Evaluation of the Feasibility of a Utility-Financed Power-Generation Facility at the FFTF

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EVALUATION OF THE FEASIBILITY OF A UTILITY FINANCED POWER GENERATION FACILITY AT THE FFTF

ABSTRACT

"The three public utilities serving the Tri-Cities area of central Washington State have entered into a Cooperative Agreement with the Department of Energy to explore the feasibility of a utility-owned power addition to the Fast Flux Test Facility (FFTF). This paper describes the results of the design and economic studies completed to date, which indicate that the addition of steam generators and a 120 MWe power plant to the FFTF is both technically feasible and economically attractive compared to alternative power sources."

INTRODUCTION

In 1983 the Department of Energy (DOE) requested the Westinghouse Hanford Company to explore the possibility of converting the waste heat from the operation of the FFTF into electricity utilizing the technology developed within the Liquid Metal Reactor (LMR) program. The result of that study was a conceptual design that confirmed the technical feasibility and the potential economic attractiveness of a power generation addition to the FFTF. Based on these results, the City of Richland, together with the Benton and Franklin County Public Utility Districts, entered into a Cooperative Agreement with DOE to explore the feasibility of a utility-owned generation facility at the FFTF known as the FFTF Power Addition (FFTF-PA). This agreement calls for the development of an advanced conceptual design and cost estimate, including plans for financing, power marketing and other considerations necessary to determine the practicality of the power addition as a utility-owned generation facility.

Development of the FFTF-PA plan by the Utilities was started last December under the management of R.L. Ferguson & Associates, Inc., with Stone & Webster Engineering Corporation as the architect-engineer. Westinghouse Hanford Company, as the operator of the FFTF, is responsible for the design of the sodium system modifications, safety evaluations and operational interfaces. The plan is scheduled to be complete by the end of 1987.

PROJECT CRITERIA

The FFTF is a 400 MW thermal sodium-cooled fast test reactor located on the government-owned Hanford reservation in south-eastern Washington State. Its primary mission is to conduct irradiation testing of fuels and materials in a prototypic LMR thermal and neutronic environment.

The purpose of the FFTF-PA is to utilize the heat currently rejected to the atmosphere by the installation of steam generators and electrical generating equipment. Since the FFTF-PA is to be financed, constructed and operated by a utility organization, the project design and economic criteria were established to meet the goals of both the DOE and the sponsoring utilities. The principal criteria are:

1. No adverse impact on the FFTF's primary research and testing mission.
2. Design the FFTF-PA such that the existing FFTF safety envelope is not adversely impacted.

3. Provide a net annual reduction in FFTF operating costs of at least $7 million from the sale of steam and reduced electricity costs.

4. A cost-of-power competitive with other available options.

At this time, the major design trade-off studies have been completed and a reference configuration selected for development of the advanced conceptual design. The following sections describe the reference configuration, the economic considerations involved in the trade-off studies and the cost-of-power from the FFTF-PA compared to alternative resources.

PROJECT DESCRIPTION

The main Heat Transport System (HTS) of the FFTF consists of three essentially identical sodium-cooled loops to remove reactor heat. A schematic diagram of one HTS loop is shown in Figure 1. Each HTS loop is composed of a primary loop (the reactor vessel being common to all three loops) and a secondary loop (the three secondary loops being completely separate from each other). Heat is transferred by the primary loops from the reactor vessel to Intermediate Heat Exchangers (IHXs) and then to the secondary loops. The heat is currently rejected from the secondary loops to ambient air via forced air flow Dump Heat Exchangers (DHXs). These three HTS loops provide both the normal heat rejection and the emergency decay heat removal functions.

The FFTF-PA will install steam generators on two of the three secondary HTS loops. The third or East loop (which contains a tornado hardened DHX) will remain in its present configuration and thus provide a dedicated decay heat removal path.

Economic and schedule considerations dictate the maximum utilization of available hardware from the Clinch River Breeder Reactor Project (CRBRP). The most important components are the "hockey-stick" steam generator/superheater modules. Although these units have not been fabricated, the long-lead materials conforming to ASME Section III are available and the design documentation is essentially complete.

The reference design configuration for the power addition utilizes one evaporator and one superheater module in each secondary loop operating in a recirculating mode as shown in Figure 2. A low recirculation ratio (approximately 2:1) has been selected. The superheater and evaporator modules will be located in the secondary loop hot leg in series with the existing DHXs. During normal operation of the FFTF-PA power plant, the DHX fans would be off and the air flow dampers closed to limit the heat loss from these units. This configuration allows the DHXs to be brought on-line in the event that the power plant is unavailable, thus minimizing any adverse impact to the FFTF testing mission. Further, maintaining the capability of the seismically qualified DHXs to provide the redundant natural circulation decay heat removal function in response to design basis accident scenarios allows the steam generation system to be designed as non-safety related.

Fig. 1. HTS Loop Schematic (One of Three)

Fig. 2. FFTF Power Addition Schematic
A steam generator building will be situated within the FFTF protected area in close proximity to the South and West loop DHTSs. Appropriate barriers will be provided to maintain separation between the sodium loops. A common sodium drain tank and a sodium water reaction product separation tank servicing either loop would also be located within the steam generator building. A single steam drum, servicing both loops, is located external to the building. All of these components are available as CRBR excess hardware.

Superheated steam from the South and West HTS loops will be combined to drive a single turbine-generator set, producing approximately 120 MWe gross. The turbine-generator and associated equipment are housed in a building located outside the FFTF protected area. This configuration will permit parallel construction of both buildings thus minimizing the overall project schedule. It also reduces the impact of security access control on construction labor productivity. Cooling towers, for the rejection of the FFTF-PA heat loads, will be located adjacent to the turbine building.

**STATUS OF DESIGN TRADE-OFF STUDIES**

As indicated previously, the major design trade-off studies leading the selection of the reference configuration have been completed. While detailed optimization studies are still in progress, the information available provides a good picture of the economics of the FFTF-PA based on the preliminary cost estimate. The principal design options evaluated in the selection of the reference configuration were:

1. Adding steam generators to all three secondary loops.
2. Adding steam generators to two loops and increasing the power transferred to these two loops by unbalancing the FFTF loop flows and temperatures.
3. Operating the steam generators in the one-through mode rather than in the recirculation mode.
4. Increasing the FFTF primary outlet temperature.
5. Locating the steam generators at grade level rather than below grade.

The results of the evaluation of adding steam generators to the third loop or increasing the power transferred to two loops are summarized in Table 1. As can be seen, both the two-loop power shift and the three-loop options lead to lower power costs than the two loop base case. While the three-loop option has the lowest power cost, most of these savings can be achieved by the two-loop power shift option. Further, the marginal cost of additional capacity and the payback ratios for the two-loop power shift option are much more attractive than the three-loop option.

| TABLE 1 |
|---|---|---|
| **2-LOOP** | **11.5%** | **3-LOOP** |
| **TOTAL COST** | **154.6** | **157.2** | **211.5** |
| **Net Power** | **102.6** | **114.4** | **153.9** |
| **$/KWe** | **1510** | **1370** | **1370** |
| **Cost of Power** | **23.6** | **21.8** | **20.9** |
| **Payback Ratio** | **n/a** | **8.2** | **1.6** |
| **For Additional Capacity** | **n/a** | **220** | **1110** |
| **Capacity ($/KWe)** | **n/a** | **220** | **1110** |

*Value of the additional capacity $1800/kWe divided by the cost of the additional capacity, relative to the base case.

**Cost of the additional capacity divided by the amount of the additional capacity, relative to the base case.

Both the two-loop power shift and three loop options are technically feasible. However, the two-loop power shift option was selected as the more prudent approach in that it preserves the inherent natural circulation decay heat removal capability for the tornado-hardened East loop. Maintaining the tornado-hardened East loop as a dedicated shutdown cooling path minimizes the FFTF-PA cost and schedule uncertainty associated with assuring that the FFTF remains within the existing safety design envelope. The operating parameters for the reference two-loop power shift option are shown in Table 2.
### TABLE 2

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>EAST LOOP</th>
<th>SOUTH OR WEST LOOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power, MWt</td>
<td>102.6</td>
<td>148.7</td>
</tr>
<tr>
<td><strong>Primary Sodium</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot Leg Temperature, C</td>
<td>503(938°F)</td>
<td>503(938°F)</td>
</tr>
<tr>
<td>Cold Leg Temperature, C</td>
<td>360(680°F)</td>
<td>360(680°F)</td>
</tr>
<tr>
<td>Flow, m³/min</td>
<td>39.1(10329gpm)</td>
<td>56.8(15000gpm)</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow, m³/min</td>
<td>50(13200gpm)</td>
<td>50(13200gpm)</td>
</tr>
<tr>
<td><strong>Superheater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Temperature In, C</td>
<td>453(847°F)</td>
<td>467(873°F)</td>
</tr>
<tr>
<td>Sodium Temperature Out, C</td>
<td>----</td>
<td>438(820°F)</td>
</tr>
<tr>
<td>Water/Steam Temperature In, C</td>
<td>----</td>
<td>329(624°F)</td>
</tr>
<tr>
<td>Steam Temperature Out, C</td>
<td>----</td>
<td>466(872°F)</td>
</tr>
<tr>
<td>Steam Outlet Pressure, mPa</td>
<td>----</td>
<td>12.1(1750psi)</td>
</tr>
<tr>
<td><strong>Evaporator</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Temperature In, C</td>
<td>----</td>
<td>438(820°F)</td>
</tr>
<tr>
<td>Sodium Temperature Out, C</td>
<td>343(649°F)</td>
<td>307(585°F)</td>
</tr>
<tr>
<td>Water Temperature In, C</td>
<td>----</td>
<td>257(495°F)</td>
</tr>
<tr>
<td>Water/Steam Temperature Out, C</td>
<td>----</td>
<td>329(624°F)</td>
</tr>
</tbody>
</table>

*No steam generators in East loop. Conditions are at inlet and outlet of the DHXs.

The incentive for operating the steam generators in the once-through mode was to eliminate the separate superheater modules thus reducing the number of steam generator modules to be fabricated and the size of the steam generator building. However, thermal hydraulic analyses indicated that a single CRBR steam generator module, when operated in the once-through mode under FFTF-PA conditions, would not be stable.

The feasibility of achieving once-through operation with a single steam generator module by increasing the FFTF temperature or using heat transfer enhancement devices (e.g. swirl tapes) was also considered. Increasing the FFTF temperature was rejected on the basis of the impact on FFTF operations and its testing mission. The use of heat transfer enhancement devices is quite attractive. However, it was concluded that the state of the technology did not support their selection as the reference design for immediate application. We will continue to follow their development to assess the feasibility of incorporating this option during the detailed design phase.

The incentive for locating the steam generators at grade level, rather than below grade, was the potential for reducing the cost of the steam generator building. This configuration would result in the steam generators being the high point in the secondary loop. However, the cost savings in steam generator building construction were offset by the cost of additional modifications to the secondary loops to preclude inadvertent flooding of the secondary pumps.

**OVERALL ECONOMIC EVALUATIONS**

Figure 3 compares the levelized cost of power (in 1/85 $) for the FFTF-PA with alternative energy supply options as described in the Northwest Conservation and Electric Power Plan (Reference 1). This comparison includes a range of financing parameters (i.e. 7.5% to 9.5% interest rates and 20 to 30 year amortization periods) that encompasses the conditions likely to be encountered in financing the power addition.

The second FFTF-PA case shown in Figure 3 includes operation of the power addition with both the FFTF and an oil-fired supplemental steam supply. Other cases, which included a coal or gas-fired supplemental steam supply, produced very similar results. Inclusion of a fossil fired supplemental steam supply is one of the alternatives under consideration to provide security for financing of the power addition in the event that the FFTF is not operated for the desired life of the project.
LEVELIZED COST OF POWER (millis/kwhr)

- FFTF-PA Reference Case
- FFTF-PA with Oil Boiler
- Low Cost Geothermal
- New Hydro or Cogeneration
- 2 x 600 MWe Coal Units
- 2 x 250 MWe Coal Units
- 110 MWe Fluidized Bed Coal Unit

Fig. 3. Comparison of FFTF-PA Power Costs

As can be seen, the FFTF-PA reference case represents a very attractive power supply when compared to any of the available alternatives. The inclusion of a supplemental fossil-fired steam supply, while more expensive, is still comparable to the lowest cost alternative resources.

CONCLUSIONS

The work completed to date continues to establish that the addition of a cogeneration facility to the FFTF is both technically feasible and economically attractive. In addition, the FFTF-PA provides the opportunity to acquire valuable long term operating experience with the CRBRP steam generator modules.

REFERENCES