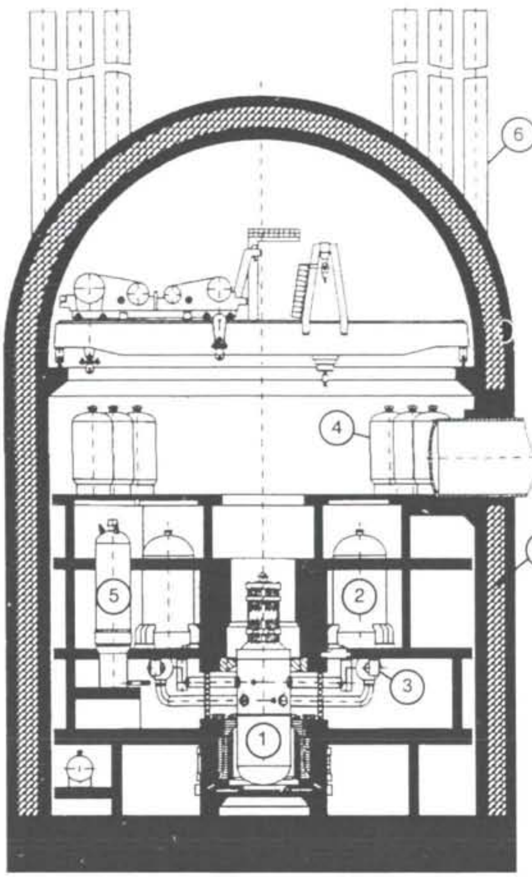
The focus is on enhancing safety by passive means. Note that in other advanced PWR designs, the passive systems are used only for medium-power reactors (up to 600 megawatts) and the core power is considerably reduced. Additionally, a comprehensive experimental validation seems to be needed.

Medium-sized power plant projects

Hydropress and other Russian firms also are designing a medium-sized power reactor, the WWER-500/600. The primary circuit is a conventional four-loop arrangement with horizontal steam generators that are structurally similar to those that have established a good performance record in operating WWER-440s. The reactor vessel is similar to that of the WWER-1000 (V-320).

The design of the WWER 500/600 focuses on improved operational reliability, with safety objectives primarily attained by improving the reliability of the basic technological equipment and optimizing safety-related systems.

It should be noted that the adopted solutions for this project conform with global tendencies for improving the safety of medium-sized loop-type power reactors. Among these solutions are the reduction of the unit power and specific core power; passive systems with natural convection for removal of decay heat; application of a primary circuit depressurization system; implementation of a passive system intended to compensate for water loss from steam generators; and application of external cooling by natural convection for the steel containment.

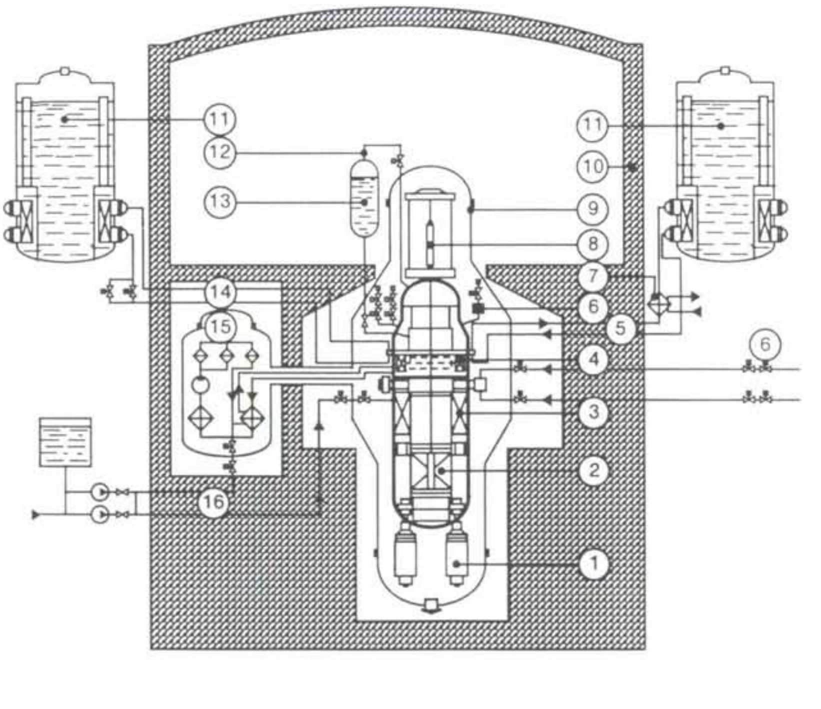


Schematic of WWER-92 reactor building

1. Reactor
2. Steam generator
3. Reactor coolant pump
4. Emergency core cooling system water tank
5. Pressurizer
6. Decay heat removal system (passive)
7. Containment

Flow diagram of VPBER-600 plant

1. Main circulating pump
2. Reactor
3. Steam generator
4. Heat exchanger-condenser
5. Continuous heat removal system
6. Self-actuating devices
7. Intermediate heat exchanger
8. Control rod drive mechanisms
9. Guard vessel
10. Containment
11. Heat exchanger unit
12. Liquid absorber injection
13. Tank with boron solution
14. Passive heat removal system
15. Coolant cleanup & boron reactivity control system
16. Primary circuit makeup system



Innovative projects: VPBER-600

A more innovative nuclear plant project is being designed by OKBM (Nizhnii Novgorod) in Russia. A number of versions of this reactor, known as the VPBER-600, are now in various developmental stages.

In contrast to operating PWRs, all components of the VPBER-600 are arranged in a single pressure vessel. This structure substantially simplifies the primary circuit by dispensing with large pipelines. *(See schematic and table.)* The integrated reactor arrangement features the placement inside the reactor vessel of the steam

Selected specifications of advanced reactors being developed in Russia

	VPBER-600	WWER-500/600 (V-407)	WWER-88 (V-392)	WWER-92 (V-410)
Reactor service life	60 years	60 years	40 years	60 years
Thermal power rating	1800 MW	1800 MW	3000 MW	3000 MW
Electrical generating capacity	600 MWe	635 MWe	1000 MWe	1100 MWe
Number of loops	Integral	4	4	4
System pressure	15.7 MPa	15.7 MPa	15.7 MPa	15.7 MPa
Core inlet/outlet temperature	294°/325° C	296°/327° C	290°/320° C	296°/330° C
Specific core power	69.4 kW/l	69.4 kW/l	106 kW/l	118.9 (76.6) kW/l
Number of fuel assemblies	151	163	163	199-211
Nominal natural convection rate	17%-20%	10%-15%	10%-15%	10%-15%
Overall vessel height	22.5 m	14.1 m	14.1 m	14.9 m
Vessel outer diameter	6.03 m	4.57 m	4.57 m	4.57 (5.83) m
Primary circuit pump	6/canned vertical rotor at vessel	4/canned vertical rotor	4/vertical single-stage shaft seal	4/vertical single-stage shaft seal
Steam generator	12/vertical straight tube	4/horizontal	4/horizontal	4/vertical
Number of decay heat removal passive systems	2 + 2	4 + 4	4	4 x1000 m^3 tank

generator, pressurizer, and heat exchangers for the emergency core cooling systems. Main circulation pumps are mounted on the reactor bottom. The reactor and the primary systems are located inside a safety (or guard) vessel. The secondary vessel protects the core so that in the event of the most severe loss-of-coolant accident, the core remains covered by coolant. The emergency core cooling system itself incorporates two independent systems, each including two independent heat removal loops, with natural convection. No operator intervention is required for at least 72 hours after any accident. The containment is a single cylindrical structure of reinforced concrete.

Because of the innovative nature of some of the VPBER-600's features, a deep theoretical analysis and experimental validation probably will be required, and some difficulties may be encountered in project licensing. Large efforts would be required to perfect the core of all Russian advanced LWRs because at present it seems to be the most conservative component of the designs. But it should be noted that any change in fuel element, fuel assembly, or manufacturing processes, for example, would require long experimental examination.❐

Further technical reading

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