Proceedings of ICAPP ‘06
Reno, NV USA, June 4–8, 2006
Paper 6055

Alternative Passive Decay-Heat Systems for the Advanced High-Temperature Reactor

Charles W. Forsberg
Oak Ridge National Laboratory*
P.O. Box 2008; Oak Ridge, TN 37831-6165
Tel: (865) 574-6783; Fax: (865) 574-0382
E-mail: **forsbergcw@ornl.gov**

File Name: DecayHeat06ICAPP.Paper
Manuscript Date: January 23, 2006
Final Paper Due Date: March 15, 2006

Conference Paper Number 6055
Session 3.08: Liquid-Salt-Cooled High-Temperature Reactors-II
2006 International Congress on the Advances in Nuclear Power Plants (ICAPP’06)
Embedded Topical in the 2006 American Nuclear Society Annual Meeting
American Nuclear Society
June 4–8, 2006
Reno, Nevada

---

[*] Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725. File: DecayHeat06ICAPP.Paper

Proceedings of ICAPP '06
Reno, NV USA, June 4–8, 2006
Paper 6055

Alternative Passive Decay-Heat Systems for the Advanced High-Temperature Reactor

Charles W. Forsberg
Oak Ridge National Laboratory
P.O. Box 2008, Oak Ridge, TN 37831-6165,
Tel: 865-574-6783; Fax: 865-574-0382; E-mail: forsbergcw@ornl.gov

Abstract ─ *The Advanced High-Temperature Reactor (AHTR) is a low-pressure, liquid-salt-cooled high-temperature reactor for the production of electricity and hydrogen. The high-temperature (950°C) variant is defined as the liquid-salt-cooled very high-temperature reactor (LS-VHTR). The AHTR has the same safety goals and uses the same graphite-matrix coated-particle fuel as do modular high-temperature gas-cooled reactors. However, the large AHTR power output [2400 to 4000 MW(t)] implies the need for a different type of passive decay-heat-removal system. Because the AHTR is a low-pressure, liquid-cooled reactor like sodium-cooled reactors, similar types of decay-heat-removal systems can be used. Three classes of passive decay heat removal systems have been identified: the reactor vessel auxiliary cooling system which is similar to that proposed for the General Electric S-PRISM sodium-cooled fast reactor; the direct reactor auxiliary cooling system, which is similar to that used in the Experimental Breeder Reactor-II; and a new pool reactor auxiliary cooling system. These options are described and compared.*

I. INTRODUCTION

The Advanced High-Temperature Reactor (AHTR) is a new reactor concept with three design goals: (1) high reactor-coolant exit temperatures (700 to 1000°C) to enable the efficient production of hydrogen by thermochemical cycles and the efficient production of electricity, (2) passive safety systems to encourage public acceptance and enable reduced costs, and (3) competitive economics. Within the U.S. Department of Energy Generation IV Program, the AHTR is being developed as a liquid-salt-cooled very high-temperature reactor (LS-VHTR), the high-temperature variant of the AHTR that is required for hydrogen production. A preconceptual point design has been developed;[1,2] however, alternative design configurations have not been evaluated. A series of studies are under way to evaluate alternative decay-heat-removal systems.

Because of the specific requirements involved, the design of the decay-heat-removal systems present unique challenges.[3]

- *Passive safety*. The safety characteristics should match or exceed those of a 600-MW(t) modular high-temperature gas-cooled reactor (MHTGR).
- *Economics*. The AHTR is to provide competitive economic production of hydrogen and electricity. For electrical production, this requires significantly lower capital costs per unit output than large [~1600 MW(e)] light-water reactors. The requirement implies high power outputs [2400 and 4000 MW(t)] to obtain economics of scale.
- *Temperature*. To achieve the temperatures needed for hydrogen production, the peak coolant outlet temperatures may be as high as 950°C, with higher core outlet temperatures under accident conditions. Like that of the MHTGR, the AHTR neutronics safety case depends upon allowing the reactor to go to higher temperatures under transient conditions to shut down the reactor, using the negative temperature coefficient of the reactor core. The limited availability of high-temperature materials for components places significant limits on the design options.

The reactor concept, the alternative decay-heat-removal systems, the advantages or disadvantages of each decay-heat-removal system, and the status of the technology are described.

II. AHTR DESCRIPTION

The AHTR [shown in Fig. 1 with a reactor vessel auxiliary cooling system (RVACS)] is a liquid-salt-cooled high-temperature reactor that uses the same type of coated-particle graphite-matrix fuel that has been successfully used in high-temperature gas-cooled reactors such as the Peach Bottom Reactor, the Fort St. Vrain Reactor, the Arbeitsgemeinshaft Versuchsreaktor, and the Thorium High-Temperature Reactor. The optically transparent liquid-salt coolant is a mixture of fluoride salts with freezing points near 400°C and atmospheric boiling points of ~1400°C. Several different salts can be used as the primary coolant, including lithium-beryllium and sodium-zirconium fluoride salts. Studies are under way to determine the optimum fluoride salt.[4,5] The reactor operates at near-atmospheric pressure, and at operating conditions, the liquid-salt heat-transfer properties are similar to those of water.

Heat is transferred from the reactor core by the primary liquid-salt coolant to an intermediate heat-transfer loop. The intermediate heat-transfer loop uses a secondary liquid-salt coolant to move the heat to a thermochemical hydrogen production facility or to a turbine hall to produce electricity. If electricity is produced, a multi-reheat nitrogen or helium Brayton power cycle (with or without a bottoming steam cycle) is used.

The baseline 2400-MW(t) AHTR layout (Fig. 2) was selected to be similar to the S-PRISM sodium-cooled 1000-MW(t) fast reactor designed by General Electric. Both reactors operate at low coolant pressure and high temperature; thus, they have similar design constraints. The 9.2-m-diameter vessel is the same size as that used by the S-PRISM design. The baseline AHTR therefore uses a passive RVACS similar to that developed for decay-heat removal in the General Electric sodium-cooled S-PRISM. The design parameters are shown in Table I.

III. DECAY-HEAT SYSTEMS

Three classes of passive decay-heat-removal systems have been identified that can potentially meet the requirements. All of these systems are based on technologies originally developed for sodium-cooled reactors. This common technological base exists because both reactor concepts are high-temperature, low-pressure reactors. There are, however, important differences.

- *Temperature*. The peak AHTR temperatures will be 200 to 450ºC higher than those in sodium-cooled reactors. This implies different materials of construction and increased importance of thermal radiation transport, including infrared heat transport through the optically transparent salt. The melting points are also higher, which imposes other design constraints.

- *Volumetric heat capacity*. The volumetric heat capacity of liquid salts is about a factor of four greater than that of sodium. The size of the heat exchangers, internal piping, valves, pumps, and other components are much smaller, with fewer space constraints within the reactor vessel.

The decay-heat-cooling options all have several common components.

- *Heat capacity*. All systems have significant heat capacity to absorb decay heat in the fuel, coolant, and graphite moderator for hours to tens of hours after reactor shutdown. This provides time for operator action and decreases the required size of the decay heat removal system. Graphite has a high heat capacity, is fully compatible with the salt, and is relatively inexpensive therefore, for each design the option exists to fill empty space within the vessel with either graphite or salt. The designer of the reactor selects the total heat capacity within the reactor vessel.

- *Heat removal.* Each system has a passive decay-heat-removal system. In the various conceptual designs, the decay-heat-generation rate (which decreases with time) matches the heat-removal-system capacity 30 to 60 hours after reactor shutdown. Before that time, excess decay heat raises the temperature of the fuel, coolant, and vessel components. Typically, the average core temperature after reactor shutdown (with failure of the active heat-removal systems) rises to approximately the same temperature as that of the hottest fuel during normal operations.

- *Silo siting*. All of these systems are located in a below-grade silo to ensure that no credible accident occurs where the reactor core is uncovered.

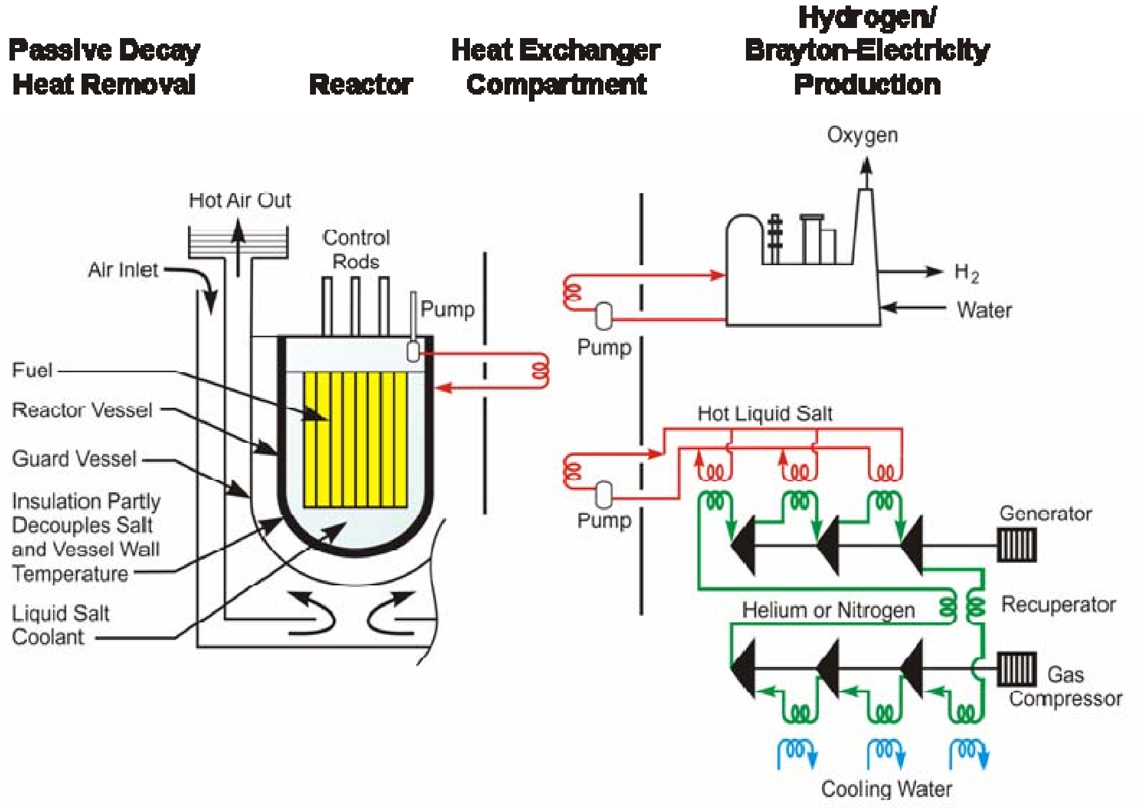

Fig. 1. Schematic of an AHTR with RVACS and external intermediate heat exchanger.

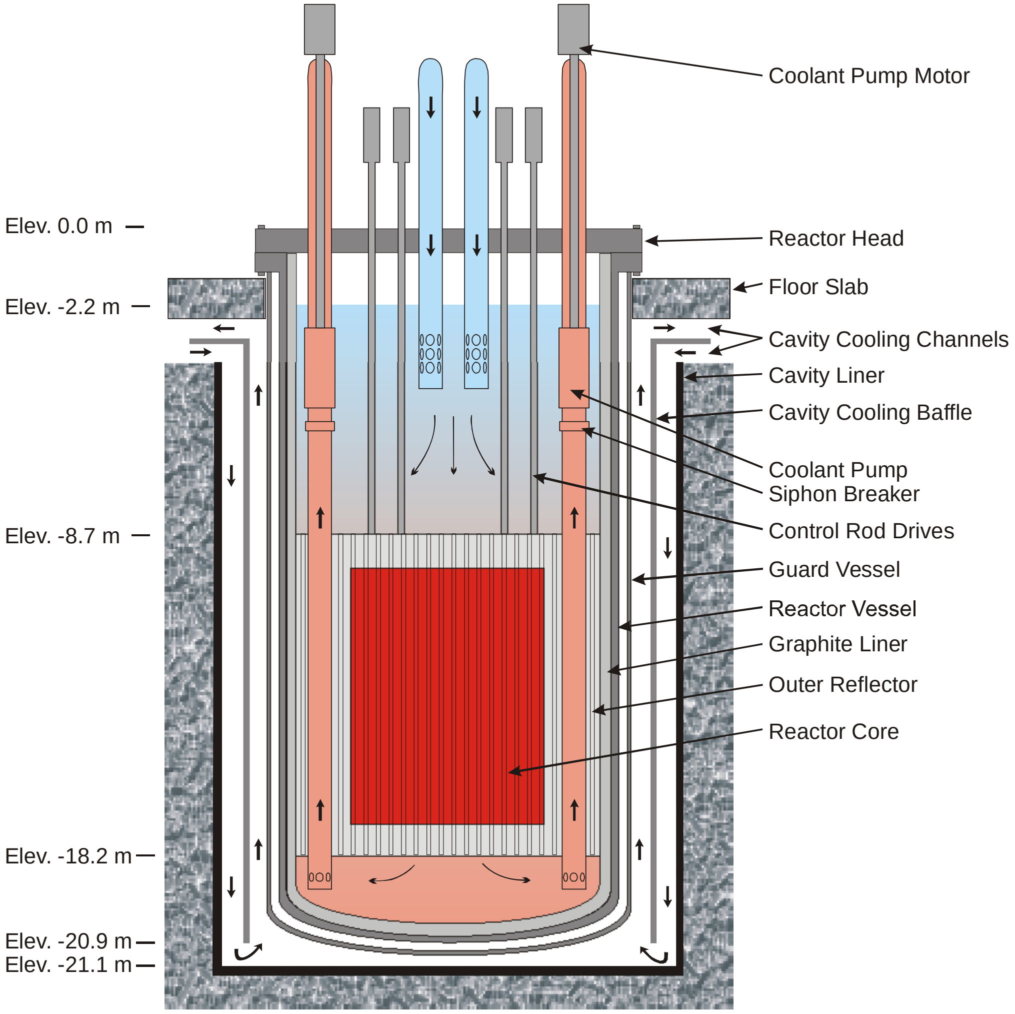

Fig. 2. Elevation view of baseline LS-VHTR.

TABLE I

Conceptual Baseline AHTR Plant Design Parameters

Parameter	Value	Parameter	Value
Total power output	2400 MW(t)	Power cycle	3-Stage Brayton Multi-reheat
Core inlet/outlet temperature (options)	900°C/1000°C 700°C/800°C 670°C/705°C	Electricity (output at different peak coolant temperatures)	1357 MW(e) at 1000ºC 1235 MW(e) at 800ºC 1151 MW(e) at 705ºC
Vessel – Diameter – Height	 9.2 m 19.5 m	Power-cycle working fluid	Nitrogen or helium
Decay-heat system	Air cooled	Core geometry	Cylinder
Coolant salt (base case)	$2(^{7}\text{LiF})\text{-BeF}_2$	Discharge burnup	~150 GWd/t
^{7}Li isotopic concentration	99.995%	Fuel cycle length	≥18 months
Fuel		Fuel element	
– Form	Prismatic	– Graphite density	1.74 g/cm^3
– Kernel composition	$U_{1.0}C_{0.5}O_{1.5}$	– Diameter (across flats)	36.0 cm
– Kernel diameter	425 µm	– Height	79.3 cm
– Particle diameter	845 µm	– Fuel channel diameter	1.27 cm
– Kernel density	10.5 g/cm^3	– Number of fuel channels	216
– ^{235}U enrichment	~15%	– Coolant channel diameter	0.953 cm
– Particle packing fraction	≤25 vol %	– Number of coolant channels	108
		– Pitch between channels	1.88 cm
Baseline outlet coolant temperature	950°C	Power density	10.0 MW/m^3
Baseline inlet coolant temperature	≥850°C	Number of fuel columns	265
		Number of fuel blocks per column	10

III.A. Reactor Vessel Auxiliary Cooling System

RVACS was originally developed for the General Electric S-PRISM sodium-cooled fast reactor. With RVACS (Fig. 3), AHTR decay heat is (1) transferred from the reactor core to the reactor vessel graphite reflector by natural circulation of the liquid salt, (2) conducted through the graphite reflector and reactor vessel wall, (3) transferred across an argon gap by radiation to a guard vessel, (4) conducted through the guard vessel, and then (5) removed from outside of the guard vessel by natural circulation of ambient air. The graphite reflector also acts as a partial insulator; thus, the reactor vessel temperature is cooler than the peak coolant temperature.

The rate of heat removal is controlled primarily by the radiative heat transfer through the argon gas from the reactor vessel to the guard vessel. Radiative heat transfer increases by the temperature to the fourth power (T^4); thus, a small rise in the reactor vessel temperature (as would occur upon the loss of normal decay-heat-removal systems) greatly increases heat transfer out of the system. Under accident conditions such as a loss-of-forced-cooling accident, natural circulation flow of liquid salt up the hot fuel channels in the core and down the edge of the core rapidly results in a nearly isothermal core with about a 50°C temperature difference between the top and bottom plenums.[2] The average core temperature in this accident rises to approximately the same temperature as the hottest fuel during normal operations.

The use of RVACS offers several advantages, most of which are associated with the experience base. Because of the RVACS development work for the GE S-PRISM reactor, the fundamental characteristics of this decay heat system are relatively well understood.

At the same time, several disadvantages are associated with RVACS for some AHTR applications.

- *Reactor size*. The ultimate decay-heat-removal capability and thus the ultimate reactor power output are limited by the reactor vessel size and the maximum allowable vessel temperature under accident conditions.
- *Multifunction reactor vessel*. The reactor vessel has two functional requirements that may conflict with one another: (1) containment of the reactor system and (2) transfer of decay heat under accident conditions. To maximize vessel integrity, vessel temperatures should be minimized. However, for removal of decay heat, the vessel should operate at high temperatures under certain accident conditions. The different requirements demand (1) a vessel that can operate at very high temperatures or (2) a vessel with an internal insulation system to protect the vessel but, at the same time, allowing heat rejection under defined conditions.
- *Integral effects test (IET) scaling*. The development and licensing process for advanced reactors places a strong emphasis on integral effects testing[6] for modern code validation. For large nonmodular systems such as RVACS, the important roles of thermal radiation phenomena and the surface-area-to-volume scaling significantly complicate IET scaling.

III.B. Direct Reactor Auxiliary Cooling System

The direct reactor auxiliary cooling system (DRACS) which was originally developed for the sodium-cooled Experimental Reactor Reactor-II has been used in multiple fast reactors and is proposed for the European Fast Reactor. DRACS (Fig. 4) consists of a natural circulation heat-transport loop that moves heat from a heat exchanger in the primary reactor vessel to a heat exchanger with the ultimate heat sink. In most designs, the atmosphere is the heat sink. In sodium-cooled reactors, the heat transfer fluid is usually sodium. DRACS (1) can operate continuously or (2) can be designed to minimize heat loss during normal operations. In many cases, the air heat exchanger is located in a box that has a door with an electromagnetic latch that falls open upon the loss of electrical power. The power can cut by a variety of signals, including overheating of the sodium in the reactor vessel.

Several studies are in the process of evaluating alternative versions of DRACS for the AHTR. There are multiple potential coolants (gases, liquid salts, etc.) and multiple conditions or actuating devices that can trigger the system into operation based on high temperatures.

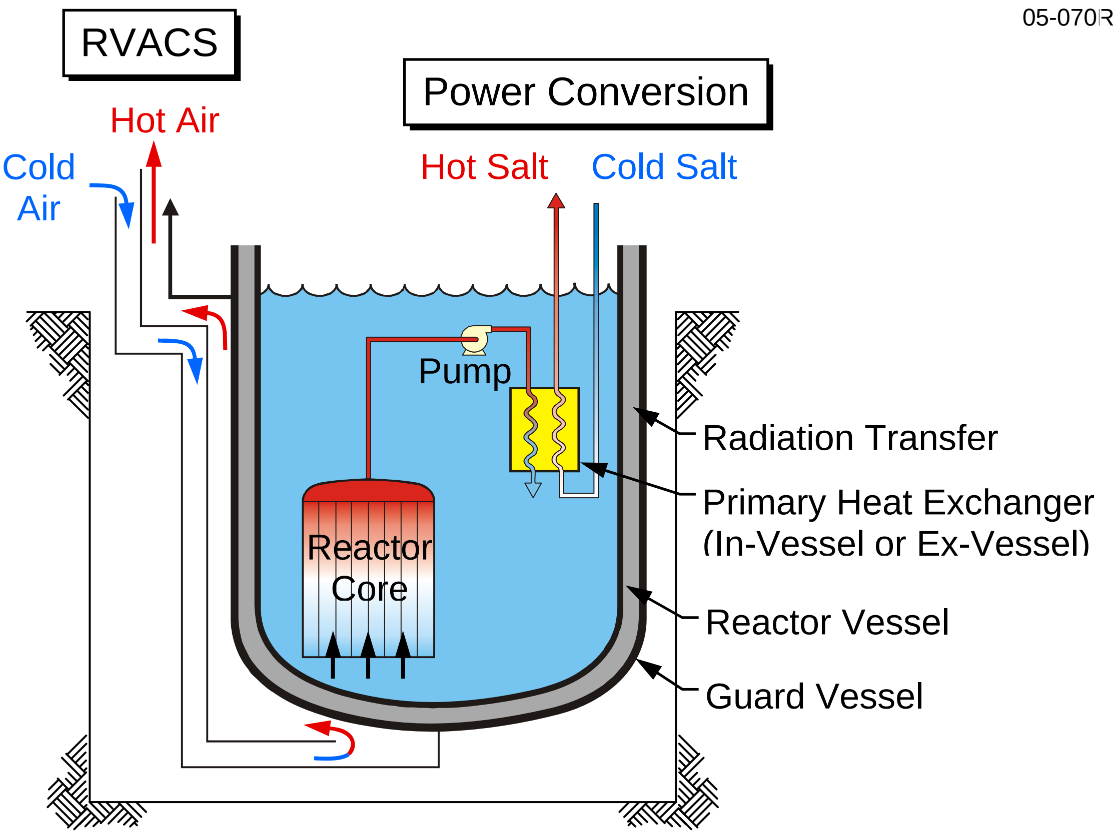

Fig. 3. Reactor vessel auxiliary cooling system

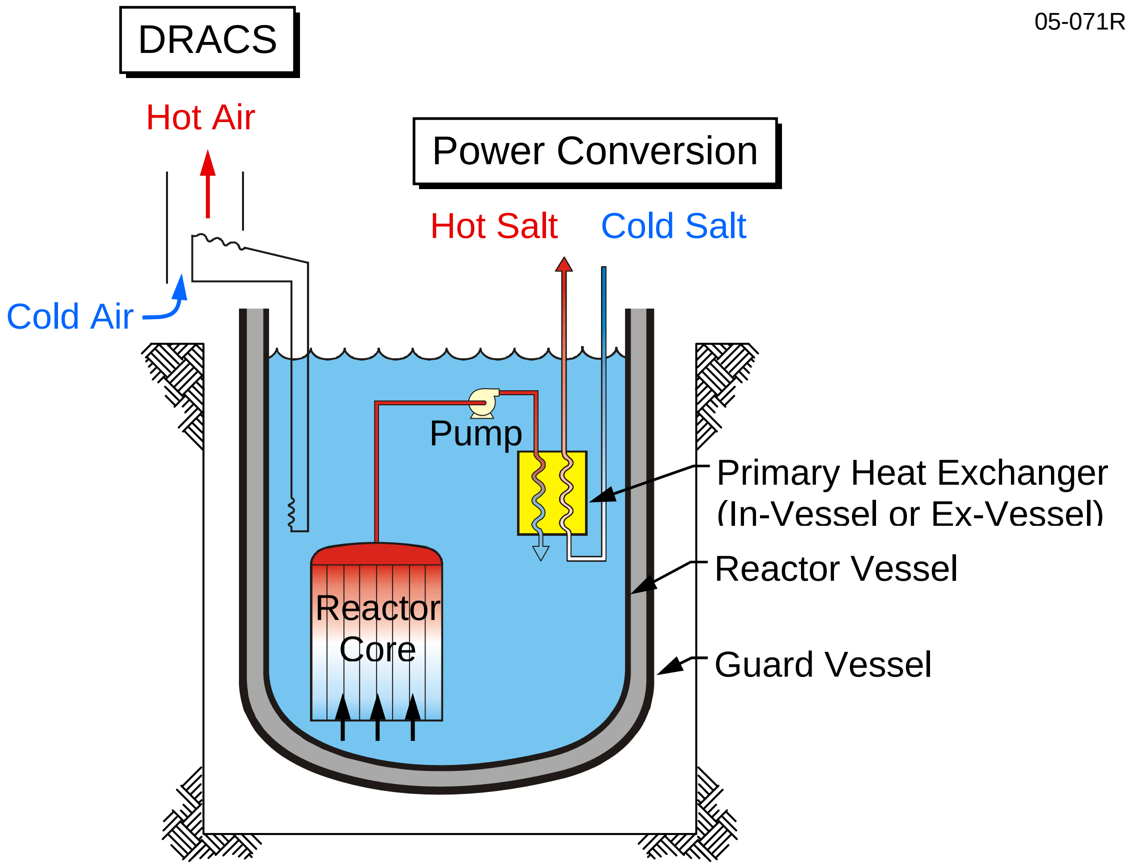

Fig. 4. Direct reactor auxiliary cooling system

DRACS has several desirable features relative to those of alternative systems.

- *Primary vessel integrity*. The temperature-limited safety components in the primary system are the reactor vessel and piping. Unlike RVACS, DRACS is located inside the reactor vessel and can help minimize system temperatures and thus may reduce challenges to the reactor vessel.

- *High-temperature DRACS*. The decay heat is rejected to the pool where DRACS is located. The temperatures in the pool will be higher than those available for RVACS, where the heat must be conducted through the vessel to reach the decay-heat-removal system. The higher heat rejection temperatures reduce the required size of DRACS relative to that of RVACS.

- *Size*. The reactor power output is not limited by the ability of the reactor vessel to reject heat, as is the case with RVACS. The reactor silo size and complexity may be reduced by using an insulated silo with a water-cooled liner system, eliminating the requirement for air-cooling ducting and a guard vessel.

- *Modularity*. The modular characteristics of DRACS allow additional decay-heat-removal modules to be added as plant sizes are increased. Development costs and time may be reduced because a single full-scale modular DRACS unit can be tested. Reduced-power, reduced-temperature IET experiments using simulant fluids (light mineral oils with matching Prandtl numbers) can be designed to provide low-distortion IET data for code validation and licensing.

The use of DRACS for an AHTR presents several challenges. DRACS for the AHTR is not yet fully developed. The different chemical characteristics of liquid salts compared with those of sodium and the different ranges of operating temperatures imply different system designs. A DRACS for the AHTR will require the evaluation of alternative DRACS coolants and other design features.

III.C. Pool Reactor Auxiliary Cooling System

The pool reactor auxiliary cooling system (PRACS)[7] is a new decay-heat-removal system that has some of the characteristics of the ABB PIUS pressurized-water reactor that was partly developed in the 1980s. As shown in Fig. 5, the primary reactor system is located at the bottom of a pool of a liquid buffer salt. The primary liquid-salt coolant does not mix with the buffer salt in the pool. Salt coolant from the reactor goes through the reactor core, is heated, flows to the intermediate heat exchanger, dumps its heat to the secondary loop, goes through the primary pumps, and returns to the reactor core. The pool has a DRACS. During normal operation the buffer salt is at the same temperature (or lower) than the coldest primary salt, that is, less than the core inlet temperature.

During normal operation, heat leaks from the primary system to the pool though the reactor vessel and uninsulated piping. Normally, heat losses are small because the exit temperature of the primary coolant from the heat exchanger is near the temperature of the buffer salt. If the main circulation pumps are shut down, a natural circulation flow of salt occurs in the primary system. If the intermediate heat exchangers do not remove the heat for any reason, the primary system coolant heats up. As the hotter primary coolant exits the heat exchanger, the temperature difference between the primary coolant and the buffer salt increases and more decay heat is dumped to the pool. The primary coolant piping surface area can be adjusted to ensure efficient removal of decay heat.

Decay-heat removal from the primary system to the pool upon loss of a circulation pump can be enhanced by a secondary loop containing a fluidic diode and heat exchanger that is connected between the top and bottom reactor core plenums. The fluidic diode is a no-moving-parts device that allows high primary-system salt-coolant flow in one direction with low pressure drops but low primary salt flow in the other direction with high pressure drops. When the primary pump is operating, the fluidic diode minimizes flow in this loop from the bottom to top reactor plenums. If the pump stops, hot salt from near the top of the reactor flows by natural circulation down the loop, through the heat exchanger, dumps its heat to the pool, and enters the bottom of the reactor core plenum. This option may limit the temperatures seen by noncore reactor components during high-temperature transients.

PRACS has several potential advantages.

- *Reactivity control*. As a two salt system, PRACS has a relatively small inventory of primary salt coolant that can respond rapidly to changes in reactor core temperatures and a larger buffer salt inventory that responds slowly to temperature changes in the reactor core. If heat removal by the intermediate heat exchangers stops and the reactor is not shut down, the primary coolant can heat up rapidly and ensure rapid shutdown of the reactor under a wide variety of conditions because of negative fuel Doppler and moderator temperature coefficients. The primary salt assists in ensuring reactor reactivity control while the high-heat-capacity buffer salt is available for longer-term decay heat removal.

- *Heat capacity*. The buffer salt is normally at a much lower temperature than the reactor core or primary coolant and thus can absorb very large amounts of decay heat relative to the alternative decay-heat-system designs with equal amounts of salt but in which almost all the salt is at a single temperature.

- *Primary-system integrity*. The temperature-limited safety components in the primary system are the reactor vessel and piping. These structures can be protected from extreme temperatures by insulation on the inside; however, in that case, insulation integrity becomes a temperature-limited safety component. In a pool reactor, the outside of the reactor vessel and piping is bathed in a cooler buffer salt. The lower-temperature buffer salt and the excellent heat transfer provided by a cool liquid provide a method to limit primary metal component temperatures independent of any insulation system and thus provide a high level of assurance of primary-system protection from excessive temperatures.

- *High-temperature DRACS*. The decay heat that is rejected from the primary system to the pool is rejected at specific locations—such as the primary system PRACS heat exchanger with the fluidic diode. DRACS heat exchangers can be located directly above these locations, and baffling can be used so the hottest salt in the pool enters the DRACS heat exchangers. This maximizes decay-heat removal by DRACS by maximizing buffer salt temperatures flowing into DRACS heat exchangers, as well as minimizes pool temperatures and promotes mixing in the buffer salt pool to minimize thermal stratification.

- *Capital-cost economics of the salts*. The primary and buffer salt can have different compositions optimized for their different functional requirements. Salts containing ^{7}Li have some of the best properties as primary coolants. However, because of the need for lithium isotopic separation, the use of separate primary and buffer salt minimizes the primary salt inventory and cost. A lower-cost buffer salt can then be used. The lower-cost salts have substantially higher nuclear cross sections. This has the secondary advantage that if a primary system failure were to occur, the higher-cross-section pool salt would enter the primary circuit and provide a secondary reactor shutdown mechanism.

- *Modularity*. PRACS shares the same modularity advantages as DRACS, including advantages for IET experimental design.

At the same time, PRACS has several potential disadvantages.

- *New system*. This is a new system approach, which presents design uncertainties.

- *Dual-salt system*. The primary and buffer salt could be the same salt, or two different salts may be used. In that case, there are two salt systems to manage. The complexity also depends upon the choice of the intermediate heat-transport system salt. If the buffer salt is the same as that in the intermediate heat-transport system salt, operations are simplified.

- *DRACS status*. DRACS for the AHTR is not fully developed. The different chemical characteristics of liquid salts versus those of sodium and the different temperature operating ranges dictate different system designs. DRACS for the AHTR will require the evaluation of alternative DRACS coolants and other design features.

IV. COMPARISONS

The three alternative decay-heat-removal systems were ranked from 1 to 3 (1: best) based on multiple criteria (Table II) to help understand the strengths and weakness of each option. The choice of a decay-heat-removal system depends upon the reactor size, material limits, and development program constraints. Nine criteria were defined.

- *Maximize reactor output*. Economics favors large power outputs and thus designs that can ultimately be scaled to very large reactors [4000 MW(t)].

- *Relevant experience*. Plant designs and decay-heat cooling systems that have been tested have relatively small uncertainties. This is a major practical advantage.

- *System complexity*. All other factors being equal, simpler systems are preferred.

- *Reactivity control*. If a failure of the reactor control system with loss of heat sink occurs, the reactor can be shut down by allowing the reactor core to go to a higher temperature. From a decay-heat perspective, the best systems minimize the number of components and the volume of the system that must go to higher temperatures for reactor shutdown.

- *Minimize structural component temperatures*. The temperature-limiting safety components within the system are the structural components (vessel, piping, etc.). Designs that protect those components (such as cold salt on one side and hot salt on the other) are preferred.

- *Maximize temperature to decay-heat system*. Higher temperature differences between the reactor and the environment reduce the challenge of dumping decay heat to the environment. Decay-heat-removal systems should cool the hottest fluids.

- *Minimize insulation requirements*. Each of these systems requires insulation to meet economic and safety objectives. There are strong incentives to minimize systems where insulation systems are part of the primary safety case, such as is the case for in-vessel insulation with RVACS (unless very high-temperature material is used for the reactor vessel).

- *System heat capacity*. Maximizing heat capacity increases time for operators to react before there is equipment damage and also reduces the size of the decay-heat-removal system.

- *Modularity*. Decay-heat-removal systems that are modular (1) allow the reactor size to be changed without altering the design of the decay-heat-removal system—only the number of modular decay-heat-removal systems changes and (2) reduce development costs, because it allows prototypical component testing of one module, which is then applied to the full reactor.

V. CONCLUSIONS

The AHTR is a new reactor concept; consequently, systems studies are required to evaluate alternative options to meet goals and requirements. Three potentially viable decay-heat-systems have been identified. Further studies, including the development and comparison of Phenomena and Identification Ranking Tables,[6] will determine the preferred option.

REFERENCES

1. C. W. FORSBERG, "The Advanced High-Temperature Reactor: High-Temperature Fuel, Liquid Salt Coolant, and Liquid-Metal Plant," *Progress in Nuclear Energy*, **47**, *1-4*, 32-43 (2005).

2. D. T. INGERSOLL, K. T. CLARNO, C. W. FORSBERG, J. C. GEHIN, R. W. CHRISTIANSEN, C. B. DAVIS, G. L. HAWKES, J. W. STERBENTZ, T. K. KIM, T. A. TAIWO, and W. S. YANG, *Status of Physics and Safety Analysis for the Liquid-Salt-Cooled Very High-Temperature Reactor (LS-VHTR),* ORNL/TM-2005/218, Oak Ridge National Laboratory, (December 2005).

3. C. W. FORSBERG, *Passive Decay-Heat Systems for the Advanced High-Temperature Reactor: Goals, Requirements, and Options*, ORNL/GEN4/LTR-05-016, Oak Ridge National Laboratory, Oak Ridge, Tennessee (2006).

4. D. F. WILLIAMS et al., *Assessment of Properties of Candidate Liquid Salt Coolants for the Advanced High Temperature Reactor (AHTR)*, ORNL/GEN4/LTR-05-001, Oak Ridge National Laboratory, Oak Ridge, Tennessee (June 30, 2005).

5. D. F. WILLIAMS and L. M. TOTH, *Chemical Considerations for the Selection of the Coolant for the Advanced High-Temperature Reactor*, ORNL/GEN4/LTR-05-011, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 14, 2005).

6. U.S. NUCLEAR REGULATORY COMMISSION, *Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large Break, Loss of Coolant Accident*, NUREG/CR-4249, EGG-2552 (1989).

7. P. F. PETERSON and H. ZHAO, "A Flexible Baseline Design for the Advanced High-Temperature Reactor Using Metallic Reactor Internals (AHTR-MI), Preliminary Design Description for a First-Generation Liquid-Salt VHTR with Metallic Vessel Internals (AHTR-MI)," *Proc. of the 2006 International Congress on the Advances in Nuclear Power Plants (ICAPP'06), Embedded Topical in the 2006 American Nuclear Society Annual Meeting, Reno, Nevada* (June 4–8, 2006).

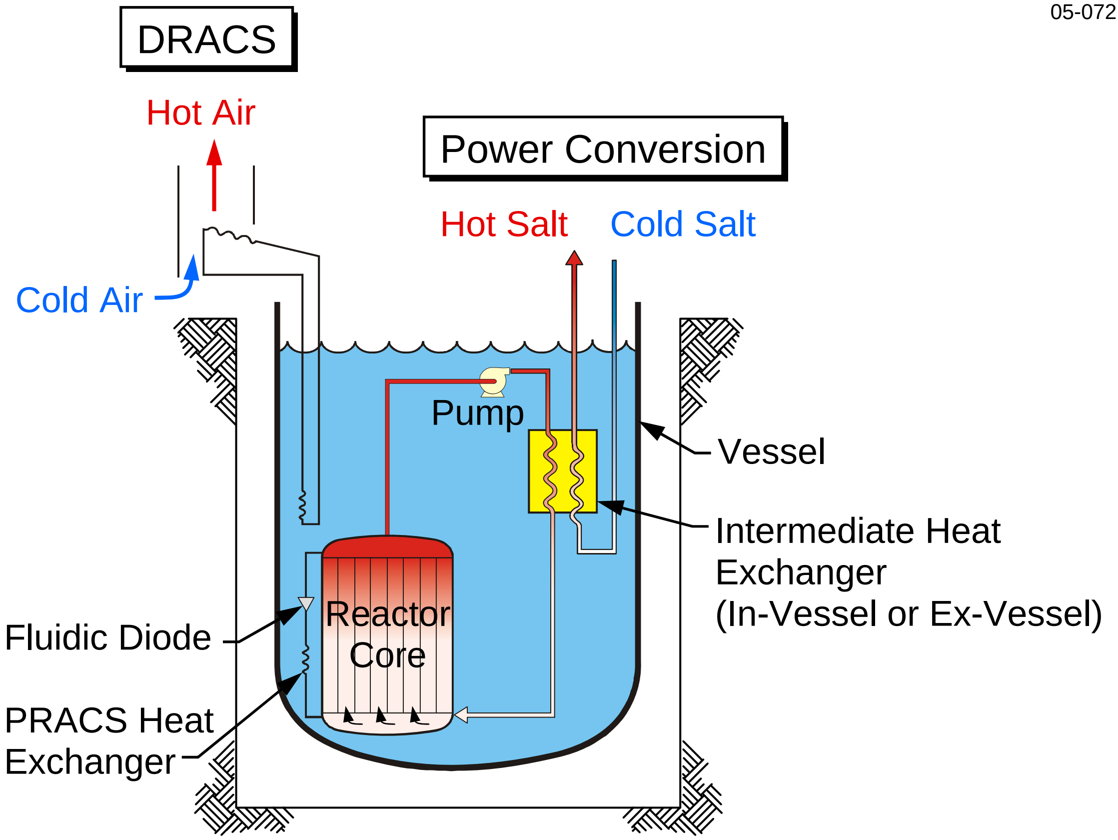

Fig. 5 Pool reactor auxiliary cooling system

TABLE II

Ranking of Alternative Decay-Heat-Removal Systems by Criteria (Rating 1 = Best)

Criteria	RVACS	DRACS	PRACS
Maximize reactor output	3	1	1
Relevant experience	1	2	3
System complexity	1	2	3
Reactivity control	2	3	1
Minimize structural component temperatures	3	2	1
Maximize temperature to decay-heat system	3	2	1
Minimize insulation requirements	3	2	1
System heat capacity (time)	3	2	1
Modularity (scalability and simplicity of IET design)	3	1	1