OVERVIEW OF GENERAL ELECTRIC'S ADVANCED TURBINE SYSTEMS PROGRAM

CONTRACT INFORMATION

Cooperative Agreement	DE-FC21-95MC31176
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OBJECTIVES

GE Power Systems, with the support of the U.S. Department of Energy, has continued to design, develop, and initiate the manufacture of its H class, gas turbine combined cycle power generation system. As stated previously (1), program goals remain consistent with the original overall DOE Advanced Turbine Systems goals of 60 percent combined cycle efficiency (LHV), <10 ppm NOx emissions at 15% O_2, and a 10 percent reduction in the cost of electricity. As originally constituted, Phase 3 of the utility scale ATS program was intended to allow DOE support of detailed gas turbine design, assessment of overall combined cycle system performance and, most importantly, allow test validation of component and subassembly designs, many of which have been severe technical challenges for the gas turbine industry and its suppliers.

BACKGROUND INFORMATION

GE Power Systems has been developing an extensively steam cooled gas turbine design, which has evolved from early systems studies more than a decade ago. A large number of variations in cycle configuration were evaluated prior to settling on the current concept and starting to address its design challenges. As a result of having made a basic cycle configuration selection in advance of the initiation of the DOE ATS program, GE did not elect to participate in the ATS program until its selection for award in Phase 2, Conceptual Design and Project Development. Through participation in Phase 2, GE was able to analytically and experimentally examine many of the critical technology issues associated with the use of closed circuit steam cooling in a very large, utility-scale gas turbine combined cycle system. These technology issues included material steam compatibility, steam cleanliness requirements, heat transfer in steam-cooled rotating components, combined cycle performance, and system startup requirements.

The basic concepts of the GE steam-cooled gas turbine design and overall combined cycle configuration have been discussed previously (1), (2), and (3), and are driven by the need to increase turbine inlet temperature to augment cycle efficiency and specific output while retaining a low enough combustion temperature to provide the required NOx emission performance. The gas turbine can then operate as an intermediate pressure reheater for the bottoming cycle and is fully integrated with the combined cycle's steam system. Heat rejected to the coolant in the gas turbine is directly transferred to the bottoming cycle rather than being lost to the gas turbine's exhaust.

PROJECT DESCRIPTION

GE Power Systems concluded negotiations for a Cooperative Agreement with DOE for Phase 3 of the ATS program, allowing a program start in July 1995, and started work on detailed design and component testing activities. A detailed work breakdown structure (WBS), shown previously (1), addresses both the 7H (60 Hz) and 9H (50 Hz) configurations of the ATS gas turbine combined cycle system. A large amount of commonality exists between the 60 Hz and 50 Hz versions of the gas turbine, and the design of these components and subassemblies continues to be supported by the ATS program. Proof of concept and subscale aerodynamic, heat transfer, and material testing and data evaluation are all generally common elements for both gas turbine designs and have been a part of the ATS program. Further, the overall operational strategy for starting, loading, unloading, and unscheduled loss of load have been evaluated as a part of the ATS program and viewed as common to both single-shaft combined cycle systems.

In March 1997, DOE issued a Request for Proposals to the ATS contractors for a restructured program. Instead of the original demonstration phase (Phase 4) of the ATS program, which included the siting of the first commercial unit at a host site, the program was restructured to extend the Technology Readiness Testing phase (Phase 3). The restructured program (Phase 3R) features Full Speed No Load (FSNL) testing of the ATS (7H, 60 Hz), including design, procurement, and installation of unique tooling and test instrumentation. Importantly, the restructured program is designed to achieve the ATS program's technical goals in the time frame established by the ATS program plan.

In July 1997, GE responded to the Department of Energy with a proposal for a restructured ATS program. Subsequently, in December 1997, GE submitted a final revised proposal to DOE. Negotiations with DOE regarding the restructured ATS program concluded in late March 1998, with the execution of a modification to the existing Cooperative Agreement for the ATS program, which extends the Agreement through December 31, 2000.

The modified Cooperative Agreement reflects the continuing commitment of GE and DOE to the ATS program. The central goal of the ATS program - producing technology by 2000 that is ready for commercial application – remains unchanged. Under the restructured ATS Phase 3, GE will manufacture and perform a FSNL test on a 60 Hz machine by the end of 1999 at GE's Greenville, SC facility. Figure 1 shows the GE ATS program by year.

RESULTS

Many of the system design considerations and results related to overall gas turbine configuration, startup, and shutdown steam and air cooling issues and system performance have been discussed previously, (1-4), and will not be repeated here. Much of the effort during 1999 has been in combustion system development, continued materials characterization, continued heat transfer testing, continued thermal barrier coating (TBC) development and testing, and component rig tests.

Two of the key components successfully tested in 1999 are: a scaled 7H compressor rig test (3Q99), and an ongoing full-scale combustor development testing program.

In addition, 7H component manufacture was completed, and assembly to support a 4Q99 FSNL test is on schedule. The 9H FSNL product acceptance testing has been completed, and has provided important technology validation that was incorporated into the 7H hardware design and subsequent test program.

Gas Turbine Description

GE's MS7001H ATS gas turbine contains an 18-stage compressor, a can-annular Dry Low NOx (DLN) combustion system similar to those utilized on prior GE gas turbines, and a 4-stage turbine. A 2600F-class firing temperature and closed-circuit steam cooling are used in the turbine. A cross-section is shown in Figure 2. The compressor provides a 23:1 pressure ratio with 1230 pps airflow. It is derived from GE's high-pressure compressor used in the CF6-80C2 aircraft engine and Industrial Aeroderivative (IAD) LM6000 gas turbine. The MS9001H compressor is similar in design and has an airflow of 1510 pps.

The turbine employs closed-loop steam cooling of the first- and second-stage nozzles and buckets. Steam from the combined cycle steam system is introduced into the turbine components, provides cooling, and is returned to the combined cycle for work extraction in the steam turbine. Air cooling is used for the third-stage nozzles and buckets, with the fourth stage being uncooled.

MS7001H Compressor Test

The 7H compressor rig test was completed in 3Q99 at GEAE's Lynn, MA test facility. The compressor rig rotor and stator are shown in Figure 3.

MS7001H Compressor Test Results. The MS7001 compressor provides 1230 pps of airflow at a 23:1 pressure ratio, and its design forms the core aerodynamics for the 7H. This scales to 180 pps and 23:1 pressure ratio for the test rig. Test objectives included performance, operability, stall margin, and aeromechanics. The rig was tested for more than 150 hours with more than 800 test points recorded.

Power turndown performance and operability testing were successfully conducted, with airflow turndown capability exceeding the 40 percent target. All of the compressor vibratory stresses were within allowable limits.

An important part of the test was establishment of the high-speed compressor map shown in Figure 4. In addition, testing was used to validate the no-load operating line, full-load operating line, and stall margin. Start testing was performed to validate starting characteristics. The results of this test were used to determine the variable vane settings in the 7H FSNL test program.

The 7H compressor has been built upon a foundation of successful CF6-80C2 operation and validated by previous 9H compressor testing.

Rotor Steam Delivery System

The rotor steam delivery system delivers steam for cooling stages 1 and 2 turbine buckets. This steam delivery system relies on tubular seals, or "spoolies", to effectively deliver steam to the buckets without detrimental leakage of steam, which would lead to performance loss and adverse thermal gradients within the rotor structure. The basic concept for power system steam sealing is derived from many years of successful application of spoolies in GE aircraft engines.

Spoolies were used on the 9H FSNL test machine. Although steam cooling was not utilized, assembly and disassembly tooling and processes were developed. Post-FSNL test evaluation of the seals was correlated with previous spoolie component tests.

A rotating steam delivery rig was designed and fabricated, and will demonstrate cyclic endurance characteristics of the steam delivery system under simulated 9H and 7H engine operating conditions. The rotating rig will subject components to the same centrifugal forces and thermal gradients that occur during actual operation of the turbine. The rig is shown in Figure 5, and is scheduled to run in late 4Q99.

Combustor Design

The H machine combustor design is based on the current GE commercial DLN combustion system, with modifications being made for improved use of available air, reduced cooling, and greater load turndown capability. The design is similar for both the 9H and 7H machines.

Development testing continued in 1999 in the GEAE-Evendale, OH combustor test facility, which has full H machine flow, pressure, and temperature capability. Testing focused on producing a combustion system that produced single digit NOx emissions with acceptable dynamics, turndown, and metal temperatures. Several configuration choices were made. The combustor length (longer of two options), and the number of fuel injectors per chamber were determined. Operating metal temperatures were characterized, and lifing analyses were completed with positive results. Testing will continue for the remainder of 1999 to develop margin to single digit NOx for the 7H. The combustor test rig is shown in Figure 6.

7H Full Speed No Load Test

The initial 7H full speed no load (FSNL) product acceptance test is scheduled for late 4Q99 at GE's Greenville, SC manufacturing facility. Testing will validate scale-up effects of the 7H compressor (flow, operability, aeromechanics), rotor dynamics, secondary airflow systems, bearing systems, and controls. The 7H FSNL test will benefit from the previous 9H FSNL product acceptance test program, which provided an initial validation of the H technology platform and the GE Mark VI control system. The 7H test machine is shown in Figures 7 and 8.

Initial 9H Site

GE Power Systems and BP Amoco (UK) received British government approval for construction of a 500-megawatt 9H-based power plant at the Baglan Bay Energy Park in South Wales. The new plant is scheduled to enter service in 2002. An artist's view of the Baglan Energy Park is shown in Figure 9.

Initial 7H Site

GE Power Systems and Sithe Energies announced plans for an 800-megawatt 7H-based power plant in Scriba, NY. The plant is scheduled to begin operation and testing in the last quarter of 2002. An artist's view of the "Heritage Station" plant is shown in Figure 10.

CONCLUSIONS

GE is continuing on its path to introduce the H product line, providing the customer with the highest thermal efficiency, lowest cost of electricity option for future power generation. The successful compressor rig tests, nozzle cascade testing, and combustor development are key milestones on that path. Initial FSNL testing of the 9H gas turbine at GE's Greenville, SC manufacturing plant allowed validation of a large number of system components, and the results are being factored into the ongoing 9H and 7H designs. The MS7001H ATS will follow with FSNL testing in late 1999.

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4. Cook, C. S., November 1998. Overview of General Electric's Advanced Turbine Systems Program. Advanced Turbine Systems Annual Review, November 2-4, 1998. Washington, DC.

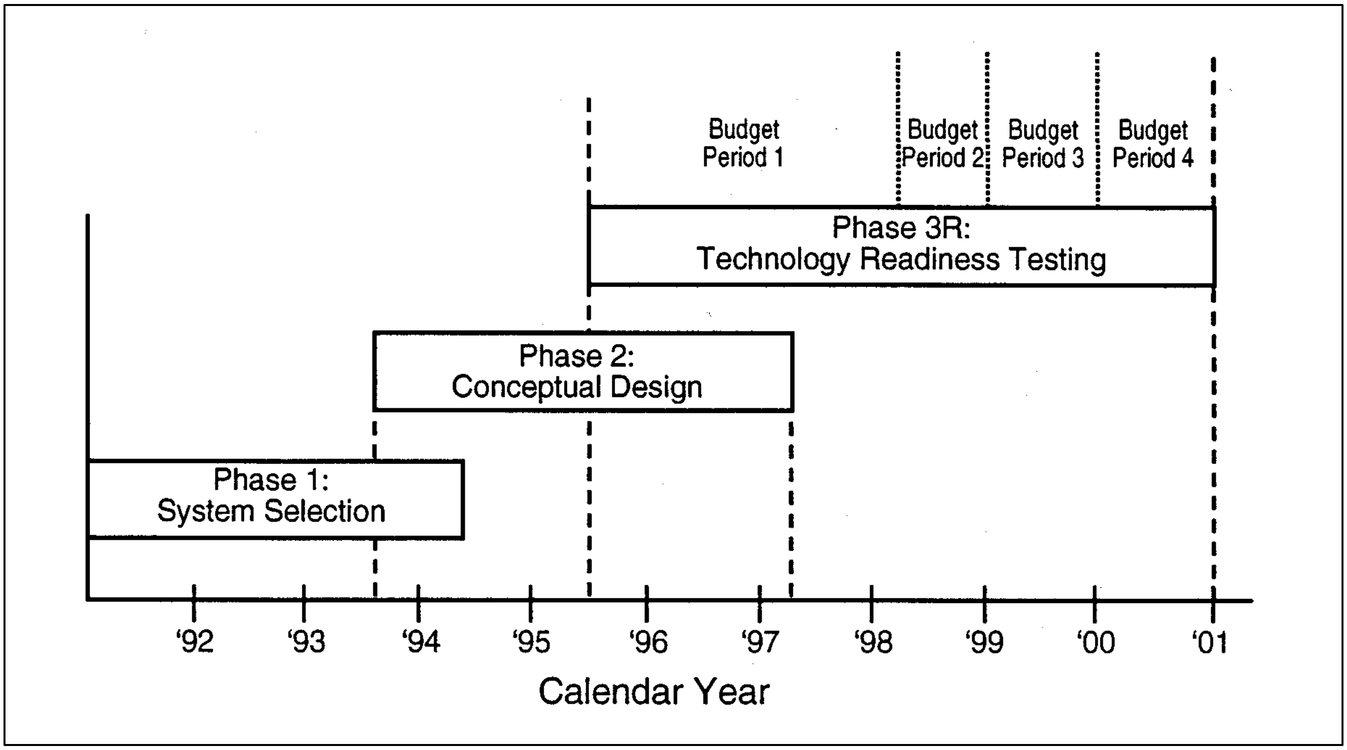

Figure 1. ATS Program Timeline

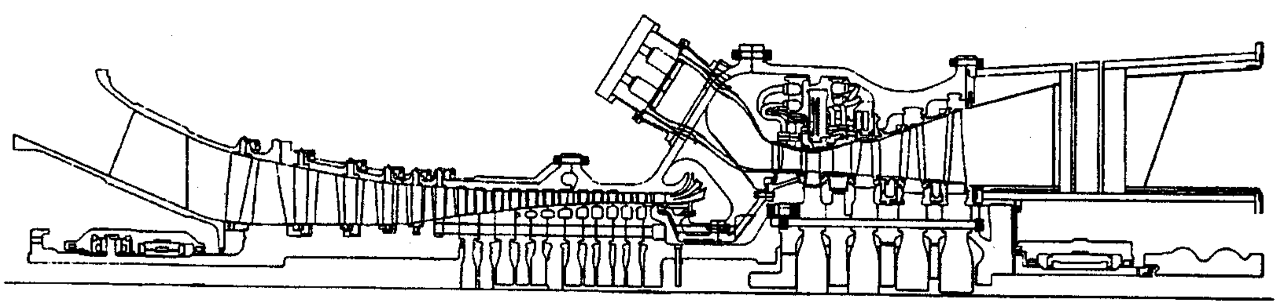

Figure 2. 7H Gas Turbine

7H Compressor Rig Stator
(During Buildup)

7H Compressor Rig Rotor
(During Buildup)

Figure 3. 7H Compressor Rig Test Hardware

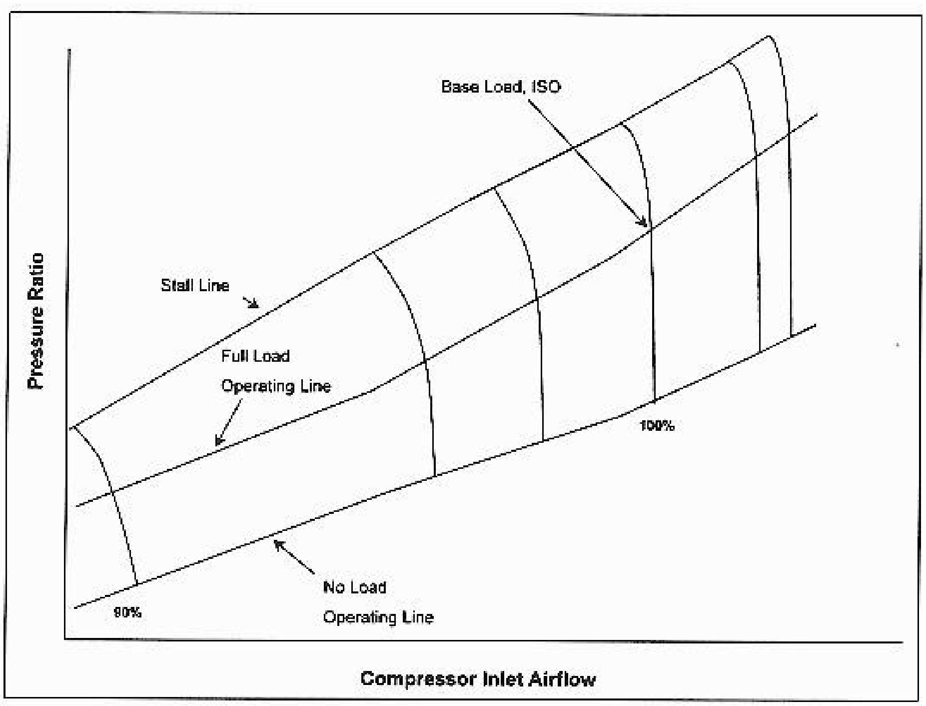

Figure 4. 7H Compressor Test Validates High-Speed Compressor Map

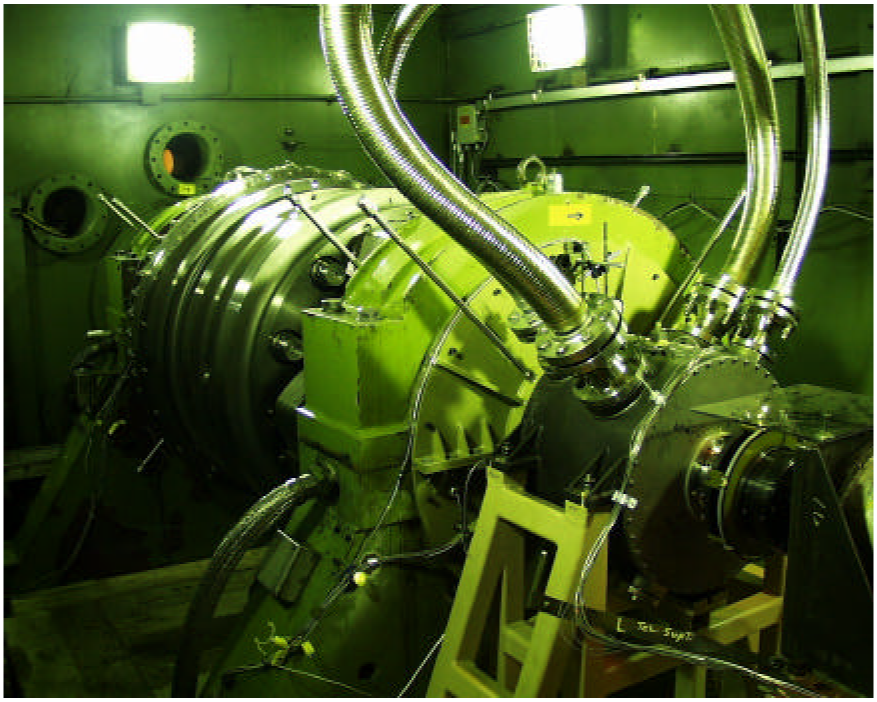

Figure 5. Turbine Rotor Rig

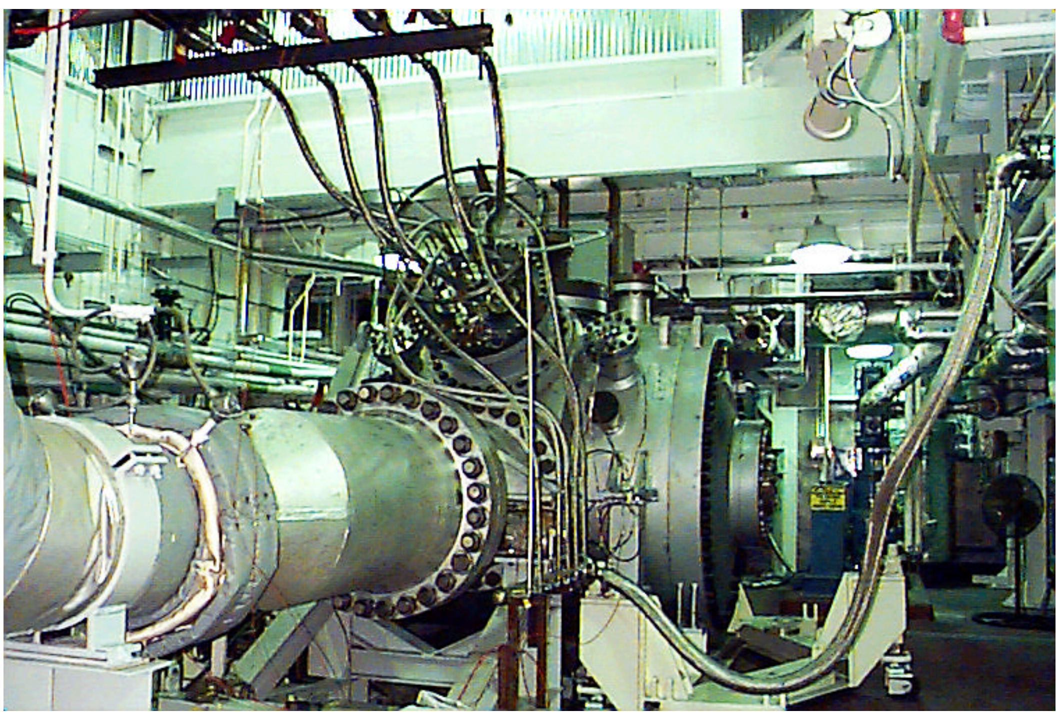

Figure 6. Combustor Test Stand at GEAE – Evendale, OH

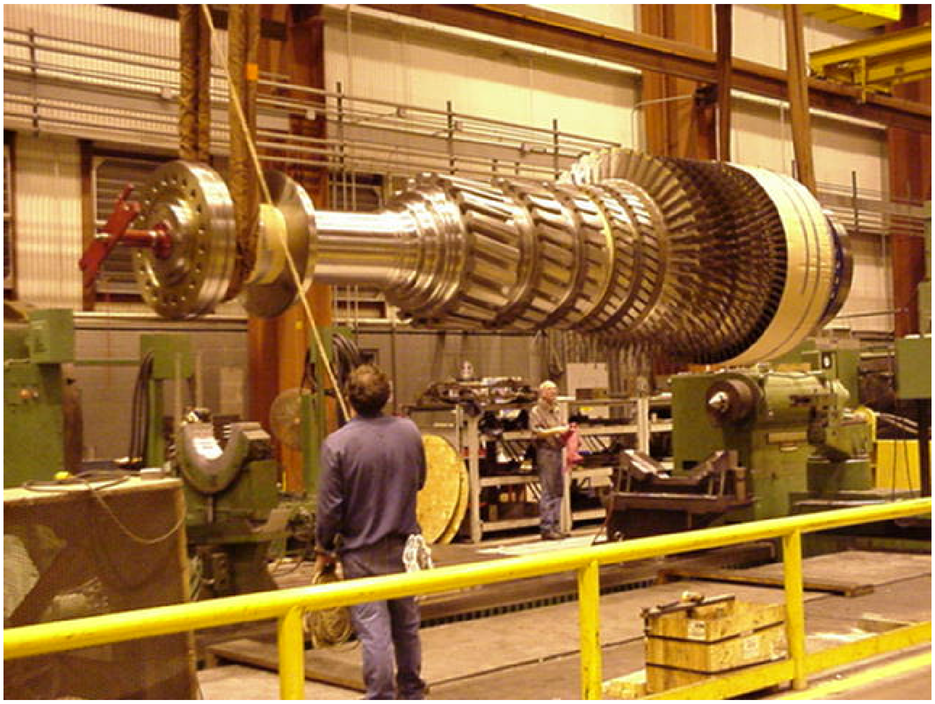

Figure 7. 7H Compressor Rotor During Assembly

Figure 8. 7H Turbine Rotor During Assembly

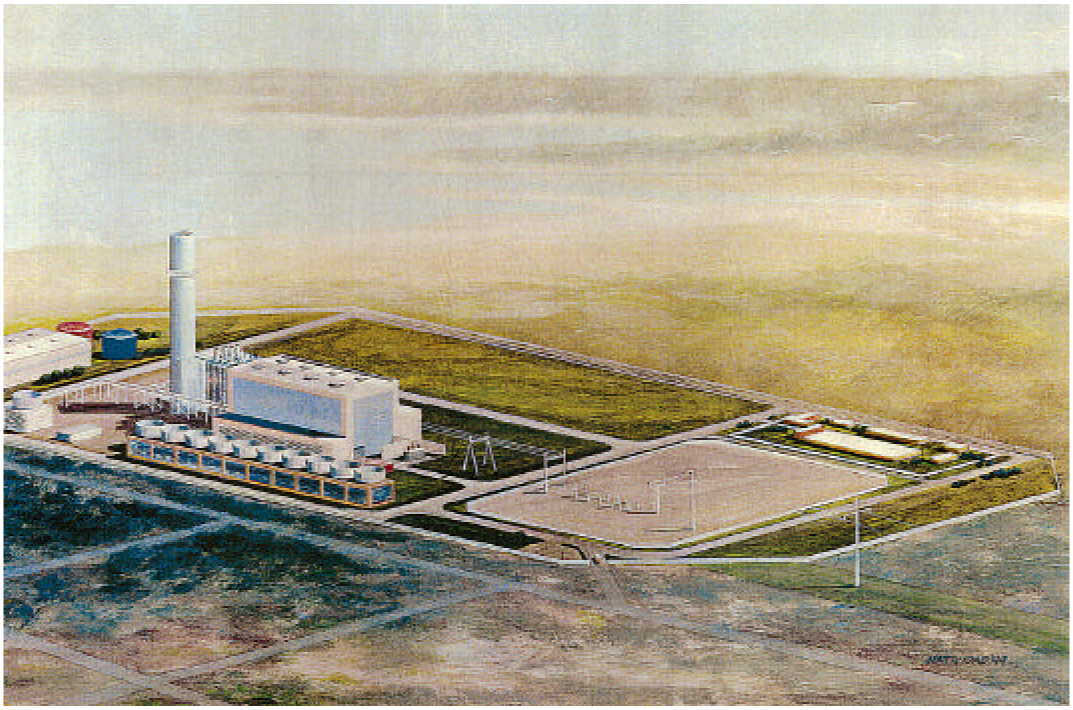

Figure 9. 9H Site, South Wales, UK
Baglan Bay Project

Figure 10. 7H Site at Heritage Station, Scriba, NY