—TRANSACTION—

A Nuclear-Fossil Combined-Cycle Power Plant for Base-Load and Peak Electricity

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INTRODUCTION

A combined-cycle power plant is proposed that uses heat from a high-temperature reactor and natural gas to meet base-load and peak electrical demands. For base-load electricity production, heat from a high-temperature reactor is delivered through heat exchangers to a high-temperature air-breathing gas turbine to raise the compressed air inlet temperatures to between 700 and 850°C. The high-temperature gas turbine produces electricity. The hot exhaust is then fed to a heat recovery steam generator (HRSG) that provides steam to a steam turbine for added electrical power production.

To meet peak electrical demand, natural gas or jet fuel is burnt after the nuclear heating of the compressed air to increase power levels. This process raises the inlet temperatures to both the gas turbine and the steam turbine. In this mode of operation, the peak gas-turbine inlet temperature is ~1300°C─about the same temperatures and operating conditions of a standard natural-gas-fired utility Brayton-cycle gas turbine that exhausts its heat to a bottoming Rankine steam turbine.

INCENTIVES FOR USE OF THE POWER CYCLE

The nuclear-fossil combined-cycle power plant offers five potential advantages.

1. *Higher efficiency*. Gas turbines, with technologies such as actively cooled hollow blades, can operate at much higher temperatures than nuclear reactors. The combined nuclear-fossil system allows higher temperatures and thus higher efficiencies than nuclear-only systems.

2. *Small reactors for small electrical grids*. The developing world has small electrical grids with highly variable energy demands. There is a need for small reactors that are economic and can load follow. This combined power cycle is the same as that used worldwide for natural gas and oil-fired power plants. Thus, many developing countries have experience in the operation and maintenance of such systems.

3. *Reduced carbon dioxide emissions*. Fossil fuels are universally used to provide peak electrical power because (1) they are storable and (2) the cost of equipment to convert the fuel to electricity is low relative to the cost of the fuel. A long-term constraint is the release of greenhouse gases. For peak power production, the nuclear heat preheats the air approximately half way to its peak temperature and thus can reduce up to a factor of 2 the use of fossil energy for peak electrical production.

4. *Improved economics*. The system has the potential for improved economics by combining low-cost base-load nuclear heat production that allows full utilization of the nuclear heat source with peak power production using low-capital-cost combined-cycle systems.

5. *Available technology*. The power conversion technology is an existing technology that can be coupled to high-temperature reactors. Thus, the development of high-temperature reactors is not coupled to development of new power conversion systems—except for the nuclear heat exchanger.

TECHNOLOGY CONSIDERATIONS

The general concept of combining nuclear and fossil heat sources is not a new idea. The Indian Point I pressurized-water reactor in New York had a high-temperature steam cycle in which the reactor provided saturated steam that was then superheated with a fossil-fired superheater. Recent studies [1] have examined a nuclear-fossil combined cycle for steady-state electricity production. The technology to combine nuclear heat sources with Brayton power systems is not new. The billion-dollar Aircraft Nuclear Propulsion program [2] of the 1960s, which had its goal the development of a nuclear-powered aircraft, developed designs and conducted non-nuclear tests that integrated heat from a secondary liquid heat-transport loop into a gas turbine.

The proposed power cycle would be coupled to the Advanced High-Temperature Reactor (AHTR), a liquid-salt-cooled high-temperature reactor [3] that uses the same coated-particle fuels as are used in helium-cooled high-temperature reactors. The AHTR has an intermediate liquid heat-transport loop that allows for (1) efficient transport of heat from the reactor to the power cycle and (2) separation of the reactor from the partly fossil-fueled power cycle to ensure safety and to avoid the need for nuclear-plant security. A high-temperature reactor is required because heat input into a Brayton cycle must be >600°C for the base-load Brayton cycle operations.

Preliminary studies [4] have begun to map the options for such a system. A wide variety of system configurations exist (such as steam injection into the gas turbine after air compression but before nuclear heating or preheating of the boiler water with nuclear heat in the HRSG system) to boost base-load or peak power levels, boost efficiency, or increase the nuclear heat fraction when the plant is operating in a peak power production mode.

Initial studies indicate that the turbine conditions will be similar to the existing General Electric model MS7001FA gas turbine in terms of gas pressure ratios and peak temperatures. The operating points for base-load electricity production are near the peak efficiency operating conditions for the gas turbine at the lower inlet temperatures, whereas the operating points for peak power production are near the maximum power output condition for the gas turbine at the higher inlet temperatures. A combined-cycle system was simplistically modeled with a single gas turbine having the same pressure ratio and gas flow rates as the GE turbine and a steam cycle representative of the commercial GE combined-cycle machine. The calculations showed a base-load power output (both gas and steam turbine) of 68.5 MW(e) and a peak-load power output of 276.5 MW(e). For base-load operations, the reactor provides 175 MW(t) at 800°C. For peak power production, the fossil fuel provides an additional 323 MW(t) at a peak gas-turbine inlet temperature of 1300°C.

CONCLUSIONS

Combined nuclear-fossil systems have the potential to offer the best of both worlds: low-cost base-load electricity and lower-cost peak power relative to the existing combination of base-load nuclear plants and separate fossil-fired peak-electricity production units. Significant work is required to fully understand and develop this new electricity generation option.

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