DOE/SF/02034--T56

AN OVERVIEW OF THE
SITING CHARACTERISTIC
OF THE HTGR STEAM CYCLE/COGENERATION

MASTER

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The licensing procedure permits separation of the site review process from the plant review process which makes possible resolution of safety and environmental issues related to site selection well in advance of a decision to locate a nuclear power station at the specific site. This approach requires that the facility design assumed for the site must have numerical values of performance characteristics that are within design envelopes specified by the Nuclear Regulatory Commission (NRC) for siting nuclear power stations. A performance characteristic is defined as any property of a nuclear power facility which can affect the environmental impact of that facility. Examples of performance characteristics include the rate of release of various facility effluents (e.g. radiological and chemical source terms) and the heat rejection rates of the facility cooling system.

This report presents an overview of the siting characteristics of the HTGR-SC/C design and compares them to current NRC limiting criteria for radiological impact considerations. A systems advantage comparison is also made to an equivalent size PWR. Data is presented in summary tabular format that is derived from existing plant designs and published safety and environmental analysis for both the HTGR and the PWR.

BASIS OF STUDYSITE

The reference site conditions are assumed to be for a nuclear power station located approximately 25 miles from a large city in the Southeastern coastal region of the U.S. The nearest population center of 25,000 people is also assumed to be 10.5 miles from the proposed plant boundary.

Logistic growth projections indicate that no one will live within 2 miles of the plant site through the year 2030. Projections also indicate that within the 2 to 3 mile region the average population density will not exceed 500 persons per square mile by the year 2030. The minimum low population zone (LPZ) according to NRC criteria is estimated to be 3 miles from the center of the reactor to the outer boundary. The defined NRC exclusion are boundary (EAB) is established at 3/4 of a mile. There are no highways, railways, or public facilities and social institutions in the area. Land uses adjacent to the site are primarily agriculture or open space and no one lives within the low population zone.

In general, the site meteorology is characteristic of a subtropical climate consisting of prolonged warm, rainy summer and a mild dry winter. There are no unusual geological or seismological conditions to be considered, and water use is limited to controlled use of brackish ground water.

PLANT DESIGN

The nuclear power stations compared are the 2240 MW(t)/860 MW(e) HTGR-SC/C plant and an "equivalent size PWR". Both plants are designed to meet current NRC regulations using present-day technology, design features and standards. Table 1 summarizes the major performance parameters for the two reactor systems.

COMPARISONS AND CONCLUSIONS

First, the inherent safety features of the HTGR, as they differ from those of the PWR are shown in Table 2. Major key engineered safety systems for the HTGR and the PWR are compared in Table 3. Whereas Table 1 generally illustrates differences in thermal plant performance parameters for the two reactor systems. Tables 4 thru 16 summarize numerical values of plant thermal and radiological performance for the HTGR-SC/C that are significant to siting. Where appropriate, comparisons are made to the PWR and/or to NRC criteria. The tables are organized as follows:

Water Requirements.....	Table 4
Chemical and Biocide Discharges.....	Table 5
Radioactive Wastes.....	Tables 6 thru 9
Containment Access.....	Table 10
Design Basis Events.....	Table 13, 14
Siting Events.....	Table 13, 14
Safety Risk Assessment.....	Table 15, 16
EAB and LPZ Sizing.....	Table 17
Emergency Planning.....	Table 18

The information presented indicates that both a PWR or HTGR reactor system can meet the environmental and/or radiological siting criteria presently contained in NRC regulations and guidelines. The HTGR-SC/C, however, consistently exhibits a substantially lower impact to the environment, reduced exposure to the general public from both normal plant releases and under accident conditions, reduced exposures to plant personnel with increased assess time for maintenance and operation, reduced risk to the public from low-probability catastrophic events, and a definite potential for reduction in emergency planning requirements when compared to the PWR.

Finally in Table 19, conclusions are summarized that show the potential of the HTGR-SC/C for being more easily sited than a PWR due mainly to lower radiological impact and reduced cooling water requirements.

TABLE 1
EXPECTED PERFORMANCE PARAMETERS

	<u>HTGR</u>	<u>PWR</u>
NOMINAL REACTOR POWER, MW(T)	2240	2578
NUMBER OF PRIMARY LOOPS	4	4
NOMINAL ELECTRIC OUTPUT (NET), MW(E)	858	858
NOMINAL NET STATION EFFICIENCY (%)	38.3	33
PLANT LAYOUT	SINGLE UNIT	SINGLE UNIT
AVAILABILITY FACTOR (%)	90	90
FUEL CYCLE	LEU/TH STOW-AWAY	LEU STOW-AWAY
CORE POWER DENSITY, KW/LITER	7.15	105
FUEL LIFETIME, YR.	4	3
REFUELING CYCLE TIME, YR.	1	1
ANNUAL MAKEUP WATER USAGE	3.9×10^6	4.9×10^6
STEAM OUTLET CONDITIONS, PSIA/°F	2515/1005	925/535

TABLE 2

HTGR AND PWR INHERENT AND PASSIVE SAFETY FEATURES

Item	HTGR	PWR
Coolant	<p>Helium</p> <ul style="list-style-type: none"> • Chemically inert, single-phase • Negligible activation/reactivity • Low stored energy content 	<p>H₂O</p> <ul style="list-style-type: none"> • Chemically active, two-phase • Activation/reactivity effects • Higher stored energy and pressure
Core/Moderator	<p>Ceramic coated fuel particles/graphite</p> <ul style="list-style-type: none"> • High heat capacity and high temperature limits mean longer time before failure from overheating • No fuel-coolant reaction • Ceramic material does not melt • Graphite get stronger as temperature increases 	<p>Metal-clad ceramic fuel/water</p> <ul style="list-style-type: none"> • Lower heat capacity, lower temperature limits on metal clad mean less time before failure from overheating • Fuel-coolant reaction at elevated temperature is exothermic, producing H₂
Reactor vessel	<p>Prestressed concrete reactor vessel (PCRV)</p> <ul style="list-style-type: none"> • Multiple tendons insensitive to single tendon failure • Primary system components contained within PCRV 	<p>Steel vessel</p> <ul style="list-style-type: none"> • Structural member failure not allowed • External primary system piping and components subject to leakage/rupture

TABLE 3

HTGR AND PWR ENGINEERED SAFETY FEATURES

Safety Feature	HTGR	PWR
Residual heat removal	Core auxiliary cooling system, completely independent from main loops out to ultimate heat sink	Similar concept, but not independent of main loops
Shutdown systems	Two - Normal control rod drive - Diverse boronated-graphite pellet backup system	Two - Normal control rod drive - Diverse coolant poison injection
Isolation system	Steam generator isolation and dump system	Steam generator isolation system
Containment	Secondary containment and isolation system	Secondary containment and isolation

TABLE 4
WATER REQUIREMENTS

	<u>HTGR</u>		<u>PWR</u>	
	<u>GPM</u>	<u>ACRE-FT/YR</u>	<u>GPM</u>	<u>ACRE-FY/YR</u>
RAW WATER MAKEUP	290	300	420	470
CIRCULATING WATER MAKEUP	10600	11970	13300	15020
WASTE WATER - DISPOSAL	3600	4060	4500	5080

HTGR WATER REQUIREMENT 80% OF PWR, REFLECTING HTGR CAPABILITY OF HTGR TO PRODUCE STEAM AT MUCH HIGHER TEMPERATURES AND PRESSURE, RESULTING IN HIGHER TURBINE-GENERATOR CYCLE THERMAL EFFICIENCY.

TABLE 5

CHEMICAL AND BIOCIDES DISCHARGES

CONCENTRATIONS - SAME FOR HTGR AND PWR

QUANTITIES - HTGR ABOUT 80% OF PWR

ASSUMING MECHANICAL DRAFT WET COOLING TOWERS.

TABLE 6
SOLID RADIOACTIVE WASTES
 (DESIGN BASIS)

	<u>HTR</u>	<u>PWR</u>
QUANTITIES (FT ³ /YR)	2300	9830
ACTIVITY (CI/YR)	14500*	7300

*INCLUDES REPLACEABLE REACTOR CORE GRAPHITE REFLECTOR BLOCKS AND SPENT TRITIUM
 ABSORPTION MEDIUM (TITANIUM SPONGE FROM THE HELIUM PURIFICATION SYSTEM).

TABLE 7

LIQUID RADIOACTIVE WASTES

(DESIGN BASIS)

NORMAL RELEASES

	<u>HTGR</u>	<u>PWR</u>
*TOTAL ACTIVITY RELEASED (CI/YR)	8.54×10^{-3}	1.1
TRITIUM RELEASED (CI/YR)	12	530

*EXCLUDING TRITIUM

TABLE 8

LIQUID RADIOACTIVE WASTES

(DESIGN BASIS)

DOSE FROM NORMAL RELEASES

	<u>HTGR</u>	<u>PWR</u>
<u>*EAB</u>		
WHOLE BODY δ (MREM/YR)	1.03×10^{-2}	1.38
APPENDIX I GUIDELINE - 3 MREM/YR		
ANY ORGAN (MREM/YR)		
BONE	6.43×10^{-3}	9.38×10^{-1}
THYROID	6.17×10^{-5}	1.97
APPENDIX I GUIDELINE - 10 MREM/YR		

*EAB - 1200 M

TABLE 9

GASEOUS RADIOACTIVE WASTES

(DESIGN BASIS)

DOSE FROM NORMAL RELEASES

	<u>HTGR</u>	<u>PWR</u>
EAB WHOLE BODY ⁸ (MREM/YR)	0.12	0.7
APPENDIX I GUIDELINE - 5 MREM/YR		
MAXIMUM ADULT ORGAN (MREM/YR)	2×10^{-4}	85
INFANT MILK CHAIN (MREM/YR)	7×10^{-4}	352
APPENDIX I GUIDELINE - 15 MREM/YR		
COLLECTIVE POPULATION DOSE* (MAN-REM/YR)		
WITHIN 50 MILES		
WHOLE BODY	0.2	2.4
THYROID	NEGLECTIBLE	5.5

*BASED ON YEAR 2000 POPULATION

TABLE 10

CONTAINMENT ACCESS

DURING NORMAL REACTOR OPERATIONS

	<u>HTGR</u>	<u>PWR</u>
*ESTIMATED EXPOSURE RATE (MREM/HR)	1.3	18.4
**ACCESS TIME (HRS/WK)	76	5.4

*BASED ON EXPECTED GASEOUS RADIOACTIVITY CONCENTRATIONS ONLY

**BASED ON 10CFR20 LIMIT OF 5 REM/YR

TABLE 11

DESIGN BASIS EVENTS

HTGR - RAPID DEPRESSURIZATION OF PRIMARY SYSTEM
TO CONTAINMENT - DBDA

100 SQ IN. OPENING IN PCRV

PWR - LOSS OF COOLANT ACCIDENT - LOCA
PRIMARY COOLANT PIPE BREAK

TABLE 12

OFF-SITE DOSES

DESIGN BASIS EVENT

	HTGR		PWR	
	WHOLE BODY γ	THYROID	WHOLE BODY γ	THYROID
EAB				
2 HOUR EXPOSURE (REM)	6.8×10^{-5}	1.7×10^{-3}	9.1×10^{-2}	1.723

10CFR100 LIMITS - FOR 2 HOUR EXPOSURE

25 REM WHOLE BODY γ

300 REM THYROID

* LPZ

30 DAY EXPOSURE (REM)	4.9×10^{-5}	5.5×10^{-4}	3.7×10^{-2}	1.84
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*LPZ - 4800 M

TABLE 13

SITING EVENTS

HTGR - MAXIMUM HYPOTHETICAL FISSION PRODUCT RELEASE (MHFPR)
(UNRESTRICTED CORE HEATUP-FISSION PRODUCT RELEASED
DIRECTLY TO CONTAINMENT)

PWR - LOSS OF COOLANT ACCIDENT (LOCA)
(TID-14844 FISSION PRODUCT RELEASE DIRECTLY TO CONTAINMENT
IN ACCORDANCE WITH 10CFR100).

TABLE 14

OFF-SITE DOSES

SITING EVENT

	<u>HTGR</u>		<u>PWR</u>	
	<u>WHOLE BODY</u>	<u>THYROID</u>	<u>WHOLE BODY</u>	<u>THYROID</u>
EAB				
2 HOUR EXPOSURE (REM)	7.3×10^{-5}	2.2×10^{-3}	4.0×10^{-1}	22.7
10CFR100 LIMITS - FOR 2 HOUR EXPOSURE - 25 REM WHOLE BODY & - 300 REM THYROID				
LPZ				
30 DAY EXPOSURE (REM)	1.2×10^{-1}	4.02	4.0×10^{-1}	26.3

TABLE 15

SAFETY RISK ASSESSMENT

RISK ASSESSMENT OF ACCIDENTS THAT RESULT IN SUBSTANTIAL PHYSICAL DETERIORATION OF THE REACTOR CORE. THE MORE SEVERE CONSEQUENCE SCENARIOS INCLUDE REDUCTION OF CAPABILITY OF THE SECONDARY CONTAINMENT AND ENGINEERED SAFETY FEATURES TO LIMIT THE RELEASE OF RADIOACTIVE MATERIAL TO THE ENVIRONMENT.

BASED ON GA-A1500 USING SITE-SPECIFIC METEOROLOGY AND POPULATION DATA.

TABLE 16

SAFETY RISK ASSESSMENT

YEAR 2000 POPULATION
WITHIN 500 MI

<u>ACCIDENT CONSEQUENCES</u>	<u>10^{-6}/RTR YR HTGR</u>	<u>10^{-7}/RTR YR HTGR</u>	<u>10^{-9}/RTR YR HTGR</u>
EARLY FATALITIES	0	0	0
EARLY ILLNESS	0	0	0
LATENT CANCER FATALITIES* OVER 30 YRS	2	10	30

*GENETIC EFFECTS WOULD BE APPROXIMATELY TWICE THE NUMBER OF LATENT CANCERS.

TABLE 17

EAB AND LPZ

MINIMUM RADIUS

	<u>HTGR</u>	<u>PWR</u>	<u>REF.</u> <u>STUDY</u>
MINIMUM EAB (M)	<50	235	1200
MINIMUM LPZ (M)	220	855	4800

RADIUS CALCULATION BASED UPON DOSE LIMITS OF 10CFR100.

TABLE 18

HTGR ADVANTAGES FOR
EMERGENCY PLANNING

REDUCED EPZ RADIUS

PLUME EXPOSURE PATHWAY	-	5 MI	VS.	10 MI*
INGESTION PATHWAY	-	20 MI	VS.	50 MI*

NO REQUIREMENT FOR 15-MIN. WARNING OF POPULATION

LONG TIMES AVAILABLE TO RESPOND (DAYS)

STAY AT LOWER PROTECTION ACTION GUIDE LEVELS (NO EVACUATION)

REQUIRES RECOGNITION OF DIFFERENT CHARACTERISTICS BY NRC/FEMA

*NRC PRESENT PRACTICE FOR PWR

TABLE 19
STUDY CONCLUSIONS

THE HTGR-SC/C AND A TYPICAL PWR CAN MEET PRESENT-DAY LIMITING RADIOLOGICAL SITE CRITERIA. HOWEVER, THE HTGR-SC/C PROVIDES THE FOLLOWING ADVANTAGES/DISADVANTAGES WHEN COMPARED TO THE PWR:

- LOWER WATER REQUIREMENTS
- LOWER CHEMICAL AND BIOCIDES DISCHARGES
- GREATER QUANTITY (CI) OF SOLID RADIOACTIVE WASTE
- LOWER RELEASE OF RADIOACTIVE MATERIAL - NORMAL OPERATION
- LOWER PUBLIC EXPOSURE - NORMAL OPERATION
- UNLIMITED CONTAINMENT ACCESS TIME
- SMALLER EAB AND LPZ
- LOWER PUBLIC EXPOSURE - ACCIDENT CONDITIONS
- LOWER RISK TO PUBLIC - LOW PROBABILITY EVENTS
- REDUCED EMERGENCY PLANNING REQUIREMENTS

SMALLER EPZs

15-MIN EARLY WARNING SYSTEM NOT REQUIRED