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GCRA Review and Appraisal
of HTGR ~~Reactor-Core-Design~~ Program

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GCRA Review and Appraisal of HTGR Reactor Core Design Program

Introduction and Overview

The Reactor Core Design Program has as its principal objective and responsibility the design and resolution of major technical issues for the reactor core and core components on a schedule consistent with the plant licensing and construction program. The task covered in this review includes three major design areas:

- Core physics
- Core thermal and hydraulic performance fuel element design
- In-core fuel performance evaluation

The reactor core design task also covers replaceable reflector element design and fuel and reflector element stress analysis, control rods, neutron sources, reserve shutdown material, and reactor plenum elements. These latter items are part of the reactor internals tasks, and review of these topics is covered elsewhere.

The reactor core is one of the unique design features of the HTGR and allows it to deliver high-temperature heat to be utilized in efficient, high-grade steam production, or through suitable heat exchangers, it can serve as a high-temperature heat source for a variety of industrial applications. The current program is directing its attention toward employing the HTGR for either a steam cycle application or the reformer application. The steam cycle application would employ a core having a gas outlet temperature of approximately 700°C, whereas the reformer application is currently focused on 850°C applications, but also considers core outlet temperatures up to 950°C. To date, preliminary core design studies have been completed for a 2240-MWt steam cycle plant. These studies have identified feasible core design for applications with a 1362°F (approximately 750°C) core exit temperature. Basic design configurations have been established for an HTGR-Reformer (HTGR-R) and HTGR-Process Steam (HTGR-PS) core having an 1170-MWt output; however, a complete thermal-hydraulic design has not been

produced. The HTGR-SC, P/S core design parameters derived for the 2240-MWt and 1170-MWt plants are presented in Table 1 for reference, and these can be compared with initial core design parameters developed over the past few months for the HTGR-R [and HTGR-Nuclear Heat Source Demonstration Reactor (HTGR-NHSDR)] application studies, Table 2. The design basis for the HTGR-GT core for the application studies is given in Table 3. The gas turbine core and the core for the reformer and NHSDR applications are similar except for their size and configuration, whereas the reformer and NHSDR cores are similar in configuration to the 1170-MWt steam cycle design but differ in the fuel design and outlet temperature.

GCRA Reactor Core Program Activities During FY 1980

GCRA maintained cognizance of the HTGR Reactor Core Design Program through frequent interfacing meetings with personnel from the General Atomic Company (GA), which has the primary responsibility for the design and design verification for this major component. A detailed review of FY 1980 activities as well as of planned work for FY 1981 was conducted in September 1980.

Program Task Definition

The following lists the work areas and funding levels for the core design and design verification programs being performed at GA:

<u>Task Description</u>	<u>Funding level (\$K)</u>	
	<u>FY 1980</u>	<u>FY 1981</u>
Generic Component Design (WBS 123)		
<u>Reactor Core Engineering (WBS 12318)</u>		
Reactor Core Nuclear Design	216	350
Reactor Performance Analysis	166	220
Reactor Fission Product Analysis	133	221
Application Study Support: PH, NHSDR	130	0
Fuel Element Stress Analysis	216	350
Alternate Design Studies, Core Flow Analysis	84	0
Subtotal	945	1141

<u>Task Description</u>	<u>Funding level (\$K)</u>	
	<u>FY 1980</u>	<u>FY 1981</u>
Generic Components (DV&S) (WBS 124)		
<u>Reactor Core (WBS 12418)</u>		
Fuel Element Design Verification	85	250
Core Nuclear, Thermal and Flow, and Component DV&S	0	135
Reactor Core Fluctuation Program	<u>880</u>	<u>943</u>
Subtotal	<u>965</u>	<u>1328</u>
•Program Total	1910	2469

Program Review and Recommendations

Under the Reactor Core Engineering Program (WBS 123-18), the major emphasis has been directed toward performing design optimization studies to determine the core configuration yielding optimum economics and fuel and core materials performance. During the first quarter of FY 1980, this work emphasized the gas turbine application having an requirement for an 850°C outlet temperature. The HTGR Program was redirected in early 1980 to undertake the application studies; however, the core design optimization effort was able to continue with little perturbation because of the similarity between core performance requirements of the different applications. Here a principal guiding design criterion was the requirement for an 850°C core outlet temperature for three of the four applications under study (i.e., HTGR-GT, HTGR-R, and HTGR-NHSDR). Different core configurations had to be developed for the HTGR-R and HTGR-NHSDR because of their smaller size, 1170 MWt, compared to the HTGR-GT design of 2170 MWt.

As part of the application studies, priority technical issues have been identified for key HTGR components, and several issues have been identified which affect the core design area. Identified technical issues pertinent to this review of core design are (a) high temperatures, (b) fuel element stresses, (c) core fluctuations, and (d) LEU/Th fuel cycle. Some of

these technical issues are interrelated and their selection will be one of design optimization among the various affected components. For example, for higher-temperature applications (issue a), a steeper axial power profile is desired to keep fuel temperatures as low as possible. This leads to a more difficult axial zoning problem with LEU fuel and may require some modification of the LEU/Th fuel cycle (issue b).

In the area of fuel element stresses (issue b), a program to demonstrate structural adequacy of fuel blocks under combined thermal, irradiation, and dynamic loads is ongoing, supported by graphite development and structural mechanics base technology work. Work to date has been directed toward defining the accuracy limits of available methods, benchmark analysis of "simple" geometries, and analysis of test results from the French RWG experiments on irradiated specimens.

Work on optimization of standard fuel block configurations to reduce thermal stresses has shown that peak stresses can be reduced by modification of fuel and coolant hole patterns near peak stress areas. Work is continuing on control block optimization, and preliminary indications are that proper choice of hole patterns can substantially reduce thermal stresses.

The issue of possible core outlet temperature fluctuations (issue c) in the Large High-Temperature Gas-Cooled Reactor (LHTGR), similar to those observed at Fort St. Vrain, is being addressed in several ways. Analysis of model tests made in FY 1979 has been performed, and an attempt to produce a computer model to predict the flow behavior observed in the model has achieved some success. A long-range plan of design, testing, and analysis has been prepared, and work is under way to resolve the issue of fluctuations in the LHTGR core.

Fuel performance analysis has been performed on a number of core designs, and the results to date show that the steam cycle designs with LEU/Th fuel (issue d) are below regulatory limits for fission product release and plateout. Analysis of higher-temperature cores using existing fuel models show them exceeding circulating activity for the steam condi-

tions by about 40% and metal plateout criteria by about a factor of 2. It is expected that improvements in power distributions, fuel product improvements, and better fuel behavior models will show the calculated fission product release and distribution to be within criteria limits established for all design options.

TABLE 1
BASIC CORE PARAMETERS FOR HTGR-SC

Nominal core power, MWt	1170	2240
Nominal core power density, W/cm ³	6.6	7.15
Core outlet temperature, °C	686	686
Number of fuel blocks per column	8	8
Number of fuel columns	247	439
Number of 7-column regions with variable orifices	31	55
Number of 5-column regions with fixed orifices	6	6
Number of 2-column regions with fixed orifices	0	12
Number of control rod pairs	37	67
Number of power rods	37	61
Number of reserve shutdown hoppers	33	55
Core volume, m ³	177	312
Fuel cycle		
Initial fuel cycle	LEU/Th	LEU/Th
Refueling cycle ^(a)	4 yr	4 yr
Fissile material/particle coating	UC ₂ /TRISO	UC ₂ /TRISO
Fertile material/particle coating	ThO ₂ /BISO	ThO ₂ /BISO
Fuel enrichment, percent U-235	19.9	19.9

(a) 25% reload annually.

TABLE 2
BASIC CORE PARAMETERS FOR HTGR-R AND
HTGR-NHSDR APPLICATION STUDIES

Nominal core power, MWt	1170
Nominal core power density, W/cm ³	6.6
Core outlet temperature, °C	850
Number of fuel blocks per column	8
Number of fuel columns	247
Number of 7-column regions with variable orifices	31
Number of 5-column regions with fixed orifices	6
Number of control rod pairs	37
Number of power rods	37
Number of reserve shutdown hoppers	33
Core volume, m ³	177
Fuel cycle	
Initial fuel cycle	1.EU/Th
Refueling cycle	4 yr 25% reloaded each year or "thick buffer"
Fissile material/particle	UC ₂ /TRISO
Fertile material/particle	ThO ₂ /TRISO
Fuel enrichment, percent U-235	19.9

TABLE 3
BASIC CORE PARAMETERS FOR HTGR-GT

Nominal core power, MWt	2000
Nominal core power density, W/cm ³	6.6
Core outlet temperature, °C	850
Number of fuel blocks per column	8
Number of fuel columns	415
Number of 7-column regions with variable orifices	55
Number of 5-column regions with fixed orifices	6
Number of control rod pairs	61
Number of power rods	61
Core volume, m ³	301.4
Fuel cycle	
Initial fuel cycle	LEU/Th
Refueling cycle	4 yr 25% reloaded each year or "thick buffer"
Fissile material/particle	UC ₂ /TRISO
Fertile material/particle	ThO ₂ /TRISO
Fuel enrichment, percent U-235	19.9