ORNL/TM-5844

Heat Transfer Calculations for the High Flux Isotope Reactor (HFIR) Technical Specifications—Bases for Safety Limits and Limiting Safety System Settings

T. M. Sims
J. H. Swanks

MASTER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

ORNL/TM-5844

Contract No. W-7405-eng-26

Operations Division

HEAT TRANSFER CALCULATIONS FOR THE HIGH FLUX ISOTOPE REACTOR (HFIR) TECHNICAL SPECIFICATIONS - BASES FOR SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS

T. M. Sims
J. H. Swanks

Date Published - September 1977

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
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CONTENTS

	Page
INTRODUCTION	1
SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS FOR THE HFIR	1
BASES FOR SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS - HFIR	3
Mode 1 Operation	3
Pressure at Safety Limit (100% Flow)	3
Inlet Temperature at Safety Limit (100% Flow)	5
Flux (Power) to Flow at Safety Limit (100% Flow)	5
Low-Low Flow at Safety Limit	5
Pressure at Safety Limit	6
Inlet Temperature at Safety Limits (9.375% Flow)	7
Flux (Power) to Flow at Safety Limit (9.375% Flow)	7
Mode 2 Operation	8
Power Level at Safety Limit	8
Inlet Temperature at Safety Limit	8
Coolant Flow at Safety Limit	9
Mode 3 Operation	9
Power Level at Safety Limit	9
CALCULATIONS	10
Mode 3 Calculations	10
With Symmetric Control Rods	10
With Asymmetric Control Rods	10
Sample Calculation: Case No. 1, Table 3	11
Sample Calculation: Case No. 4, Table 3	15
Sensitivity of Burnout Power Level to Small Changes in Inlet Coolant Temperature and Pressure at 100% Flow - Mode 1 Operation	17
Sensitivity of Incipient Boiling Power Level to Small Changes in Coolant Flow and Inlet Coolant Temperature Near 10% Flow - Mode 2 Operation	17
REFERENCES	18
DISTRIBUTION	19

ABSTRACT

Heat transfer analyses, in support of the preparation of the HFIR technical specifications, were made to establish the bases for the safety limits and limiting safety system settings applicable to the HFIR. The results of these analyses, along with the detailed bases, are given herein.

INTRODUCTION

In the preparation of the Technical Specifications for the High Flux Isotope Reactor (HFIR), heat transfer calculations were made to establish the bases for the safety limits and limiting safety system settings. These calculations were necessitated by a criterion, imposed by the Energy Research and Development Administration (ERDA), concerning heat removal limitations in the operation of the HFIR. The imposed criterion, applicable to steady-state operation of the reactor is: With any given variable at its safety limit, all other variables at their limiting safety system setting, and all uncertainties in the technical knowledge of the process resolved unfavorably, no hot spot burnout can occur.

The analyses were made using a calculational method for burnout power level proposed by W. R. Gambill.[1,2] Input parameter values for these calculations were obtained from the output of appropriate calculations made using H. A. McLain's HFIR steady-state heat transfer code.[3] In order to ensure conservative results, numerous uncertainty factors were taken into account in the analyses (Reference 3, pages 18, 68, and 69). Application of these uncertainty factors guarantees that the calculated incipient boiling power levels and burnout power levels are truly minimum expected values. The pertinent results are summarized in the report and sample calculations are presented.

Values of the safety limits and limiting safety system settings applicable to the HFIR as set forth in the Technical Specifications are given for reference. Bases therefor are set forth in extensive detail herein.

SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS FOR THE HFIR

The three operating modes applicable to the HFIR are described in Reference 4 (page 1-3). The safety limits on the HFIR process variables applicable to each of the operating modes is given in Table 1 (Reference 4, page 2-1).

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Table 1. Safety Limits on Process Variables

Process Variable	Safety Limits Mode 1	Safety Limits Mode 2	Safety Limits Mode 3
Reset neutron flux (power) to flow ratio[a]	1.37 (@ 16,000 gpm) 2.40 (@ 1,500 gpm)	None	None
Neutron power	None	4 MW	175 kW
Inlet coolant temperature	140°F	140°F	None
Coolant pressure[b,c]	550 psig	None	None
Coolant flow[b]	1,350 gpm	1,350 gpm	None

[a]"Flux to flow" ratio is the ratio of percent nominal full power (100 MW) to percent nominal full flow (16,000 gpm).
[b]Minimum values.
[c]At the location of PS-128A, B, and C.

Limiting safety system settings applicable to the HFIR process variables are given in Table 2 (Reference 4, page 2-3).

Table 2. Limiting Safety System Settings for Process Variables

Process Variable	Limiting Safety System Settings Mode 1	Limiting Safety System Settings Mode 2	Limiting Safety System Settings Mode 3
Reset neutron flux (power) to flow ratio[a]	1.3 (all flow rates)	None	None
Neutron power	None	3.25 MW	130 kW
Inlet coolant temperature	135°F	135°F	None
Coolant pressure[b,c]	575 psig	None	None
Coolant flow[b]	1,500 gpm	1,500 gpm	None
Rate of rise of power	20 MW/sec	None	None
Main pump cutoff	315 psig	N/A	N/A

[a]"Flux to flow" ratio is the ratio of percent nominal full power (100 MW) to percent nominal full flow (16,000 gpm).
[b]Minimum values.
[c]At the location of PS-128A, B, and C.

BASES FOR SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS - HFIR

The bases for the safety limits (SL) and limiting safety system settings (LSSS) are set forth in detail in this section. The general approach is to set each variable separately at the SL, concurrent with setting all other variables at the LSSS, and to examine the heat transfer situation at this condition. The situation is examined in operating Modes 1, 2, and 3. Only start-of-cycle conditions are considered since these are limiting (Reference 3, Table 5, pages 72 and 73). In Mode 1 the evaluations are made at 100% flow, since this is the limiting condition in terms of the "nearness" of the flux (power) to flow burnout point and the flux (power) to flow scram (Reference 5, page 120) and at very low flows (1,350-1,500 gpm) due to the relatively large increase in the inaccuracy of the flux (power) to flow instrumentation in this region (Reference 6, page 4 and Figures 4, 5, 8, and 9).

Mode 1 Operation

Pressure at Safety Limit (100% Flow)

In Mode 1 operation, with the system coolant flow rate at 16,000 gpm (100% flow), the inlet coolant temperature at 135°F (LSSS), and the system pressure (at the location of PS-128A, B, and C) at 550 psig (SL), the calculated minimum burnout flux (power) to flow ratio is 1.404 (see Table 3, Case No. 2). The inaccuracy in the inlet coolant temperature instrumentation is less than ± 2.2°F (Reference 6, Figure 2). The corresponding decrease in the calculated minimum burnout flux (power) to flow ratio is 0.007 (see page 17). Thus, the "temperature inaccuracy adjusted" calculated minimum burnout flux (power) to flow ratio for this condition is 1.404 - 0.007 = 1.397. The inaccuracy (3 σ value) on the flux (power) to flow ratio trip at 16,000 gpm is 6 MW (Reference 6, Figure 8) or 0.06 on flux (power) to flow ratio. Thus, with the flux (power) to flow ratio measured at 1.3 (LSSS), the actual flux (power) to flow ratio might be as high as 1.36. However, at these conditions no burnout would occur since 1.36 is less than 1.397.

Table 3. Results of Heat Transfer Calculations - Modes 1 and 2

Case No.	Operating Mode	System Pressure at PS128P (psig)	Inlet Coolant Temperature (°F)	Total System Flow Rate (gpm)	Flow Velocity at Point of Incipient Boiling and Burnout (ft/sec)	Power Level at Incipient Boiling (MW)	Power Level at Hot Spot Burnout (MW)	Flux-to-Flow Ratio at Hot Spot Burnout
1	1	575 (LSSS)	140 (SL)	16,000 (100%)	47.56	121.06	140.58	1.406
2	1	550 (SL)	135 (LSSS)	16,000 (100%)	47.56	120.94	140.38	1.404
3	1	575 (LSSS)	135 (LSSS)	16,000 (100%)	47.62	123.05	142.25	1.423
4	1	559[a]	140 (SL)	1,500 (LSSS)	5.00	18.57	>24.94	>2.660
5	1	559[a]	137.2[b]	1,500 (LSSS)	4.99	18.71	>25.13	>2.681
6	1	550 (SL)	137.2[b]	1,500 (LSSS)	4.99	18.62	>25.01	>2.668
7	1	559[a]	137.2[b]	1,350 (SL)	4.55	17.16	>22.90	>2.743
8	2	10.84	135 (LSSS)	1,500 (LSSS)	---	5.49	---	---
9	2	10.84	140 (SL)	1,500 (LSSS)	---	5.23	---	---
10	2	10.84	135 (LSSS)	1,350 (SL)	---	5.03	---	---

[a]LSSS (575 psig) minus instrumentation inaccuracy allowance.

[b]LSSS (135°F) plus instrumentation inaccuracy allowance.

Inlet Temperature at Safety Limit (100% Flow)

In Mode 1 operation with the system coolant flow rate at 16,000 gpm (100% flow), the inlet coolant temperature at 140°F (SL), and the system pressure (at the location of PS-128A, B, and C) at 575 psig (LSSS), the calculated minimum burnout flux (power) to flow ratio is 1.406 (see Table 3, Case No. 1). The inaccuracy in the system pressure instrumentation is 0.5% of span (Reference 6, page 13) or $\pm$16 psi. The corresponding decrease in the calculated minimum burnout flux (power) to flow ratio is 0.012 (see page 17). Thus, the "pressure inaccuracy adjusted" calculated minimum burnout flux (power) to flow ratio is 1.406 - 0.012 = 1.394. At a measured flux (power) to flow ratio of 1.3 (LSSS), the actual value may be as high as 1.36 due to inaccuracies in the flux (power) to flow measuring instrumentation as previously discussed. However, at these conditions, no burnout would occur since 1.394 is greater than 1.36.

Flux (Power) to Flow at Safety Limit (100% Flow)

In Mode 1 operation with the system coolant flow rate at 16,000 gpm (100% flow), the inlet coolant temperature at 135°F (LSSS), and the system pressure (at the location of PS-128A, B, and C) at 575 psig (LSSS), the calculated minimum burnout flux (power) to flow ratio is 1.423 (see Table 3, Case No. 3). As previously discussed, the corresponding "pressure and inlet temperature inaccuracy adjusted" calculated minimum burnout flux (power) to flow ratio is 1.423 - 0.012 - 0.007 = 1.404. At these conditions, and with the ratio of flux (power) to flow at 1.37 (SL), no burnout would occur since 1.404 is greater than 1.37.

Low-Low Flow at Safety Limit

In Mode 1 operation, with the system flow rate at 1,350 gpm (SL), the inlet coolant temperature at 137.2°F (LSSS plus instrumentation inaccuracy allowance), and the system pressure (at the location of PS-128A, B, and C) at 559 psig (LSSS minus instrumentation inaccuracy allowance), the calculated minimum power level at which the coolant subcooling goes to zero, which is above the incipient boiling power level but below the burnout power level, is 22.90 MW (see Table 3, Case No. 7) corresponding to a flux (power) to flow ratio of 2.743.* At 1,350 gpm the inaccuracy (3 σ value) in the flux (power) to flow ratio trip is 9.2 MW (Reference 6, Figure 8) or 1.090** on flux (power) to flow ratio. Thus, with the flux (power) to flow ratio measured at 1.3 (LSSS) (or 8.3475% x 1.3 = 10.969% or 10.97 MW), the actual flux (power) to flow ratio might be as high as 1.3 + 1.090 = 2.390 (or 10.97 + 9.2 = 20.17 MW). However, at these conditions, no burnout will occur since 2.743 is greater than 2.390 (or 22.90 MW is greater than 20.17 MW).

Pressure at Safety Limit (9.375% Flow)

In Mode 1 operation, with the system flow rate at 1,500 gpm (LSSS), the inlet coolant temperature at 137.2°F (LSSS plus instrumentation inaccuracy allowance), and the system pressure (at the location of PS-128A, B, and C) at 550 psig (SL), the calculated minimum power level at which the coolant subcooling goes to zero, which is above the incipient boiling power level but below the burnout power level is 25.01 MW (see Table 3, Case No. 6) corresponding to a flux (power) to flow ratio of 2.668.*** At 1,500 gpm the inaccuracy (3 σ value) in the flux (power) to flow ratio trip is 9 MW (Reference 6, Figure 8) or 0.96**** on flux (power) to flow ratio. Thus, at 1,500 gpm with the flux (power) to flow ratio measured at 1.3 (LSSS) (or 9.375% x 1.3 = 12.1875% or 12.19 MW), the actual flux (power) to flow ratio may be as high as 1.3 + 0.96 = 2.26 (or 12.19 + 9 = 21.19 MW). However, at these conditions no burnout would occur since 2.668 is greater than 2.26 (or 25.01 MW is greater than 21.19 MW).

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*22.90 MW = 22.9% power, 1350 gpm = $\frac{1350 \times 100}{16,000}$% flow = 8.3475% flow, 22.9%/8.3475% = 2.743.

**9.2 MW = 9.2% power, 1350 gpm = 8.3475% flow, 9.2%/8.3475% = 1.090.

***25.01 MW = 25.01% power, 1500 gpm = 9.375% flow, 25.01%/9.375% = 2.668.

****9 MW = 9% power, 1500 gpm = $\frac{1500 \times 100}{16,000}$% flow = 9.375% flow, 9%/9.375% = 0.96.

Inlet Temperature at Safety Limit (9.375% Flow)

In Mode 1 operation, with the system flow rate at 1,500 gpm (LSSS), the inlet coolant temperature at 140°F (SL), and the system pressure (at the location of PS-128A, B, and C) at 559 psig (LSSS minus instrumentation inaccuracy allowance), the calculated minimum power level at which the coolant subcooling goes to zero, which is above the incipient boiling power level but below the burnout power level, is 24.94 (see Table 3, Case No. 4) corresponding to a flux (power) to flow ratio of 2.660.* As discussed previously, at 1,500 gpm with the flux (power) to flow ratio measured at 1.3 (LSSS) (or 12.19 MW), the actual flux (power) to flow ratio might be as high as 2.26 (or 21.19 MW) due to flux (power) to flow ratio instrumentation inaccuracies. However, at these conditions no burnout would occur since 2.660 is greater than 2.26 (or 24.94 MW is greater than 21.19 MW).

Flux (Power) to Flow at Safety Limit (9.375% Flow)

In Mode 1 operation, with the system flow rate at 1,500 gpm (LSSS), the inlet coolant temperature at 137.2°F (LSSS plus instrumentation inaccuracy allowance), and the system pressure (at the location of PS-128A, B, and C) at 559 psig (LSSS minus instrumentation inaccuracy allowance), the calculated minimum power level at which the coolant subcooling goes to zero, which is above the incipient boiling power level but below the burnout power level is 25.13 MW (see Table 3, Case No. 5) corresponding to a flux (power) to flow ratio of 2.681.** Thus, at these conditions and at a flux (power) to flow ratio of 2.4 (SL) (or 22.50 MW)*** no burnout would occur since 2.681 is greater than 2.4 (or 25.13 is greater than 22.5 MW).

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*24.94 MW = 24.94% power, 1500 gpm = 9.375% flow, 24.94%/9.375% = 2.660.

**25.13 MW = 25.13% power, 1500 gpm = 9.375% flow, 25.13%/9.375% = 2.681.

***% power/9.375% = 2.4, % power = 22.50% = 22.50 MW.

Mode 2 Operation

Power Level at Safety Limit

In Mode 2 operation, with the system coolant flow rate at 1,500 gpm (LSSS), and the inlet coolant temperature at 135°F (LSSS), the calculated minimum incipient boiling power level, which is below the burnout power level, is 5.49 MW (see Table 3, Case No. 8). The inaccuracy in the inlet coolant temperature instrumentation is less than ±2.2°F (Reference 6, Figure 2). The corresponding decrease in the calculated minimun incipient boiling power level is 0.106 MW (see page 17). The inaccuracy in the flow instrumentation initiating scram at 1,500 gpm is ±90 gpm (Reference 6, Figure 6). The corresponding decrease in the calculated minimum incipient boiling power level is 0.38 MW (see page 17). Thus, the "flow and temperature inaccuracy adjusted" calculated minimum incipient boiling power level is 5.49 - 0.106 - 0.38 = 5.00 MW. At these conditions and with the neutron power at 4 MW (SL), no burnout would occur since 5.00 MW is greater than 4.00 MW.

Inlet Temperature at Safety Limit

In Mode 2 operation, with the system coolant flow rate at 1,500 gpm (LSSS), and the inlet coolant temperature at 140°F (SL), the calculated minimum incipient boiling power level is 5.23 MW (see Table 3, Case No. 9). As discussed previously, the decrease in the calculated minimum incipient boiling power level associated with inaccuracies in the flow instrumentation is 0.38 MW; thus, the "flow inaccuracy adjusted" calculated minimum incipient boiling power level for these conditions is 5.23 - 0.38 = 4.85 MW. The inaccuracy in the neutron power instrumentation in Mode 2 is ±0.102 MW (Reference 6, page 14). Thus, at a measured neutron power level of 3.25 MW (LSSS) the actual neutron power may be as high as 3.25 + 0.102 = 3.35 MW. However, at these conditions no burnout will occur since 4.85 MW is greater than 3.35 MW.

Coolant Flow at Safety Limit

In Mode 2 operation with the system flow rate at 1,350 gpm (SL), and the inlet coolant temperature at 135°F (LSSS), the calculated minimum incipient boiling power level is 5.03 MW (see Table 3, Case No. 10). As discussed previously the decrease in the calculated minimum incipient boiling power level associated with inaccuracies in the temperature instrumentation is 0.106 MW. Thus, the "temperature inaccuracy adjusted" calculated minimum incipient boiling power level is 5.03 - 0.106 = 4.92 MW. At a measured neutron power level of 3.25 MW (LSSS) the actual neutron power may be as high as 3.35 MW due to inaccuracies in the neutron power instrumentation as discussed previously. However, no burnout would occur at these conditions since 4.92 MW is greater than 3.35 MW.

Mode 3 Operation

Power Level at Safety Limit

Mode 3 operation is essentially a natural convection cooled, pool type reactor utilized for occasional critical studies at very low power. It has been experimentally determined that for HFIR Mode 3 conditions, with external recirculation completely prevented (i.e., no downcomer), the burnout heat flux is in excess of 12.500 BTU/hr-ft^2 (Reference 7, pages 11, 12, and 15). At a power level of 175 kW (SL)* the peak hot spot heat flux in the HFIR for the symmetric rod configuration condition is less than 4,000 BTU/hr-ft^2 (see page 10). Hence, at these conditions a safety factor in excess of 12,500/4,000 = 3.125 exists. Assumption of the "no downcomer" condition is very conservative since external recirculation paths exist in the reactor.

For the "worst asymmetric" case the peak hot spot flux in the reactor at 175 kW (SL) is less than 12,000 BTU/hr-ft^2 (see page 10). Hence, at these conditions the ratio of the burnout heat flux to peak hot spot flux is in excess of 1.0.

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*The nominal LSSS for Mode 3 is 130 kW. Inaccuracies in the neutron power measuring instrumentation in Mode 3 amount to 4.08 kW (Reference 2, page 5). Thus, at a measured power level of 130 kW, the actual power level may be as high as 130 + 4 = 134 kW, well below the safety limit.

CALCULATIONS

The results of pertinent calculations for Modes 1 and 2 are summarized in Table 3 (see page 4 of this report). Mode 3 calculations are summarized on page 10. Sample calculations, illustrating the method used to obtain the results given in Table 3, are presented. Calculations of the sensitivity of burnout and incipient boiling power level to small changes in process variables are given.

Mode 3 Calculations

With Symmetric Control Rods

At the point in the core where burnout would occur in Mode 3 operation (natural convection cooled mode), a calculation made using H. A. McLain's heat transfer code[3] indicated a hot spot heat flux of 87,559 BTU/hr-ft^2 at 5.45 MW. This must be increased by a factor of 1.23 to account for the fact that one of the hot spot factors has not been applied at this location by the code (Reference 3, pages 17 and 63). Thus, the appropriate value of the limiting heat flux at the Mode 3 power level safety limit of 175 kW is:

$$87{,}559 \times 1.23 \times \frac{0.175}{5.45} = 3{,}458 \text{ BTU/hr-ft}^2.$$

With Asymmetric Control Rods

To account for the effect on power distribution of asymmetric control rod configurations, the above symmetric core heat flux must be increased by a factor of 2.9/1.173 (Reference 8. page 6, and Reference 3, page 57). Further, an uncertainty factor of 1.35 should be applied (Reference 8, page 7). Thus, for the asymmetric case, the limiting heat flux is:

$$3{,}458 \times \frac{2.9}{1.173} \times 1.35 = 11{,}541 \text{ BTU/hr-ft}^2.$$

Sample Calculation: Case No. 1, Table 3

Process Variable Values:

T_{IN}; inlet coolant temperature	= 140°F (SL)
PS-128 pressure; pressure at PS-128	= 575 psig (LSSS)
VP, vessel pressure	= 559.7 psia
Total system flow	= 16,000 gpm (100%)
Fuel region flow	= 13,100 gpm
Operating Mode 1	

Flow Velocity:

$$V = \frac{1.44 \times 10^5\ w_i}{e\rho}\ \text{ft/sec}$$

where:

w_i = mass flow rate per unit width of channel, lb/sec-in. (output by heat transfer code)

ρ = coolant density at temperature and pressure of coolant at hot streak outlet at incipient boiling, lb/ft^3

e = hot streak local channel thickness, mils (output by heat transfer code)

w_i = 0.7369 lb/sec-in.

e = 39.0 mils

$P_{hot\ streak,\ outlet}$ = 468.39 psia (output by heat transfer code)

$T_{coolant,\ hot\ streak,\ outlet}$ = 306.18°F (output by heat transfer code)

ρ(P = 468.39 psia, T = 306.18°F) = 57.21 lb/ft^3

$$V = \frac{1.44 \times 10^5\ (0.7369)}{(39.0)(57.21)} = 47.56\ \text{ft/sec}$$

Therefore, use $\phi_{burnout,\ min.}$ vs. pressure curves derived from Reference 2 (Figures 5, 6, and 7) for V = 47.27 ft/sec (Figure 1). This is slightly conservative.

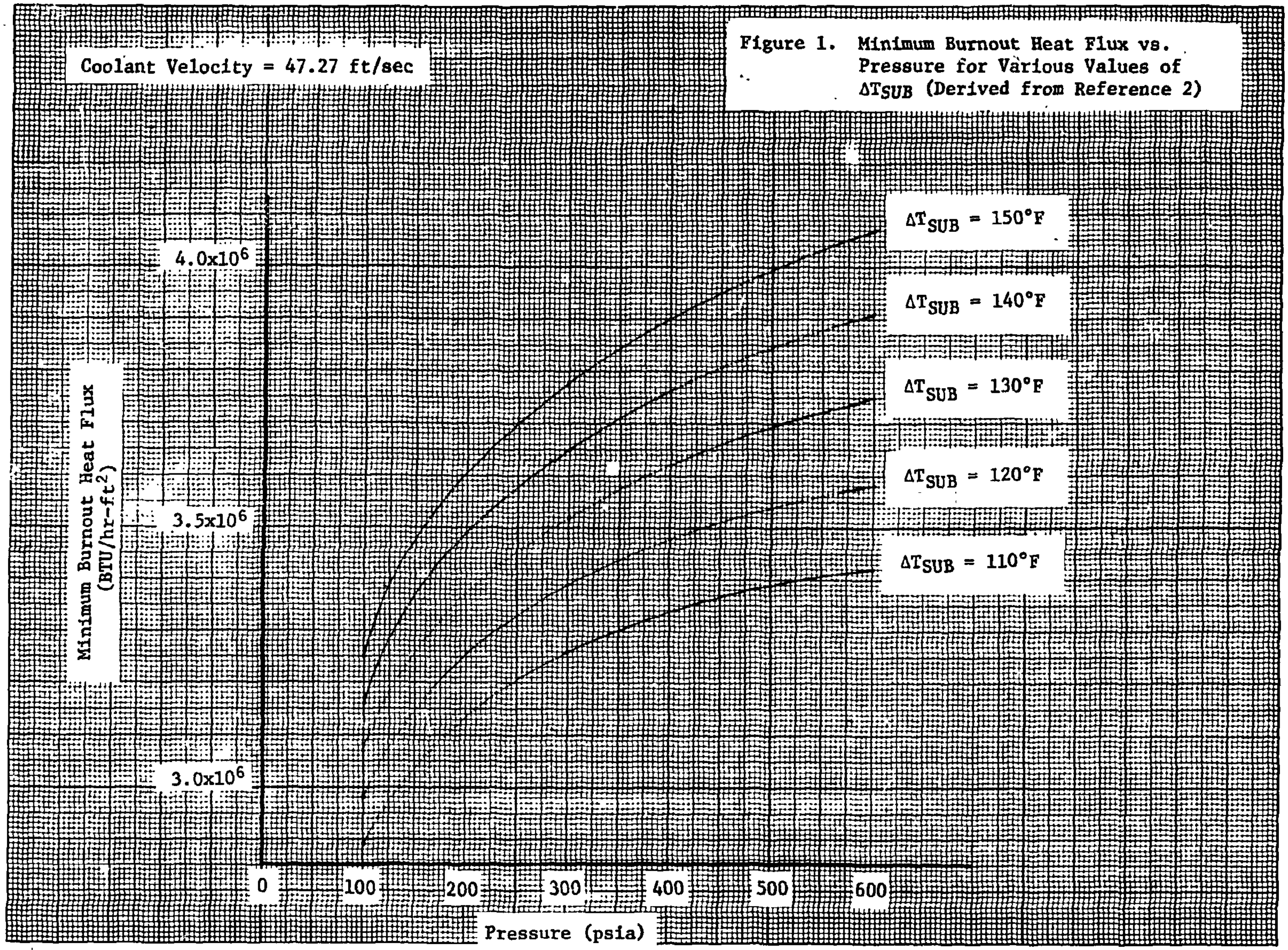


Figure 1. Minimum Burnout Heat Flux vs. Pressure for Various Values of ΔT_{SUB} (Derived from Reference 2)

Power Level (MW)	T_{SAT} (°F)	Hot Streak ΔT (°F)	Bulk Fluid Outlet Temperature at Hot Streak (°F)	ΔT_{SUB} (°F)	ϕ_x, Heat Flux at Hot Spot (BTU/hr-ft^2)
121.06[a,b]	460.96	166.18	306.18[b]	154.78	3.1338×10^6[b]
124.54	460.96	170.96	310.96	150	3.2239×10^6
131.83	460.96	180.96	320.96	140	3.4125×10^6
139.11	460.96	190.96	330.96	130	3.6011×10^6
146.40	460.96	200.96	340.96	120	3.7897×10^6
153.68	460.96	210.96	350.96	110	3.9783×10^6

[a]Incipient boiling power level.
[b]Output by heat transfer code.

At V = 47.27 ft/sec and P = 468.39 psia:

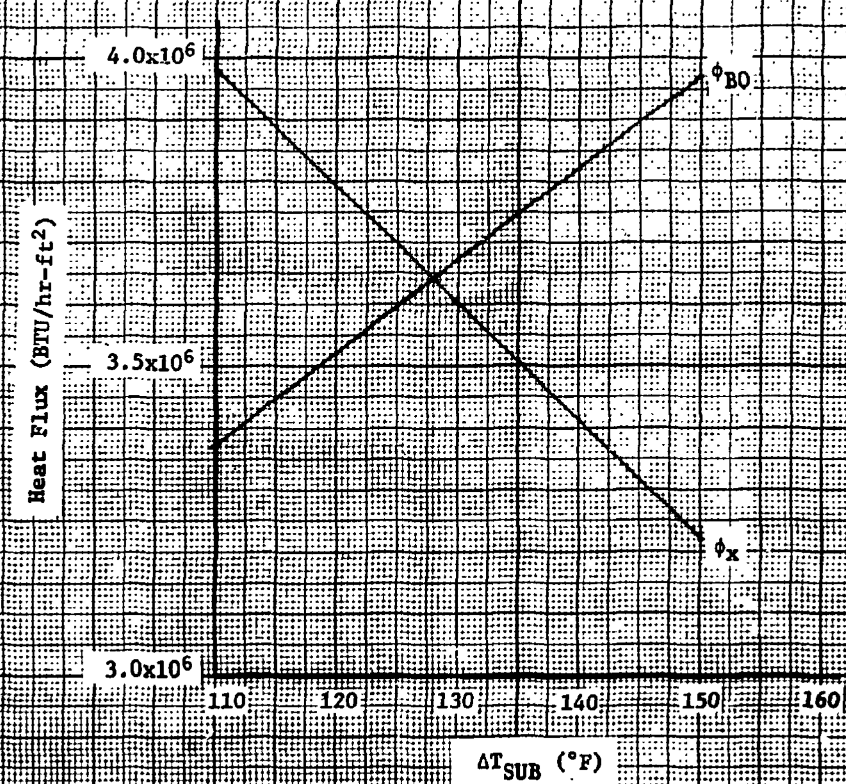
ΔT_{SUB} (°F)	ϕ_{BO}, Minimum Burnout[a] Heat Flux (BTU/hr-ft^2)
110	3.376×10^6
120	3.521×10^6
130	3.673×10^6
140	3.822×10^6
150	3.968×10^6

[a]From Figure 1.

ϕ_x vs. ΔT_{SUB} and ϕ_{BO} vs. ΔT_{SUB} are plotted in Figure 2. The intersection of these two curves gives the heat flux at which burnout occurs in the reactor. Examination of Figure 2 indicates that the value is 3.639×10^6 BTU/hr-ft^2. The corresponding burnout power level is:

$$1.21.06 \times \frac{3.639 \times 10^6}{3.1338 \times 10^6} = 140.58 \text{ MW.}$$

Figure 2. ϕ_{BO} vs. ΔT_{SUB} and ϕ_x vs. ΔT_{SUB} for Case No. 1, Table 3



Sample Calculation: Case No. 4, Table 3

Process Variable Values:

T_{IN}; inlet coolant temperature	= 140°F (SL)
PS-128 pressure; pressure at PS-128	= 559 psig*
VP, vessel pressure	= 571.7 psia
Total system flow	= 1,500 gpm (LSSS)
Fuel region flow	= 1,290 gpm
Operating Mode 1	

Flow Velocity:

$$V = \frac{1.44 \times 10^5 \, w_i}{e\rho} \text{ ft/sec}$$

where:

w_i = mass flow rate per unit width of channel, lb/sec-in. (output by heat transfer code)

ρ = coolant density at temperature and pressure of coolant at hot streak outlet at incipient boiling, lb/ft^3

e = hot streak local channel thickness, mils (output by heat transfer code)

w_i = 0.07365 lb/sec-in.

e = 39.3 mils

$P_{\text{hot streak, outlet}}$ = 570.39 psia (output by heat transfer code)

$T_{\text{coolant, hot streak, outlet}}$ = 394.30°F (output by heat transfer code)

ρ(P = 570.39 psia, T = 394.30°F) = 54.0 lb/ft^3

$$V = \frac{1.44 \times 10^5 \ (0.07365)}{(39.3)(54.0)} = 5.00 \text{ ft/sec}$$

*LSSS (575) minus instrumentation inaccuracy allowance.

Power Level (MW)	T_{SAT} (°F)	Hot Streak ΔT (°F)	Bulk Fluid Outlet Temperature at Hot Streak (°F)	ΔT_{SUB} (°F)	ϕ_x, Heat Flux at Hot Spot (BTU/hr-ft^2)
18.57[a,b]	481.48	254.30	394.30[b]	87.18	3.3060×10^5[b]
21.29	481.48	291.48	431.48	50.0	3.7893×10^5
24.94	481.48	341.48	481.48	0.0	4.4394×10^5

[a]Incipient boiling power level.
[b]Output by heat transfer code.

The hot spot heat flux in the reactor corresponding to $\Delta T_{SUB} = 0$ is 4.4394×10^5 BTU/hr-ft^2. At P = 570.39 psia, $\Delta T_{SUB} = 0$ the minimum burnout heat flux for pool boiling is 9.15×10^5 BTU/hr-ft^2.* Thus, at 24.94 MW, the ratio of the minimum burnout heat flux for pool boiling to the peak hot spot heat flux in the reactor is:

$$\frac{9.15 \times 10^5}{4.4394 \times 10^5} = 2.06.$$

The flux (power) to flow ratio corresponding to 24.94 MW at 1,500 gpm is calculated as follows:

$$24.94 \text{ MW} = 24.94\% \text{ power}$$

$$1{,}500 \text{ gpm} = \frac{1{,}500 \times 100}{16{,}000} = 9.375\% \text{ flow}$$

$$\frac{\text{Power}}{\text{Flow}} = \frac{24.94\%}{9.375\%} = 2.660$$

*Reference 2, Figure 3.

Sensitivity of Burnout Power Level to Small Changes in Inlet Coolant Temperature and Pressure at 100% Flow - Mode 1 Operation

Comparison of the results of Case No. 1, Table 3, with Case No. 3, Table 3, indicates that an increase of 5°F in the inlet coolant temperature results in a decrease of 142.25 - 140.58 = 1.67 MW in the burnout power level. The inaccuracy in the inlet coolant temperature instrumentation is $<\underline{+}2.2$°F (Reference 6, Figure 2). The decrease in burnout power level associated with a 2.2°F increase in inlet coolant temperature is thus 1.67 x 2.2/5 = 0.735 MW. The corresponding decrease in flux to flow ratio is 0.735/100 ≈ 0.007.

Comparison of the results of Case No. 2, Table 3, with Case No. 3, Table 3, indicates that a decrease in system pressure of 25 psi results in a decrease of 142.25 - 140.38 = 1.87 MW in the burnout power level. The inaccuracy in the system pressure instrumentation is 0.5% of span (Reference 6, page 13) or ±16 psi. The decrease in burnout power level associated with a 16 psi decrease in pressure is thus 1.87 x 16/25 = 1.197 MW. The corresponding decrease in flux to flow ratio is 1.197/100 ≈ 0.012.

Sensitivity of Incipient Boiling Power Level to Small Changes in Coolant Flow and Inlet Coolant Temperature Near 10% Flow - Mode 2 Operation

Calculations made with McLain's heat transfer code[3] at a total system flow of 1,500 gpm indicate that a 5°F increase in the inlet coolant temperature results in a decrease in incipient boiling power level of 0.24 MW. The inaccuracy in the inlet coolant temperature instrumentation is $<\underline{+}2.2$°F (Reference 6, Figure 2). The decrease in incipient boiling power level associated with a 2.2°F increase in inlet coolant temperature is thus 0.24 x 2.2/5 = 0.106 MW.

Calculations made with McLain's heat transfer code[3] indicate that a decrease in fuel element flow of 105 gpm results in a decrease in incipient boiling power level of 0.44 MW. The inaccuracy in the total system flow at a flow rate of 1,500 gpm is ±90 gpm (Reference 6, Figure 6). The decrease in incipient boiling power level associated with a decrease of 90 gpm in fuel element flow is thus 0.44 x 90/105 = 0.38 MW.

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