ANL-FRA--164

DE89 012772

ANL-FRA-164

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**THE STEADY-STATE THERMAL-HYDRAULIC PERFORMANCE
OF 3500 MWth METAL AND OXIDE FUELED LMRs***

by

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MARCH 1989

*Work supported by the U.S. Department of Energy, Nuclear Energy Programs, under Contract No. W-31-109-ENG-38.

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ABSTRACT

The thermal-hydraulic performance of a 3500 MWth metal and oxide fueled LMR is reported. Orifice zones are defined and coolant flowrates are given for use in safety analyses. The flux calculations were carried out in three-dimensional hexagonal-Z geometry using a finite differenced diffusion theory code. The heating calculations included the transport and deposition of gamma energy. The assembly temperature calculations were performed using a subchannel code.

I. INTRODUCTION

A joint US-European study has been initiated to investigate and identify safety related differences between metal and oxide fuel behavior. Reference core designs have been selected and are being analyzed to assess the safety performance of each fuel type for unprotected loss-of-flow (LOF), loss-of-heat-sink (LOHS) and transient overpower (TOP) accidents. The technical merits of each fuel type will then be reported for these accidents.

The metal and oxide core designs selected for analysis have been developed at ANL. Both cores have been optimized for neutronic and thermal-hydraulic performance at normal operating conditions. The reactor global design specifications are summarized in Table I. The core layouts for the oxide and metal cores are shown in Figures 1 and 2. Fuel pin and assembly design specifications are shown in Tables II and III.

This report describes the steady-state thermal-hydraulic performance characteristics of these metal and oxide cores. The orifice zone definitions and flowrates presented in this report were used in subsequent safety analyses⁽¹⁾.

II. COOLANT ALLOCATION SCHEME

The basis for allocating coolant flow to the core assemblies is the same in both the metal and oxide designs as described below. Since fuel and blanket assemblies remain in the same lattice position through life, control of assembly flowrate can be achieved by nozzle orificing rather than less flexible grid plate orificing.

The number of fueled orifice zones was set to ten. This number represents a nominal upper limit for the number of unique discriminators that can be fabricated. A discriminator helps prevent an assembly from being inadvertently inserted in an orifice region where it does not belong.

Orificing zones were defined by grouping assemblies with respect to maximum value of power times skew over life. Assemblies with similar values were placed in the same orifice zone. Mixing of driver and blanket assemblies within a zone is not permitted.

Of the total available flow, a fixed percentage is allocated for non-fueled assemblies. Reflector assemblies receive a total of 1.4 percent and the control assemblies receive a total of 0.5 percent. An additional 1.4 percent is allocated for cold bypass.

The remainder of the total flow is allocated among driver and blanket assemblies. This coolant is distributed so as to minimize the peak two-sigma cladding midwall temperature over all fueled orifice zones, over all times in an equilibrium cycle reload interval.

III. CALCULATIONAL MODEL

A. Neutronics

The core power distribution was obtained from a coupled neutron-gamma heating rate calculation. The heating calculation methodology is characterized by the use of KERMA (Kinetic Energy Release in Materials) factors. A KERMA factor is defined as the product of the microscopic cross section and the energy release per reaction type. The heating rate, $H(E)$ is:

$$\text{Heating Rate} = H(E) = \sum_i \sum_j N^j k_{ij}(E) \phi(E) \quad (1)$$

for isotope i , reaction j . Heat deposition rates are calculated separately for neutron and gamma particles using the neutron and gamma KERMA factors and fluxes. The neutron KERMA factors include the energy which is locally deposited by all other particles.

Neutron and gamma KERMA factor, gamma production matrix, and gamma interaction group constants were generated using the NJOY code^[2] with 231 neutron energy groups and 94 gamma energy groups. The gamma production group constants were converted into yield factors. This allows the properly self-shielded neutron interaction group constants generated using the standard MC²-2 code^[3] to be used in both the neutron flux and gamma source calculations. All group constants were collapsed using the SDX code^[4] to 9 neutron and 21 gamma energy groups. The neutron group collapsing utilized a one-dimensional diffusion flux calculation; whereas, the gamma group collapsing was based on the fundamental mode spectrum within each region.

The heating calculation is coupled in that neutron interactions are the source of the photons. Thus, the first step in the calculational procedure involves a neutron flux calculation. From this neutron flux, the corresponding gamma source is calculated; then a fixed source gamma flux calculation is performed. The two flux profiles are then multiplied by their respective KERMA factors to calculate the neutron and gamma heating rates.

Flux calculations were carried out in three-dimensional triangular-Z geometry (6 triangles per assembly) using finite differenced diffusion theory in the DIF3D code^[5]. The BOEC and EOEC nuclide concentrations are taken from the equilibrium cycle calculation described in Reference 6; the composition of each assembly is "batch-averaged" in this approach. The control rods are withdrawn at BOEC and inserted 9.14 cm at EOEC to model the critical configuration of the metal core. The control rods are inserted 10.2 cm at BOEC and withdrawn at EOEC to simulate the critical configuration of the oxide core.

Regional breakdowns of the gamma and neutron heating for the oxide and metal cores are shown in Tables IV and V. 10% of the total core heating is from gamma rays. 15-20% of the blanket and radial shield (B_4C) heating is attributed to gamma energy deposition; in the radial shield, the (n, α) reaction in boron (α energy deposition is included in the neutron heating) is the primary heat source. About 50-70% of the heating in the control regions is deposited by photons. The total heating in the primary control assemblies (PCR) increases and the gamma heating fraction decreases with control rod insertion depth (see EOEC metal and BOEC oxide) since the rods contain boron (alpha heating). In the radial reflectors which contain only stainless steel and sodium, fully 90% of the total heating comes from photons; therefore, accurate treatment of gamma transport is critical in this region.

The equilibrium cycle hex-Z total power distributions are used as input to the orificing calculation. However, the thermal-hydraulic evaluation must take into account the **assembly-wise** local power peaking. "Batch-averaged" power values are inadequate since they do not model the higher power levels of fresh driver assemblies introduced into a core of partially burned neighbors. Therefore, the computed assembly powers are adjusted by applying "stage factors" to obtain the maximum power in the life of each assembly for use in the orificing calculation. These stage factors are simply a power multiplier based on the ratio of the assembly smeared macroscopic fission cross section

for a given batch (i.e., fresh, once-burned, etc.) to the batch-averaged assembly-smeared macroscopic fission cross section (weighted with the appropriate regional spectrum). Thus, since the macroscopic fission cross section of core assemblies will decrease with burnup, the maximum stage factor for each core region will occur for fresh drivers at BOEC. Conversely, since blanket assemblies breed plutonium which increases the macroscopic fission cross section, the maximum stage factor for each blanket region will occur for the longest residence blanket assemblies.

B. Thermal-Hydraulics

Core orificing was performed using the multi-assembly, steady-state thermal-hydraulic code SUPERENERGY-2^[7]. The SUPERENERGY-2 code is fast running and well validated in the range of typical liquid metal reactor assembly designs. The fast running nature of the code results from replacing the momentum and continuity equations by an enhanced eddy diffusivity of heat and a ratio of transverse swirl velocities for the interior and periphery regions of the bundle. This simplified energy equation mixing model is applicable only to steady-state forced convection flow in assemblies as is found at full power conditions. The code has been enhanced at ANL by the addition of various features useful for core orificing tasks.

The hot channel subfactor data used to compute the two-sigma cladding midwall temperatures for the oxide core is given in Tables VI and VII for the driver and blanket assemblies respectively. These two sets are taken directly from Reference 8. The hot channel subfactor data used for the metal core is given in Tables VIII and IX. This data is again taken from Reference 8 but with two minor changes to account for the sodium bond used in metal fuel. These changes are shown in Tables VIII and IX. The rationale for using the Clinch River Breeder Reactor (CRBR) values directly comes from the fact that the fuel and blanket assemblies for the metal core and CRBR are of similar dimensions and that assembly power, inlet temperature and outlet temperature are also similar. Additionally, both cores employ a heterogeneous configuration of assemblies. Note that the CRBR values used are beginning of life for the driver and end of life for the blanket.

The semi-statistical horizontal method^[9] was used to combine the subfactor data with nominal temperatures to yield the two-sigma cladding midwall temperatures. The subfactor data was also collapsed by the vertical method^[9] to give hot channel factors,

and these are listed at the bottom of Tables VI through IX. These values were, however, not used in the orificing calculations.

IV. OXIDE CORE

A. Core Description

The oxide core is the heterogeneous design developed in Reference 6 and is shown in Figure 1. Reactor global design specifications are summarized in Table I. Fuel pin and assembly dimensions are given in Table II.

B. Thermal Performance

The peak and average power densities are presented in Figures 3-6. The average power densities are the assembly average power values; the actual heating calculation uses six triangles per assembly allowing a gradient within each assembly. The values given in Figs. 3-6 are based on "batch-averaged" number densities at BOEC and EOEC as described in Section III.A.

It is necessary to perform the orificing calculation using the maximum possible power for each assembly to assure adequate cooling throughout each assembly's core residence. In general, this requires particular attention to be paid to fresh drivers at BOEC and long residence blankets at EOEC. The maximum power density caused by the burnup variation is estimated by multiplying the regional maximum stage factors described in Section III.A to the BOEC and EOEC power distributions leading to an orificing core model with a power greater than 3500 MWth. The set of stage factors is shown in Table X; the correspondence between the region names in Table X and lattice positions in Figs. 3-6 is given in Figure 7. The data in the remaining tables and figures presented in this section are stage factor adjusted values. The correspondence between lattice position and assembly type for these figures is given in Figure 8.

Assembly integrated power is given in Figures 9 and 10.

The orifice zones are defined in Table XI and the orifice zone flowrates are given in Table XII.

The peak two-sigma cladding midwall temperature reached in the core over all

cycles is 1230° F. The peak value within each orifice zone is given in Table XIII. The peak value within each assembly at BOEC is given in Figure 11. The value at EOEC is given in Figure 12.

Intra-assembly thermal-hydraulic data for the peak assembly at the time of its maximum power, which is the beginning of life, is given in Table XIV. The peak assembly is defined as the assembly with the maximum power-to-flow ratio taken over all fueled assemblies.

V. METAL CORE

A. Core Description

The metal core is the heterogeneous design developed in Reference 6 and is shown in Figure 2. Reactor global design specifications are summarized in Table I. Fuel pin and assembly dimensions are given in Table III.

B. Thermal Performance

The peak and average power densities are presented in Figures 13-16. The average power densities are the assembly average power values; the actual heating calculation uses six triangles per assembly allowing a gradient within each assembly. The values in Figs. 13-16 are cycled averaged and are the analogs of Figs. 3-6 for the oxide core. A set of stage factors is given in Table XV for determining from the values in Figs. 13-16, the maximum power for each assembly. This table is the analog of Table X for the oxide core. The correspondence between region names in Table XV and lattice positions in Figs. 13-16 is given in Figure 17.

The data in the remaining tables and figures presented in this section are the stage factors adjusted values (see the second paragraph of Section IV.B for definition). The correspondence between lattice position and assembly type for these figures and tables is given in Figure 18.

Assembly integrated power is given in Figures 19 and 20.

The orifice zones are defined in Table XVI and the orifice zone flowrates are given in Table XVII.

The peak two-sigma cladding midwall temperature reached in the core over all cycles is 1246° F. The peak value within each orifice zone is given in Table XVIII. The peak value within each assembly at BOEC is given in Figure 21. The values at EOEC are given in Figure 22.

Intra-assembly thermal-hydraulic data for the peak assembly at the time of its maximum power, which is the beginning of life, is given in Table XIX. The peak assembly is defined as the assembly with the maximum power-to-flow ratio taken over all fueled assemblies.

VI. SUMMARY

Coolant orifice zones were defined and orifice zone flowrates were calculated for a 3500 MWth metal and oxide fueled liquid metal reactor. This data was used in subsequent safety calculations.

The peak two-sigma cladding midwall temperature for the oxide core is 1230° F; the corresponding value for the metal core is 1246° F. While the hot channel factors are slightly greater for the oxide core, a greater power shift in the metal core assemblies dominates and is responsible for the larger peak two-sigma cladding midwall temperature in the metal core. The greater power shift in the metal core is caused by the higher internal conversion ratio; more Pu is bred in the internal blankets. The higher internal conversion ratio is a consequence of the harder spectrum and the higher U-238 concentration in the metal blanket pins.

FIGURE 1. CORE LAYOUT FOR 3500 MWth OXIDE CORE

FIGURE 2. CORE LAYOUT FOR 3500 MWth METAL CORE

HETEROGENEOUS OXIDE CORE 3500 MWTH - HEATING, BOEC

HETEROGENEOUS OXIDE CORE 3500 MWTH - HEATING, EOC

Average Power Density by Assembly, kw/liter

FIGURE 4
AVERAGE POWER DENSITY BY ASSEMBLY AT EOEC FOR 3500 MWth OXIDE CORE

HETEROGENEOUS OXIDE CORE 3500 MWth - HEATING, BOEC

Peak Power Density by Assembly, kw/liter

FIGURE 5

PEAK POWER DENSITY BY ASSEMBLY AT BOEC FOR 3500 MWth OXIDE CORE

HETEROGENEOUS OXIDE CORE 3500 MWTH - HEATING, EOEC

*C1 for oxide core, B1 for metal core.

FIGURE 7
REGION MAP FOR OXIDE CORE FOR USE WITH AVERAGE POWER DENSITY
AND PEAK POWER DENSITY FIGURES

Label Assembly Type

D Driver
 IB Internal Blanket
 RB Radial Blanket
 S Radial Shield
 CR Control Rod

FIGURE 8
LATTICE POSITIONS AND ASSEMBLY TYPES FOR 3500 MWth OXIDE CORE

<u>Label</u>	<u>Assembly Type</u>
--------------	----------------------

D	Driver
IB	Internal Blanket
RB	Radial Blanket
S	Radial Shield
CR	Control Rod

FIGURE 9
POWER BY ASSEMBLY AT STAGE FACTOR ADJUSTED BOEC
FOR 3500 MWth OXIDE CORE

Label Assembly Type

D Driver
 IB Internal Blanket
 RB Radial Blanket
 S Radial Shield
 CR Control Rod

FIGURE 10
POWER BY ASSEMBLY AT STAGE FACTOR ADJUSTED EOEC
FOR 3500 MWth OXIDE CORE

FIGURE 11
PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE BY ASSEMBLY
AT STAGE FACTOR ADJUSTED BOEC FOR 3500 MWth OXIDE CORE

FIGURE 12
PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE BY ASSEMBLY
AT STAGE FACTOR ADJUSTED EOC FOR 3500 MWth OXIDE CORE

HETEROGENEOUS METAL CORE 3500 MWTH - HEATING

Average Power Density by Assembly, kw/liter

FIGURE 13

AVERAGE POWER DENSITY BY ASSEMBLY AT BOEC FOR 3500 MWth METAL CORE

HETEROGENEOUS METAL CORE 3500 MWTH - HEATING

Average Power Density by Assembly, kw/liter

FIGURE 14

AVERAGE POWER DENSITY BY ASSEMBLY AT EOC FOR 3500 MWth METAL CORE

HETEROGENEOUS METAL CORE 3500 MWth - HEATING

Peak Power Density by Assembly, kw/liter

FIGURE 15

PEAK POWER DENSITY BY ASSEMBLY AT BOEC FOR 3500 MWth METAL CORE

HETEROGENEOUS METAL CORE 3500 MWth - HEATING

Peak Power Density by Assembly, kw/liter

FIGURE 16

PEAK POWER DENSITY BY ASSEMBLY AT EOEC FOR 3500 MWth METAL CORE

FIGURE 17
REGION MAP FOR METAL CORE FOR USE WITH AVERAGE POWER DENSITY
AND PEAK POWER DENSITY FIGURES

Label Assembly Type

D Driver
 IB Internal Blanket
 RB Radial Blanket
 S Radial Shield
 CR Control Rod

FIGURE 18
LATTICE POSITIONS AND ASSEMBLY TYPES FOR 3500 MWth METAL CORE

Label Assembly Type

D Driver
 IB Internal Blanket
 RB Radial Blanket
 S Radial Shield
 CR Control Rod

FIGURE 19
POWER BY ASSEMBLY AT STAGE FACTOR ADJUSTED BOEC
FOR 3500 MWth METAL CORE

<u>Label</u>	<u>Assembly Type</u>
D	Driver
IB	Internal Blanket
RB	Radial Blanket
S	Radial Shield
CR	Control Rod

FIGURE 20
POWER BY ASSEMBLY AT STAGE FACTOR ADJUSTED EOEC
FOR 3500 MWth METAL CORE

FIGURE 21
PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE BY ASSEMBLY
AT STAGE FACTOR ADJUSTED BOEC FOR 3500 MWth METAL CORE

FIGURE 22
PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE BY ASSEMBLY
AT STAGE FACTOR ADJUSTED EOC FOR 3500 MWth METAL CORE

TABLE I
GLOBAL DESIGN SPECIFICATION
FOR 3500 MWth OXIDE AND METAL CORES

REACTOR POWER, MWth	3500
CORE CONCEPT	Heterogeneous
CYCLE LENGTH, days	365
CAPACITY FACTOR	80%
REACTOR INLET TEMPERATURE, °F	675
REACTOR OUTLET TEMPERATURE, °F	950
REACTOR FLOWRATE, lb/hr	1.43×10^6

TABLE II
FUEL PIN AND ASSEMBLY DESIGN SPECIFICATIONS
FOR 3500 MWth OXIDE CORE

	DRIVER	BLANKET ^a
FUEL MATERIAL	UO ₂ PuO ₂	UO ₂
CLADDING AND DUCT MATERIAL	HT-9	HT-9
NUMBER OF PINS PER ASSEMBLY	271	169
FUEL PIN DIAMETER, in.	0.285	0.392
CLADDING THICKNESS, in.	0.022	0.022
PITCH/DIAMETER RATIO	1.18	1.087
FUEL SMEAR DENSITY, % T.D.	82.5	93.3
ACTIVE LENGTH, in.	40	68
AXIAL BLANKET THICKNESS, in.	14 ^b	0
DUCT OUTSIDE FLAT-TO-FLAT, in.	5.931	5.931
DUCT WALL THICKNESS, in.	0.15	0.15
INTERASSEMBLY GAP, in.	0.200	0.200
ASSEMBLY LATTICE PITCH, in.	6.131	6.131

^aInternal and radial blanket.

^bUpper and lower blankets.

TABLE III
FUEL PIN AND ASSEMBLY DESIGN SPECIFICATIONS
FOR 3500 MWth METAL CORE

	DRIVER	BLANKET ^a
FUEL MATERIAL	UPu10Zr	U10Zr
CLADDING AND DUCT MATERIAL	HT-9	HT-9
NUMBER OF PINS PER ASSEMBLY	271	169
FUEL PIN DIAMETER, in.	0.285	0.392
CLADDING THICKNESS, in.	0.022	0.022
PITCH/DIAMETER RATIO	1.18	1.087
FUEL SMEAR DENSITY, % T.D.	75	85
ACTIVE LENGTH, in.	36	36
AXIAL BLANKET THICKNESS, in.	0	0
DUCT OUTSIDE FLAT-TO-FLAT, in.	5.931	5.931
DUCT WALL THICKNESS, in.	0.15	0.15
INTERASSEMBLY GAP, in.	0.200	0.200
ASSEMBLY LATTICE PITCH, in.	6.131	6.131

^aInternal and radial blanket.

TABLE IV
REGIONAL HEATING RATES FOR 3500 MWth OXIDE CORE

REGION	<u>BOEC</u>		
	$\gamma + n^a$	γ^b	$\% \gamma / \gamma + n$
IB	7.127 + 7	1.466 + 7	20.6
CORE	4.816 + 8	4.586 + 7	9.52
RB	1.782 + 7	3.526 + 6	19.8
SS RR	6.382 + 5	5.820 + 5	91.2
B ₄ C RS	8.326 + 5	1.657 + 5	19.9
PCR	9.367 + 5	5.605 + 5	59.8
SCR	4.166 + 5	2.824 + 5	67.8

REGION	<u>EOEC</u>		
	$\gamma + n$	γ	$\% \gamma / \gamma + n$
IB	1.035 + 8	1.697 + 7	16.4
CORE	4.410 + 8	4.260 + 7	9.66
RB	1.902 + 7	3.516 + 6	18.5
SS RR	5.963 + 5	5.430 + 5	91.1
B ₄ C RS	7.732 + 5	1.535 + 5	19.9
PCR	7.680 + 5	5.032 + 5	65.5
SCR	4.261 + 5	2.847 + 5	66.8

^a $\gamma + n$ denotes total heating (power) in watts.

^b γ denotes gamma heating in watts.

TABLE V
REGIONAL HEATING RATES FOR 3500 MWth METAL CORE

REGION	<u>BOEC</u>		
	$\gamma + n^a$	γ^b	$\% \gamma / \gamma + n$
IB	7.361 + 7	1.349 + 7	18.3
CORE	4.859 + 8	4.646 + 7	9.56
RB	1.878 + 7	3.347 + 6	17.8
SS RR	7.654 + 5	6.785 + 5	88.6
B ₄ C RS	1.245 + 6	2.367 + 5	19.0
PCR	1.020 + 6	5.062 + 5	49.6
SCR	4.862 + 5	2.565 + 5	52.8

REGION	<u>EOEC</u>		
	$\gamma + n$	γ	$\% \gamma / \gamma + n$
IB	1.081 + 8	1.600 + 7	14.8
CORE	4.495 + 8	4.338 + 7	9.65
RB	1.976 + 7	3.162 + 7	16.0
SS RR	6.941 + 5	6.148 + 5	88.6
B ₄ C RS	1.118 + 6	2.124 + 5	19.0
PCR	1.101 + 6	5.114 + 5	46.5
SCR	4.931 + 5	2.592 + 5	52.6

^a $\gamma + n$ denotes total heating (power) in watts.

^b γ denotes gamma heating in watts.

TABLE VI

CLADDING MIDWALL HOT SPOT SUBFACTORS
FOR OXIDE DRIVER ASSEMBLY FROM CRBR AT BOL

SUBFACTORS	COOLANT	FILM	CLADDING
<u>DIRECT</u>			
Inlet flow maldistribution	1.02		
Flow distribution calculational uncertainty	1.03	1.006	
Cladding circumferential temperature variation		2.1	0.9
Fuel to cladding eccentricity		1.14	1.14
Physics modeling	1.02	1.10	1.10
Control rod banking	1.02	1.02	1.02
<u>STATISTICAL (3σ)</u>			
Reactor delta T and inlet temperature variation	1.146		
Inlet flow maldistribution	1.059	1.016	
Loop temperature imbalance	1.027		
Wire wrap orientation	1.01		
Subchannel flow area	1.019		
Film heat transfer coefficient		1.12	
Fuel to cladding eccentricity		1.174	1.174
Coolant properties	1.017		
Flow distribution calculational uncertainty	1.058	1.005	
Experimental	1.07	1.07	1.07
Criticality	1.01	1.01	1.01
Fissile fuel distribution	1.052	1.052	1.052
Hot channel factors (2 σ)	1.23	3.12	1.30

TABLE VII

CLADDING MIDWALL HOT SPOT SUBFACTORS
FOR OXIDE BLANKET ASSEMBLY FROM CRBR AT EOL

SUBFACTORS	COOLANT	FILM	CLADDING
<u>DIRECT</u>			
Inlet flow maldistribution	1.02		
Flow distribution calculational uncertainty	1.03	1.008	
Cladding circumferential temperature variation		3.8	0.8
Fuel to cladding eccentricity		1.14	1.14
Physics modeling	1.02	1.12	1.12
Control rod banking	1.02	1.02	1.02
Experimental (nuclear)	1.03	1.07	1.07
Criticality	1.01	1.01	1.01
Heavy metal	1.01	1.01	1.01
U-235	1.01	1.01	1.01
<u>STATISTICAL (3σ)</u>			
Reactor delta T and inlet temperture variation	1.146		
Inlet flow maldistribution	1.059	1.018	
Loop temperature imbalance	1.027		
Wire wrap orientation	1.01		
Film heat transfer coefficient		1.21	
Fuel to cladding eccentricity		1.0	1.0
Coolant properties	1.017		
Flow distribution calculational uncertainty	1.203	1.006	
Hot channel factors (2σ)	1.36	6.27	1.15

TABLE VIII
CLADDING MIDWALL HOT SPOT SUBFACTORS
FOR METAL DRIVER ASSEMBLY FROM CRBR AT BOL

SUBFACTORS	COOLANT	FILM	CLADDING
DIRECT			
Inlet flow maldistribution	1.02		
Flow distribution calculational uncertainty	1.03	1.006	
Cladding circumferential temperature variation		2.1	0.9
Fuel to cladding eccentricity		1.14 (1.01) ^a	1.14 (1.01) ^a
Physics modeling	1.02	1.10	1.10
Control rod banking	1.02	1.02	1.02
STATISTICAL (3σ)			
Reactor delta T and inlet temperature variation	1.146		
Inlet flow maldistribution	1.059	1.016	
Loop temperature imbalance	1.027		
Wire wrap orientation	1.01		
Subchannel flow area	1.019		
Film heat transfer coefficient		1.12	
Fuel to cladding eccentricity		1.174 (1.01) ^a	1.174 (1.01) ^a
Coolant properties	1.017		
Flow distribution calculational uncertainty	1.058	1.005	
Experimental	1.07	1.07	1.07
Criticality	1.01	1.01	1.01
Fissile fuel distribution	1.052 (1.1) ^a	1.052 (1.1) ^a	1.052 (1.1) ^a
Hot channel factors ^b (2σ)	1.24	2.67	1.10

^aValues in parentheses are suggested for metal fuel.

^bBased on values in parentheses.

**TABLE IX
CLADDING MIDWALL HOT SPOT SUBFACTORS
FOR METAL BLANKET ASSEMBLY FROM CRBR AT EOL**

SUBFACTORS	COOLANT	FILM	CLADDING
<u>DIRECT</u>			
Inlet flow maldistribution	1.02		
Flow distribution calculational uncertainty	1.03	1.008	
Cladding circumferential temperature variation		3.8	0.8
Fuel to cladding eccentricity		1.14 (1.01) ^a	1.14 (1.01) ^a
Physics modeling	1.02	1.12	1.12
Control rod banking	1.02	1.02	1.02
Experimental (nuclear)	1.03	1.07	1.07
Criticality	1.01	1.01	1.01
Heavy metal	1.01	1.01	1.01
U-235	1.01	1.01	1.01
<u>STATISTICAL (3σ)</u>			
Reactor delta T and inlet temperature variation	1.146		
Inlet flow maldistribution	1.059	1.018	
Loop temperature imbalance	1.027		
Wire wrap orientation	1.01		
Film heat transfer coefficient		1.21	
Fuel to cladding eccentricity		1.0 (1.01) ^a	1.0 (1.01) ^a
Coolant properties	1.017		
Flow distribution calculational uncertainty	1.203	1.006	
Hot channel factors ^b (2σ)	1.36	5.56	1.02

^aValues in parentheses are suggested for metal fuel.

^bBased on values in parentheses.

TABLE X
STAGE FACTORS FOR 3530 MWth OXIDE CORE

REGION	BOEC	EOEC
C1	1.08789	1.07847
C2	1.09278	1.08200
C3	1.09472	1.08345
C4	1.09345	1.08242
C5	1.08933	1.07903
C6	1.08983	1.07970
C7	1.08587	1.07662
C8	1.08094	1.06733
C9	1.07085	1.06496
C10	1.05680	1.05294
B1	1.47566	1.24691
B2	1.47187	1.22688
B3	1.46147	1.22709
B4	1.44467	1.22619
B5	1.42070	1.22017
B6	1.39412	1.22224
R	1.46735	1.33681

TABLE XI
ORIFICE ZONE ASSIGNMENTS FOR 3500 MWth OXIDE CORE

ORIFICE ZONE	ASSEMBLY TYPE	ASSEMBLY LATTICE POSITION	TOTAL NUMBER OF ASSEMBLIES IN REACTOR
1	Driver	5, 7, 13, 14, 15, 18, 19	66
2	Driver	6, 8, 9, 20, 21, 27, 30 31, 32, 35	102
3	Driver	26, 37, 39, 42	42
4	Driver	28, 40, 44, 45, 48	60
5	Driver	43, 47, 52, 53, 54, 56	66
6	Driver	51, 60, 61, 62, 63, 64	66
7	Internal Blanket	11, 12, 16, 17, 23, 24	60
8	Internal Blanket	3, 4, 22, 33, 34, 36, 38 41, 55	90
9	Internal Blanket	2, 50, 59	24
10	Internal Blanket	1, 58, 68, 69, 70, 71, 72	73
11	Radial Shield	57, 65, 66, 67, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106	420
12	Control Rod	10, 25, 26, 46, 49	36

TABLE XII
ORIFICE ZONE FLOWRATES FOR 3500 MWth OXIDE CORE

ORIFICE ZONE	ASSEMBLY TYPE	ASSEMBLY FLOWRATE (10⁵ lb/hr)	TOTAL FLOWRATE PER ZONE (10⁵ lb/hr)
1	Driver	2.875	189.8
2	Driver	2.730	278.4
3	Driver	2.637	110.7
4	Driver	2.545	152.7
5	Driver	2.439	160.9
6	Driver	1.986	131.1
7	Internal Blanket	1.961	117.7
8	Internal Blanket	1.752	157.7
9	Internal/Radial Blanket	0.954	22.9
10	Internal/Radial Blanket	0.790	57.6
11	Reflector	4.670-2	19.6
12	Control	1.938-1	7.0
13	Cold Bypass		<u>20.0</u>
REACTOR TOTAL			1426.0

TABLE XIII
STAGE FACTOR ADJUSTED PEAK TEMPERATURES
BY ORIFICE ZONE FOR 3500 MWth OXIDE CORE

ORIFICE ZONE	ASSEMBLY TYPE	TEMPERATURES (°F)		ASSEMBLY	
		NOMINAL	TWO-SIGMA	LATTICE ^a POSITION	POWER ^b (MWt)
<u>PEAK CLADDING MIDWALL</u>					
1	Driver	1110	1227	14	9.36
2	Driver	1112	1227	32	8.99
3	Driver	1111	1227	37	8.65
4	Driver	1111	1226	28	8.45
5	Driver	1112	1227	47	8.03
6	Driver	1116	1230	51	5.92
7	Internal Blanket	1062	1227	11	5.75
8	Internal Blanket	1064	1227	22	5.22
9	Internal/Radial Blanket	1077	1228	2	2.79
10	Internal/Radial Blanket	1082	1228	1	2.43
<u>PEAK MIXED MEAN OUTLET</u>					
11	Reflector	816	-	67	0.05
12	Control	874	-	26	0.25

^aSee Figure 8.

^bStage factor has been incorporated.

TABLE XIV

**THERMAL HYDRAULIC PARAMETERS FOR PEAK DRIVER ASSEMBLY^a
FOR 3500 MWth OXIDE CORE**

	BOL
<u>ASSEMBLY GLOBAL PARAMETERS</u>	
Power, Stage Factor Adjusted (MWt)	9.06
Stage Factor (BOL/Batch Average BOEC)	1.09
Flow rate (lbm/hr)	272,978
Inlet Temperature (°F)	675
<u>ASSEMBLY OUTLET PARAMETERS</u>	
Mixed Mean Average Temperature (°F)	1046
Ratio of Peak Subchannel Coolant ΔT to Mixed Mean Average ΔT	1.13
Peak Subchannel Coolant	1096
<u>PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE LOCATION PARAMETERS</u>	
Height, Fraction of Active Fuel Length	0.97
Subchannel Coolant (°F)	1087
Cladding Surface Temperature (°F)	1098
Cladding Midwall Temperature (°F)	1114
Two-Sigma Subchannel Coolant (°F)	1181
Two-Sigma Cladding Surface Temperature (°F)	1211
Two-Sigma Cladding Midwall Temperature (°F)	1230

^aAssembly 31 is the peak driver assembly.

TABLE XV
STAGE FACTORS FOR 3500 MWth METAL CORE

REGION	BOEC	EOEC
C1	1.05507	1.05051
C2	1.06324	1.05722
C3	1.07506	1.06698
C4	1.07657	1.06811
C5	1.07529	1.06699
C6	1.07535	1.06721
C7	1.07152	1.06418
C8	1.06719	1.06092
C9	1.05862	1.05391
C10	1.04742	1.04428
B1	1.41591	1.23829
B2	1.43620	1.22497
B3	1.43592	1.21875
B4	1.41994	1.21687
B5	1.39403	1.21064
B6	1.36872	1.21210
R	1.44488	1.32667

TABLE XVI
ORIFICE ZONE ASSIGNMENTS FOR 3500 MWth METAL CORE

ORIFICE ZONE	ASSEMBLY TYPE	ASSEMBLY LATTICE POSITION	TOTAL NUMBER OF ASSEMBLIES IN REACTOR
1	Driver	14, 18, 19, 21, 27, 31, 32	72
2	Driver	13, 15, 29, 30, 35	54
3	Driver	20, 37, 39, 42	42
4	Driver	28, 40, 44, 45, 47, 48	72
5	Driver	6, 7, 8, 9, 43, 52, 53 54, 56	90
6	Driver	51, 60, 61, 62, 63, 64	66
7	Internal Blanket	11, 16, 17, 22, 23, 24, 36	66
8	Internal Blanket	5, 12, 33, 34, 38, 41, 55	78
9	Internal Blanket	3, 4, 50, 59	30
10	Internal Blanket	1, 2, 58, 68, 69, 70, 71, 72	79
11	Radial Shield	57, 65, 66, 67, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106	420
12	Control Rod	10, 25, 26, 46, 49	36

TABLE XVII
ORIFICE ZONE FLOWRATES FOR 3500 MWth METAL CORE

ORIFICE ZONE	ASSEMBLY TYPE	ASSEMBLY FLOWRATE (10⁵ lb/hr)	TOTAL FLOWRATE PER ZONE (10⁵ lb/hr)
1	Driver	2.794	201.2
2	Driver	2.758	148.9
3	Driver	2.659	111.7
4	Driver	2.616	188.4
5	Driver	2.467	222.0
6	Driver	2.025	133.6
7	Internal Blanket	2.038	134.5
8	Internal Blanket	1.810	141.2
9	Internal/Radial Blanket	1.154	34.6
10	Internal/Radial Blanket	0.793	62.6
11	Reflector	4.782-2	20.1
12	Control	2.036-1	7.3
13	Cold Bypass		<u>20.0</u>
		REACTOR TOTAL	1426.0

TABLE XVIII

**STAGE FACTOR ADJUSTED PEAK TEMPERATURES BY ORIFICE ZONE
FOR 3500 MWth METAL CORE**

ORIFICE ZONE	ASSEMBLY TYPE	TEMPERATURES (°F)		ASSEMBLY	
		NOMINAL	TWO-SIGMA	LATTICE ^a POSITION	POWER ^b (MWt)
<u>PEAK CLADDING MIDWALL</u>					
1	Driver	1123	1246	32	9.23
2	Driver	1121	1244	30	9.06
3	Driver	1123	1245	39	8.82
4	Driver	1122	1244	28	8.72
5	Driver	1122	1245	7	8.17
6	Driver	1123	1243	51	6.01
7	Internal Blanket	1074	1244	17	5.79
8	Internal Blanket	1078	1246	34	5.18
9	Internal/Radial Blanket	1081	1244	3	3.17
10	Internal/Radial Blanket	1084	1244	2	2.29
<u>PEAK MIXED MEAN OUTLET</u>					
11	Reflector	845	-	57	0.06
12	Control	879	-	28	0.28

^aSee Figure 18.

^bStage factor has been incorporated.

TABLE XIX

**THERMAL HYDRAULIC PARAMETERS FOR PEAK DRIVER ASSEMBLY
FOR 3500 MWth METAL CORE**

	BOL
<u>ASSEMBLY GLOBAL PARAMETERS</u>	
Power, Stage Factor Adjusted (MWt)	8.72
Stage Factor (BOL/Batch Average BOEC)	1.075
Flow rate (lbm/hr)	261,604
Inlet Temperature (°F)	675
<u>ASSEMBLY OUTLET PARAMETERS</u>	
Mixed Mean Average Temperature (°F)	1047
Ratio of Peak Subchannel Coolant ΔT to Mixed Mean Average ΔT	1.13
Peak Subchannel Coolant	1097
<u>PEAK TWO-SIGMA CLADDING MIDWALL TEMPERATURE LOCATION PARAMETERS</u>	
Height, Fraction of Active Fuel Length	0.97
Subchannel Coolant (°F)	1087
Cladding Surface Temperature (°F)	1101
Cladding Midwall Temperature (°F)	1122
Two-Sigma Subchannel Coolant (°F)	1186
Two-Sigma Cladding Surface Temperature (°F)	1222
Two-Sigma Cladding Midwall Temperature (°F)	1244

^aAssembly 28 is the peak driver assembly.

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