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EVALUATION OF INTEGRALLY FINNED CLADDING FOR LMFBR FUEL PINS

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INTRODUCTION

Fuel pin and subassembly designs which allow improved performance in terms of either component lifetimes or fuel doubling time are desirable to help meet the long range objectives of the LMFBR program.

One potential design improvement recently evaluated by HEDL is that of an integrally finned fuel pin cladding design. The major emphasis on this design, up till now, has come from Germany where results indicate the integral fin design to be a promising spacer concept. As conceived, the integral fins would serve the same purpose as the current wire wrap spacer with the potential for improved fuel pin performance through reduced maximum cladding temperatures. The analysis conducted by HEDL was aimed at quantifying this improved performance capability and addresses three areas:

1. Subassembly thermal/hydraulics.
2. Fuel pin structural performance.
3. Subassembly duct performance.

THERMAL/HYDRAULIC ANALYSIS

Thermal/hydraulic calculations were performed using the computer program COBRA-IIIC and consisted of comparing the pressure drop, peak coolant temperature, and coolant temperature adjacent to the duct wall for the integral fin design and a comparative wire wrap design. Calculations were made for 19, 61, and 217 pin subassemblies. The fin width, number of fins, and fin pitch were evaluated as design variables. Fin height for each case was sized such that the across-flats bundle dimensions matched the design envelope for the comparative wire wrap bundle. Only fin-on-fin designs were evaluated. Fin-on-pin designs were considered to have no performance benefit relative to the reference wire wrap design.

<u>Slide 1</u>: Results of the analysis for the 19 pin subassembly are shown on the screen. ~~As indicated,~~ Each design concept shown was evaluated under the constraints of constant subassembly power, coolant inlet temperature, and mixed mean coolant outlet temperature. The 19 pin subassembly was used to evaluate the effects of the number of fins per pin, the spacer pitch, and the mixing effects on temperature distribution and coolant pressure drop. Specifically, the results show the integral fin design effectively reduces the radial coolant temperature gradient by reducing the maximum coolant temperature and increasing the mid-flat coolant temperature. Varying the number of fins was found to have little effect except on pressure drop. A 2 fin design was found to have a slightly lower pressure drop than a comparative wire wrap design. Varying the spacer axial pitch over the range from 6 to 24 inches was found to have virtually no effect on either pressure drop or temperature distribution.

Spacer-induced cross-flow mixing was found to have a pronounced effect on calculated pressure drop but negligible effect on the temperature distribution. This latter effect indicates the temperature distribution is determined primarily by the flow distribution as dictated by the distribution of flow areas rather than by spacer-induced cross-flow mixing. This fact was used to eliminate consideration of spacer-induced cross-flow coolant mixing in the 61 and 217 pin subassemblies and expedite the analysis by reducing code running time.

Slide 2: Results of the analysis for the 61 pin subassembly are shown on the next slide. As can be seen, reducing the fin width had a negligible effect on temperature distribution but did reduce the pressure drop. Relative to the wire wrap design, the reduction in the coolant temperature gradient induced by the integral fin design was qualitatively the same as for the 19 pin S/A.

Slide 3: Results for the 217 pin subassembly, shown on the screen, yielded no surprises, with temperature distribution results being very similar to those for the 19 and 61 pin subassembly.

Slide 4: The next slide shows the effect of the integral fins on the temperature distribution as affected by the number of pins per subassembly for a nearly constant decrease in radial temperature gradient. As shown here, the decrease in maximum coolant temperature decreases with increasing number of pins per subassembly. The increase in the coolant temperature adjacent to the duct wall increases with increasing number of pins per subassembly. This effect is a consequence of the relative flow split between interior and exterior (i.e., edge and corner) flow channels as affected by the number of pins per subassembly and by the introduction of the fins.

FUEL PIN STRUCTURAL ANALYSIS

The next step of the analysis was to do a fuel pin structural analysis. This was performed under the direction of HEDL by the Control Data Corporation using the MARC finite element computer code. The objectives of the analysis were to identify the optimum fin geometry from the stress standpoint and to evaluate the potentially improved fuel pin performance from the strain standpoint consistent with the reduced peak cladding temperature indicated by the thermal/hydraulic results.

To achieve these objectives, the analysis was done in two steps:

1. Perform heat transfer and elastic analyses to identify the optimum configuration.
2. Perform inelastic analysis on the selected optimum design and compare with the standard cylindrical tube.

Slide 5: The integral fin cladding model selected for the analysis consisted of a thin cylindrical tube of constant wall thickness with six helical integral fins equally spaced in the circumferential direction, as shown on this slide. Because of symmetry, only one twelfth of the cross-section was modeled. The main parameters which were varied were fillet radius and fin width.

Slide 6: Specific geometries analyzed are summarized on the next slide. Case 1 was the base case, about which the elastic analyses were performed. Cases 2, 3, and 5 represent changes in fillet design; Case 4 is a change in cladding design.

Slide 7: The next slide shows the results of the elastic analyses for each geometry. As can be seen, stress concentration effects associated with the fin geometry are not significantly affected by variations in fin width or fillet radius. On this basis, Case 2 was selected for the inelastic analysis in order to minimize the temperature spike under the fin.

Slide 8: Results of the inelastic analysis are summarized on the next slide. Case 1 corresponds to conditions occurring at the top of an EBR-II fuel pin, while Case 2 corresponds to conditions at the mid-plane of an EBR-II fuel pin. As can be seen, both the effective stress and total creep strain of the cylindrical tube are less than that for the integral fin design. This indicates that the integral fin design has no definite structural advantage and does not offer improved fuel pin performance with respect to the current reference wire wrap design.

SUBASSEMBLY DUCT STRUCTURAL ANALYSIS

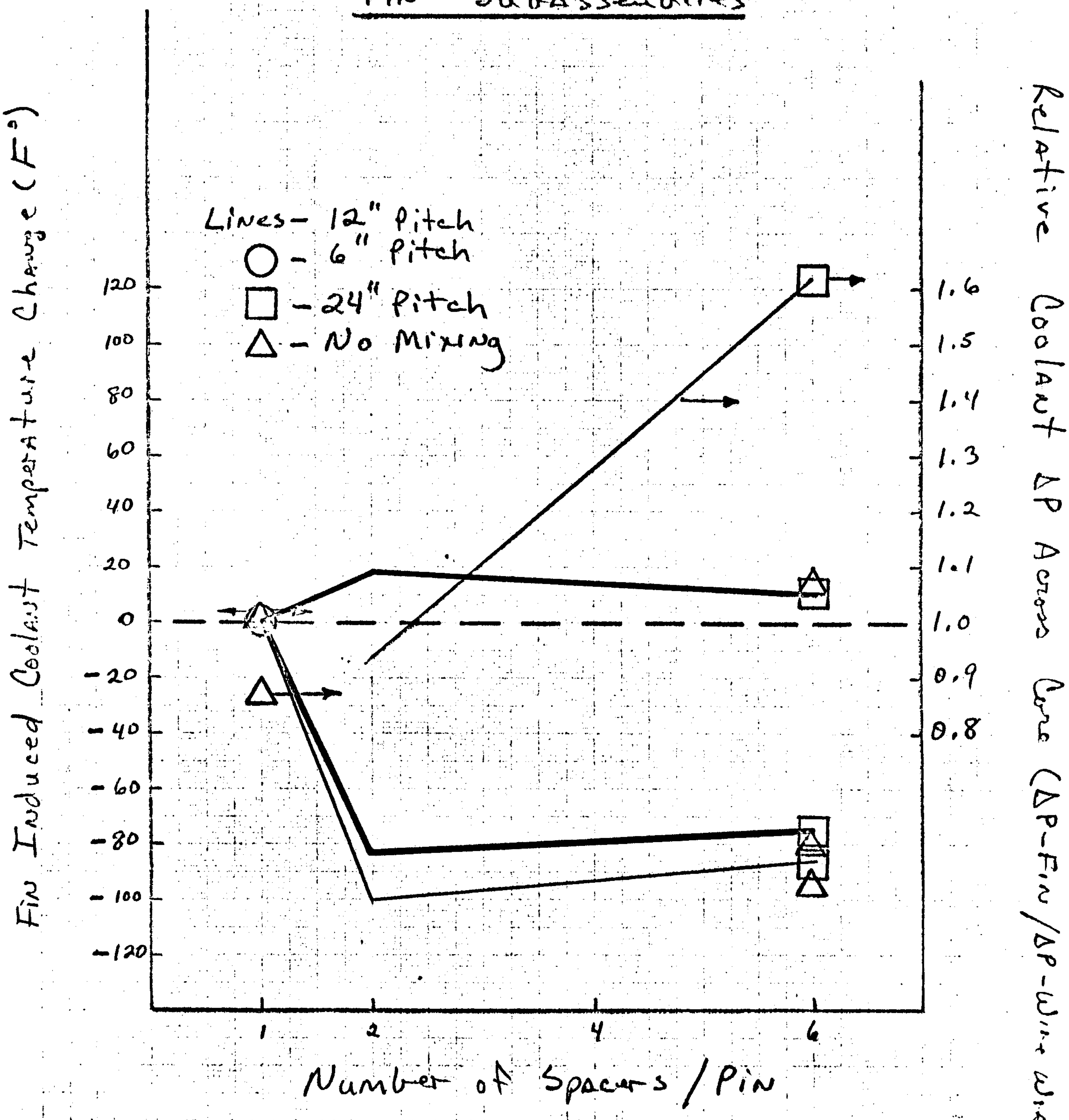
Associated with the decrease in fuel pin temperature due to the integrally finned cladding design is an increase in the duct wall temperature. This increase amounts to about 75°F for the 217 pin subassembly for the conditions analyzed. In order to evaluate the effect of this increased temperature, the computer code BEAMCRP was used to calculate the additional duct dilation.

Slide 9: Results of this analysis are summarized in the next slide. Assuming a duct lifetime criterion of duct-to-duct contact due to swelling and creep dilation, the integral fin fuel pin design would result in a $\sim$ 6000 hour reduction in design lifetime. It is noted, however, that these calculations were made using 20% CW 316 stainless steel properties. Materials with improved swelling and creep properties could substantially alter this result.

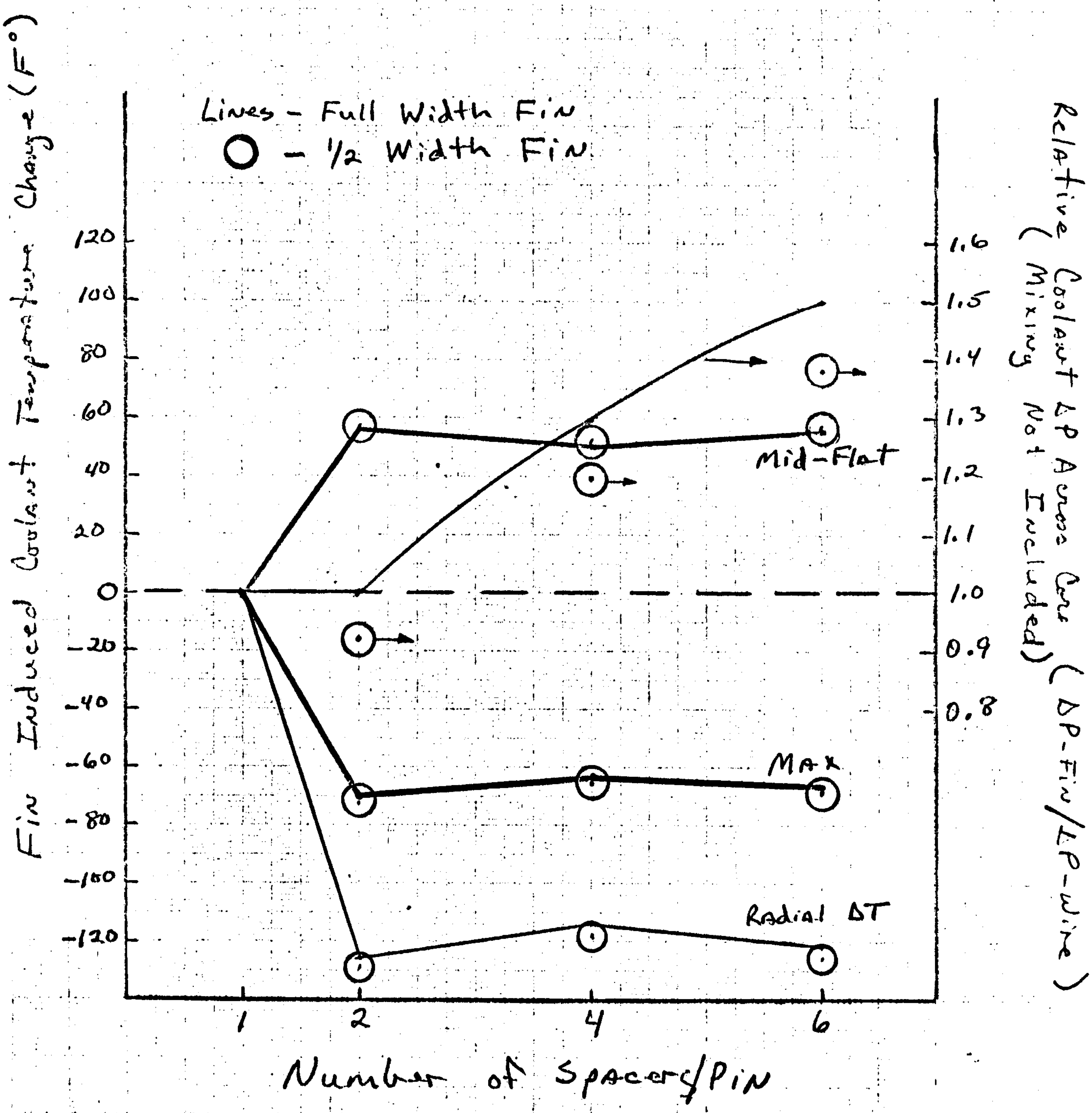
CONCLUSIONS AND SUMMARY

Slide 10: An integral fin design does effectively reduce the coolant temperature gradients within an LMFBR subassembly by redistributing coolant flow so as to reduce the maximum cladding temperature and increase the duct wall temperature. The reduced cladding temperatures are offset by strain concentrations resulting from the fin geometry, so there is little net effect on predicted fuel pin performance. The increased duct wall temperatures, however, significantly reduce the duct design lifetime so that the final conclusion is that the integral fin design is inferior to the standard wire wrap design. This result, however, is dependent upon the material correlations used. Advanced alloys with improved irradiation properties could alter this conclusion.

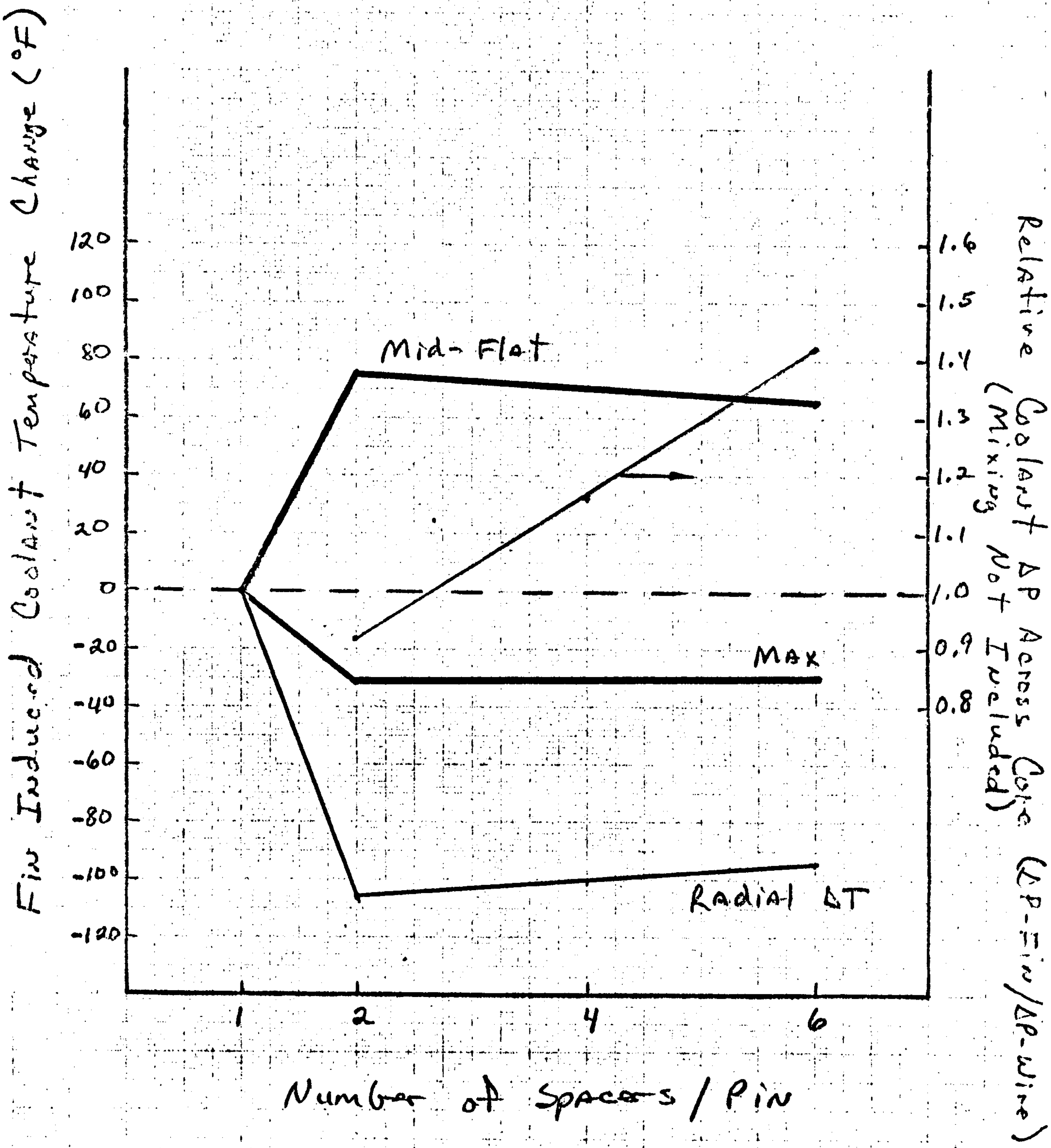
Thermal / Hydraulic Performance For 19 Pin Subassemblies



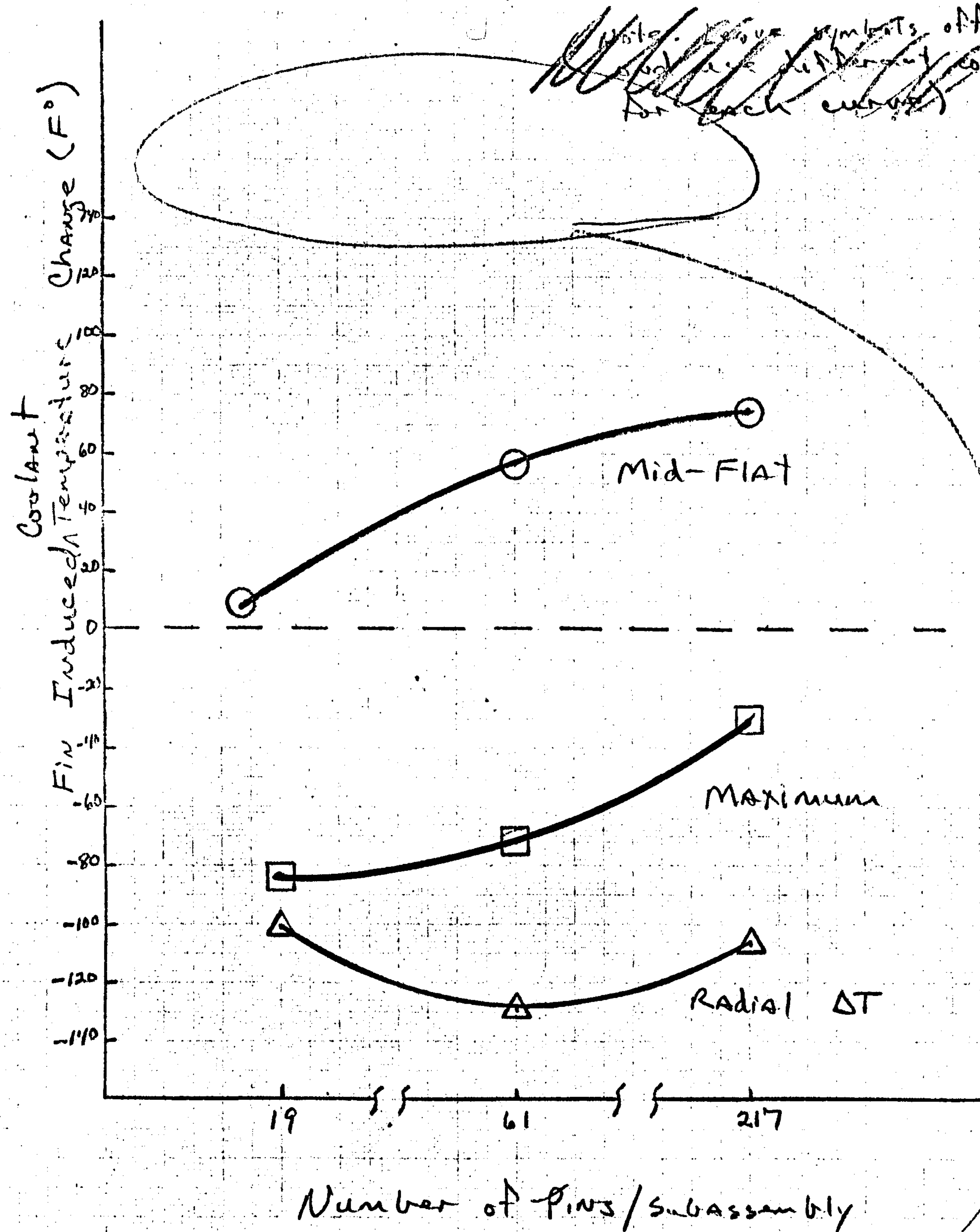
Thermal/Hydraulic Performance For 61 Pin Subassembly



Thermal/Hydraulic Performance For 217 Pin Subassembly



~~Note: leave symbols off or use a different color for each curve~~



Subassemby Size Effects

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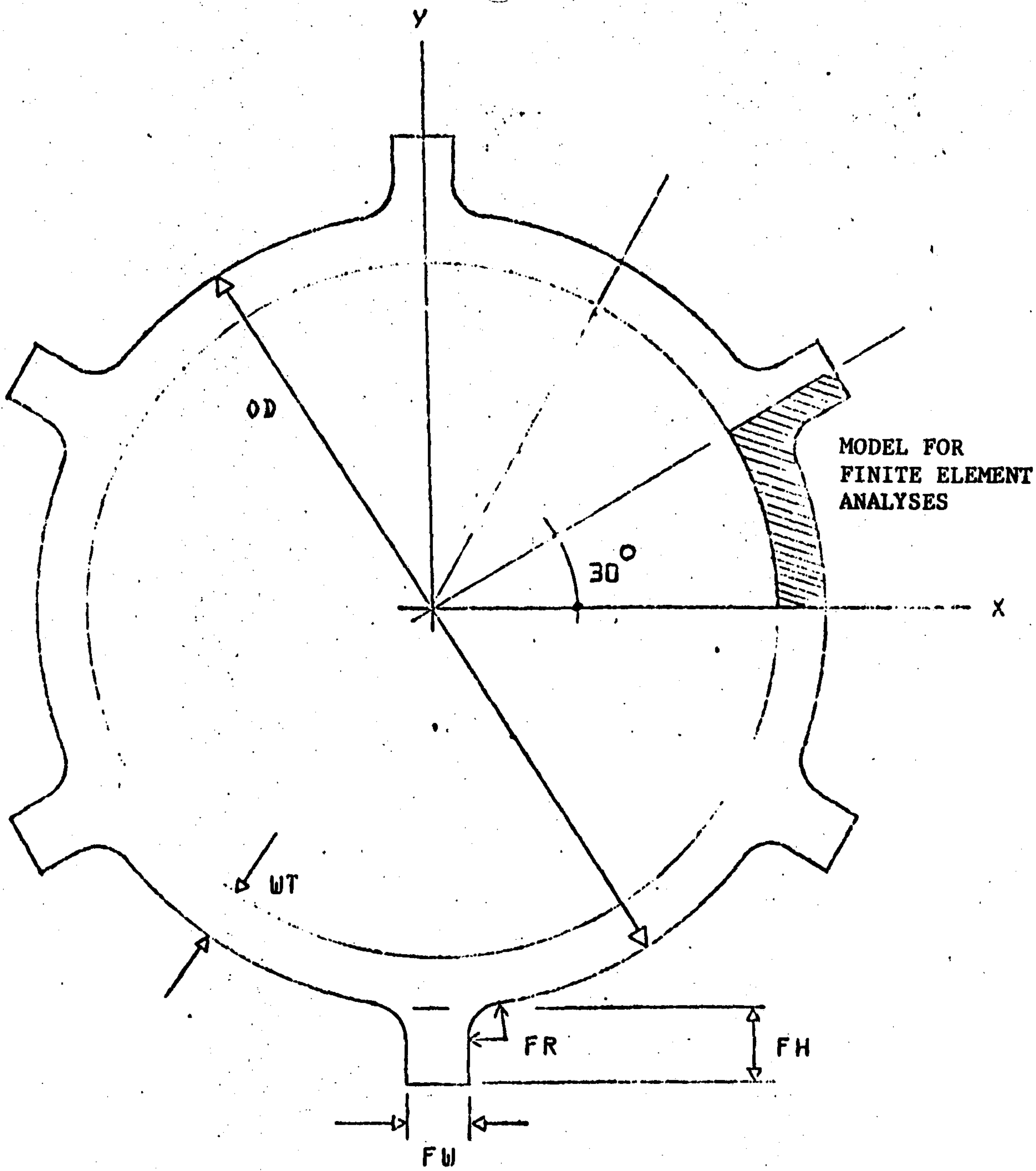

OD: OUTER DIAMETER
WT: WALL THICKNESS
FH: FIN HEIGHT
FW: FIN WIDTH
FR: FILLET RADIUS

[redacted]. Axially Finned Fuel Clad Cross Section.

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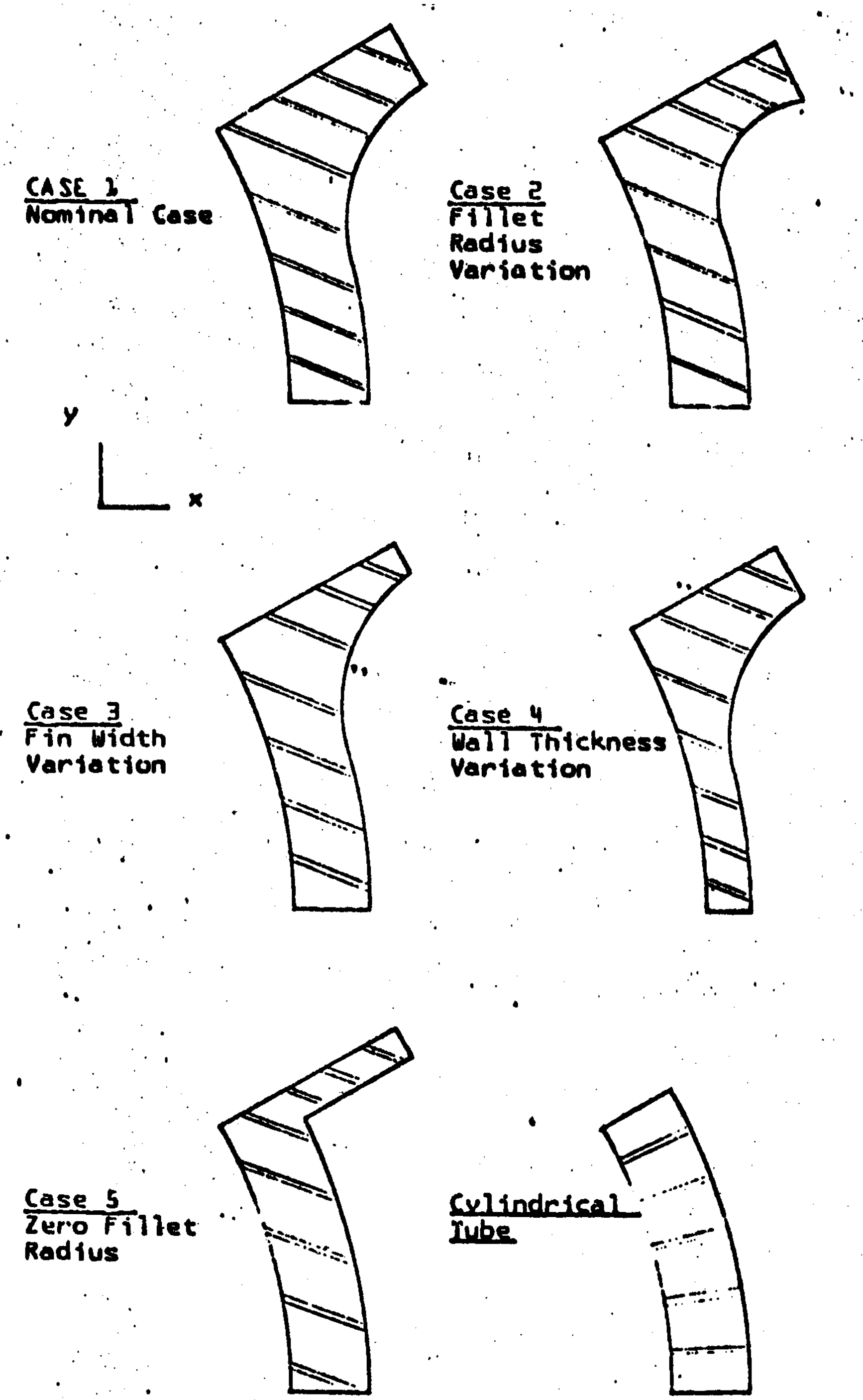


FIGURE 3. Geometric Configurations of Axially Finned Clad line Models and the Cylindrical Tube.

II

TABLE VIII MAXIMUM TEMPERATURES AND EFFECTIVE STRESSES OF AXIALLY FINNED MODELS

(CASE 1 THROUGH CASE 5)

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	NOMINAL CASE	FILLET RADIUS VARIATION	FIN WIDTH VARIATION	WALL THICKNESS VARIATION	ZERO FILLET RADIUS
(1) MAX. SURFACE NODAL TEMPERATURE (°F)	1141	1129	1130	1116	1106
(2) MAX. TEMPERATURE (°F) GRADIENT BETWEEN INNER AND OUTER SURFACE OF THE CLAD	136	128	127	110	96
(1) MAX. TEMPERATURE (°F) GRADIENT ALONG INNER SURFACE OF THE CLAD	33	23	24	44	0
(2) MAX. EFFECTIVE STRESS (THERMAL) - KSI	15.4	14.1	14.1	10.5	12.8
(3) MAX. EFFECTIVE STRESS (PRESSURE) - KSI	15.8	15.9	16.0	23.9	15.5

#7

8

[redacted] MAXIMUM EFFECTIVE STRESS AND MAXIMUM TOTAL CREEP STRAIN
(Cylindrical Tube and Tube Region of Case 2)

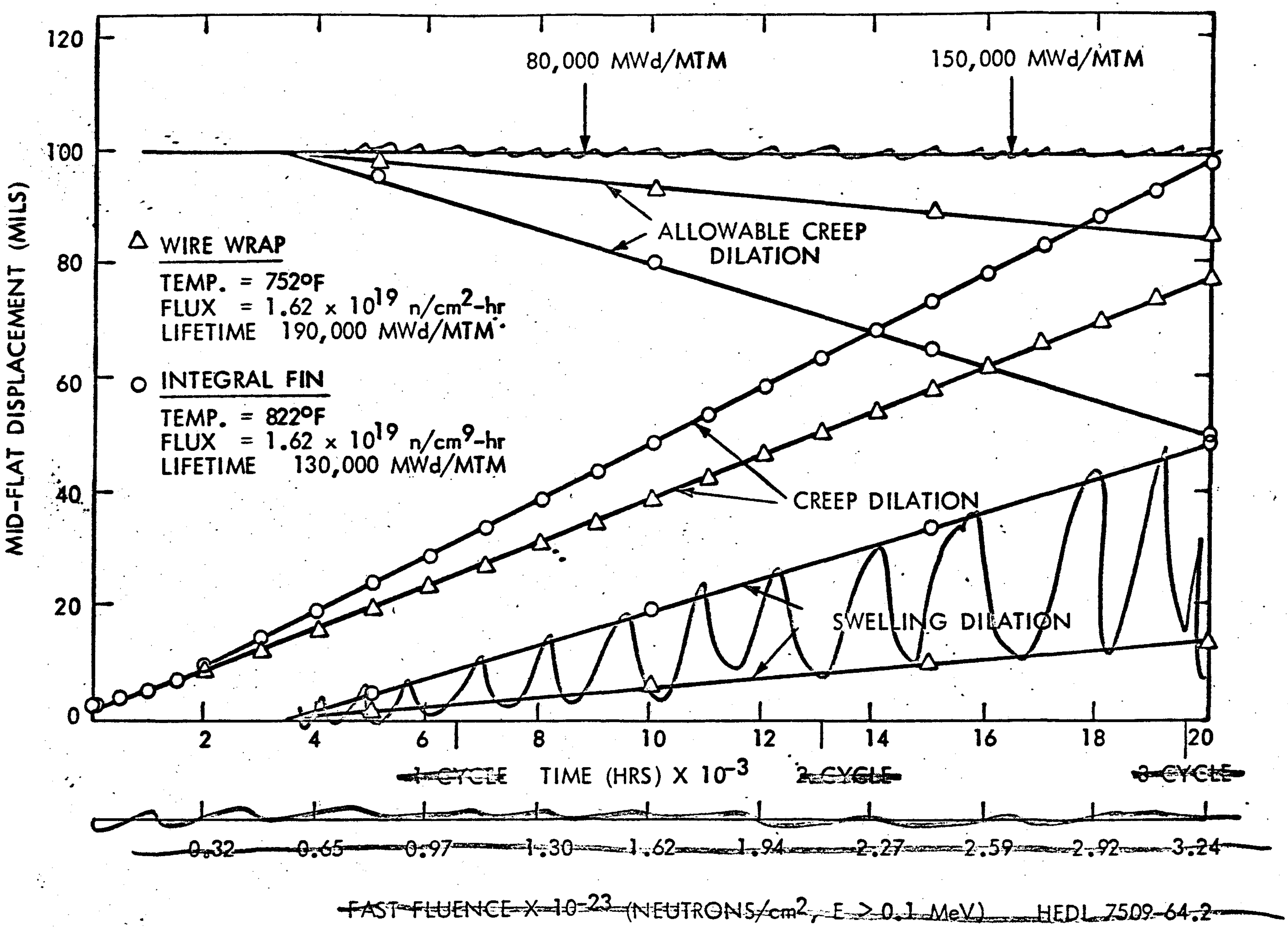
CREEP ANALYSIS COMPARISON		MAX. EFFECTIVE STRESS (KSI)	* MAX. TOTAL CREEP STRAIN (%)
1	TUBE 1	21+	0.42+
	2A	25+	0.46+
2	TUBE 2	17	0.57
	2B	20	0.70
3	2A	25	0.46
	2B	23	0.47
4	2C	20	0.70
	2D	20	0.70

\+ Max. Effective Stress and Max. Total Creep Strain Occurred at the Outer Element of the Cylindrical Tube

\+ Max. Effective Stress and Max. Total Creep Strain Occurred at the Outer Element of the Cylindrical Tube

++ Max. Effective Stress and Max. Total Creep Strain Occurred at the Outer Elements of the Tube Region

* Total Creep Strain = Irradiation Creep + Irradiation Swelling + Thermal Creep



120
100
80
60
40
20
0
MID-FLAT DISPLACEMENT (MILS)
80,000 MWd/MTM
150,000 MWd/MTM
ALLOWABLE CREEP DILATION
△ WIRE WRAP
TEMP. = 752°F
FLUX = 1.62 x 10^19 n/cm^2-hr
LIFETIME 190,000 MWd/MTM
○ INTEGRAL FIN
TEMP. = 822°F
FLUX = 1.62 x 10^19 n/cm^9-hr
LIFETIME 130,000 MWd/MTM
CREEP DILATION
SWELLING DILATION
2
4
6
8
10
12
14
16
18
20
1 CYCLE
TIME (HRS) X 10^-3
2 CYCLE
3 CYCLE
0.32
0.65
0.97
1.30
1.62
1.94
2.27
2.59
2.92
3.24
FAST FLUENCE X 10^-23 (NEUTRONS/cm^2, E > 0.1 MeV)
HEDL 7509-64.2

Conclusions

- Coolant temperature gradients significantly reduced
- No significant net effect on predicted fuel pin performance.
- significant reduction in duct design lifetime
- Integrally : finned cladding design is inferior.