FORT SAINT VRAIN OPERATIONAL EXPERIENCE

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Abstract

Fort St. Vrain (FSV), on the system of the Public Service Company of Colorado, is the only high temperature gas-cooled (HTGR) power reactor in the United States. The plant features a helium-cooled reactor with a uranium-thorium fuel cycle. The paper describes the experience made during its operation.

PLANT DESIGN

The entire primary coolant system, including the reactor, the steam generators, and the helium circulators, is housed within a prestressed concrete reactor vessel (Figure 1). A total of 1,482 hexagonal fuel elements forms the active core. Each of these fuel elements consists of a graphite block which is loaded with triso-coated uranium and thorium particles which have been bonded into cylindrical rods (Figure 2). Helium at a pressure of approximately 700 psia is directed by four circulators through the core, where it absorbs the heat from the fission process. The helium is then distributed to twelve steam generator modules which transfer the heat to the secondary system.

The secondary system is similar to that found in any modern fossil-fueled facility (Figure 3). Main steam at 2,400 psig and 1,000°F is produced in the steam generators and enters the high pressure stages of the turbine generator. The steam is exhausted to the single stage turbines of the helium circulators where it provides the motive force for rotation of the circulator compressors. The steam is then reheated to 1,000°F, and directed back to the intermediate and low pressure sections of the turbine generator. Use of the reheat cycle improves overall plant thermal efficiency to about 39%.

Conventional features of the condensate system include full-flow demineralization, three stages of low pressure heating, and deaeration. One motor driven and two turbine driven boiler feed pumps take suction from the deaerator and provide feedwater to the steam generator modules by way of two high pressure heaters.

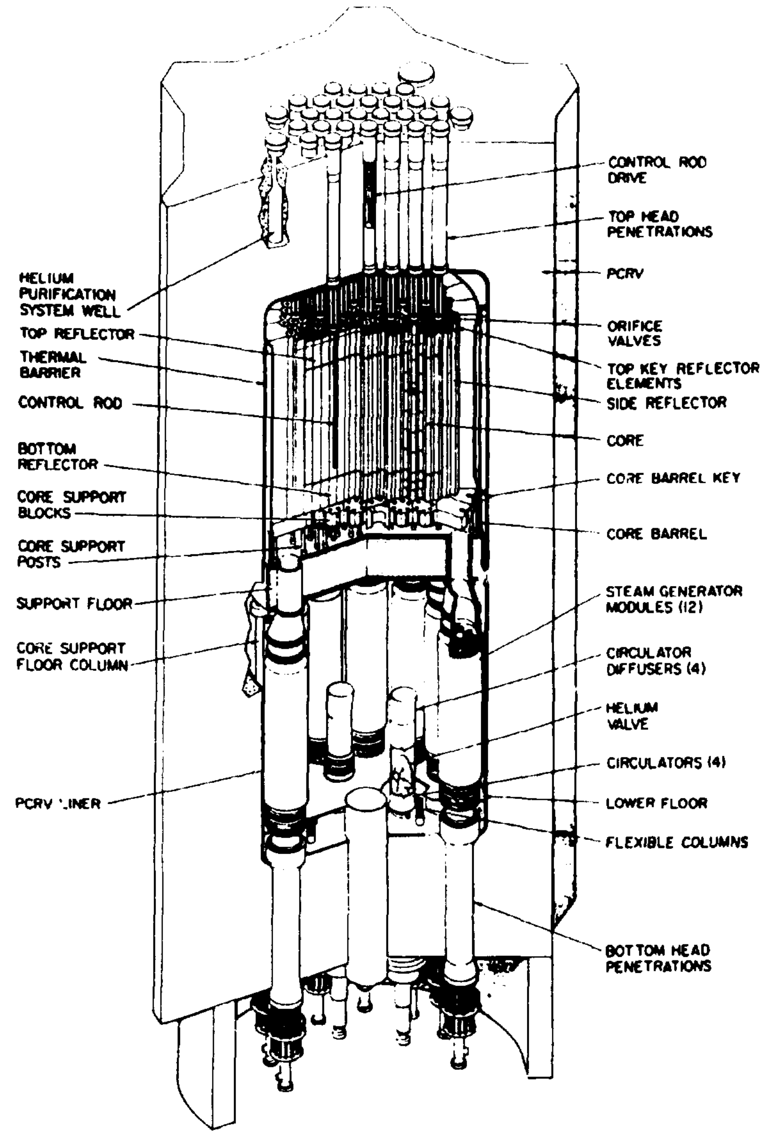

FIGURE 1-PCRV AND INTERNALS

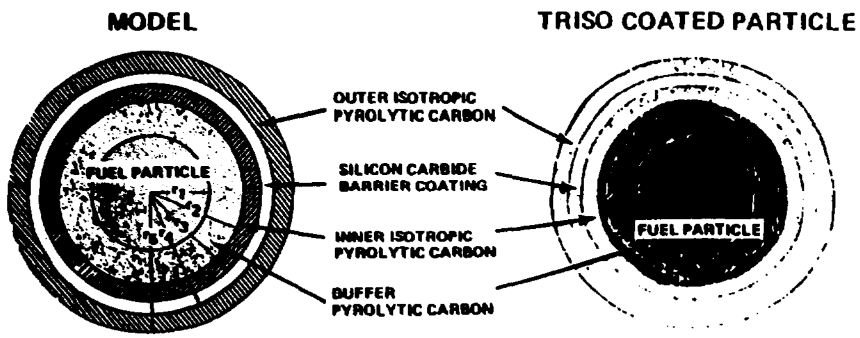

FIGURE 2-Trisco-Coated Fuel Particle

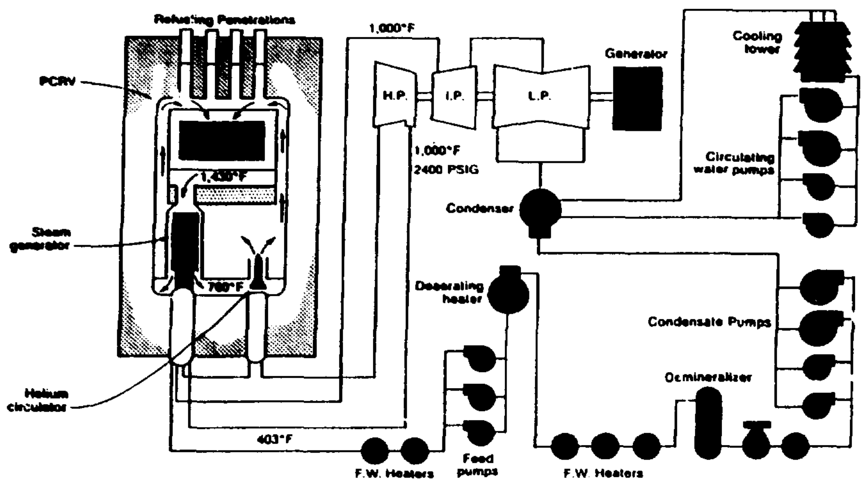

FIGURE 3-Overall Plant Simplified Schematic

OPERATIONAL HISTORY

The operational history of Fort St. Vrain can be characterized by low availability and inconsistent production. One of the major reasons for these difficulties has been the lack of an industry-wide experience base for resolution of specific plant problems. Consequently, the lessons that have been learned at other facilities had to be researched and adapted as appropriate for Fort St. Vrain

In the regulatory arena, a prime example of this adaptation has been the implementation of the Environmental Qualification (EQ) program for electrical equipment mandated by our Nuclear Regulatory Commission as specified by 10CFR50.49. The concern addressed by the regulation is the need to assure that electrical equipment important to safety will continue to operate in the adverse environmental conditions created by a steam line break. It is ironic that the excellent steam conditions afforded by the advanced design of the Fort St. Vrain plant are exactly the conditions most detrimental to electrical equipment in a steam-filled environment. The Nuclear Regulatory Commission and Public Service Company of Colorado worked closely to address the issue. However, the long-term resolution directly contributed to the unavailability of Fort St. Vrain for much of 1985 and 1986.

The unique design of Fort St. Vrain has also had an impact on the reliability of the plant. Foremost among the difficulties experienced has been the complexity of the helium circulator auxiliary system. Transients in this system have been initiated by improper or inadequate response to control signals. Frequently, this has resulted in relatively large quantities of circulator bearing water entering the primary coolant helium. The subsequent cleanup of moisture from the primary coolant has been a principle contributor towards low plant availability.

The circulators themselves have also experienced failures in bolting due to chloride stress corrosion cracking. Although this problem was responsible for the current 12-week scheduled maintenance outage, long-term effects on plant availability are not expected.

More recently, a significant improvement in plant operations has been achieved. Specifically, sustained operation at high power levels has resulted in plant capacity factors more than four times the lifetime average. In addition, three of the top ten months of operation for Fort St. Vrain have been achieved in 1988.

With this type of inconsistent, but improving, reliability, what does Fort St. Vrain have to offer to the development and operation of future reactor designs, particularly the Modular High Temperature Gas-Cooled Reactor (MHTGR)? The answer lies in the experience gained at Fort St. Vrain, both from a management perspective and from a design perspective.

MANAGEMENT RESPONSIBILITIES

In any endeavor, the responsibility for success or failure rests with the management of the program. Management defines the objectives, determines the best way to meet the objectives, allocates the resources, and adjusts the methodology to changing conditions. Although these are fundamental principles, they become even more important when managing a project involving new or innovative features such as that found in the MHTGR.

When undertaking an advanced project, the management of the organization must first recognize that the project will not be well understood outside the sphere of those most directly involved. The established perspective will invariably result in the tendency to address problems from within the historical framework. At Fort St. Vrain, this has been most evident when attempting to apply regulatory requirements, which are based on the experience of water-cooled reactors to the gas-cooled design. It is clear that the intent of the regulatory requirement applies in most situations; however, implementation of the requirement often involves a significant effort on the part of the regulating agency and the facility owner/operator. Therefore, the objective of management is to develop and maintain an atmosphere which facilitates the discussion of advanced design concepts while acknowledging the existing viewpoint.

To accomplish this objective, the internal culture of the organization must project all aspects of responsibility associated with operating a nuclear facility.

Most importantly, a safety culture must permeate the organization. All actions and interactions of individuals and the organization must be evaluated for their impact on nuclear safety. Policies must be established which not only result in safe work practices, but which also sustain the environment of safety. Administrative procedures which direct the organization towards this goal are of paramount importance, since they convey management expectations. The benefits to the plant, its workers, and the public are obvious. Not so obvious, however, is the higher level of confidence it creates with your regulatory agency. This confidence is a prerequisite to success when advocating advanced design concepts.

Secondly, all information which is relevant to reliable and safe operation of the plant must be openly discussed. Feedback mechanisms must be in place which permit experiences gained by the staff to be factored into future operation and design. A variety of programs have been implemented at Fort St. Vrain, with this objective in mind. The result has been improved operation, correction of long-standing deficiencies, and the development of a more effective teamwork approach to problems. Additionally, the experiences gained at Fort St. Vrain have been instrumental in designing the MHTGR. Some of these design considerations will be discussed later.

With respect to the external culture, the establishment of an effective interface with the regulating agency is of prime importance to advanced design reactors. In the past, Fort St. Vrain had not utilized a proactive approach with the Nuclear Regulatory Commission. Consequently, a number of unnecessary delays in the implementation of regulatory requirements have been experienced. These delays were primarily the result of adapting existing regulations to the advanced design. Since the burden of proof of compliance with the intent of the regulation lies with the owner/operator, it is in the best interests of the facility to anticipate, rather than react to, regulatory changes. A Licensing group, with the explicit purpose of evaluating proposed rulemakings, has been established within the Fort St. Vrain organization. This group actively participates in the regulatory process, thereby ensuring that the interests of Fort St. Vrain are addressed.

Another area closely related to the regulatory process is the implementation of the facility Technical Specifications. It should be remembered that the Technical Specifications address only those aspects of operation that are minimally acceptable, which assures that operation will be within the design basis for the plant. On the other hand, operation under minimally acceptable conditions will probably result in plant capacity factors which are unacceptable. At Fort St. Vrain, a complementary set of testing requirements for components not included in the Technical Specifications has been developed. The plant staff undertook a program for identifying the components to be included in the Non-Technical Specification program. Criteria for inclusion were governed by the operational history of the component, the effect that failure of the component would have on plant operation, and the availability of redundant components. At the present time, the scope of the Non-Technical Specification program exceeds that of the Technical Specification program.

PROCEDURAL COMPLIANCE

A major line of defense for safe and reliable operation of a nuclear facility is the establishment of appropriate administrative controls which are implemented by a procedural system. Again, advanced reactor designs somewhat complicate this process, primarily because the operational boundaries and the equipment involved are not yet standardized in the industry.

A strict policy of procedural adherence must be promulgated and enforced. It is not uncommon to experience some resistance to such a policy. However, the basis for procedures is to ensure that operational parameters do not result in conditions which are outside that assumed in the design bases. Maintenance practices must also deliver equipment which is capable of performing as intended, particularly under accident conditions. Once these principles are commonly understood throughout the organization, staff appreciation for procedural adherence is greatly enhanced.

However, it is not reasonable to expect that the staff will strictly adhere to procedures when the procedures themselves are deficient and no easy method for correction is present. A feedback mechanism must exist whereby the staff can recommend changes to the procedures. As a result of such a mechanism put in place at Fort St. Vrain, a significant procedural upgrade program has been undertaken. This program has resulted in procedures which provide more detail, are easier to use, and provide better documentation. One of the side benefits of the program has been better participation from the staff in identifying procedural weaknesses.

TESTING

A significant amount of electrical generation has been lost at Fort St. Vrain as the result of conducting testing while the plant has been in operation. Because of its unique design, special testing has been performed to confirm design assumptions or to gain additional information needed as the result of unanticipated experiences. The nature of these special tests has often resulted in rather slow rise-to-power ascensions, or in delays in placing the turbine generator into service. An excellent example of this has been the "core fluctuation" testing performed in recent years.

The core fluctuation phenomenon was caused by small movements of the fuel and reflector elements (moving as a column) as the result of thermal and hydraulic effects (Figure 4). These small column movements resulted in slight variations of primary coolant flow through the reactor core regions, accompanied by changes in individual region outlet temperatures and steam generator module inlet temperatures. After a testing period of about 2 1/2 years, the core fluctuation problem was corrected by the installation of constraining devices on the upper elements between each refueling region (Reference 1).

Fortunately, it appears that the vast majority of this type of testing at Fort St. Vrain has been completed. The results of many of these types of tests are directly applicable and have been incorporated into the MHTGR design. Consequently, the MHTGR should be able to capitalize on the Fort St. Vrain experience.

By its very nature, testing almost invariably puts the plant in a condition of more jeopardy than that experienced during normal operation. Consider, for example, the performance of routine, monthly surveillance testing on the Plant Protective System. Typically, one instrument of a redundant set of instruments is taken out of service for calibration or functional testing. The remaining in-service instruments continue to monitor plant parameters. In this situation, continued plant operation is highly dependent on the absence of electrical "noise" on the circuitry, the perfect performance of the technician, non-interference of other work, etc. At Fort St. Vrain, a number of plant shutdowns have resulted from placing the plant in this higher level of jeopardy.

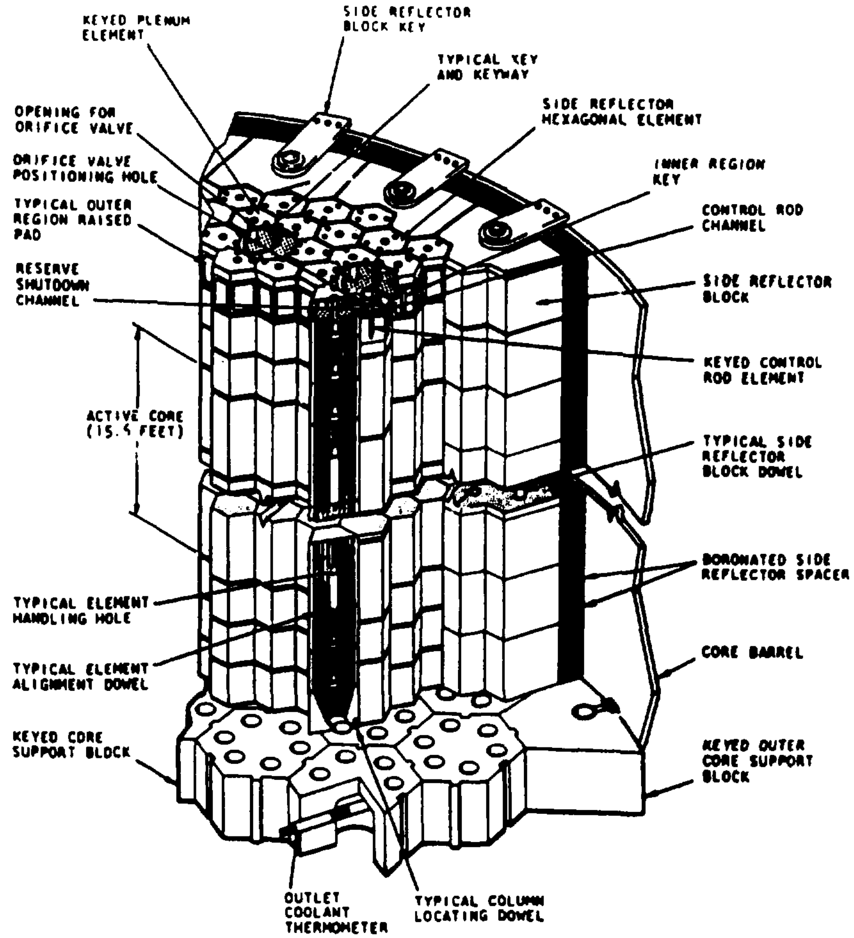

FIGURE 4-Cross Section of Reactor, Showing Representative Column Of Fuel Elements

An effective program for dealing with the problem has been implemented. Those tests which historically have a higher incidence of causing a plant transient have been identified. The tests were then reviewed to ensure that the most efficient means possible for performance were incorporated. Finally, the tests have been scheduled to be performed as a set of tests rather than individually. This approach minimizes the number of days throughout the month that the plant is subjected to these high sensitivity tests. It also affords the opportunity to consistently provide the highest level of expertise to perform the testing.

As a result of surveillance testing at Fort St. Vrain, the type, frequency, and complexity of similar testing at the MHTGR should be carefully considered. It should also be noted that the design of the Plant Protective System in the MHTGR has been significantly modified as a result of Fort St. Vrain experience.

DEFENSE IN DEPTH

The primary means of addressing the defense in depth concept at nuclear power plants involves the incorporation of physical barriers to the release of radioactive materials. A more generalized approach recognizes the importance of the human barrier to complement the physical barriers. The human barrier can be fortified by the application of appropriate administrative controls.

One such administrative control is the implementation of an Independent Verification program. At Fort St. Vrain the program is extensive and has been effective in preventing human errors from affecting operation of the facility.

In the area of maintenance, the removal of equipment is independently verified to have been correctly performed prior to the commencement of work. Special emphasis is placed on the isolation of the component from the remainder of the system. All "clearances" are independently verified to be correctly placed. After completion of the work, the proper returning of the equipment to service is also independently verified. Since the introduction of this program, a significant reduction in the number of human errors has been achieved.

A second example for application of the independent verification process involves the installation of temporary configurations. Temporary configurations can be particularly detrimental since they frequently involve affecting a system such that the system behaves differently than originally intended. The potential implications on the design basis for the system are apparent. A critical, independent review of the impact of the temporary configuration is essential to assuring that adverse consequences are not introduced.

An area often overlooked as one barrier in the defense in depth concept is that of the planning and scheduling of work activities. Nuclear plants are always designed and constructed with several layers of equipment redundancy. However, when equipment is unavailable because of poor planning and scheduling of maintenance, the benefits of redundancy are lost. Advanced reactor designs complicate the planning and scheduling process because the availability of spare parts for non-standard components is less. At Fort St. Vrain, we have found it effective to designate some of our more operationally experienced personnel to the planning and scheduling process.

DESIGN CARRYOVER TO THE MODULAR HTGR

What has been discussed thus far are managerial principles and programs. Particular emphasis has been placed on these specific issues, because they will probably be those most impacted by advanced reactor designs. Obviously, the many other principles for nuclear reactor design also apply to the MHTGR.

Attention is now turned to the equipment which is envisioned to be translated from the Fort St. Vrain experience to the MHTGR. A number of years ago, General Atomic instituted a formal carryover program to capture the experience gained from various systems in operation at Fort St. Vrain. The program was based on a "problem analysis" technique, wherein a problem was defined as any unexpected difficulty which had occurred in the design, construction, operation, or maintenance of the plant. After analysis, the information was then directed towards ensuring that designers, manufacturers, constructors, operators, and others directly involved in future HTGR programs could benefit from the experiences at Fort St. Vrain (Reference 2).

Table I provides a few examples of the components or systems which have been translated from Fort St. Vrain into the MHTGR with little or no modifications. Probably the most significant of these is the ceramic coatings on the fuel particles. Outstanding fission product retention capabilities of these coatings continues to be demonstrated at Fort St. Vrain. This performance, in conjunction with similar performance data from other facilities, has provided the experimental basis for its use as the primary containment in the MHTGR.

Fort St. Vrain has also been instrumental in identifying necessary design improvements for similar components and systems in the MHTGR. Table II provides examples of components which fall into this latter category. In some cases, such as the helium circulators and the Plant Protective System, major redesign has occurred as a result of less than satisfactory performance at Fort St. Vrain.

With this type of first hand input, the MHTGR has a firm foundation on which to build.

TABLE I

COMPONENTS/SYSTEM DESIGNS ADOPTED IN MHTGR AS A RESULT OF PERFORMANCE IN FORT ST. VRAIN

COMPONENT OR SYSTEM	REASONS FOR ACCEPTANCE OR COMMENTS ON PERFORMANCE
Steam Generators	Basic FSV helical coil, once through units; however, much larger and without reheat.
H451 Graphite Fuel Elements	Generally, good graphite performance in Fort St. Vrain.
Ceramic-Coated Fuel Particles	Excellent fission product retention with these coatings.
Helium Purification System High Temperature Adsorber, Desiccant Dryer LN_2, Delay Bed	Good FSV performance with these purification system components.
Confinement Building	• Primary and secondary containment is PCRV at FSV. • MHTGR primary and secondary containment includes fuel particle coatings and steel pressure vessel, respectively.
Primary System Components Such as Insulation, Permanent Reflector, Graphite Posts Retained for MHTGR	Component technology is retained in MHTGR, but their configuration has been adapted to the steel vessel concept.

TABLE II

DESIGN ENHANCEMENTS AS A RESULT OF FORT ST. VRAIN EXPERIENCE

COMPONENT OR SYSTEM FROM FORT ST. VRAIN	MHTGR DESIGN MODIFICATION	REASON FOR DESIGN CHANGE
Control Rod Drives	Lower gear ratio on drive system	Prevent rods from hanging up due to friction on motor drive shaft.
Reserve Shutdown System	1) Boron Carbide pellets are oval instead of spherical 2) Mechanical gate and double thermal fuse link actuation	1) Oval design will inhibit pellet bridging. 2) Simplified release mechanism provides automatic operation.
Helium Circulators	1) Magnetic bearings instead of water bearings 2) Motor Drive instead of single stage steam turbine utilizing reheat steam	1) Prevent moisture ingress into primary system. Simplifies circulator auxiliaries. 2) Simplifies circulators high energy steam system.
Helium Purification System	Copper-Oxide bed utilized instead of titanium sponge for hydrogen removal	Titanium sponge bed was only partially successful at Fort St. Vrain in removing hydrogen.
Plant Protective System	2 out of 4 logic instead of 2 out of 3	Allows for testing and operation with less chance of spurious trips.
Reactor Configuration	1) No flow controlling orifices in MHTGR as compared to 37 individual fuel regions in FSV 2) Lower overall core pressure drop in MHTGR compared to FSV	1) & 2) These design changes will minimize the thermal/hydraulic conditions that caused temperature fluctuations in Fort St. Vrain.

CONCLUSIONS

Considerable input to the operation and design of the modular HTGR has been obtained as the result of experiences at Fort St. Vrain. Fundamental management principles which deserve increased attention as the result of operating an advanced reactor design have been identified. Design concepts which are directly applicable to the MHTGR can be incorporated. Design concepts needing further attention have received detailed analyses. The continued operation of Fort St. Vrain will further enhance the MHTGR concept.

ACKNOWLEDGEMENTS

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THE PRESENT STATE OF THE HTR CONCEPT BASED ON EXPERIENCE GAINED FROM AVR AND THTR

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Abstract

During the past ten years the development of a specific HTR concept has made remarkable progress. This has been mainly characterized by making use of the safety characteristics typical of the High-Temperature Reactor (HTR).

In the design, construction and operation of High-Temperature Reactors - expecially AVR (15 MWe plant in Juelich, FRG) and THTR (300 MWe plant in Hamm-Uentrop, FRG) - comprehensive experience has been gained in the field of operational availability and safety, accident topology and plant risk of HTRs in recent years. This experience is relevant for the entire HTR line independent of specific projects.

1. HTR 500

The HTR 500 is the first commercial High-Temperature Reactor with a pebble bed core. Its design principles and the design of its systems are based on the earlier AVR and THTR projects. These plants were both designed, constructed and commissioned by BBC/HRB, now both members of the ASEA Brown Boveri (ABB) Group. The AVR has been successfully operating for 20 years; the THTR was synchronized to the grid for the first time late in 1985 and has been in power operation since February 1987.