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HIGH-TEMPERATURE GAS-COOLED REACTOR
STEAM CYCLE/COGENERATION
LEAD PROJECT STRATEGY PLAN

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GAS-COOLED REACTOR ASSOCIATES

MARCH, 1982

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<u>SECTION</u>	<u>PAGE</u>
OVERVIEW	1
1.0 INTRODUCTION	1-1
1.1 Basis for HTGR Program and Lead Project	1-1
1.2 Need for HTGR-SC/C Lead Plant	1-3
1.3 Lead Project Objectives	1-5
2.0 LEAD PLANT DESCRIPTION/APPLICATION OVERVIEW	2-1
2.1 Design Overview	2-1
2.2 Cogeneration Application	2-1
3.0 LEAD PROJECT PROGRAM	3-1
3.1 Lead Project Structure/Arrangements	3-1
3.1.1 Baseline and Plans for Management Control	3-1
3.1.2 Project Phasing	3-3
3.1.3 Participant/Organizational Arrangements	3-4
3.2 Lead Project Schedule	3-9
3.3 Lead Project Costs	3-9
4.0 LEAD PROJECT DEPLOYMENT STRATEGY	4-1
4.1 Lead Project Cost-Sharing	4-1
4.2 Lead Project Financing	4-2
4.3 Lead Project Risk-Sharing	4-4
4.4 Cost Sharing Projections	4-8

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OVERVIEW

The Utility industry has a long record of support for the High Temperature Gas-Cooled Reactor (HTGR) because of its versatility and flexibility. In addition to its demonstrated application for highly efficient electricity generation, the HTGR, because of its high temperature capability, is ideally suited to cogeneration applications with various industrial processes that are presently dependent on fossil energy sources. For all these applications, the energy cost estimates associated with the HTGR indicate the potential for significant economic savings. Other important attributes are associated with the inherent safety and low environmental impact characteristics of the HTGR. These characteristics result in less reliance on engineered safety systems, added margins for meeting certain licensing criteria, greater siting flexibility and reduced radiation exposure to plant personnel. Given the multibillion dollar investment required for a central power plant today, the HTGR's inherent safety provides important plant investment protection to the shareholders and rate payers. Furthermore, the HTGR is an evolutionary technology that leads to several concept applications, wherein the incremental effort in evolving from one application to another is relatively modest.

The strategy, contained herein, for developing the HTGR system and introducing it into the energy marketplace is based on using the most developed technology path to establish a HTGR-Steam Cycle/Cogeneration (SC/C) Lead Project. Given the status of the HTGR-SC/C technology, a Lead Plant could be completed and operational by the mid 1990s. While there is remaining design and technology development that must be accomplished to fulfill technical and licensing requirements for a Lead Project commitment, the major barriers to the realization a HTGR-SC/C Lead Project are institutional in nature, e.g. Project organization and management, vendor/supplier development, cost/risk sharing between the public and private sector, and Project financing. These problems are further exacerbated by the overall pervading issues of economic and regulatory instability that presently confront the utility and nuclear industries. This document addresses the major institutional issues associated with the HTGR-SC/C Lead Project and provides a starting point for discussions between prospective Lead Project participants toward the realization of such a Project. This document was prepared by Gas-Cooled Reactor Associates (GCRA) and as such reflects the Utility/User viewpoint, as well as the GCRA progress to date for establishing a strategy framework supported by all Program participants.

In brief, the strategy contained herein is based on a phased commitment for the construction of the Lead Plant whereby all parties are able to progressively negotiate their role and financial exposure based on definitive decision oriented information established within each phase. This approach advances the technical programs to provide the decision oriented information on evaluated performance, economics and licensing, while the institutional issues are being resolved in concert with the overall efforts to stabilize the utility and

nuclear industries. The basic premise is that a private sector Lead Project entity will support the Lead Plant costs to the extent of its commercial value. In addition, the Utility/User industry, through GCRA and EPRI, will support a share of front-end costs associated with the Lead Project. Vendor/supplier support for the Lead Project is expected through an industrial team that will provide the design and manufacturing capabilities required for the Project. The vendor/supplier team would share in the Lead Project risks through firm prices on the plant components and fuel supply and provide a broadened vendor/supplier infrastructure for subsequent HTGR commercial plants. Government financial support is required for the front-end design and technology development of nuclear systems and components, fuel cycle development and demonstration, and Project financing support to offset first-of-a-kind costs and risks associated with the Lead Project. As developed herein, the intent is to finance the Lead Project through a cooperative private/public sector effort with industry paying the major fraction, approximately 75%, of the total Lead Project costs. Upon completion of the Lead Project, the private sector should be able to deploy the HTGR-SC/C system on a commercial basis.

1.0 INTRODUCTION

1.1 Basis for HTGR Program and Lead Project

A major factor in the historical industrial/economic growth of the United States has been the abundant supply of low-cost and readily available oil and gas resources which currently supply over 70% of our energy needs. During the last decade, however, the U.S. has experienced significantly increased oil and gas prices and great uncertainty with respect to the supply of these fuels.

For the foreseeable future, the two major energy growth markets are projected to be electricity and process heat, wherein coal and nuclear are acknowledged as the principal energy sources to satisfy these markets. Coal is versatile and can be used for generating electricity, process heat, and as a feedstock for synfuel (liquid and gas) production. Additionally, the export market for coal is rapidly expanding. Thus, the demand for coal is multifaceted, and the ultimate risk of over reliance on it and the attendant environmental impact associated with its greater use are of National concern. To date, nuclear energy's contribution to energy supply has been confined to electricity generation wherein the light water reactor (LWR) system presently contributes about 4% of the total U.S. energy supply. However, during the past few years, a myriad of uncertainties have pervaded the LWR industry. The result has been the cancellation and deferral of an increasing number of LWR plants with no immediate prospects for new orders.

In light of these uncertainties with coal and present nuclear systems, National consideration of alternative nuclear energy systems is warranted. Recognizing the magnitude of effort involved, any alternative nuclear energy system should have the following attributes:

- Potential for a long economic lifetime.
- Adaptability to multiple applications and low incremental costs to evolve from one application to another.
- Inherent safety and low environmental impact characteristics.

A nuclear system that satisfies all of these attributes is the High-Temperature Gas-Cooled Reactor (HTGR). The HTGR is an advanced converter reactor system that offers efficient and unique applications of nuclear power to meet varied energy requirements. In addition to its demonstrated application for electricity generation, the HTGR, because of its high temperature capability, is ideally suited to cogeneration applications for industrial process heat. For all these applications, the evaluated energy cost estimates associated with the HTGR indicate the potential for significant economic savings.

For example, the HTGR-Steam Cycle/Cogeneration (HTGR-SC/C) system produces superheated steam to generate electricity at high efficiencies and/or serve a broad range of process steam requirements through the cogeneration mode. In particular, the HTGR-SC/C system is ideally suited for cogeneration with

central, baseloaded industrial user(s) such as petroleum refineries, chemical plants, and the emerging synfuel industries. The HTGR-SC/C technology is sufficiently developed such that it is on the threshold of commercial deployment--needing only the construction and operation of a Lead Plant to provide demonstration of integrated system performance, licensability, and economic viability.

With the more advanced HTGR-Reformer (HTGR-R) system, reactor thermal energy may be converted to a storable/transportable energy form through the use of a reversible chemical reaction whereby methane and water are combined to form a synthesis gas of hydrogen and carbon monoxide that would be utilized in industrial cogeneration applications, such as the ammonia and methanol industries as well as the emerging synfuel industries. Modular concepts of the HTGR-SC/C and HTGR-R systems offer the potential for high availability service for process steam and heat applications that require limited heat source capacity. Another advanced concept, the HTGR-Gas Turbine (HTGR-GT), offers the potential for high efficiency electricity generation with near-dry cooling. Alternatively, the HTGR-GT may be coupled with higher efficiency bottoming power cycles or with cogeneration applications. Further, a combination of the technology from HTGR systems and the LMFBR system would provide eventual access to an alternate breeder concept - the Gas-Cooled Fast Breeder Reactor (GCFR) - viewed by many as having a better economic potential than the LMFBR.

Hence, the HTGR is an energy option capable of multiple applications with an evolutionary flexibility that makes it adaptable to many market requirements today and in the future. Furthermore, the inherent safety and low environmental impact characteristics of the HTGR provide added incentive for its deployment. These characteristics offer the potential for less reliance on engineered safety systems, greater siting flexibility, added plant investment protection, and reduced levels of radiation exposure to the plant personnel. It is further noted that HTGR development programs are under way in the Federal Republic of Germany and Japan making international cooperation in this area both practical and economically desirable.

In summary, there are compelling reasons for according a high priority to National support for securing the HTGR as a commercial option. To meet this objective, the following requirements have been recognized:

- Identification of a sufficient market that serves as a necessary impetus for commercialization.
- Specific Utility/Users' support and commitment that is based on the benefits the HTGR system offers.
- An industrial base of vendor/suppliers that are committed to supporting the commercial deployment of the HTGR systems.
- Stable Government support and commitment that is based on National benefits and compatibility with other National energy development programs.

Further, any National HTGR Program must be based on equitable cost-sharing arrangements between the private sector and the Government and focused on a specific Project.

During 1980, a comprehensive evaluation of Project candidates was conducted that has served to establish a consensus on the status and merits of the technical, economic, and market characteristics of various HTGR systems. Through this effort, the four-loop, 2240 MW(t) HTGR-Steam Cycle/ Cogeneration (SC/C) Lead Project has been established as the primary focus for the HTGR Program for the following reasons: (1) the technical feasibility of the system is assured through long-standing design experience and the solution of problems experienced with the Fort St. Vrain demonstration plant; (2) relative to the other Project options, the HTGR-SC/C system requires the least resources, involves the least technical risks, and can be deployed on the earliest schedule. Accordingly, this option warrants the greatest private sector financial support; (3) the deployment of the HTGR-SC/C system provides a large fraction of the technology and industrial infrastructure required for the more advanced follow-on HTGR systems; and (4) the HTGR-SC/C system serves the large electricity generation market and is ideally suited for cogeneration with central, baseloaded industrial applications requiring process steam and electricity. Further, with the modular loop concept, the two-loop or six-loop designs may also be applied to meet broad Utility/User power rating needs for follow-on commercial plants.

During 1981, a series of HTGR-SC/C Lead Project evaluation and development activities have begun with specific Utilities/Users that have an interest in hosting such a Lead Project. This evaluation and development effort has been coordinated by Gas-Cooled Reactor Associates (GCRA) and supported by all the Program participants. In support of this effort, GCRA has developed this document to establish a framework for planning and negotiations between the prospective Lead Project participants toward the realization of such a Lead Project.

1.2 Need for HTGR-SC/C Lead Plant

Over the past two years, Utility/User directed studies have identified the performance characteristics necessary for an HTGR-SC/C system in the generation/ cogeneration market. Design work has provided the detailed information needed to confirm the economics of an HTGR-SC/C plant that fulfills Utility/User needs while meeting present day safety standards and licensing requirements. While strategic and commercial incentives for the HTGR-SC/C system are favorable, commercial deployment of the system is not an option until utility and vendor industries have sufficient information on plant costs and licensing to undertake business ventures on the basis of traditional buyer-seller terms. A HTGR-SC/C Lead Plant in which the Utility/User and Regulatory requirements are met is necessary for the industry to commit to broad scale deployment of the system.

In addressing the need for a HTGR-SC/C Lead Plant, it is necessary to assess the relevant experience and information now available for considering such a venture. Direct experience is derived from the 40 MW(e) Peach Bottom I developmental power plant operated by Philadelphia Electric from 1967 through 1974, and the 330 MW(e) Fort St. Vrain demonstration plant which is owned and operated by the Public Service Company of Colorado. The mission of the HTGR-SC/C Lead Plant is to bridge the technological and institutional gap between the Fort St. Vrain plant and that required for a commercial HTGR-SC/C industry.

The Fort St. Vrain plant was conceived nearly 20 years ago as part of the AEC Demonstration Reactor Program. The design philosophy of that era placed a high premium on low plant capital costs and high thermal efficiency while meeting then current safety and licensing requirements. Consideration of the relationship of the plant to future commercial units was secondary to the establishment of key engineering technologies unique to the HTGR, notably the prestressed concrete reactor vessel (PCRVR) and the graphite moderated, prismatic core. It was also to provide experience with reactor control features and plant maintenance in an operating utility environment. While Fort St. Vrain has experienced difficulties in its rise to full power, it has provided confirmation and demonstration of many HTGR concepts.

In considering the step from Fort St. Vrain to a commercial HTGR-SC/C system, the following must be considered:

- To achieve competitive energy costs and respond to Utility/User requirements for the size of capacity additions, the plant size for commercial HTGR-SC/C systems is nearly a factor of three larger than the Fort St. Vrain plant. This requirement imposes the need to scale-up the reactor core and primary system components and to reconfigure the PCRVR vessel.
- Design seismic ground accelerations required for siting commercial HTGR-SC/C systems are a factor of three greater than can be accommodated with a Fort St. Vrain plant design. This requirement can be met with the adoption of the low profile, multicavity PCRVR and improved mechanical and structural design.
- The Fort St. Vrain plant was designed and licensed on the basis of using power generating systems for purposes of decay heat removal. Current licensing practices applied to the HTGR require three dedicated auxiliary heat removal systems for that purpose. These systems also require reconfiguration of the PCRVR, as well as changes to overall plant control.
- The Fort St. Vrain plant was designed and licensed on the basis of a confinement building to assure filtration of accidental radioactivity releases and to provide missile protection. Current licensing practices require a containment structure to retain any accidentally released radioactivity. This requirement impacts reactor plant configuration, the overall plant layout and the construction sequence for the plant.
- Utility/User and Regulatory requirements demand improved access for the purposes of inspection and maintenance over Fort St. Vrain. These requirements are met by reconfiguring the PCRVR to house the major components in separable cavities, as well as design changes to the major components.

In accommodating the changes enumerated above, most components of the reactor system require redesign and requalification to meet present day Utility/User and Regulatory requirements. Accordingly, neither the commercial replication or the direct commercial extrapolation of the Fort St. Vrain plant is a viable option. Therefore, the immediate hurdle for the

commercialization of the HTGR-SC/C system is the front-end design and development of the nuclear steam supply system (NSSS) that does meet Utility/User and Regulatory requirements. Support is required to advance the design and development of the NSSS to the level at which the risks and incentives are sufficiently understood to permit commercial arrangements to be made between Utility/Users and vendors/suppliers. These conditions will have been achieved through a Lead Project when:

- The first-of-a-kind engineering and manufacturing activities have been successfully completed.
- The reactor plant system and key elements of the supply infrastructure are shown to be licensable.
- Equipment and other plant capital costs, construction and delivery schedules and other cost factors are sufficiently established to permit the system to be evaluated as competitive with alternate systems.
- Systems performance capability (e.g., operability, reliability) is demonstrated or extrapolable from design analysis and testing programs.

1.3 Lead Project Objectives

Pursuant to the requirements enumerated above, the overall objective of the HTGR-SC/C Lead Project is to design, license, build and operate the HTGR-SC/C Lead Plant in order to establish the commercial viability of the HTGR-SC/C system and its supporting industry. Supporting objectives are delineated as follows:

- Demonstrate HTGR systems and components that have evolved since Fort St. Vrain.
 - Redundant, dedicated decay heat removal systems.
 - Multicavity PCRV for improved access, scalability, and seismic resistance.
 - In-vessel refueling to minimize down-time.
 - Electrically driven main circulators.
 - Low enriched uranium, oxide particle fuel cycle.
 - Design and fabrication of the graphite core and reactor internals, high-temperature metallic components, etc. to current standards.
 - Scale-up to commercial size with reactor system/containment/nuclear island integration.
- Confirm incentives and characterize risks associated with commercializing the HTGR-SC/C system.
 - Demonstrate licensability of the HTGR-SC/C system and relevant elements of the supply infrastructure (e.g., fuel supply).
 - Establish plant construction schedule and cost components (capital, fuel, O&M).
 - Verify system performance capability (e.g., capacity factor, plant efficiency, operability, and reliability).

- Establish foundation of Utility/User, vendor/supplier and licensing basis for follow-on commercial HTGR-SC/C systems and advanced HTGR systems.
 - Establish broad Utility/User participation in the Lead Project to assure future market for follow-on systems.
 - Establish vendor/supplier participation in the Lead Project to assure competitive vendor/supplier infrastructure for follow-on systems.
 - Establish licensing criteria pertinent to the HTGR.

Firm agreement by the Project participants on the Lead Project objectives and the approach to achieve these objectives is mandatory. Lessons learned from the Clinch River Breeder Reactor Project serve to underline the importance of this agreement.

2.0 LEAD PLANT DESCRIPTION/APPLICATION OVERVIEW

2.1 Design Overview

With the HTGR, several advanced concepts are introduced for the application of nuclear power. The core is cooled with pressurized helium, moderated and reflected with graphite, and fueled with a mixture of uranium and thorium fuel particles with individual ceramic coatings. The core is constructed of prismatic hexagonal graphite blocks with vertical holes for coolant channels, fuel rods and control rods. The entire reactor core, together with other major primary system components, is contained in a multicavity, prestressed concrete reactor vessel (PCRVR). In addition to primary coolant loops, auxiliary cooling loops each consisting of a helium/water heat exchanger and electric-motor-driven circulator are provided. The PCRVR and ancillary systems are housed inside a reactor containment building which is a conventional steel-lined reinforced concrete structure.

In the HTGR-SC/C design, reactor thermal energy is extracted from the primary coolant loops to generate high temperature, high pressure steam for either high efficiency electricity production or for the cogeneration of steam and electricity for process applications. To achieve this efficient energy conversion, steam is generated at the elevated conditions of 2400 psi/1000°F, whereas the primary helium gas conditions are maintained in the low range of HTGR capability, approximately 1300°F. The high quality steam conditions produced by the HTGR are compatible with the modern, 3600-rpm steam turbines, currently being used in conventional fossil-fired plants. The 2240 MW(t) HTGR-SC/C Lead Plant design is based on GCRA's functional specifications and is viewed as a standard plant design for intended replication. Summary design parameters are given as follows:

Reactor Power	2240 MW(t)
Total Prime Steam Flow	7.3×10^6 lbs/hr
Steam Conditions	2400 psi/1000°F
All Electric Generation	
Electric Output	858 MW(e)
Net Efficiency	38.5%
Full Cogeneration (Typical)	
Electric Output	285 MW(e)
Steam Supply	5.2×10^6 lbs/hr
Core Exit Helium Temp.	1280°F
Average Fuel Temp.	1610°F
Fuel Cycle	LEU/Th - Stowaway
Power Density	7.1 watts/cc
Average Burnup	100,000 MWd/tonne

2.2 Cogeneration Application

As noted earlier, the HTGR-SC/C can serve a large potential market that ranges from baseload electricity generation to industrial cogeneration applications requiring electricity and process steam. In the cogeneration application, the HTGR-SC/C differs from the all electric generation application only with respect to how the steam is utilized. Since distribution

and storage of steam are subject to practical and economic limitations, HTGR-SC/C systems would be most appropriately utilized for large concentrated points of use where relatively close-in siting is feasible. Typical examples would be energy parks, large refineries, synthetic fuel facilities, and development of shale oil and tar sands resources. To prevent process disruptions resulting from reactor unavailability, multiple HTGR-SC/C units and/or backup steam generation capacity with fast-start capability would likely be required. Typically, backup capacity would be in the form of low-capital-cost/high-fuel-cost systems such as gas- or oil-fired boilers.

In Figure 1, a simplified turbine plant and steam delivery system are illustrated which are typical of HTGR-SC/C cogeneration applications. Note that in this cycle, the output of the condensing turbine (No. 2) would be varied depending upon the demand for process steam. In the optimum cogeneration mode, the condensing turbine would be shut down and the steam delivered to industrial users. While Figure 1 illustrates the basic concept, other temperatures and pressures and/or multiple temperatures and pressures can be obtained by alternate topping turbine configurations, cascading turbines, or varying the reactor operating conditions. Note, however, that to obtain the efficiency benefits of cogeneration, the energy in the steam must be used in series, with electrical generation being basically a topping cycle. For this reason, temperature-limited reactor systems such as the LWR are practically limited to the cogeneration of very low quality steam (typically 350°F, 150 psi).

Relative joint-product cost characteristics for the HTGR-SC/C system illustrated in Figure 1 are given in Figure 2. Lines 1, 2, and 3 in the figure correspond to plant operation in the all-electric mode, at 50% of the maximum cogeneration potential, and at 100% of the maximum cogeneration potential respectively. The plant operating parameters for each case are shown below:

Application	All Electric	50% Cogeneration Potential	100% Cogeneration Potential
Power Rating-MW(t)	2240	2240	2240
Net Electrical Output-MW(e)	860	585	350
Process Steam Flow (10 ⁶ Lbs/hr)	-	2.4	4.8

Note that each line corresponds to the possible allocations of cost between electricity and steam for a given plant under the specified operating conditions. The cost of single-product competing technologies is indicated for both electricity and steam.

The area within the dashed lines represents the domain of cost allocation in which a joint-product cost benefit can be realized by some combination of the electric rate payer, the steam user, and the investors in the plant. Note that evaluated incentives exist for even the 50% cogeneration potential case when compared to the steam costs from a large coal plant. Relative to the projected cost for oil- and gas-derived steam, the evaluated incentives for the HTGR-SC/C system are most significant.

FIGURE 1
CYCLE DIAGRAM—2240 MW(t) APPLICATION
MAXIMUM COGENERATION AND MAXIMUM ELECTRICITY MODES

LEGEND

W = FLOW (10^6 LB/HR)

P = PRESSURE (PSIA)

T = TEMPERATURE ($^{\circ}$ F)

FIGURE 2

HTGR-SC/C Relative Product Costs

While economic evaluations provide a strong incentive for the HTGR-SC/C system, the difficulty in obtaining commitments from existing or projected industrial users is a key institutional difficulty. The joint-product cost curves of Figure 2, however, suggest a strategy which would facilitate deployment of the HTGR-SC/C systems without the requirement for prior user commitments. Based upon a projected growth in both electric and industrial demand, the HTGR-SC/C system could be deployed on the basis of all-electric operation. As seen in Figure 2 (Line 1), generation costs are projected to be slightly higher than an optimized all-electric HTGR facility. As demand for process steam is developed by the prospects for low-cost energy, the plant could evolve to a mode of partial (Line 2) or full (Line 3) cogeneration.

The HTGR-SC/C system comprises a unique potential for the utility industry to access the industrial cogeneration market. This would result in a substantial decrease in required energy resources plus substantial economic savings that would be shared by rate payers, steam users and investors.

3.0 LEAD PROJECT PROGRAM

3.1 Lead Project Structure/Arrangements

The Lead Project must accomplish the objectives set forth in Section 1.3 with acceptable technical and financial risks to the participants. A balance must be reached between: a) developing the technology to the level where a reasonable/high confidence that the systems will perform reliably, b) the time interval over which the Project would be completed, and, c) the overall resources that are available.

The LWR experience in project execution must be examined and the lessons learned and applied carefully. For example, the history of LWRs shows that changes in design and licensing must be minimized and controlled and that construction activities must be well planned and organized. This can be accomplished in the ideal sense if:

- A completely engineered and designed plant is submitted for licensing.
- There are no changes in licensing requirements after the construction permit is issued.
- All software, equipment and material are produced according to quality requirements and are delivered when needed in a well-planned construction sequence.
- Manpower employed in all phases of the project are qualified and productive, and available when needed.

Recognizing that the real world is not ideal, one can only take steps to achieve as much of the ideal as technological and institutional constraints allow. The following discussion addresses the key elements of structure and management control for the HTGR-SC/C Lead Project.

3.1.1 Baseline and Plans for Management Control

Recognizing the multi-party involvement and funding arrangements and constraints, it is imperative to establish a firm structure for controlling and advancing the Lead Project. To this end, the HTGR-SC/C Baseline Review was initiated in the fall of 1981. Representatives from potential Lead Project participants have been engaged in a technical review of the HTGR-SC/C plant design and the supporting design and technology development plans that have been developed to date primarily by General Atomic and United Engineers and Constructors. The objectives for the Baseline Review have been to obtain reviewer concurrence on the technical adequacy of the proposed Lead Plant design and the supporting design and technology development programs for the purposes of:

- Establishing a basis for cost and risk sharing considerations in the Lead Project.
- Establishing a Baseline for the management of the Lead Project.

The organizations participating in the review are:

Bechtel Group Incorporated
Combustion Engineering, Inc.
Department of Energy
Electric Power Research Institute
Gas-Cooled Reactor Associates
General Atomic Company
General Electric Company
Idaho National Engineering Laboratory
Nuclear Regulatory Commission
Oak Ridge National Laboratory
United Engineers and Constructors

Further, GCRA and EPRI have engaged consultants including S. M. Stoller Corporation; Pickard, Lowe, and Garrick; and Kortec Engineering to assist in in-depth technical reviews of specialized areas. In addition, key utility representatives from GCRA, including candidate Lead Utility personnel, are directly involved in this Baseline Review process.

The HTGR-SC/C Baseline Review is subjecting the technical effort projected as necessary for the Lead Project to the scrutiny of a broad segment of the nuclear vendor/supplier and utility industry. The Review has been oriented to the technical aspects of the Lead Plant design features (the bases for capital cost estimates), to the work planned to perform the plant design and establish the supporting technology (the bases for projected development costs and schedules), and to the bases for projected construction schedules. Emphasis has been focused on that portion of the Program for which government support is sought--the front end design and technology development work to establish the nuclear steam supply system.

The Baseline Review process will culminate with the declaration of Baseline "0" workscope and schedule data from which the balance of the Project will be managed. This work will be defined and managed per a Lead Project Plan that will evolve from the Lead Project Strategy Plan contained herein and a series of supporting, control documents. The Lead Project Plan will define the detailed scope of the Project, the responsibilities and authorities of Project participants, the corresponding document structure, work breakdown structure and management control system. This management control structure will be designed to facilitate a smooth transition to the Lead Utility project organization and management. To facilitate the management of the Project activities, detailed "Control Plans" will be established. For example:

- The Licensing Plan defines the relationship of licensing activities to the siting, design, and construction process and provides a schedule for the development and submittal of major licensing documents to the Nuclear Regulatory Commission. It includes explicit definitions of processes and activities to:
 - 1) Secure regulatory authorizations and licenses for construction and operation of the Lead Plant.

- 2) Establish a background of safety-related information to facilitate the licensing of follow-on commercial units.
- The Design and Technology Development Plan provides detailed descriptions of the development effort necessary to support the Lead Project. This Plan emphasizes the cost and schedule of activities to complete the design and technology development of the NSSS and identify the point where component/system design, development and fabrication can be assumed by the private sector. This Plan also provides the bases for the prioritization of the HTGR-SC/C Lead Project design and technology development effort.

A Baseline "0" Design and Cost Report plus the supporting Plans will culminate in a "Lead Project Decision Package" that will be completed in June 1982.

3.1.2 Project Phasing

To ensure that each forward financial commitment for the Project is made on a sound technical, economical, and institutional basis, the Project implementation process must be phased. The phasing is designed to minimize financial risk exposure by committing to the activities in each subsequent phase only as the information accumulated in any phase is sufficient to support the go-ahead decision. The financial exposure in each succeeding phase increases until it reaches the most crucial decision point: whether to proceed with the construction of the Project. The phases of the Lead Project and the associated principal activities are:

PHASE I - Program/Project Definition

- Complete "Project Decision Package" as a Vehicle for Advancing the Lead Project Commitment.
 - Lead Project Strategy Plan
 - Design and Cost Report
 - Design and Technology Development Plan
 - Licensing Plan
- Submit Programmatic Environmental Assessment.
- Establish Lead Utility/User Entity and Site plus Follow-on Project Candidates.
- Establish the NSSS Vendor/Supplier Team Arrangements.
- Establish Pre-Application Review Program at NRC.
- Complete Conceptual Design and Cost Estimate.
- Establish Lead Project Plan.

PHASE II - Preliminary Design and Licensing

- Complete Detailed Management/Financing Arrangements.
- Secure Project Authorization Package

- Complete design and safety analysis in sufficient detail to:
 - Support PSAR Development and Site-Specific Environment Report.
 - Complete Optimization Studies to Fix Design Parameters of Major Components and Systems.
- Submit PSAR and Site-Specific Environmental Report to NRC.

PHASE III - Final Design and Licensing

- Complete Final Design in Sufficient Detail to Support a Decision Regarding Plant Construction.
- Prepare Contract Bidding Documents Necessary for Procurement of Components, Systems, and Structures.
- Secure, Analyze and Evaluate Construction Bids for Components, Systems, and Structures.
- Detail Cost and Schedule Based upon Actual Equipment Cost and Delivery Date Quotes.
- Order Long-Lead Materials and Components.
- Obtain Construction Permit.
- Commit to Procurement, Manufacturing and Construction.

PHASE IV - Construction and Startup

- Complete Final Design of Plant, Systems and Components.
- Submit FSAR to NRC.
- Complete Plant Construction.
- Train and License Plant Operators.
- Obtain Operating License.
- Test, Startup and Place Plant in Commercial Operation.

In order to assist the decision-making process at each phase, a technical and economic risk assessment would be prepared to augment the information being developed and accumulated. The risk assessment would address issues related to the cost and schedule of completing the Project as well as those on plant performance; based on the information accumulated during each phase.

3.1.3 Participant/Organizational Arrangements

There are three indispensable classes of participants for the successful implementation of the Lead Project: Utilities/Users, Vendor/Suppliers, and the Government. A committed, concerted and cooperative effort among these

participants will be required to put the Lead Project in place. Figures 3, 4 and 5 present summary level organizational arrangements between these participants for the various phases of the Lead Project.

The single Government entity identified in the organizational charts is DOE, through which the Government's direct financial support for the Program and Project will flow. In addition, the supporting activities through the NRC will need to be coordinated with the DOE activities.

Upon completion of Phase I whereby the Lead Project is established, the Program management and Project management entities would emerge. It is important that Project management and Program management be structured to ensure that Project-specific activities and required technology development are well coordinated for scope, schedule of deliverables, cost and technical resources. In particular, Project management would be singularly focused upon the Lead Project implementation with the intent of delivering the Lead Plant within budget, on schedule and quality to assure safe, reliable operation. The Project management organization must be unencumbered by broad programmatic issues so that it may concentrate on ensuring an efficient Project proceeds. Project management responsibility must be with the entity with the largest vested interest in the Project: The owner(s).

Program management would manage technology development programs and foster Project initiatives for follow-on systems. The concept posed for the HTGR Program is to utilize Gas-Cooled Reactor Associates as the Program manager. This approach assures an effective interface between the Program management and Project management, nurtures the deployment of follow-on systems, and encourages greater private sector interest and financial support.

Utility/users require assurance that a reliable manufacturing base will be available to supply the systems, components, fuel, software, and services before they can accept a new system as a viable alternative to existing systems. Limited financial resources eliminate any possibility of independent, multiple reactor system vendor/supplier development like that now existing in the LWR industry. As such, it becomes important to induce several potential vendor/suppliers during the initial Lead Project phases such that competitive, multiple vendor/suppliers will emerge as the market size becomes large enough to support them. Towards this end, a cooperative "team" from the existing nuclear infrastructure is envisioned for the Lead Project and possibly a limited number of follow-on projects. The advantage of a "team" is that several potentially independent vendor/suppliers could be centralized wherein it would be assured that each one would be equitably exposed to the technology. This team must be brought to bear for the Lead Project such that it fulfills the following requirements:

- Makes effective utilization of existing industrial infrastructure for the associated design and manufacturing requirements.
- Permits first-hand exposure of the technology to potential NSSS vendor/suppliers who would offer future HTGR's commercially.
- Avoid time delays in the conduct of the Project.

FIGURE 3

HTGR PROGRAM ORGANIZATIONAL STRUCTURE

LEAD PROJECT - PHASE I

FIGURE 4

HTGR PROGRAM ORGANIZATIONAL STRUCTURE

LEAD PROJECT - PHASE II & III

————— MANAGEMENT
----- COORDINATION

FIGURE 5

HTGR PROGRAM ORGANIZATIONAL STRUCTURE

LEAD PROJECT - PHASE IV

Such a team would naturally include the General Atomic Company where the majority of the U.S. HTGR technology resides. Other potential team members involved to date are Combustion Engineering and General Electric. Specific arrangements must be established as part of Phase I - Program/Project Definition.

3.2 Lead Project Schedule

It is recognized that the Lead Project schedule will evolve as required and driven by the Lead Utility entity. However, regulatory uncertainties, potential design changes and resource availability uncertainties will translate into schedule uncertainties beyond the Lead Utility's control. For example, it is likely that the Lead Project schedule will be impacted by developing requirements in the regulatory process. In addition, the schedule may be impacted by unexpected results from planned design and testing activities in key technical areas relating to critical path systems and components.

Figure 6 represents the present "target" schedule to design, license and build the HTGR Lead Plant. This schedule is based on previous HTGR experience, related LWR experience, and on the perceived impact of recent developments in regulatory requirements. Key, near-term elements of the target schedule are the identification of candidate Lead Utility sites and the initiation of a pre-application review program in 1982. The pre-application review program provides a mechanism for defining licensing criteria and the resolution of safety related issues. It is intended that the pre-application review program will facilitate the formal review process of the PSAR and issuance of a construction permit within 24 months. The purchase of long-lead materials and components has been balanced between the impact on the schedule's critical path and the associated financial exposure. Most significant is the long-lead materials for the steam generators which are placed two years prior to the construction permit issuance in order to initiate steam generator fabrication upon construction commitment. Overall, the construction period and startup duration is projected to be 87 months, which is 15 months longer than projected for commercial plants. Taking everything into consideration, full power commercial operation for the Lead Plant is projected to start by 1995.

3.3 Lead Project Costs

The major elements of costs associated with the HTGR-SC/C Lead Project are:

- Design and Technology Development Costs, including
 - Design of Nuclear Systems and Components.
 - Design Verification and Support (DV&S) for Nuclear Systems and Components.
 - Base Technology Development (including Spent Fuel Management).

FIGURE 6

SUMMARY SCHEDULE HTGR-SC/C LEAD PLANT

● Lead Plant Specific Costs, including

- Project Indirects, including Engineering, Licensing and Project Integration/Management Activities.
- Construction and Component Manufacturing.
- Owner's Costs, including Site Qualification, In-House Staff Support, and Startup Costs.
- Allowance for Funds Used During Construction (AFUDC).

● Lead Plant Operating Costs, including

- Fuel Cycle Costs.
- Operation and Maintenance Costs.

The total design and technology development cost to complete the HTGR-SC/C Lead Project is estimated to be \$479M (1982 dollars), as presented in Table 1. Note that these costs are applicable for the cogeneration or generation application of the HTGR-SC/C system. These cost estimates must be viewed as preliminary. The detailed Design and Technology Development Plan that is being developed as part of the Lead Project Decision Package will document a controlled Baseline "0" version of these costs. It is noted that the supporting safety research and pre-application review activities at NRC are not included in these costs.

Table 2 presents the Lead Plant base costs (excluding escalation and AFUDC) for the "Variable Cogeneration" and the "All Electric" applications of the HTGR-SC/C system. Table 2 also includes the cost estimate for the equilibrium, commercial HTGR so that the incremental first-of-a-kind (FOAK) plant cost estimates are identified. Reference LWR and coal plant cost estimates are also presented for comparison purposes.

Table 3 presents the associated revenue requirements and generation costs for each of the systems identified in Table 2 for a 1995 startup plant. The Variable Cogenerator HTGR figures represent an all electric operating mode. The fuel cost input and financial assumptions utilized in developing the product costs on Table 3 are provided on Table 4. All costs displayed on Table 3 assume regulated utility ownership, hence an AFUDC rate of 10.5% and a levelized fixed charge rate of 17.7% were applied. The data for the Federal Government is utilized later in the development of possible Lead Project financing alternatives. Note that the Lead Plant generation costs are based on a 15 month longer schedule and a 5 percentage points lower capacity factor as compared to the equilibrium nuclear plants. These factors allow for potential FOAK difficulties associated with the Lead Plant. The higher fuel cycle costs for the Lead Plant are based on the conservative assumption that no follow-on HTGR plants would materialize. This results in higher unit fuel fabrication costs and higher fuel carrying charges attendant with a low throughput fabrication plant serving the Lead Plant.

TABLE 1
HTGR-SC/C DESIGN AND TECHNOLOGY DEVELOPMENT COST ESTIMATE (1982 M\$)
(PRELIMINARY)

<u>COST CATEGORIES</u>	<u>RECENT SUNK COSTS</u> <u>('81 & '82)</u>	<u>COST-TO-COMPLETE</u> <u>('83 →)</u>
<u>NUCLEAR SYSTEMS & COMPONENTS DESIGN</u>		
SYSTEMS DESIGN AND INTEGRATION	1.4	27.2
SAFETY ASSESSMENT AND LICENSING SUPPORT	.8	9.8
REACTOR VESSEL	1.1	19.8
REACTOR INTERNALS	1.3	9.6
REACTOR CORE	1.9	19.9
REACTOR CONTROL	.2	4.1
PRIMARY COOLANT SYSTEM	3.1	35.9
AUXILIARY COOLANT SYSTEM	.6	15.7
FUEL HANDLING	.3	12.3
SYSTEM CONTROL AND INSTRUMENTATION	.3	19.1
REACTOR SERVICES	.1	6.5
HELIUM SERVICES	.2	4.5
PROGRAM MANAGEMENT & SUPPORT	1.8	15.1
SUBTOTAL	13.1	199.5
<u>DESIGN VERIFICATION & SUPPORT FOR</u> <u>NUCLEAR SYSTEMS AND COMPONENTS</u>		
REACTOR VESSEL	.5	10.2
REACTOR INTERNALS	.2	6.9
REACTOR CORE	1.9	22.7
REACTOR CONTROL	.2	2.8
PRIMARY COOLANT SYSTEM	1.1	21.4
AUXILIARY COOLANT SYSTEM	.3	13.3
FUEL HANDLING	-	3.1
SYSTEMS CONTROL & INSTRUMENTATION	-	.5
REACTOR SERVICES	-	1.9
HELIUM SERVICES	-	.4
PROGRAM MANAGEMENT	.7	4.2
SUBTOTAL	4.9	87.4
<u>BASE TECHNOLOGY DEVELOPMENT</u>		
FRESH FUEL PROCESS	1.6	17.6
FUEL MATERIALS	2.2	20.9
FISSION PRODUCT & COOLANT CHEMISTRY	1.1	10.8
FUEL CYCLE	.2	2.1
GRAPHITE	1.6	28.1
STRUCTURAL MATERIALS	2.6	30.6
METHODS	2.0	15.9
SAFETY & RELIABILITY	.8	9.4
ENGINEERING TECHNOLOGY	1.1	31.9
TECHNOLOGY TRANSFER	1.1	6.2
SPENT FUEL STORAGE TECHNOLOGY	.1	10.0
PROGRAM MANAGEMENT	2.3	9.2
SUBTOTAL	16.7	192.7
GRAND TOTAL -	34.7	479.6

TABLE 2 - BASE PLANT COST ESTIMATES

COST CATEGORIES	HTGR - 2240 MW(t)				REF. PWR 2400 MW(t)	REF. COAL 2245 MW(t)
	VAR. COGEN.	ALL ELECTRIC				
	LEAD	EQUIL.	LEAD	EQUIL.		
● CONSTRUCTION & MANUFACTURING COSTS ('80\$×10 ⁶)						
- STRUCTURES & IMPROVEMENTS	130	124	119	113	121	54
- REACTOR PLANT EQUIPMENT	262*	218*	262*	218*	157	233**
- TURBINE PLANT EQUIPMENT	167	139	91	91	110	84
- ELECTRIC PLANT EQUIPMENT	50	48	47	45	47	35
- MISC. PLANT EQUIPMENT	13	13	12	12	16	11
- MAIN COND. HEAT REJECT SYS.	22	22	21	21	22	17
- CONSTRUCTION SERVICES	87	78	85	76	84	60
- CONTINGENCY (15%)	110	96	96	87	84	74
SUBTOTAL	841	738	733	663	641	568
● PROJECT INDIRECT COSTS + CONTINGENCY ('80\$×10 ⁶)						
	223	145	206	136	118	85
● BASE COST + CONTINGENCY ('80\$×10 ⁶)						
	1064	883	939	799	759	653
● OWNER'S COST (7%)						
	74	62	66	56	53	46
TOTAL CAPITAL COSTS ('80\$×10 ⁶)	1138	945	1005	855	812	699
● 1981/1982 ESCALATION (9.5%/YEAR)						
	226	188	200	170	162	139
TOTAL CAPITAL COST ('82\$×10 ⁶)	1364	1133	1205	1025	974	838
UNIT PLANT COST ('82\$/kwe)	1707	1418	1404	1195	1217	1048

*INDIRECTS FOR NSSS INCLUDED IN "PROJECT INDIRECT" COSTS; **BOILER PLANT.

TABLE 3 - TOTAL PRODUCT COSTS/REVENUE REQUIREMENTS

COST CATEGORIES	HTGR - 2240 MW(t)				REF. PWR 2400 MW(t)	REF. COAL 2245 MW(t)
	VAR. COGEN. LEAD	EQUIL.	ALL ELECTRIC LEAD	EQUIL.		
TOTAL CAPITAL COST ('82\$ $\times 10^6$)	1364	1133	1205	1025	974	838
● CONSTRUCTION PERMIT TO COMMERCIAL OPERATION (MONTHS)	87	72	87	72	72	48
● ESCALATION (8.0%/YEAR)	1352	1239	1195	1121	1113	1116
● AFUDC (10.5%/YEAR)	1354	958	1196	867	757	432
TOTAL INSTALLED COST ('95\$ $\times 10^6$)	4070	3330	3596	3013	2844	2386
ANNUAL ENERGY PRODUCTION						
● CAPACITY FACTOR (%)	65	70	65	70	70	70
● ELECTRICITY (10 ⁶ KWe-HR/YR)	4550	4900	4885	5261	4906	4906
ANNUAL REVENUE REQUIREMENTS						
FIXED (17.7% FCR)	720	589	636	533	503	422
FUEL	296(1)	255	296(1)	255	194	512/883(3)
O&M	165(2)	154	161(2)	150	168	199
TOTAL ('95\$ $\times 10^6$)	1181	998	1093	938	865	1133/1504
MILLS/KWe-HR ('95\$)	260	204	224	178	176	230/307

(1) BASED ON HIGH FABRICATION COST FROM LOW THROUGHPUT FAB. PLANT PLUS HIGH CARRYING CHARGES FOR REQUIRED LONG LEAD TIME ON ENRICHED URANIUM AT FAB. PLANT.

(2) ASSUMES 10% INCREASE OVER EQUILIBRIUM PLANT WITH EQUIVALENT CAPACITY FACTOR.

(3) BASED ON TYPICAL U.S. COAL PRICE OF \$1.65/mBtu IN 1982 WITH 0% OR 2% REAL ESCALATION PER YEAR AND 8% INFLATION PER YEAR.

TABLE 4 - FUEL INPUT AND ECONOMIC ASSUMPTIONS

<u>FUEL COST ASSUMPTIONS</u>	<u>UNIT COST ('82\$)</u>	<u>REAL ESCALATION</u>
URANIUM (\$/lbU ₃ O ₈)	45 (1995 Delivery)	2%
SEPARATIVE WORK (\$/SWU)	110	0%
COAL (\$/mBtu)	1.65	0%/2% (Low/High Range)
<u>O&M COST STRUCTURE</u>	<u>FIXED COSTS ('82M\$/YEAR)</u>	<u>VARIABLE COSTS ('82 MILLS/KWt-HR)</u>
HTGR - COGENERATION	15.3	1.1
HTGR - GENERATION	15.0	0.6
LWR	15.0	0.75
COAL	14.0	1.2
<u>FINANCIAL ASSUMPTIONS (ASSUMING 8% INFLATION RATE)</u>	<u>REGULATED UTILITY</u>	<u>FEDERAL GOVERNMENT</u>
<u>CAPITAL STRUCTURE %</u>		
DEBT	50	100
PREFERRED EQUITY	15	-
COMMON EQUITY	35	-
<u>FINANCING COSTS %</u>		
BOND YIELD	13.5	11.5
PREFERRED EQUITY YIELD	13.0	-
COMMON EQUITY YIELD	15.0	-
WEIGHTED COST OF CAPITAL	13.95	11.5
PROPERTY TAXES AND INSURANCE	2.0	-
EFFECTIVE TAX RATE	50.0	-
AFUDC RATE	10.5	11.5
RESULTING FIXED CHARGE RATE	17.7	
PLANT INVESTMENT LIFE (YEARS)	30	
PLANT TAX LIFE (YEARS)	10	
DEPRECIATION METHOD	DOUBLE DECLINING BALANCE	

As shown in Table 3, the Lead Plant generation costs are estimated to be 26% higher than an equilibrium HTGR plant. This increase is composed of the following FOAK factors:

Construction and Manufacturing	4%
Project Indirects	4%
AFUDC (Longer Schedule)	3%
Fuel Cycle	7%
Operation and Maintenance	2%
Capacity Factor	6%

In addition to the Lead Project costs, enumerated above, there are investment costs in manufacturing facilities to support the Lead Project. These costs are borne by the vendor/suppliers and are recovered through their charge for the respective components. For the HTGR, the only major, unique facility requirements are associated with the fuel cycle. Other components may be fabricated with existing or modified existing facilities. Fuel fabrication technology is essentially in place, with a pilot plant at General Atomic Company that serves the existing Fort St. Vrain demonstration plant. With modest expansions, this pilot plant will likely provide the initial fuel for the Lead Project. In contrast, fuel recycle requires substantial R&D and a demonstration plant. However, the timing for fuel recycle is very uncertain since it depends upon the population of deployed reactors and the associated economic incentives. Further, fuel recycle requires a highly enriched uranium fuel cycle to achieve sufficient economic incentives for recycle. With attendant high development and demonstration costs associated with fuel recycle and the uncertainties associated with civilian use of highly enriched uranium, the once-through, low enriched fuel cycle is the basis for the Lead Project commitment and the associated costs in Tables 1 through 3. Adoption of the highly enriched fuel cycle and, later, fuel recycle is considered a prudent long-term goal. In the interim, appropriate spent fuel storage and management can be assured with recycle R&D continuing at a low level commensurate with national fuel cycle developmental activities.

4.0 LEAD PROJECT FINANCIAL ARRANGEMENTS

The HTGR Lead Project deployment strategy is based on the premise that:

- The Lead Utility entity will assume those costs and risks that are equivalent to the commercial alternatives.
- The vendor/supplier team will assume those costs and risks consistent with alternative commercial investments. Any greater responsibility requires high risk investors that no longer exist in the nuclear industry.
- Cost and risks over and above the commercial norm must be covered by the Government and the Utility/User industry at large.

The following discussion presents a framework whereby the degree of support from the Government and Utility/Users is based on offsetting the equivalent incremental costs and risks attendant with the Lead Project. Emphasis has been on ensuring an "incentive-oriented" basis for the conduct of the Project plus simplicity such that the Project avoids legal and bureaucratic delays.

4.1 Lead Project Cost-Sharing

Consistent with the above premise, the major participants in the Project would assume the following cost and cost-sharing responsibilities:

Lead Utility Entity

- Owner's costs, including early site qualification costs.
- Plant construction and equipment costs with Government support through direct loan or loan guarantee (see Section 4.2).
- Major share of Project indirect costs, including engineering and licensing activities.

Utility/User Industry (Through GCRA)

- Program management support costs.
- Share of Project indirect costs to offset higher costs attendant with Lead Project.
- Effect complementary support for Project indirect costs through EPRI.

Vendor/Supplier Industry

- Final design costs of nuclear systems and components beginning with Phase IV commitment - minor support prior to Phase IV.
- Investment for facilities or modifications to facilities to support Lead Project and follow-on systems.

Government (Through DOE)

- Design verification and support activities and base technology development (including spent fuel management) activities.
- Major share of nuclear systems and components design costs through Phase III.
- Long-term spent fuel management facility investment (spent fuel management service to be supplied on cost basis).
- Project financing support to offset FOAK costs attendant with Lead Project (Project financing discussed in Section 4.2).

Application of these cost sharing principles to the costs identified in Section 3.3 are given in Section 4.4.

4.2 Lead Project Financing

Because of the additional capital costs and higher technical uncertainty associated with the design and construction of a Lead Project, conventional financing schemes are not sufficient to ensure the successful construction and operation of the Lead Project. The costs and risks associated with establishing the HTGR as a commercial option are substantial and require new, innovative financing techniques which must include government participation. Potential financing schemes must integrate government support and incentives into a unique project financing framework to take advantage of the maximum degree of private sector participation.

Government financing support for the Project should be structured so as to allow the Lead Utility to raise the required capital and avoid any undue financial burden and risk as a result of the non-commercial nature of the venture. The Government has used a number of economic incentives over the years in order to induce the marketplace to bring forth various technologies and Projects that are deemed to be in the Nation's interest, such as: direct loans, loan guarantees, purchase guarantees, price guarantees, project completion guarantees, joint venture and cost-sharing arrangements, and various tax incentives. The intent of these economic incentives is to encourage the marketplace to invest in projects of national interest by making these projects more attractive to investors.

The most effective financing structure for maximizing private sector participation and the leverage potentially available from the government is project construction financing. This form of project financing uses a separate entity (usually a partnership) to build and finance a particular project. The entity is capitalized by equity contributions of the partner companies and other third party investors, and issues conventional debt obligations that are nonrecourse to the parent companies. In the case of large, high risk projects, lenders will not be satisfied to look solely to the assets and cash flows of the project for security and the repayment of loans. In this situation the creditworthiness of the project entity must be supported by mechanisms such as purchase agreements, unconditional completion guarantees, performance bonds or other contractual arrangements from project sponsors to ensure the economic integrity of the project

entity and make it creditworthy. The project entity provides a useful vehicle for financing high risk projects by using unique contractual arrangements to exploit existing capital markets.

The use of a project financing entity has a number of advantages that will benefit any large first-of-a-kind project such as the HTGR Lead Project. Joint venture project financing enables greater flexibility in ownership. New participants may join or existing partners may increase or decrease their interest to reflect new load growth forecasts, delays in other facilities, and changing financial constraints. The project financing approach can, in certain circumstances and for certain participants, make available investment capital at more attractive rates. This results, for example, from the spreading of risks among several partners and the potential use of various leveraging techniques to take advantage of tax and other project benefits. A project financing structure with sufficient take-or-pay purchase agreements and additional credit support would allow the entity to raise debt at the project level without the debt being included, for coverage calculations and other purposes, on the parent company's balance sheet. This form of nonrecourse financing is particularly attractive to the financially troubled utility industry. In addition, current accounting practices state that purchase agreements can be disclosed in a footnote. This results in an effective off-balance sheet financing vehicle for all the participants. Finally, energy sales from the partnership entity would be classified as sale for resale in interstate commerce and subject to the jurisdiction of FERC. As a consequence, state regulatory agencies would be required to pass through these costs under a purchased power adjustment clause or as an operating expense in a rate case. One advantage of the project financing structure is that under a purchased power arrangement there is no regulatory lag as there might be in getting a facility's assets into the rate base. Also, since FERC would regulate the sale of power from the partnership entity, this opens the possibility of tariff-based financing to help support the project.

It is important to structure the project entity to minimize the exposure to regulatory bodies, both during construction and operation. During the construction phase of the project, the partnership entity would not be classified as an "electric utility company", and would not be regulated by the SEC as a utility holding company. However, state regulatory approval may be required for utilities to enter into investment and credit support contracts, such as completion and power purchase agreements. Once the project is completed and begins to sell power, then the equity participants in the project to the extent their interest exceeds 10% would become "utility holding companies" and subject to SEC regulation under the Act of 1935. This situation is under review by the SEC and it is anticipated that the SEC will exempt utility and industrial participants in project financing ventures from regulation. In addition, if the project entity sells its output on the wholesale market then it would be regulated by FERC instead of state authorities. This situation is generally preferred since FERC is perceived to be more predictable, uniform, and even handed in its rate-making treatment. FERC regulation would probably be more familiar to industrial participants in an HTGR Lead Project, than SEC regulation under the Public Utility Holding Company Act or state PUC regulation.

Figures 7 and 8 outline possible ownership and management arrangements for an HTGR Lead Project. Both schemes use a Project financing entity

(GENCO) to build and operate the Lead Project. In each case the private party participants will provide substantial equity and take-or-pay purchase agreements and performance guarantees to ensure successful completion and operation of the Project. The government, in turn, will provide either a direct Project loan or a loan guarantee and share in cost overruns related to Government supported activities, e.g. licensing and technology development. In the case of a direct loan, the government will receive interest, and it is anticipated that the loan will be repayed from Project proceeds. The direct loan approach reduces the government's risk exposure, but requires appropriated outlays and could include an interest rate subsidy. The government loan would be subordinated to the private lenders, but senior to the participants' contributions to the partnership. The loan guarantee is an off-balance sheet financing incentive, but because of larger dollar value of the guarantee, increases the potential risk in the event of project failure.

These arrangements are based on GENCO taking the maximum advantage of various incentives and contractual commitments provided by the government and private participants. Certain Congressional legislation would be required to authorize loans and loan guarantees and beneficial tax incentives that would attract increased private investment. In addition, the GENCO will be structured so that its operations are regulated by FERC. This arrangement provides an additional vehicle for the government, through a supportive rate structure, to enhance greater private sector financial support for the Project and, hence, reduce the government's overall financial contribution. Finally, relief from the Public Utility Holding Company Act of 1935 would be required to ensure that certain utility and nonutility ownership of an electric utility generating facilities would not result in exposure to unnecessary and undesirable regulation at the federal level by the SEC.

To complement government support, the private sector will provide equity, purchase agreements, completion guarantees, share in cost overrun protection, and construction and operating management to the Project. The equity contribution of the partners participating in the Lead Project entity will represent a significant fraction of the total Project costs. The participating users will provide the Project entity with take-or-pay purchase agreements designed to stabilize the Projects' revenue stream and cash flows. These contracts may also entail performance clauses that the lenders will require to guarantee loan repayment in the event of Project default or unsatisfactory plant operation. It is anticipated that the Lead Utility in the Project entity partnership will be the general partner and take responsibility for managing plant construction and operations. Construction overruns will be partially covered by the general partner and enhance his equity participation in the Project. The Lead Utility would not, however, be responsible for overruns attributable to disruptive government actions and/or policies for which the government would be liable. Through the proper combination of public and private support arrangements and Project financing mechanisms, a viable HTGR Lead Project financing structure can be established.

4.3 Lead Project Risk-Sharing

The electric utilities have not committed to new nuclear plants partly because of the difficulties in completing a nuclear project according to

Figure 7

POSSIBLE OWNERSHIP/FINANCIAL ARRANGEMENT FOR HTGR LEAD PROJECT

Figure 8

POSSIBLE OWNERSHIP/FINANCIAL ARRANGEMENT FOR HTGR LEAD PROJECT

planned schedule and at target cost. The reasons for these difficulties are primarily institutional (e.g., unstable regulatory requirements, difficulties in capital formation). On the other hand, there is confidence among utilities with substantial experience that if these institutional barriers were favorably resolved, they can design, construct and operate highly reliable nuclear power plants that would be economically competitive with coal plants and could probably be brought into commercial operation just as quickly. Given such an environment, these utilities would be willing to accept investment and operating risks that are largely dependent upon their own performance.

Since the Lead Project is still part of the HTGR-SC/C demonstration phase (albeit the last stage), it presents a higher risk profile to all participants than a standard commercial power system. Major risks associated with the Lead Project may be categorized as follows:

- Cost/Schedule Risks

- Underestimates which are caused by limited knowledge or insufficient definition; these are more likely to occur with a new technology, as they did with LWRs during initial deployment.
- Schedule delays are caused by licensing changes and iterations, engineering and design changes, delays in hardware and software deliveries, field problems (e.g., labor perturbations, strikes, etc.); this factor results in substantial increases in escalation and interest during construction costs.

- Performance Risks

- Availability/reliability deficiencies with attendant reduced capacity factor, especially during early deployment.
- Design deficiencies which increase plant downtime or component replacement frequency, hence increase cost of spare parts, maintenance, etc.
- Operating limitations as a result of exceeding technical specifications limits that result in reduced capacity factor or added investment costs to establish full operations capability.

- Nuclear Policy Risks

- Influence of changes in the licensing process and in Government policies, as well as other socio-political developments that may impact the investment and/or operating cost of the plant.

To offset these identified risks, stable Government support is required through the following mechanisms to:

- Assure that the technology is sufficiently developed so that the Lead Plant design based on it would have a sound bases for achieving its reliability and performance targets. The risk-reduction mechanism is the direct support of the design and technology development activities. The private sector must define what it considers is the benchmark at which the technology would be considered sufficiently developed. Once that is agreed between the two parties, the liabilities for non-performance would reside with the private sector.
- Assure that the system is licenseable, with a construction permit (CP) as documentation, in order to support the construction commitment. Further, post-CP licensing perturbations which are not rooted in specific safety concerns based on technical data must be eliminated. This requires early identification and resolution of safety and licensing issues.

Recognizing these risks and knowing how they manifested themselves in LWR experience presents an opportunity to institute mechanisms to control their frequency of occurrence and limit their consequences. The lessons from the past must be carefully applied.

Table 5 summarizes the proposed approach to risk control and minimization for the HTGR Lead Project.

4.4 Cost Sharing Projections

The effect of applying the cost sharing and Project financing support to the Lead Project's evaluated product cost are summarized on Table 6 for the "All Electric" version of the HTGR Lead Plant. As discussed in section 4.2, the Lead Utility entity is assumed to be structured in a project financing or generating company called GENCO. These projections are based on the utility/user industry supporting approximately 40% (\$100M) of the Project Indirect costs. The varying total cost of the Lead Plant is a result of the different capital structure and associated AFUDC cost components.

The 26% higher Lead Plant generation costs noted earlier is shown to be partially offset. The actual extent of offset would be based on the negotiations between the principals on the bases of comparative alternative energy systems, related risk sharing provisions and actual commercial value rating of the Lead Plant.

Table 7 presents the resultant cash flow and cost-sharing projections based on government financing support through a direct loan. These cash flows are approximate and are intended as a framework for Lead Project discussions and considerations by prospective participants. The following summary statements are drawn from Table 7:

- The private sector share of the total Lead Project costs, including the loan support from the government, is over 72%, based on constant 1982 dollars, and approximately 85%, based on as spent dollars.
- The required Government support level averages approximately \$75M/yr. and peaks at \$92M (1982 dollars), which is about a factor of 2 over the current funding level.

TABLE 5

APPROACH TO RISK CONTROL AND MINIMIZATION FOR HTGR LEAD PROJECT

COST/SCHEDULE RISKS

● PROJECT MANAGEMENT	● OWNER CONTROL OF PROJECT MANAGEMENT PROVIDES BASIS FOR OWNER ACCEPTANCE OF RISK
● PROJECT PERFORMANCE	● PHASED PROJECT COMMITMENT BASED ON COST/SCHEDULE/LICENSING MILESTONES LIMITS ALL PARTIES' EXPOSURE
● INADEQUATE ESTIMATES	● DETAILED DESIGN AND COST ESTIMATES WITH THIRD PARTY REVIEWS OF CRITICAL AND/OR MAJOR COST COMPONENTS PRIOR TO COMMITMENT TO MANUFACTURING AND/OR CONSTRUCTION
● LICENSING DELAYS	● NRC COMMITMENT TO PREAPPLICATION REVIEW PROGRAM AND PRIORITY REVIEW OF LICENSE APPLICATION
● LICENSING RETROFITS	● COST OVERRUNS DUE TO REGULATORY CHANGES AFTER CONSTRUCTION PERMIT IS ISSUED ARE COVERED (OR SHARED) BY GOVERNMENT
● COMPONENT COST OVERRUNS AND DELIVERY DELAYS	● DESIGN AND TECHNOLOGY PROGRAM PROVIDES BASIS FOR VENDOR/SUPPLIER COMMITMENT TO FIRM PRICES/DELIVERY SCHEDULES

PERFORMANCE RISKS

● RATED OUTPUT OF COMPONENT	● DESIGN AND TECHNOLOGY PROGRAM PROVIDES BASIS FOR VENDOR/SUPPLIER COMMITMENT TO PERFORMANCE WARRANTIES
● SYSTEMS PERFORMANCE	● LIMITED NSSS WARRANTY FROM VENDOR/SUPPLIER TEAM; OWNER CONTROL OF PLANT COST/PERFORMANCE TRADEOFFS PROVIDES BASIS FOR OWNER ACCEPTANCE OF RELATED RISK

NUCLEAR POLICY RISKS

● FUEL CYCLE CHANGES	● LEAD PLANT BASED ON ONCE-THROUGH, LOW ENRICHED FUEL CYCLE
● LONG-TERM FUEL SUPPLY	● SUPPLY COMMITMENT FROM MANUFACTURER WITH FIRM PRICE FOR EARLY SEGMENTS AND COST-PLUS PROVISION FOR LONG-TERM SUPPLY
● SPENT FUEL MANAGEMENT	● SPENT FUEL RECEIPT COMMITMENT FROM GOVERNMENT

TABLE 6

ALL ELECTRIC HTGR LEAD PROJECT PRODUCT COSTS
WITH GOVERNMENT FINANCING SUPPORT

<u>HTGR LEAD PROJECT FINANCING ALTERNATIVES</u>	<u>INVESTMENT COST ('95 M\$)</u>				<u>LEVELIZED GENERATING COST (MILLS/KW-HR)</u>
	<u>GENCO EQUITY</u>	<u>GENCO DEBT</u>	<u>GOV'T LOAN SUPPORT</u>	<u>TOTAL INV.</u>	
● NO COST SHARING; NO FINANCIAL SUPPORT	1800	1800	0	3600	224
● GOV'T LOAN GUARANTEE OF GENCO DEBT (DEBT/EQUITY = 75/25, LOAN AT 11.5% INTEREST RATE)	750	0	2250	3000 ⁽¹⁾	182
● GENCO CAPS INVESTMENT TO COAL ALTERNATIVE. GOV'T PROVIDES DIRECT LOAN AT 8% WITH PAYBACK BASED ON ACTUAL COMMERCIAL VALUE	1200	1200	900	3300 ⁽¹⁾	214
<u>COMPARATIVE CONVENTIONAL PLANT ALTERNATIVES</u>					
● 800 MWe NUCLEAR (PWR $\approx$ HTGR)	1500	1500	0	3000	178
● 800 MWe COAL	1200	1200	0	2400	230/307 ⁽²⁾

(1) INCLUDE COST SHARING BY UTILITY/USER INDUSTRY FOR 40% OF PROJECT INDIRECTS

(2) DENOTE RANGE OF LOW/HIGH COAL ESCALATION.

NOTE: FRONT-END DESIGN AND TECHNOLOGY DEVELOPMENT COSTS NOT INCLUDED.

It has been projected that a private sector Lead Utility entity would undertake the Lead Project if the Government ensures that the Lead Utility entity would not end up with a financial commitment substantially more than the equivalent commercial value compared to alternative systems. In addition, the collective Utility/User industry, through GCRA and EPRI, would financially support a share of the front-end costs associated with the Lead Project. The Government's role is required to:

- Develop the technology to the point where a licensable design is achieved and documented to be so (construction permit obtained), with reliability tests for critical components successfully passed.
- Offset the first-of-a-kind costs and risks associated with the first-of-a-kind Project through Project financing support.

Beyond this, the private sector should be able to deploy the HTGR-SC/C system on a commercial basis.

TABLE 7
HTGR LEAD PROJECT COST-SHARING PROJECTION

<u>COST ELEMENTS ('82\$)</u>	<u>PHASE I</u> <u>PROG./PROJ. DEF.</u>		<u>PHASE II</u> <u>PREL. DES./LIC.</u>		<u>PHASE III</u> <u>DET. DES./LIC.</u>		<u>PHASE IV</u> <u>CONST./STARTUP</u>	<u>TOTALS</u>
	<u>82</u>	<u>83</u>	<u>84</u>	<u>85</u>	<u>86</u>	<u>87</u>	<u>88 → 94</u>	<u>83 → 94</u>
<u>DESIGN & TECHNOLOGY DEVEL.</u>								
● NUCLEAR DESIGN								
- DOE	6.8	12.2	23.8	34.0	40.0	40.0	--	150
- VENDOR/SUPPLIERS	--	--	2.0	2.0	5.0	6.0	35	50
● DV&S AND BASE TECHNOLOGY								
- DOE	11.1	22.8	35.2	45.0	52.0	50.0	75	280
<u>LEAD PLANT SPECIFIC (ALL ELECTRIC)</u>								
● PROJECT INDIRECTS								
- GCRA/EPRI	1.5	2.0	4.0	6.0	8.0	10.0	70	100
- GENCO	--	--	2.0	4.0	8.0	10.0	120	144
- DOE	1.0	2.0	--	--	--	--	--	3
● MANUFACTURING, CONST., OWNER'S COST, AFUDC								
- GENCO	--	--	1.0	3.0	7.0	12.0	1378	1401
<u>TOTAL PROJECT ('82\$)</u>								
- GENCO	--	--	3.0	7.0	15.0	22.0	1498	1545
- GCRA/EPRI	1.5	2.0	4.0	6.0	8.0	10.0	70	100
- VENDOR/SUPPLIERS	--	--	2.0	2.0	5.0	6.0	35	50
- DOE	18.9	37.0	59.0	79.0	92.0	90.0	75	432
TOTAL	20.4	39.0	68.0	94.0	120.0	128.0	1678	2127
<u>TOTAL PROJ. (CUR. \$@8%/YR)</u>								
- GENCO	--	--	3.5	8.8	20.5	32.5	3235	3300*
- GCRA/EPRI	2.3	2.2	4.7	7.6	10.9	14.7	151	191
- VENDOR/SUPPLIERS	--	--	2.3	2.4	6.8	8.8	65	85
- DOE	29.2	40.0	69.0	99.5	125.1	132.3	128	594
TOTAL	31.5	42.2	79.5	118.3	163.3	188.3	3579	4170

*ASSUMES CONVENTIONAL FINANCING FOR \$2400M WITH GOVERNMENT LOAN FOR \$900M.