ABSTRACT

AN ECONOMIC ASSESSMENT OF U.S. MHTGR DESIGN

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GCRA's economic goal for the U.S. MHTGR design is for the equilibrium plants to have at least a 10% power cost advantage over comparably sized, state-of-the-art coal plants. In addition, the designers are challenged to limit the overall financial risk to be on par with such a coal plant.

During the past year, cost estimates and economic assessments have been updated in the U.S. MHTGR Program. Further, a major study has been completed adapting the MHTGR to a water desalination/cogeneration application. These results will be presented along with a discussion of the key GCRA design requirements that limit the overall financial risk to the prospective owner/operators of future MHTGR plants.

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Introduction

Through GCRA, U.S. utility/users have established the following economic goal for the U.S. MHTGR reference plant design:

> "A goal shall be the development of a design that has an evaluated economic advantage of at least 10% in the 30 year levelized busbar cost of electricity relative to a comparable sized, state-of-the-art coal fired plant while requiring equivalent institutional resources and posing equivalent financial risks."

The term "equivalent institutional resources" means that approximately the same level of qualified personnel and organizational capability, functioning within similar corporate cultures, is required to successfully procure, license, operate, maintain and decommission the plants. The term "equivalent financial risks" means that approximately the same level of uncertainty exists for receiving an adequate return on investment, such that investors will be equally likely to invest in the MHTGR or coal plants.

The intent of this economic goal is to guide the development of the MHTGR such that prospective owners would view the MHTGR as an attractive nuclear option that is competitive, and which affords ownership risks and returns that are on par with coal plant alternatives.

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This paper presents a summary of the background, approach and the current estimate for the U.S. reference MHTGR electric generating plant. The plant is composed of two power building blocks producing a total output of 538 MWe. Each building block consists of two reactor modules and one turbine-generator set. Additional economic results are given for a cogeneration application with a seawater desalination plant.

Background

Coal, oil and gas fired power plants have traditionally provided the backbone of U.S. electricity generation. Accordingly, the U.S. industrial infrastructure for procuring, licensing, operating and maintaining power plants evolved over many decades of successful experience with their use within the social, economic and political framework of the U.S. Moreover, the existing infrastructure also developed in response to local and regional needs for electrical power and is, therefore, quite diverse in terms of organizational styles and structures. However, prior to the introduction of nuclear power, such diversity presented no major difficulties in managing conventional power plants and was accepted as an effective means of assuring competitively priced electrical power.

Nuclear energy differs from fossil fuel alternatives in that Federal regulations exist to provide "reasonable assurance that the health and safety of the public will not be endangered." Demonstrating compliance with these regulations has proven to be onerous to the industry. During the early 1980's, many in the U.S. began to question the compatibility of the current generation of LWR plants with existing U.S. institutions. For example, the U.S. Congress' Office of Technology Assessment related the need for significant changes in the technology and management of nuclear power plants to the size and complexity of then current LWR plants and the exacting regulatory process.

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The NRC grants an operating licensing on the basis of demonstrated financial and technical capability and an acceptable plant safety analysis. The philosophy behind the regulatory process is one of assuring that the plant is operated and maintained such that the assumptions of the safety analysis (equipment performance, operator action, etc.) are valid throughout the life of the facility. When a system is identified as safety-related for the purposes of regulation, it carries with it not only capital and operating cost premiums, but the multiplicity of risks that arise from assuring and documenting that the requisite level of reliability has been provided in each step of development from design through power generation. The discipline and vigilance required for the "exacting" chore of establishing and continuously verifying the ongoing safety of the plant, in accordance with regulations, distinguishes the organizational requirements and corporate cultures of nuclear from fossil institutions.

The management of nuclear institutions must recruit, train, organize and direct specialist personnel for the design, fabrication, construction, operation and maintenance of nuclear installations and assure the accurate and auditable communication of requirements between their institutions over the life of the project and operating life of the plant. Because their performance is under continuous scrutiny and linked to the plant operating license, fluctuations in performance translate into business risks. These risks are compounded when the underlying regulations are subject to change.

Within the commercial power industry, the discipline and vigilance required of the performing organizations is unique to the nuclear energy option, as is the financial risk associated with fluctuations in organizational performance. The owner/operating entity is at the end of the trail of quality requirements and is responsible for implementing the results of the design and construction program through operational licensing requirements. The cumulative financial risks, and the risks to the organization itself, in this process have largely been borne by the owner/operating entity. These risks contribute heavily to the stagnation of the nuclear power industry in the U.S.

On the practical level of utility operations, the frequent experience with nuclear plants is that the organizational adjustments necessary to accommodate them has placed a disproportionate strain on management. As a result, many utilities have found it necessary to establish a separate "culture" within their organizations in which the necessary discipline and vigilance can be fostered. We have termed the prospect that an owner/operating entity may have to endure a disruptive transformation of its organization and corporate culture in order to accommodate a nuclear option as "institutional risk." While precedence to date has been related to the traditional utility role, even greater avoidance of this type of risk is crucial if Independent Power Producer (IPP) arrangements flourish.

The MHTGR offers a superior "containment concept," relative to its nuclear competitors, with the high quality coated fuel particle. Conceptually, the coated particle containment concept will permit the focus of regulatory scrutiny to be shifted from plant design, construction, operation and maintenance to fuel manufacture. If this shift in regulatory scrutiny can be accomplished, the owner/operator will be relieved of a substantial body of the institutional risks that plague current plants.

In implementing this goal, MHTGR development must translate inherent and passive safety characteristics into regulations that are, insofar as possible, consistent with U.S. business practices for conventional plants. Up to now, emphasis in the U.S. MHTGR Program has been on gaining

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acceptance of the MHTGR safety concept. However, in addition to the public acceptance benefits that accrue to owner/operators for enhanced safety of nuclear plants, increased safety is even more significant if it translates into decreased business risks. The following section discusses how certain key features of the MHTGR support the overall economic goal.

Approach to Achieve Economic Goal

To achieve the economic goal, several key features of the MHTGR, plus key institutional arrangements, must be carefully optimized in order to adequately compensate for lost economies of scale.

The first is the full utilization of the inherent and passive safety characteristics. This feature:

- Eliminates the need for many high cost safety systems (e.g. containment structures, auxiliary power sources).

- Allows the fabrication of many systems to industrial (non-nuclear) standards (e.g. the plant control system).

- Allows the minimization and physical separation of the nuclear island and therefore the minimization of costly nuclear grade construction.

- As a result of all the above, provides the potential for easing the plant licensing and certification process, further supported by the testing capability of the plant design. (Precluding the need for offsite public evacuation and sheltering is a key prospect of this eased licensing.)

- Provides the potential for overall simplification of operation and maintenance activities, including the operational licensing requirements.

Table 1 compares the safety related structures and systems proposed for the MHTGR plant to a recent, current generation LWR plant. This comparison highlights the basis for expected reductions in safety/licensing related costs for MHTGR.

The second feature is the optimization of modularization and factory fabrication techniques that will enhance standardization and thereby:

- Minimize plant-specific design and licensing costs.

- Minimize field construction schedule and time related costs (i.e. interest during construction).

- Maximize factory related learning benefits to reduce capital costs.

- Maximize the plant staff loading efficiency and related learning benefits to reduce training, operations and maintenance costs.

The modular nature of the power increments plus the short construction schedule provides important flexibility in responding to uncertain load growths. Further, the multi-module nuclear island and multi-turbine energy conversion area enables a zero planned outage of the total plant.

Table 2 compares the major heavy equipment, commodities and selected craft labor on a per MWe basis for the MHTGR, a "Better Experience" PWR (typical of upper range of experience with current PWRs) and a comparably sized coal plant. Whereas the vessel tonnage comparison penalizes the MHTGR relative to

TABLE 1

COMPARISON OF SAFETY RELATED STRUCTURES AND SYSTEMS

MHTGR[1]	LWR[2]
STRUCTURES:	
• REACTOR BLDG • REACTOR AUXILIARY BLDG • REACTOR SERVICE BLDG	• CONTAINMENT BLDG • AUXILIARY BLDG • CONTROL BLDG • FUEL BLDG • DIESEL GENERATOR BLDG • MAIN STREAM SUPPORT STRUCTURE • CONDENSATE TANK FOUNDATION • ESSENTIAL SPRAY PONDS & INTAKE STRUCTURE • REFUELING WATER TANK FOUNDATION
SYSTEMS:	
• REACTOR SYSTEM - FUEL ELEMENTS - CONTROL RODS - CONTROL ROD DRIVES - CORE SUPPORT STRUCTURES - UPPER PLENUM THERMAL PROTECTION STRUCTURE	• REACTOR EQUIPMENT - FUEL ASSEMBLIES - CONTROL ELEMENT ASSEMBLY - CONTROL ELEMENT DRIVES - CORE SUPPORT STRUCTURES
• VESSEL SYSTEM - REACTOR VESSEL & SUPPORTS - S/G VESSEL & SUPPORTS - PRESSURE RELIEF VALVES - CROSS DUCT VESSELS - STEAM GENERATOR ISOLATION VALVES	• PRIMARY SYSTEM COMPONENTS - REACTOR VESSEL & SUPPORTS - STEAM GENERATORS & SUPPORTS - SAFETY & RELIEF VALVES - REACTOR COOLANT PRESSURE BOUNDARY PIPING - MAIN STEAM/FEEDWATER ISOLATION VALVES - PRESSURIZER & SUPPORTS - REACTOR COOLANT PUMPS & SUPPORTS
• REACTOR CAVITY COOLING SYSTEM	• SAFETY INJECTION & SHUTDOWN COOLING SYSTEM • CONDENSATE STORAGE FACILITIES • AUXILIARY FEEDWATER SYSTEM • MAIN STREAM PIPING IN CONTAINMENT • CONTAINMENT SPRAY SYSTEM • ESSENTIAL SPRAY POND SYSTEM • ESSENTIAL COOLING WATER SYSTEM

(1) MHTGR PSID, TABLE 3.2-4
(2) PALO VERDE FSAR, TABLE 3.2-1

TABLE 1

COMPARISON OF SAFETY-RELATED STRUCTURES AND SYSTEMS
continued

MHTGR	LWR
• ESSENTIAL UNINTERRUPTABLE POWER SUPPLY SYSTEM (120v AC)	• ELECTRIC SYSTEMS - 4.16kV CLASS 1E AC - 480V CLASS 1E AC - 120V VITAL AC
• ESSENTIAL DC POWER SUPPLY SYSTEM	• CLASS 1E DC EQUIPMENT
	• DIESEL GENERATOR & FUEL SYSTEM
• PLANT PROTECTION & INSTRUMENTATION SYSTEM	• PLANT PROTECTION SYSTEM - REACTOR PROTECTIVE SYSTEM - ENGINEERED SAFETY FEATURES ACTUATION SYSTEM
	• SAFE SHUTDOWN INSTRUMENTATION AND CONTROL SYSTEMS
	• ESSENTIAL CHILLED WATER SYSTEM
	• HVAC
	• CHEMICAL AND VOLUME CONTROL SYSTEM
	• FUEL HANDLING & STORAGE
	• FUEL POOL COOLING & CLEANUP SYSTEM
	• NUCLEAR COOLING WATER SYSTEM
	• RADIATION MONITORING SYSTEM
	• CONTAINMENT BUILDING COMBUSTIBLE GAS CONTROL SYSTEMS
	• SAMPLING SYSTEM
	• GASEOUS RADWASTE SYSTEM

Table 2

COMPARISON OF COMMODITIES, CRAFT LABOR AND MAJOR EQUIPMENT QUANTITIES

	UNITS(1)	MHTGR NOAK PLANT	PWR-BE 1144MWe PLANT	COAL 488 MWe PLANT
MAJOR EQUIPMENT:				
REACTOR PLANT VESSEL (INCL. STEAM GEN.)	TN/MWe	10	2	N/A
COMMODITIES:				
FORMWORK	SF/MWe	1511	1648	1530
STRUCTURAL STEEL	TN/MWe	24	6	30
REINFORCING STEEL	TN/MWe	28	18	7
EMBEDDED STEEL	TN/MWe	1	1	1
STRUCTURAL CONCRETE	CY/MWe	232	116	115
PIPING, NUCLEAR GR	LB/MWe	315	1916	0
PIPING, INDUSTRIAL GR	LB/MWe	3725	6094	8571
WIRE AND CABLE	FT/MWe	5546	4352	5451
WIRE AND CABLE DUCT	FT/MWe	808	588	907
SELECTED CRAFT LABOR:				
BOILERMAKER	MH/MWe	326	583	1566
CARPENTER	MH/MWe	1226	1156	713
ELECTRICIAN	MH/MWe	2305	1925	2400
IRON WORKER	MH/MWe	1334	1149	1111
MILLWRIGHT	MH/MWe	407	169	336
PIPEFITTER	MH/MWe	1352	2644	4035
OTHERS	MH/MWe	2065	3028	3324
TOTAL CRAFT LABOR	MH/MWe	9014	10654	13484

(1) SF = SQUARE FEET, TN = TON, CY = CUBIC YARDS, LB = POUND, FT = FEET, MH = MANHOURS

the PWR, counter gains are made for other areas, particularly the nuclear grade (and high cost) piping and the associated valving. The respective comparisons in Table 2 provide insight to the MHTGR's safety simplicity and modularity gains in achieving competitive economics.

The third feature is the stringent operational reliability requirements posed by GCRA. For example:

- The design should facilitate in-service inspection and on-line maintenance and repair, where cost effective and within the economic goal.

- Further, the plant design must allow for the removal and replacement of all equipment, including the reactor and steam generator internals and the primary system vessels.

- An overall equivalent availability (capacity factor assuming a utilization factor of one) target of 80%, with the goal of achieving an economically optimum value through the design development process.

- Forced outages are limited to 10% of the equivalent unavailability, plus events leading to forced outages of six months or more duration should be limited to 10% of the allowed 10% equivalent unavailability (1% total).

The fourth feature is the stringent investment protection requirements posed by GCRA that essentially eliminate the potential for plant loss due to operator errors and/or equipment malfunctions. For example:

- The cumulative evaluated plant damage per year for all accidents/events when averaged over the plant lifetime shall not exceed the owner's annual property damage insurance premium.

- To assure that the likelihood of a class shutdown of all MHTGR plants is remote, the probability of exceeding any safety related design condition (i.e. exceeding the design limits of a safety related component or system regardless of damage) shall not exceed 10^{-5} per plant-year.

The fifth feature deals with institutional development underway or envisioned within the U.S. MHTGR Program. For example:

- One or more vendor entities are envisioned that will provide a fixed price, turnkey contract for the entire plant (or at least the nuclear island) plus related performance warranties.

- New generating company entities are likely to be established for much of the broad deployment of any new base load capacity in the U.S. for the foreseeable future. The roles of the utilities, vendors and other interested parties are evolving.

- Nuclear operating companies are also likely to evolve that will centralize key licensing, training, operations, maintenance, and technical support activities for the shared benefits of multiple plants.

Economic Assessment Framework

In addition to the preceding features, there is a framework of detailed groundrules, assumptions and judgement estimates that must be developed with care and consistency, particularly for comparative cost estimates. Key examples for the MHTGR estimate include:

- Three time-dependent, reference plant estimates are maintained: the initial Lead Plant; the second Replica Plant; and N^{th}-of-a-kind (NOAK) or equilibrium plant-typically the eighth plant.

- Estimates for three additional size-dependent plants are extrapolated from the reference 4 reactor module-2 turbine (4x2) plant, namely a twin reference plant (8x4); a half size (2x1) plant; and a single reactor plant (1x1) with a matching size turbine.

- The NOAK and Replica Plants are based on an economically optimum deployment sequence leading to a 44 month construction schedule and a 77 month project schedule (through commercial operation). The Lead Plant is deployed in two phases over a project interval of 103 months and a construction interval of 70 months. Phase I deploys one reactor module and one turbine-generator set. After one year of demonstration testing, Phase II deploys the other three reactor modules and the other turbine-generator set.

- Plant startup schedules are targetted for the year 2000 for the Lead Plant, the year 2005 for the Replica Plant and the year 2010 for the NOAK plant.

- Unless otherwise substantiated by specific data, direct costs learning benefits through the NOAK plant are conservatively limited to field labor and reactor equipment with learning factors of 97% and 95%, respectively. Material plus conventional components and systems are conservatively assumed to have achieved the full commercial learning experience. Equivalent learning benefits through the NOAK plant for the indirect cost elements vary, but on average correspond to a factor of 91%.

- Unless otherwise substantiated by specific data, nominal contingencies are applied at a rate of 25% for nuclear grade costs and 15% for industrial grade costs.

- A capacity factor of 80% is used for the multi-modular, multi-turbine NOAK MHTGR plant. The same capacity factor (80%) is used for generation cost comparisons with alternative plants. The Lead and Replica MHTGR Plants are assumed to have slightly lower capacity factors, 77% and 78.5% respectively.

- Comparisons are made with a range of coal costs. A representative reference coal price of 1.55$/MBtu ('88$ and delivery) is applied with a constant real escalation rate of 1.2% per year.

- The financial parameters and site related costs are representative of a private utility based owner entity with nuclear experience.

Cost Estimate Results

Costs have been developed to design, construct, operate and maintain reference MHTGR power plants and a comparison of the costs has been made primarily with coal plants. The costs were developed in general conformance with the U.S. Department of Energy cost estimating guidelines for advanced nuclear technologies.

Costs were developed by General Atomics for the reactor plant equipment. Costs for the other equipment, field labor, and field material necessary to construct the nuclear island were developed by Bechtel. Costs for all the equipment, field labor, and field material necessary to construct the energy conversion area were developed by Stone & Webster. GCRA has developed the owner's cost, integrated the cost estimates and performed the cost assessments.

Figure 1 displays the major components of total plant capital costs for each of the three reference plants under study. The first-of-a-kind development and certification costs are included with the Lead Plant costs. Progressive comparisons of the estimates in Figure 1 highlight the relative and incremental cost reductions expected for the Replica and NOAK plants through learning and factory throughput gains for the direct costs, certified design replication gains for the indirect costs, and the reduced schedule impact on the interest during construction costs.

Table 3 presents the 2 digit account summary of the NOAK MHTGR plant capital cost estimate. The nuclear grade and industrial grade components of the cost estimate are delineated and illustrates that approximately one half of the plant capital costs may be treated as a modern fossil plant. Had the total plant been treated as nuclear grade, the plant costs would have increased approximately 20%.

As discussed earlier, the O&M activities for the MHTGR are expected to benefit from the inherent and passive characteristics. Also discussed were the O&M benefits that derive from modularity, such as the efficient manpower loading on the refueling and maintenance activities for the multiple reactors and turbines. In addition, the generic HTGR features associated with the slow response to transients leads to simplified control systems and less demands on the operator for upset conditions. Further, the inert helium coolant and the excellent retention of fission products in the coated fuel particle are expected to lead to simplified maintenance, component repairs and replacement as well as low radiation exposure levels for the related plant staff. Accordingly, the staffing cultures and levels for the MHTGR plant have various bases for paralleling fossil plants. It is noted, however, that the realization of this potential will continue to require strong involvement by utility personnel with enlightened O&M management experience.

FIGURE 1

MHTGR PLANT TOTAL COSTS

(CAPITAL + DEVELOPMENT, JANUARY 88$)

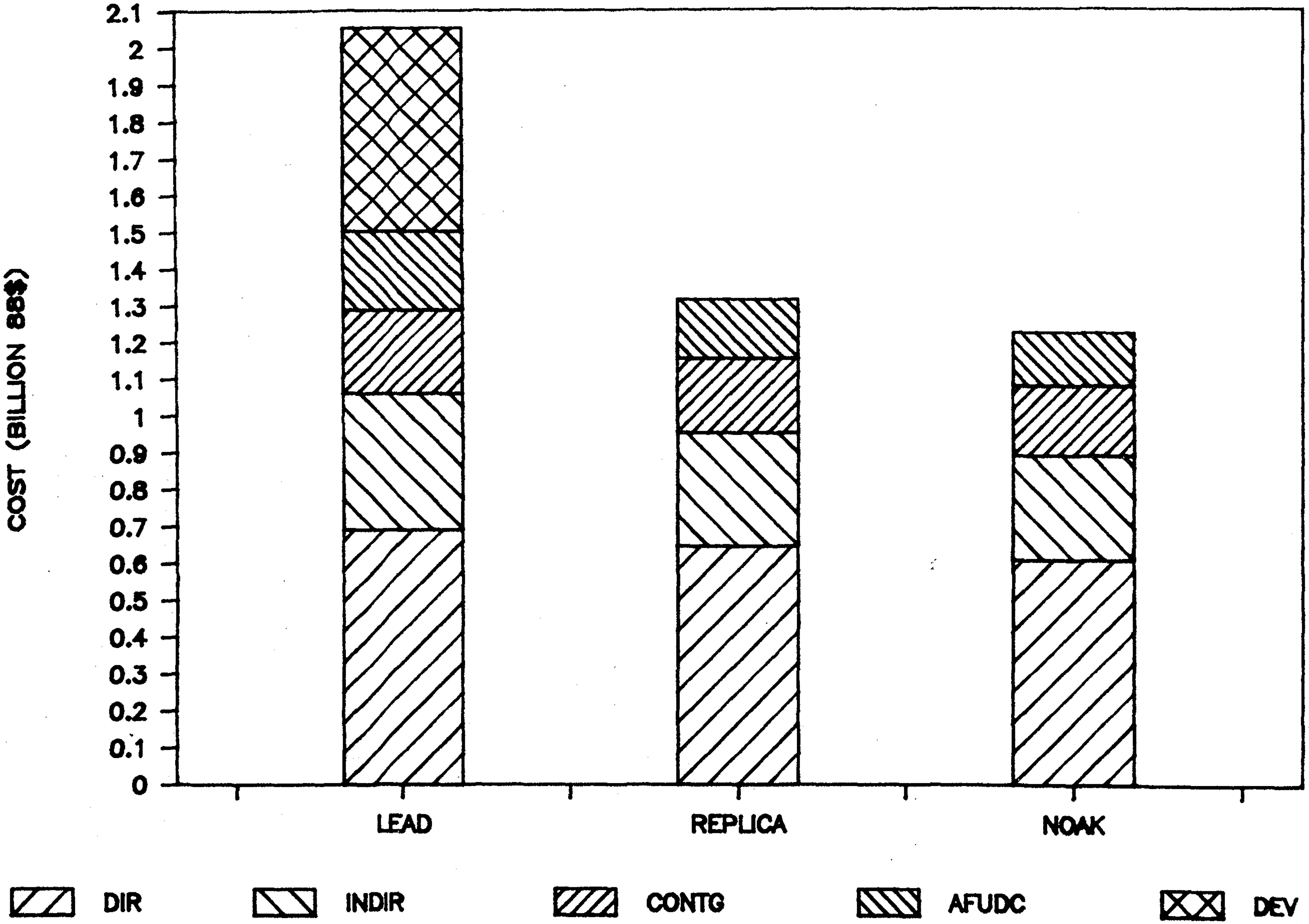


TABLE 3

NOAK MHTGR PLANT CAPITAL COST ESTIMATES
(MILLIONS OF 1988$)

		NUCLEAR GRADE COST	INDUSTRIAL GRADE COST	TOTAL COST
LAND & LAND RIGHTS		0	2	2
STRUCTURES & IMPROVEMENTS		67	43	110
REACTOR PLANT EQUIPMENT		267	1	270
TURBINE PLANT EQUIPMENT		1	128	129
ELECTRIC PLANT EQUIPMENT		19	35	54
MISCELLANEOUS PLANT EQUIPMENT		4	18	22
MAIN CONDENSER HEAT REJECTION		0	22	22
TOTAL DIRECT COST		358	249	609
CONSTRUCTION SERVICES		40	39	77
AE HOME OFFICE ENGINEERING		39	15	54
FIELD OFFICE SUPERVISION		18	13	31
OWNER'S EXPENSES		0	118	118
TOTAL INDIRECT COST		97	185	280
BASE CONSTRUCTION COSTS	- TOTAL $	456	434	891
	- $/kW(e)	849	808	1657
CONTINGENCY		123	65	187
TOTAL OVERNIGHT COST	- TOTAL $	580	500	1079
	- $kW(e)	1078	929	2007
INTEREST DURING CONSTRUCTION			143	
TOTAL CAPITAL COST	- TOTAL $			1222
	- $kW(e)			2273

An assessment of O&M requirements and costs was developed for the reference MHTGR plant by a programmatic task force familiar with nuclear generating plant O&M requirements and the MHTGR design. Table 4 presents the resulting estimate for the onsite staff and related costs for the NOAK MHTGR reference plant. Note that the estimated manpower on a per MWe basis is approximately half that experienced by the recent large LWR plants in the U.S. Table 5 presents the summary of the total annual O&M costs that includes a fixed and variable cost for maintenance materials, supplies and expenses, and offsite technical support plus overall administrative and general (A&G) costs. It is noted that the expected cost savings approach of a central staff supporting multiple plants has not been applied for such estimates.

Table 6 provides MHTGR fuel cycle cost data. The parameters were developed within the overall U.S. advanced reactor program and are given for reference. The MHTGR fuel fabrication costs were developed by General Atomics and represent the graduation from a low throughput pilot-scale fabrication plant to a fully loaded commercial-scale fabrication plant. The resultant fuel cycle costs follow.

Figure 2 presents the busbar generating cost estimates for the three reference plants under study. A decommissioning increment is included at a nominal cost of approximately $80 M ('88$). The respective comparisons highlight the overall cost reductions expected after introduction of a Lead Plant to the NOAK (equilibrium) Plant.

The economic competitiveness of the MHTGR is sensitive to several of the assumed reference parameters. Two of these are the cost of coal and the coal cost real escalation rate. The MHTGR economic advantage is given in Figure 3 as a function of the assumed coal cost and the real escalation of the coal cost. Figure 4 illustrates the sensitivity of the MHTGR economic margin to percentage variations of the coal cost,

TABLE 4

ONSITE STAFF COSTS FOR REFERENCE MHTGR PLANT

(JANUARY 1988 DOLLARS)

JOB TITLE	SALARY ($/YEAR)	NUMBER	TOTAL ($/YEAR)
PLANT MANAGER'S OFFICE			
PLANT MANAGER	104,000	1	104,000
ASSISTANT MANAGER	72,800	1	72,800
TRAINING	50,960	5	254,800
SAFETY AND FIRE PROTECTION	42,640	1	42,640
ADMINISTRATIVE SERVICES	28,080	25	702,000
HEALTH SERVICES	28,080	1	28,080
SECURITY	24,960	34	848,640
SUBTOTAL		68	2,052,960
OPERATIONS			
SUPERVISION	53,040	6	318,240
SHIFT OPERATION	44,720	32	1,431,040
SHIFT MAINT. SUPPORT	44,720	12	536,640
SUBTOTAL		50	2,285,920
MAINTENANCE			
SUPERVISOR	49,920	7	349,440
CRAFTS	35,360	133	4,702,880
ANNUALIZED PEAK MAINT.	35,360	3	106,080
QUALITY CONTROL	38,480	5	192,400
WAREHOUSE	32,240	6	193,440
SUBTOTAL		154	5,544,240
TECHNICAL AND ENGINEERING			
REACTOR ENGINEERING	53,040	3	159,120
RADIOCHEMISTRY AND WATER CHEMISTRY	49,920	8	399,360
ENGINEERING	45,760	6	274,560
TECHNICIAN	37,440	6	224,640
HEALTH PHYSICS	37,440	13	486,720
SUBTOTAL		36	1,544,400
TOTALS WITHOUT PAYROLL TAX AND INSURANCE		308	11,428,000
PAYROLL TAX AND INSURANCE (at 10%)			1,143,000
TOTAL WITH PAYROLL TAX AND INSURANCE			12.6M$

TABLE 5

ANNUAL O&M COST ESTIMATES FOR REFERENCE MHTGR PLANT

(JANUARY 1988 DOLLARS)

NET RATING MW(e)	538
CAPACITY FACTOR, %	80
ANNUAL GENERATION, kWh/year	3.77×10^9
ONSITE STAFF	308

POWER GENERATION COSTS (M$/YEAR)

ONSITE STAFF	12.6
MAINTENANCE MATERIALS	
FIXED	3.9
VARIABLE	1.3
SUBTOTAL	5.2
SUPPLIES AND EXPENSES	
FIXED	4.3
VARIABLE	
PLANT	0.4
CR AND REFLECTOR DISPOSAL	0.8
SUBTOTAL	5.5
OFFSITE TECHNICAL SUPPORT	2.3
SUBTOTAL, POWER GENERATION COSTS	
FIXED	23.1
VARIABLE	2.5
SUBTOTAL	25.6

A&G COSTS (M$/YEAR)

PENSIONS AND BENEFITS	3.2
NUCLEAR REGULATORY FEES	1.0
INSURANCE PREMIUMS	3.6
OTHER A&G	3.8
SUBTOTAL	11.6

TOTAL O&M COSTS (M$/YEAR)

FIXED	34.7
VARIABLE	2.5
TOTAL	37.2
MILLS/kWh	10.0

TABLE 6

FUEL CYCLE COSTS DATA

FUEL CYCLE COST PARAMETERS

	1987 PRICE	REAL ESCALATION (%/YR)
U_3O_8, \$/lb	23	2.0
CONVERSION, \$/kg U	8	1.0
ENRICHMENT, \$/kg SWU	109	-1.7
WASTE DISPOSALS, mills/kWh	1	0

MHTGR FRESH FUEL FABRICATION COSTS (1988$/ELEMENT)

ITEM	LEAD	REPLICA	NOAK
INITIAL CORE AND RELOADS 1-3	34,600	30,000	18,200
RELOADS 4-6	30,000	10,500	10,500
RELOADS 7-end	10,500	10,500	10,500

3 0 -YEAR LEVELIZED FUEL COSTS (1988$)

YEARS	FUEL (MILLS/kWh)	FAB (MILLS/kWh)	WASTE DISPOSAL (MILLS/kWh)	TOTAL (MILLS/kWh)	TOTAL ($/MBtu)
2000 (LEAD)	5.62	6.16	1.0	12.8	1.44
2005 (REPLICA)	5.62	4.68	1.0	11.3	1.27
2010 (NOAK)	5.71	3.50	1.0	10.2	1.15
NOAK (EQUIL. FAB)	5.71	2.65	1.0	9.4	1.05

FIGURE 2

MHTGR LEVELIZED BUSBAR COSTS

(JANUARY 1988$)

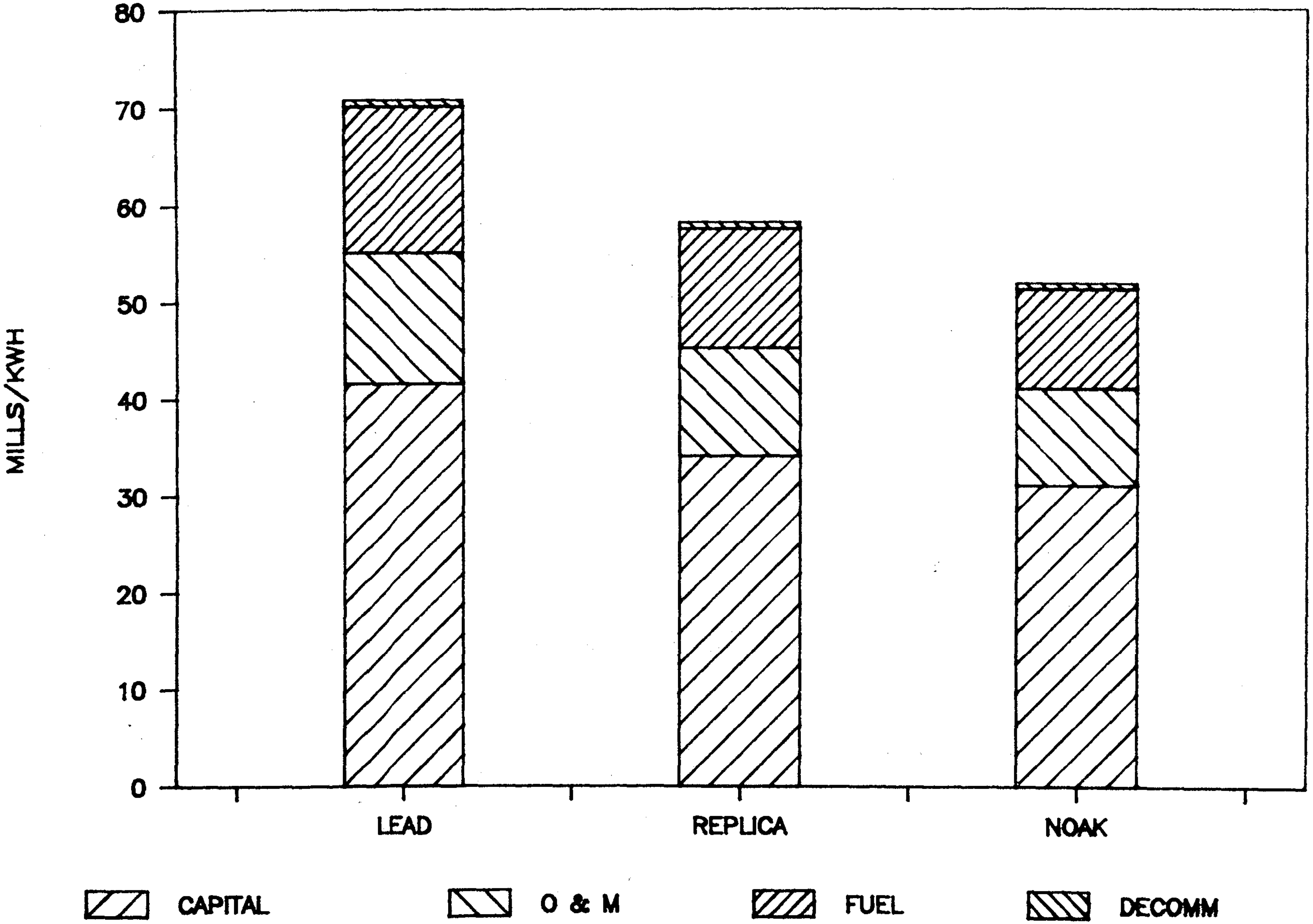


FIGURE 3

MHTGR ECONOMIC ADVANTAGE VS COAL COSTS

(80% CAPACITY FACTOR, 2010 STARTUP)

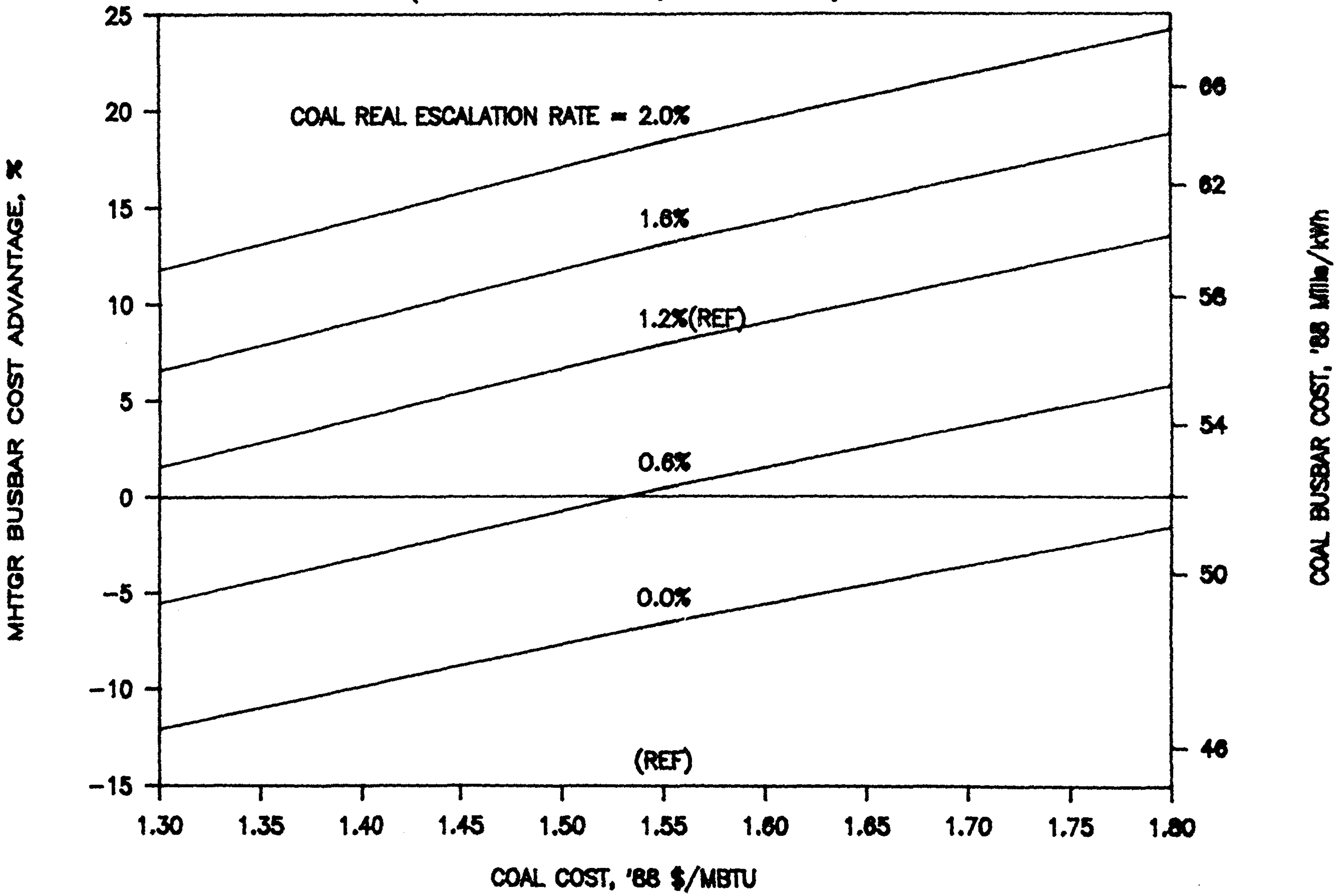
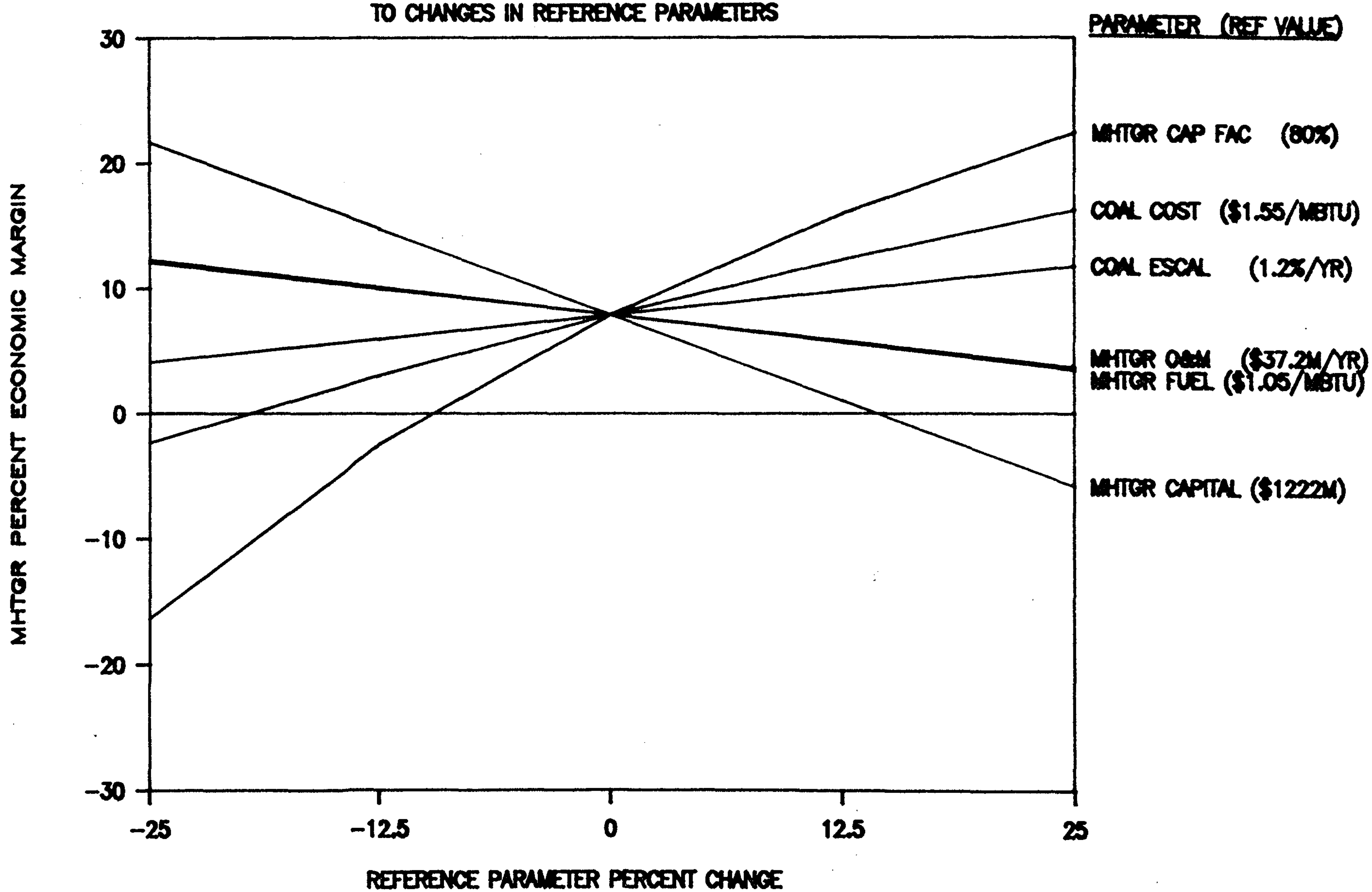


FIGURE 4

MHTGR ECONOMIC MARGIN SENSITIVITY

TO CHANGES IN REFERENCE PARAMETERS



coal real escalation rate and the major MHTGR reference parameters. This figure shows that the capital cost and the plant capacity factor have the most pronounced effect on the MHTGR economic competitiveness.

Figure 5 applies the NOAK MHTGR generating plant estimates over a range of plant sizes. The nomenclature designates the reactor x turbines combination that produce the indicated plant output. Coal plant generation cost estimates are included for the same range plus point comparisons for gas fired combined cycle plants. Key observations from this figure include:

- The reference (4x2) 540 MWe MHTGR plant continues to be evaluated as competitive with comparably sized coal plants.

- A large (8x4) MHTGR plant has only a 4-5% evaluated economic gain relative to the reference plant due to the diminishing on-site learning and shared cost benefits. The large MHTGR plant maintains the evaluated advantage relative to comparably sized coal plants.

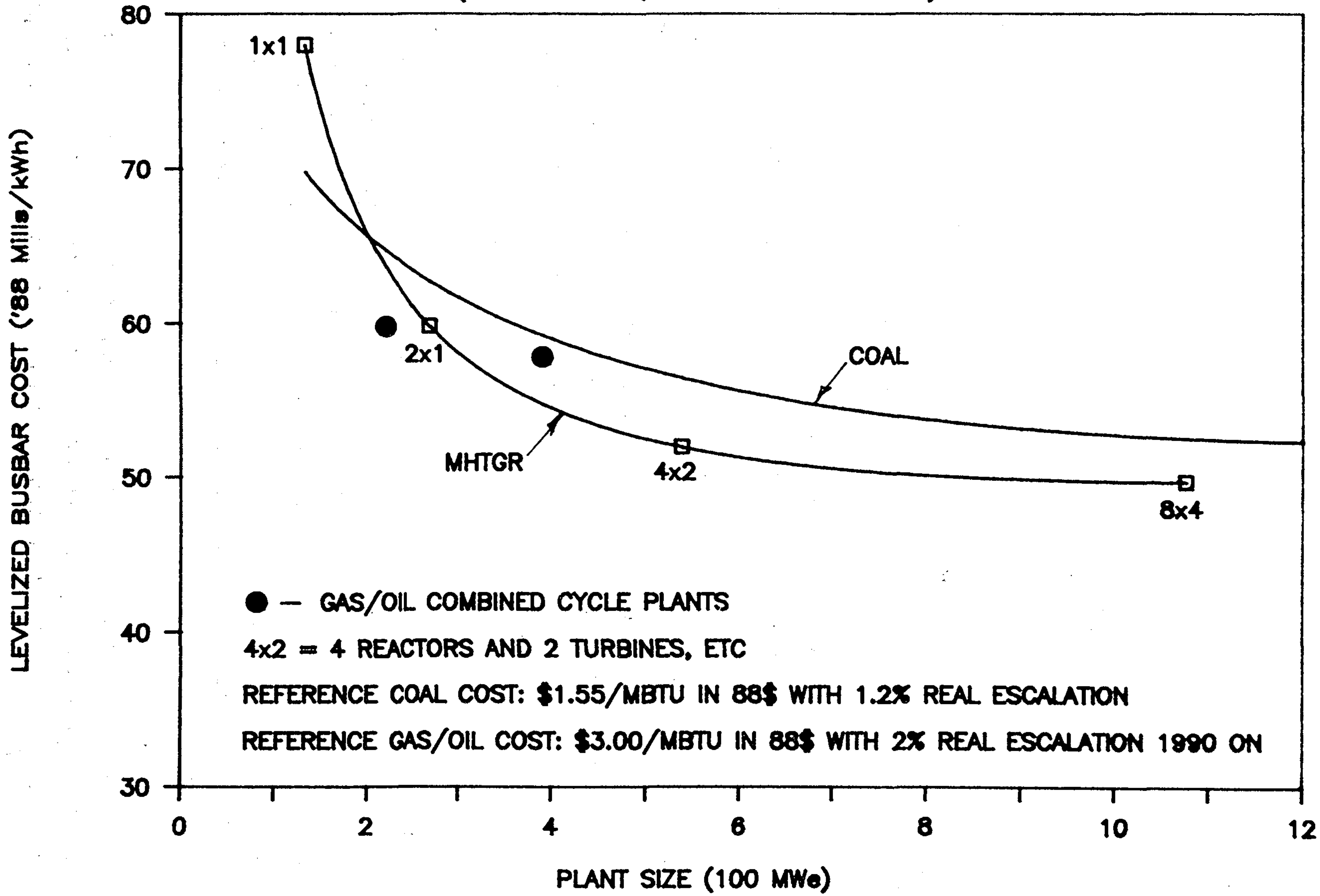
- On the other hand, a half sized (2x1) MHTGR plant has approximately a 15% evaluated economic disadvantage relative to the reference MHTGR plant and some noticeable loss in competitiveness relative to the comparably sized fossil plants. However, for high fossil fuel cost regions in the U.S., this size plant may be attractive.

- To no surprise, the one module (1x1) MHTGR plant is evaluated to be noncompetitive for any practical U.S. site. However, it may be competitive in other countries, depending on the availability and cost of the alternative technologies and related fuels.

FIGURE 5

EQUILIBRIUM PLANT POWER COST PROJECTION

(2010 STARTUP, 80% CAPACITY FACTOR)



In addition to the all-electric generating application, various cogeneration applications have been evaluated by the U.S. MHTGR Program. During the past year, a major cogeneration/seawater desalination application study was completed. Major new variables that were considered included:

- Ownership arrangements of the overall plant and the prospect of different arrangements for the MHTGR plant versus the desalination plant.

- The bases for the cost of steam to the desalination plant. Namely, is the cost of electricity based on market value, an allocated cost base or the nominal value of an all-electric plant.

- The availability, quality and cost of blending water plus the quality requirements of the product water.

Figure 4 provides a nominal joint product cost curve that illustrates the tradeoffs when determining the relative costs of product blended water and busbar generation for an NOAK (equilibrium) plant. The products produced are 466 MW of electricity and 147,000 acre feet per year (181 million cubic meters per year) of blended water.

The ownership arrangements behind this curve are based on public utility ownership of the desalination plant versus the relatively higher cost of financing for the private utility ownership of the MHTGR plant. Blended water was assumed to be available at 130$/Acre-Foot(AF) (105$/thousand cubic meters) with an impurity level of 1500 PPM total dissolved solutes (TDS). Resultant product water quality requirements were 500 PPM TDS.

As illustrated on Figure 4, applying an all-electric plant rate of 5.2 cents/kwh yields a product water cost in the range of 420$/AF (340$/thousand cubic meters). For the primary desalination regions of interest in the U.S., this is a competitive water cost compared to other major sources of new water supply projected for the turn of the century timeframe.

Conclusion

Although the MHTGR is at an early stage of preliminary design, the ongoing economic and risk assessments continue to show promise and potential for meeting GCRA's goal for evaluated cost competitiveness as well as the demands on institutional resources and exposure to financial risk.