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UNCERTAINTIES AFFECTING $BOSF_N$ FOR THE MARK 15 ASSEMBLY

INTRODUCTION

Technical and transient protection limits are specified on the nominal burnout safety factor, $BOSF_N$, to avoid significant release of fission products caused by local film boiling burnout. The risk of fission product release, BOR, due to film boiling burnout is statistically determined where allowances are made to account for differences between the 'nominal' assembly and the actual assembly. The necessary data for determining these allowances for the Mark 15 assembly are summarized. The data listed in this report enable damage calculations with COBAD to be performed for the Mark 15 assembly.

SUMMARY

The complete set of nonideality factors necessary to

calculate BOR for the Mark 15 assembly is summarized in Appendix B. A more detailed description as to how the specific numerical values were estimated is given in Appendix A. A brief description concerning the calculational model behind BOR is discussed in the main body of the report.

DISCUSSION

Technical and transient protection limits are specified on the nominal burnout safety factor, $BOSF_N$, to avoid significant release of fission products caused by local film boiling burnout of fuel and target assemblies.[1] Film boiling occurs when the surface heat flux of an assembly exceeds the maximum heat transfer rate that can be sustained by nucleate or transition boiling and is a local phenomenon. During film boiling, the heat transfer coefficient between the vapor-blanketed surface and the liquid coolant is greatly reduced and the surface temperature rises rapidly, usually to a value in excess of the melting point of most cladding materials. The phenomenon is termed film boiling burnout (BO).

The current calculational model employed for deriving the burnout risk (BOR), the risk being associated with the probability of burnout and its resulting activity release, is based on the notion of an "ideal" assembly (i.e., a 'nominal' assembly). The state of any assembly operating in a reactor charge is determined through on-line measurements of key global variables. These variables in return (through use of hydraulic, neutronic, and heat transfer correlations and/or models) predict the assembly's 'nominal' state. Departure from this predicted 'nominal' state is probable and is a manifestation of various nonidealities resulting from fabrication, correlation (and modeling), and reactor measurement uncertainties. Allowances, sometimes referred to as hot-spot factors, for each identified uncertainty (generated by a group of dependent nonidealities which express the uncertainties effect on $BOSF_N$) are incorporated into the BOR calculations. A list of the identified uncertainties along with suggested symbols is given in Table 1. A useful classification of the uncertainties as well as their dependent nonidealities for annulus monitored assemblies is given in Table 2.[2] For the Mark 15 assembly three of the uncertainties (fuel concentration, length, and nonbonds*) were considered negligible and were omitted from COBAD[3,4] damage calculations of BOR. Justification of their absence in the

*Recent experience suggests that poor bonds may exists near the end cap of the Mark 15 assembly. Calculations[16] estimate this effect to be small.

damage calculations is given in Appendix A along with a description of each nonideality range employed for the Mark 15 assembly.

$BOSF_N$, defined as the ratio of the predicted nominal burnout heat flux to the predicted operating nominal heat flux, is of the form:

$$BOSF_N = \frac{\phi_N^{bo}}{\phi_N^{op}} \tag{1}$$

Damage calculations for a given operating assembly require specification of BOSF at every local surface location (typically termed as a surface layer when discussing a specific tube). Calculation of a local surface's actual BOSF is statistical by nature, resulting from the inherent uncertainties in parameters which define its exact value. Instead, a probability distribution function, pdf, of BOSF is determined (in practice the COBAD code determines the pdf of the ratio of nominal-to-actual BOSF) based on the set of uncertainties given in Table 2 along with their nonideality ranges. These uncertainties are considered to be a mutually exclusive set and as such are statistically combined as independent events into some overall measure of BOSF variation about the nominal.[5] In equation form the overall uncertainty for a given surface layer takes the form:

$$U_A = \prod_{j=1}^{\text{number of uncertainties}} U_j = \frac{BOSF_N}{BOSF} \tag{2}$$

where

U_A - Overall uncertainty allowance applied locally.

U_j - Individual uncertainty allowance applied locally and generated from specified nonideality ranges (Complete list given in Table 2).

$BOSF_N$ - local nominal BOSF

BOSF - local actual BOSF

The individual uncertainty allowances, U_j, are generated from their associated dependent group of nonidealities. Each uncertainty's group of nonidealities is determined conservatively through numerical analysis, measurement, judgement, and operating experience. In each case the nonideality range is selected to encompass at least 99% of their statistical tolerance limits.

Appendix A contains a description of the various nonidealities and their extreme values (at the 99% confidence level) for the Mark 15 assembly. Appendix B summarizes the actual uncertainty input records used by COBAD for the Mark 15 (the records are of the form: INPUT.DITTYBOP.NONIDEAL.M15.?).

Once U_A and its distribution function, $pdf(U_A)$, on a local surface layer are determined, the probability of burnout on this local surface is determined from the relation[1]:

$$P(U_A > BOSF_N) = P(BOSF < 1)$$

$$= \int_{BOSF_N}^{U_A^{max}} pdf(U_A)\,dU_A \qquad (3)$$

where

U_A^{max} - Maximum value obtainable for the overall uncertainty allowance.

Equation (3) is illustrated in Figure 1 for operating conditions and surface site which results in a finite probability of burnout near this surface location. The consequences of such a local burnout depends on the local operating power and eqn. (6) of Ref. (1) expresses the BOR associated with the entire reactor charge. Equation (6) of Ref. (1) is a composite sum over all surface layers in the reactor core of the product of the consequences of burnout and its probability:

$$BOR = \sum_{i=1}^{\substack{\text{number of}\\ \text{assemblies}\\ \text{in core}}} \; \sum_{j=1}^{\substack{\text{number of}\\ \text{tubes in}\\ \text{i'th assembly}}} \; \sum_{k=1}^{\substack{\text{number of}\\ \text{layers in}\\ \text{tube j}}} P_{ijk} P(U_{A_{ijk}} > BOSF_{N_{ijk}}) \qquad (4)$$

where

BOR - Calculated risk of fission product release for reactor core, MW equivalent.

ijk - Specification of a specific surface layer, tube, and assembly.

P_{ijk} - Amount of reactor power generated in volume segment next to the local surface ijk, MW.

$P(U_{A_{ijk}} > BOSF_{N_{ijk}})$ - Probability of burnout at the local surface ijk, (see Figure 1).

Technical and transient protection limits are determined to limit BOR to predefined values.[1]

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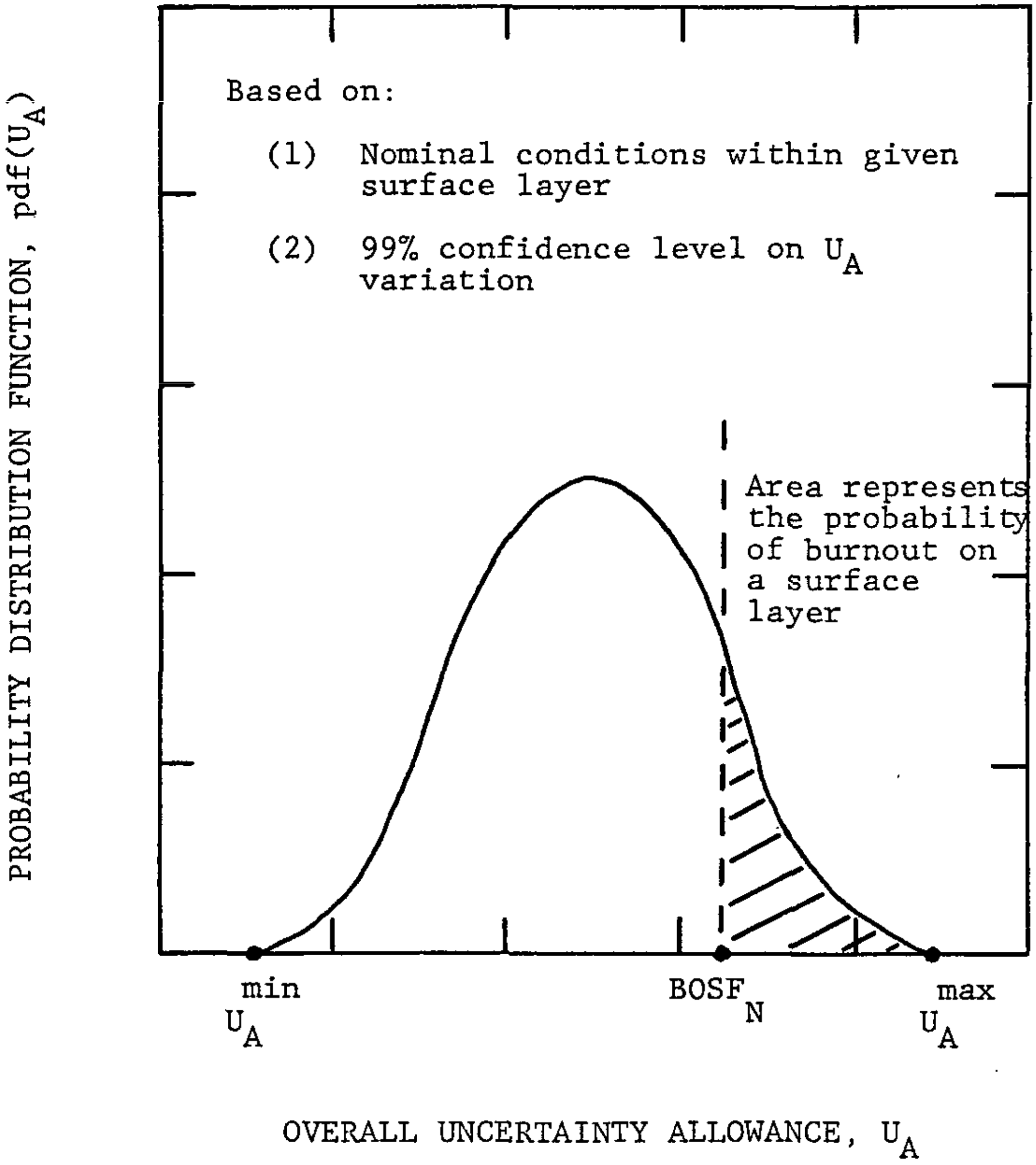


FIGURE 1. THE PROBABILITY OF BURNOUT ON A GIVEN SURFACE LAYER.

TABLE 1. LISTING OF SYMBOLS ALLOCATED TO UNCERTAINTIES WHICH AFFECT $BOSF_N$

j	UNCERTAINTY, Uj*	SYMBOL**
1	Tube eccentricity	XCEN
2	Fuel concentration variations	FUEL CONC
3	Fuel distribution among tubes	FUEL DIST
4	Fuel length	FUEL LENGTH
5	End cap effect	END CAP
6	Wilkins effect	WILKINS
7	Nonbonds	NBOND
8	BO Correlation including rib effect	BO COR
9	Physics calculations	PHYS CALC
10	CMX assembly flow	CMX ASSY FLOW
11	CMX channel flow	CMX CHAN FLOW
12	CMX Pressure	CMX PRESSURE
13	Reactor monitor pin TC	RX MPTC
14	Reactor isothermal box reference thermohm	RX THERMOHM
15	Reactor plenum inlet temperature	RX TIN
16	Reactor analog-digital conversion	RX ADC CONV
17	Reactor zone flow	RX ZONE FLOW
18	Reactor assembly flow	RX ASSY FLOW
19	Reactor channel flow	RX CHAN FLOW
20	Reactor APM chamber accuracy	RX APM ACRCY
21	Reactor APM curve fitting	RX APM FIT
22	Reactor APM discrete calculations	RX APM CALC

* The above uncertainties are considered to be a mutually exclusive set.

** Each uncertainty has one or more dependent nonideality factors associated with it. In the literature these nonideality factors have the symbols B_i or H_i and are interchangeable.

TABLE 2. UNCERTAINTIES AFFECTING $BOSF_N$ FOR ANNULUS MONITORED ASSEMBLIES

CLASS	j	INDEPENDENT UNCERTAINTIES* U_j	ALLOWANCE APPLIED TO: OPERATING HEAT FLUX	ALLOWANCE APPLIED TO: BURNOUT HEAT FLUX	DEPENDENT GROUP OF NONIDEALITIES**	PROBABILITY DISTRIBUTION FUNCTION
Fabrication	1	Eccentricity	x	x	B_5, B_6, B_7	uniform
	2	Fuel concentration	x		B_8	normal
	3	Fuel distribution among tubes	x		B_9	normal
	4	Fuel length	x		B_{13}	normal
Correlation & Modelling	5	End caps	x		B_3	constant
	6	Wilkins effect	x		B_4	constant
	7	Nonbonds	x		B_{40}	constant
	8	BO correlation (includes rib effect)		x	B_1	constant
	9	Physics calculations	x		B_{11}	uniform
	10	CMX assy flow		x	B_{15}, B_{16}	normal
	11	CMX channel flow	x	x	B_{17}, B_{18}, B_{19}	normal
	12	CMX pressure		x	B_{21}	normal
Online Measurements	13	RX monitor pin TC	x	x	B_{22}, B_{25}	normal
	14	RX isothermal box ref. therm.	x	x	B_{23}, B_{26}	normal
	15	RX plenum inlet temperature	x	x	B_{27}	normal
	16	RX analog-dig. conversion	x	x	B_{24}, B_{26}	normal
	17	RX zone flow	x	x	B_{29}, B_{30}, B_{31}	normal
	18	RX assy flow	x	x	B_{32}, B_{33}	normal
	19	RX channel flow	x	x	B_{34}, B_{35}	normal
	20	RX APM chamber accuracy	x		B_{37}	normal
	21	RX APM curve fitting	x		B_{38}	normal
	22	RX APM discrete calculations	x		B_{39}	normal

*The above set of uncertainties reasonably assumes that all significant nonidealities have been identified and considered.

**The pertinent terminology associated with the B_i's is given in Ref 2.

APPENDIX A

Appendix A contains a brief description of each uncertainty in Table 2 along with extreme values of each nonideality range associated with the uncertainty for the Mark 15 assembly.

UNCERTAINTIES AFFECTING BOSF FOR THE MARK 15

1. Tube Eccentricity - U_{XCEN}

A nominal diametral clearance is provided between spacing ribs and mating surface in the assembly to permit assembly and disassembly of the components and charge and discharge of the slug columns. These load clearances allow eccentric positioning of the slug columns. When columns are eccentric, the average temperature of the coolant in the pinched subchannel may be higher than nominal and the subchannel velocity may be lower than nominal. The maximum possible nonideality factors are calculated assuming that the columns are misaligned with complete (azimuthally coincident) eccentricity. This assumption is unrealistically conservative because:

- o The column is held in a concentric configuration at the top,
- o the slugs are randomly loaded and friction between end caps restrains slug movement,
- o the slugs have short bows and imperfections on the ribs.

All of the above tend to prevent subchannel sealing and permit intersubchannel leakage. These effects tend to reduce the nonideality factors from their maximum possible value as observed by measurements.

Because azimuthal variations in neutron flux contribute to the nonideality factors for aximuthal variation in coolant temperature and velocity, an additional allowance from azimuthal variation in neutron flux on U_{XCEN} is applied. U_{XCEN} is uniformly distributed between its maximum and minimum values.

1-a. Azimuthal temperature gradient nonideality factor - $H_t(B_5)$

The nonideality factor for temperature gradient, $H_t(B_5)$, in a coolant annulus represents the ratio of the average temperature rise in the hottest subchannel of a given annular channel to the mean value for the entire channel. H_t is applied to the BO heat flux.

The maximum possible value of H_t can be calculated by the technique of Ref. (6) or determined by measurements from instrumented thermocoupled assemblies. The H_t values from the thermocoupled assemblies are preferred since the analytical technique[6], when compared to experimental values, overestimates the nonideality factors by 30% to 50%.

Three Mark 15 thermocoupled assemblies were irradiated in 1973[7,8] and the maximum H_t values observed during the irradiation were:

Channel Number	Maximum H_t value
1	1.110
2	1.077
3	1.048

Different channel flow splits exist between the 1973 test irradiation and the proposed 1983 Mark 15 irradiation charge. Table A1 shows the small differences in flow splits. Since H_t is a measure of the subchannel temperature rise compared to the average channel temperature, the slight change in flow distribution has negligible effect on H_t. For both irradiations the nominal radial geometry was unchanged, where the measured differences in flow splits may be attributed to tolerance variations about the nominal (i.e., the limited testing of only a subset of the entire population), thus the H_t values are considered applicable to current Mark 15 assemblies.

The suggested H_t values are listed in Table A-2. The H_t values for the outer surface of the outer slug (surface 3) are given for a 0-4 year USH. Based on experience with the Mark 16B[17,18] assembly, the maximum H_t value for surface 3 would increase by 2.85% to 1.142 for a 4-5 year USH.

1-b. <u>Azimuthal velocity gradient nonideality factor</u> - $H_v(B_6)$

The nonideality factor for velocity gradient, $H_v(B_6)$, in a coolant annulus represents the ratio of the subchannel velocity in the pinched subchannel to the mean value for the entire channel.

Following similar arguments as those employed in Ref. (6) to determine an analytic expression for H_t, an analytic expression for the minimum possible value of H_v was obtained. The nonideality factor is expressed as:

$$H_v = \frac{V_{subchannel}}{V_{nominal}} = [\frac{D_e}{D_{e_N}}]^{2/3} = [\frac{R_o - (R_i + K \cdot E)}{R_o - R_i}]^{2/3} \qquad (A1)$$

where

$V_{subchannel}$ - Velocity of minimum subchannel

$V_{nominal}$ - Nominal channel velocity

D_e - Hydraulic diameter of subchannel

D_{e_N} - Hydraulic diameter of channel

R_o - Outer surface radius of channel

R_i - Inner surface radius of channel

E - Radial clearance for concentric positioning

K = 1.207 - Geometric factor used to average point effect over subchannel

Equation (A1) results in the minimum H_v values currently used for Mark 16, 22, and 31 assemblies and is employed for the Mark 15 assemblies.

The maximum variation to which eccentricity can change the coolant velocity over a subchannel from its nominal value is given in Table A3.

1-C. Azimuthal neutron flux gradient nonideality factor - $H_g(B_7)$

The neutron flux profile around the periphery of an 1600-g ^{235}U Mark XII-A assemblies and 760-lb_f depleted uranium targets (single column) was measured in a Process Development Pile (PDP)[9]. On the basis of the data, a maximum value of H_g for the Mark 15 assembly is conservatively specified as 1.12 for all slug surfaces. The nonideality in coolant temperature in a subchannel as the result of a neutron flux gradient is included in the experimentally determined H_t factor, as discussed in section 1-a. The recommended extreme variations of H_g, applied to the operating heat flux, are given in Table A4.

2. Fuel concentration - $U_{FUEL\ CONC}$

A nonideality factor, $H_c(B_8)$, is specified for each fuel tube to allow for possible variations in the local ^{235}U content as compared to the design nominal content. Variations in the ^{235}U content are caused by upset of active core material into the rib area, nonuniform core thickness from tube to tube, local segregation, and local circumferential variations in core thickness.

The core concentration variation is considered negligible when metallic mixtures of isotopes (^{235}U, ^{238}U) alone are used. As such the fuel concentration uncertainty is negligible for the Mark 15 assembly and is omitted.

3. <u>Fuel distribution</u> - $U_{FUEL\ DIST}$

The distribution of total ^{235}U, and therefore the distribution of the heat generated, among the slug columns may differ from the design nominal because of allowable variations in core dimensions. A nonideality factor, $H_m(B_9)$, applied to the operating heat flux is calculated as the ratio of relative slug power for the most severe variation to the relative slug power for a design nominal assembly. The nominal and tolerances on core diameter and core thickness are shown in Figure A1. The values are for recovered cores which have larger tolerances than new cores.

For the Mark 15 slugs, Figures A2 and A3 show the variation in slug power fraction at nominal and both tolerance limits conditions. The power fractions shown in Figures A2 and A3 were determined using the GLASS[10] code with fuel core dimensions set to (see Figure A1):

- o Nominal values
- o Extreme values (largest outer slug matched with smallest inner slug and vice versa)

In comparing the deviations in predicted power fractions, the maximum differences were

- o Outer slug, - 1.7% to 1.25%
- o Inner slug, - 1.87% to 2.50%

These differences correspond to H_m values listed in Table A5.

4. <u>Fuel Length</u> - $U_{FUEL\ LENGTH}$

A nonideality factor, $H_\ell(B_{13})$, is applied to the operating heat flux to account for increased heat generation within a tube resulting from active core length variations. For the Mark 15 assembly the varation in length of the slug column was negligible and the uncertainty is omitted.

5. End Cap Effect - $U_{END\ CAP}$

Slug columns contain a discontinuous region of fuel due to the presence of aluminum end caps. An uncertainty arises since the models are based on a continuous fuel distribution over the entire column length. From Figure A1 the nominal length of the Mark 15 slug is 8.720 inches and the length of the recovered core is 8.330 inches. A constant nonideality factor, $H_{ec}(B_3)$, applied to the operating heat flux becomes:

$$H_{ec} = \frac{\text{slug length}}{\text{core length}} = 1.047$$

6. Wilkins Effect - $U_{WILKINS}$

Nonuniform axial heat generation occurs in the slugs because of the presence of the aluminum end caps (called the Wilkins Effect). Local peaking of the neutron flux near each aluminum end cap results in a locally increased operating heat flux. An uncertainty arises since the models are based on a continuous fuel distribution over the entire column length. A constant nonideality factor, $H_w(B_4)$, is applied to the operating heat flux.

The variation in heat generation in the Mark 15 slugs was calculated[12] with the GLASS and TWOTRAN codes by the Reactor Physics Group of the Nuclear Engineering Division. From the axial center of the slug to the core end, each Mark 15 slug was divided into 32 segments. For the inner slug, the core was divided radially into seven segments while the outer slug was divided radially into 5 segments. Figures A4-A7 show the axial heat generation profile for each radial segment of each slug which is adjacent to a flow channel.

The axial surface heat flux variation was calculated by using the HEATING5[13] conduction code. Each slug was modeled as shown in Figure A8 where the core was divided into seven segments for the inner slug and five for the outer slug (shown in Figure A8). The coolant temperature in the flow channels was set equal to a representative value that was calculated by the CREDIT[14] code. The Colburn analogy is used in CREDIT for estimating the convective heat transfer coefficient. The difference in the heat flux between the case where the slug heat generation rate, q, is $q = q(r,z)$ and the case where $q = q(r)$ only is shown in Figures A4-A7 for the four slug surfaces. The effect on operating heat flux because of the increase in heat generation adjacent to the end caps is reduced by conduction through the end cap regions to the coolant. The increases in local operating heat flux near the end caps due to Wilkins Effect are expressed by H_w values which are listed in Table A6.

7. Nonbonds - U_{NBOND}

Improper bonding between the aluminum cladding - uranium fuel interface create local operating heat flux peaks. These hot spots are adjacent to the nonbonded area. A constant nonideality factor, $H_{nb}(B_{40})$, is applied to the operating heat flux. For slug type assemblies nonbonding is considered negligible and the uncertainty is omitted.

Recent information suggests that possible poor bonds may occur near the end cap for the Mark 15 assemblies. Calculations[16] indicate the effect on operating heat flux when both the Wilkins and nonbonding effects are present are small.

8. Burnout Correlation - $U_{BO\ COR}$
(includes rib effect)

A constant nonideality factor, $H_{cor}(B_1)$, of 8% is applied to the calculated burnout heat flux to account for the uncertainty associated with the correlating equation. This same nonideality allowance is applied to correlating equations for burnout for all assembly types and it includes rib effects. The value of the nonideality factor is $H_{cor} = 0.92$.

9. Physics Calculations - $U_{PHYS\ CALC}$

An allowance of $\pm 2\%$ is included to account for the nonideality, $H_p(B_{11})$, in the calculated distribution of power between the fuel columns of the Mark 15 assembly. The distribution of power is calculated by the GLASS code. The magnitude of this allowance is based on experience and technical judgement. Allowance for the nonideality is applied to the operating heat flux and is assumed to have an equal probability of occurrence (uniformly distributed) Table A7 lists the H_p values employed.

10-12. CMX Uncertainties - $U_{CMX\ ASSY\ FLOW}$, $U_{CMX\ CHAN\ FLOW}$, $U_{CMX\ PRESSURE}$

Uncertainties result from hydraulic correlations fitted to CMX measurements of assembly flows, channel flows, and pressure profiles. Nonideality factors for each uncertainty (B_{15}, B_{16} for assembly flow; B_{17}, B_{18} for channel flow;

B_{21} for pressure) are applied to the burnout and operating heat flux.

The nonideailty factor ranges in nominal coolant flows and pressures specified on the basis of CMX measurements[11] are given in Table A8. Each uncertainty is normally distributed between its minimum and maximum values. It should be noted that these specific values given in Table A8 apply only to K and C charges. More extreme values may result during the analysis of P reactor data (expected by January 1984).

13-22. Reactor Measurement Uncertainties - U_{13} to U_{22}

Nonideality factors are applied to account for various uncertainties in the on-line measurement of key variables affecting BOSF. Allowances are provided for uncertainties in the measurement of coolant temperature, axial power profile, and coolant flow. The values of these nonideality factors have been evaluated at the 99% confidence level by the Reactor and Reactor Material Technology Department (RRMT)[15].

The nonideality factors for the uncertainties in the measurement of coolant flow and temperature in the reactor are given in Table A9. The monitor pin thermocouple uncertainty is associated with inaccuracies in thermocouple measurements taken in the Bottom End Fitting, and since Mark 31 and Mark 15 BEF's are geometrically similar, the Mark 31 values are used. The nonideality factors in the axial power, applied to the operating heat flux, determined by the Axial Power Monitor (APM) are given in Table A10. These are the current APM uncertainty values. All reactor measurement uncertainties are normally distributed between their minimum and maximum values.

TABLE A1

MARK 15 FLOW DISTRIBUTIONS

Channel	Flow Splits 1973	1983[b]	1983[c]
1	0.368	0.364	0.361
2	0.467	0.467	0.466
3	0.170	0.169	0.168
Axial Purge	0.005[a]	0.0	0.005

a - Calculated.
b - Measured values from hydraulic tests (Ref. 11).
c - Values used for heat transfer calculations. The axial purge flow was estimated.

TABLE A2

H_t VALUES FOR MARK 15 assembly

		H_t Range	
Slug	Surface	Min.	Max.
outer	outer	0.890[a]	1.110[b]
	inner	0.923	1.077
inner	outer	0.923	1.077
	inner	0.952	1.048

a - For a 4-5 year USH reduce value by 0.032
b - For a 4-5 year USH increase value by 0.032

TABLE A3

H_V VALUES FOR MARK 15 assembly

		H_V Range	
Slug	Surface	Min.	Max.
outer	outer	0.893	1.107
	inner	0.944	1.056
inner	outer	0.944	1.056
	inner	0.924	1.076

TABLE A4

Hg VALUES FOR MARK 15 assembly

Slug	Surface	Hg Range Min.	Hg Range Max.
outer	outer	0.88	1.12
	inner	0.88	1.12
inner	outer	0.88	1.12
	inner	0.88	1.12

TABLE A5

H_m VALUES FOR MARK 15 assembly

		H_m Range	
Slug	Surface	Min.	Max.
outer	outer	0.983	1.013
	inner	0.983	1.013
inner	outer	0.981	1.025
	inner	0.981	1.025

TABLE A6

H_w VALUES FOR MARK 15 ASSEMBLY

Slug	Surface	H_w
outer	outer	1.069
	inner	1.084
inner	outer	1.084
	inner	1.081

TABLE A7

H_p VALUES FOR MARK 15 ASSEMBLY

		H_p Range	
Slug	Surface	Min.	Max.
outer	outer	0.98	1.02
	inner	0.98	1.02
inner	outer	0.98	1.02
	inner	0.98	1.02

TABLE A8

CMX UNCERTAINTIES FOR MARK 15 ASSEMBLY*

UNCERTAINTY U_j	RANGE OF FACTORS APPLIED TO BURNOUT HEAT FLUX						RANGE OF FACTORS APPLIED TO OPERATING HEAT FLUX		
	FACTOR	SAT. TEMP., °C min.	SAT. TEMP., °C max.	FACTOR	VELOCITY min	VELOCITY max	FACTOR	min.	max.
Assembly Flow	B_{16}	-0.2	0.001	B_{15}	0.99	1.00	-	-	-
Channel Flow	B_{18}	-0.2	0.1	B_{17}	0.99	1.00	B_{19}	0.99	1.00
Coolant Pressure	B_{21}	-0.2	0.2	-	-	-	-	-	-

**Currently only valid for K and C charges.*

TABLE A9

REACTOR COOLANT FLOW AND TEMPERATURE MEASUREMENT UNCERTAINTIES FOR MARK 15 ASSEMBLY

UNCERTAINTY U_j	RANGE OF FACTORS APPLIED TO BURNOUT HEAT FLUX									RANGE OF FACTORS APPLIED TO OPERATING HEAT FLUX		
	FACTOR	SAT. TEMP., °C		FACTOR	T Coolant, °C		FACTOR	VELOCITY		FACTOR		
		min.	max.		min.	max.		min	max		min.	max.
Monitor Pin Thermocouple (avg. of 4)	-	-	-	B_{22}	-0.5	0.5	-	-	-	*B_{25}	-0.5	0.5
Isothermal Box Ref. Thermohm	-	-	-	B_{23}	-0.1	0.1	-	-	-	*B_{26}	-0.1	0.1
Plenum Inlet Temperature	-	-	-	-	-	-	-	-	-	*B_{27}	-0.1	0.1
Analog-Digital Conversion and Computer	-	-	-	B_{24}	-0.1	0.1	-	-	-	*B_{28}	-0.1	0.1
Zone Flow	B_{31}	-1.6	1.6	-	-	-	B_{30}	0.98	1.02	B_{29}	0.98	1.02
Assembly Flow	-	-	-	-	-	-	B_{33}	0.98	1.02	B_{32}	0.98	1.02
Channel Flow	-	-	-	-	-	-	B_{35}	0.95	1.05	B_{34}	0.95	1.05

Nonideality factor given in degrees centigrade form.

TABLE A10

REACTOR AXIAL POWER UNCERTAINTIES FOR MARK 15 ASSEMBLY

UNCERTAINTY U_j	RANGE OF FACTORS APPLIED TO OPERATING HEAT FLUX		
	FACTOR	MIN.	MAX.
APM Chamber Accuracy	B_{37}	0.96	1.04
APM Curve Fitting	B_{38}	0.96	1.04
APM Discrete Calculations	B_{39}	0.98	1.02

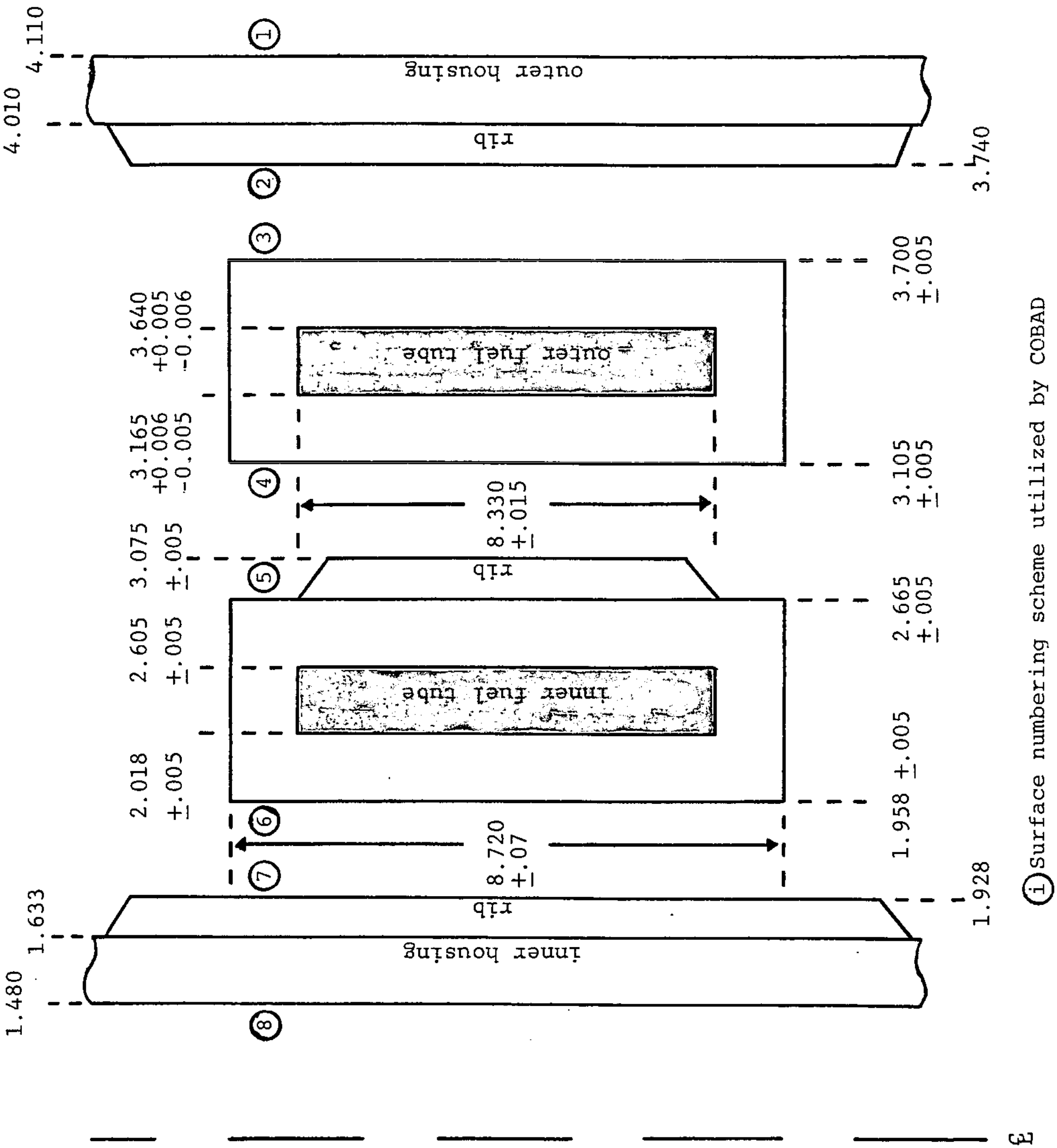


FIGURE A1. MARK 15 ASSEMBLY MANUFACTURING TOLERANCES NECESSARY FOR UNCERTAINTY ANALYSES.

FIGURE A2
Power Fraction Variation of Inner Mark 15 Slug for Different Radial Specifications

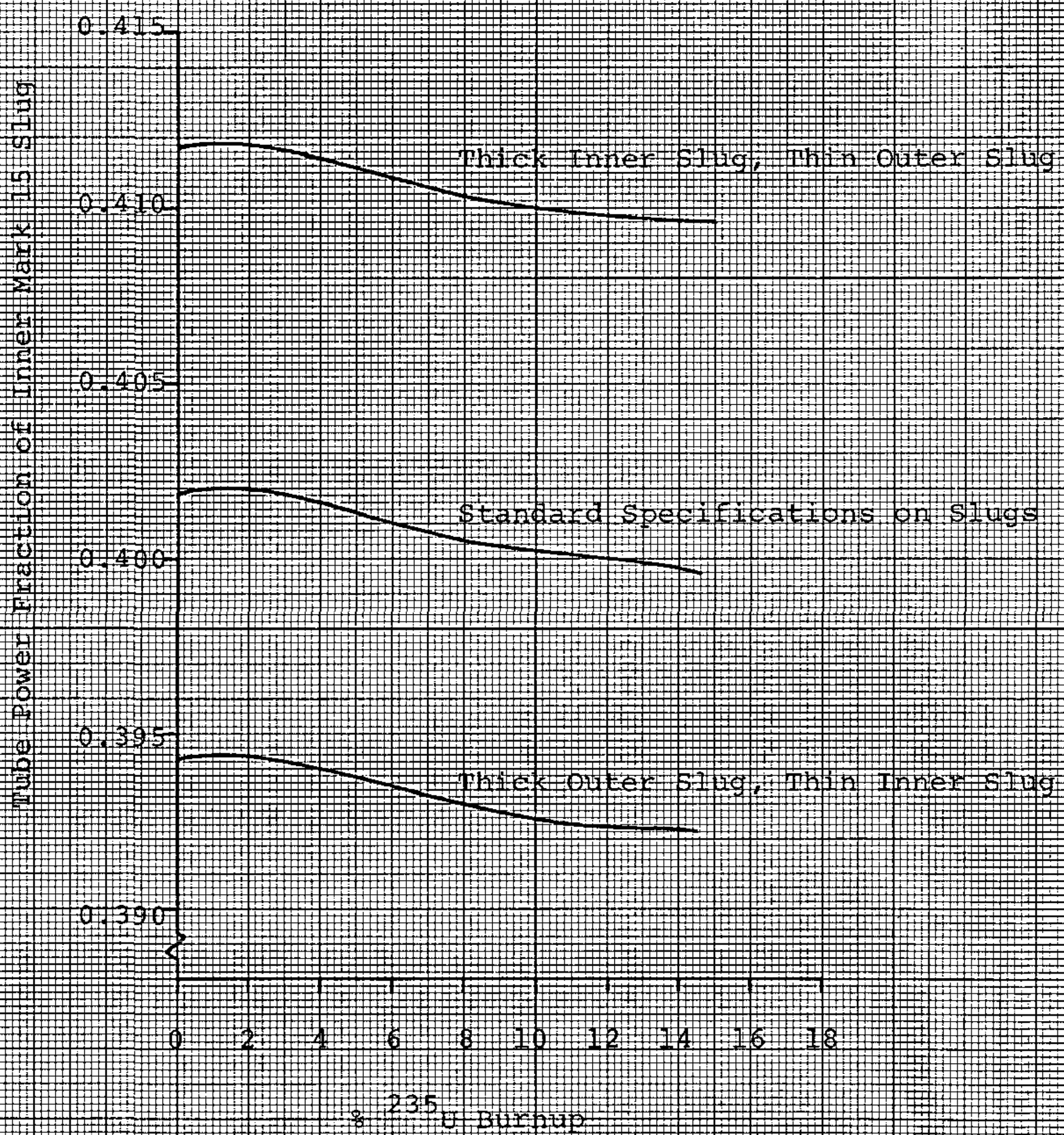
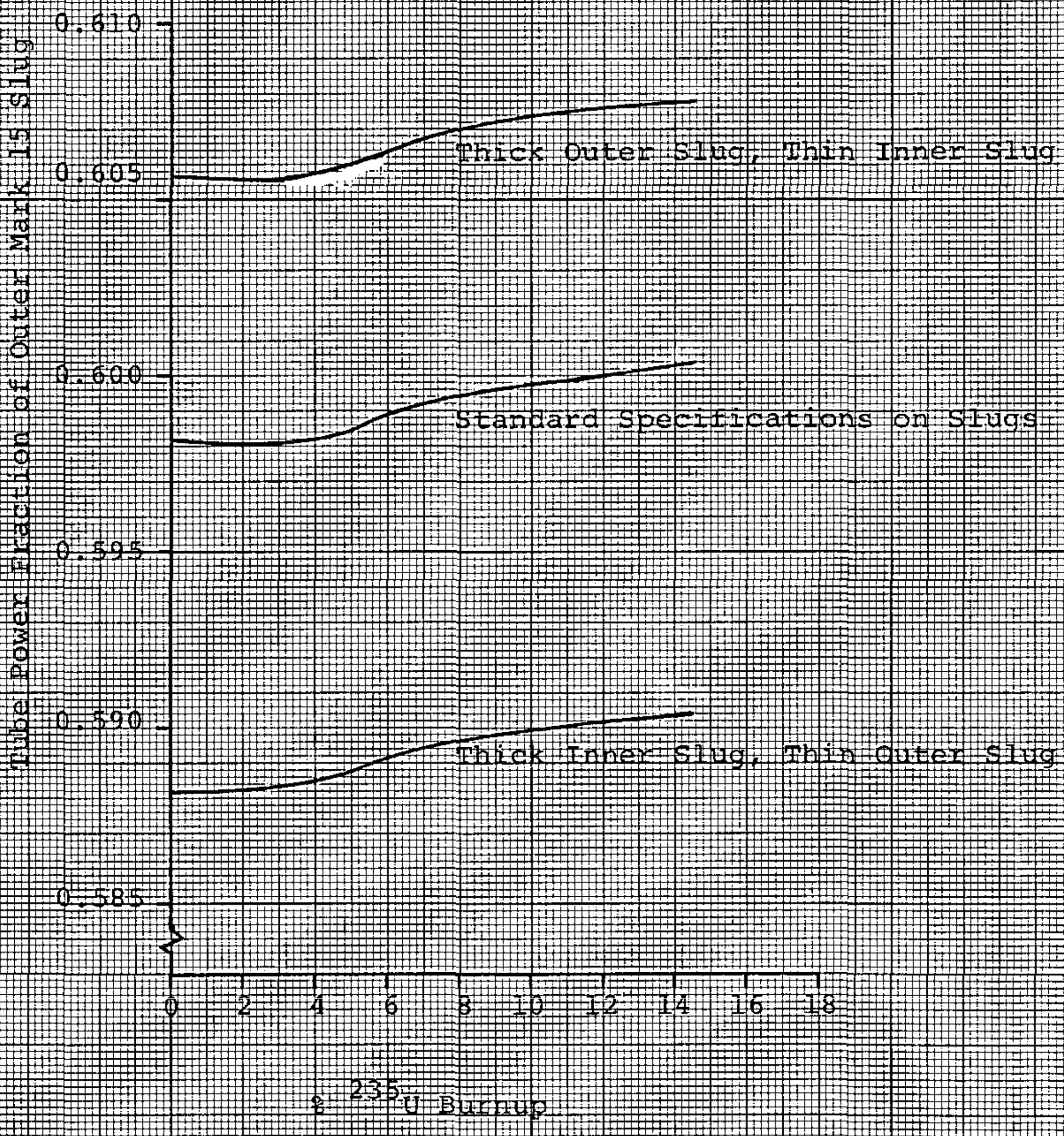


FIGURE A3
Power Fraction Variation of Outer
Mark 15 Slug for Different
Radial Specifications



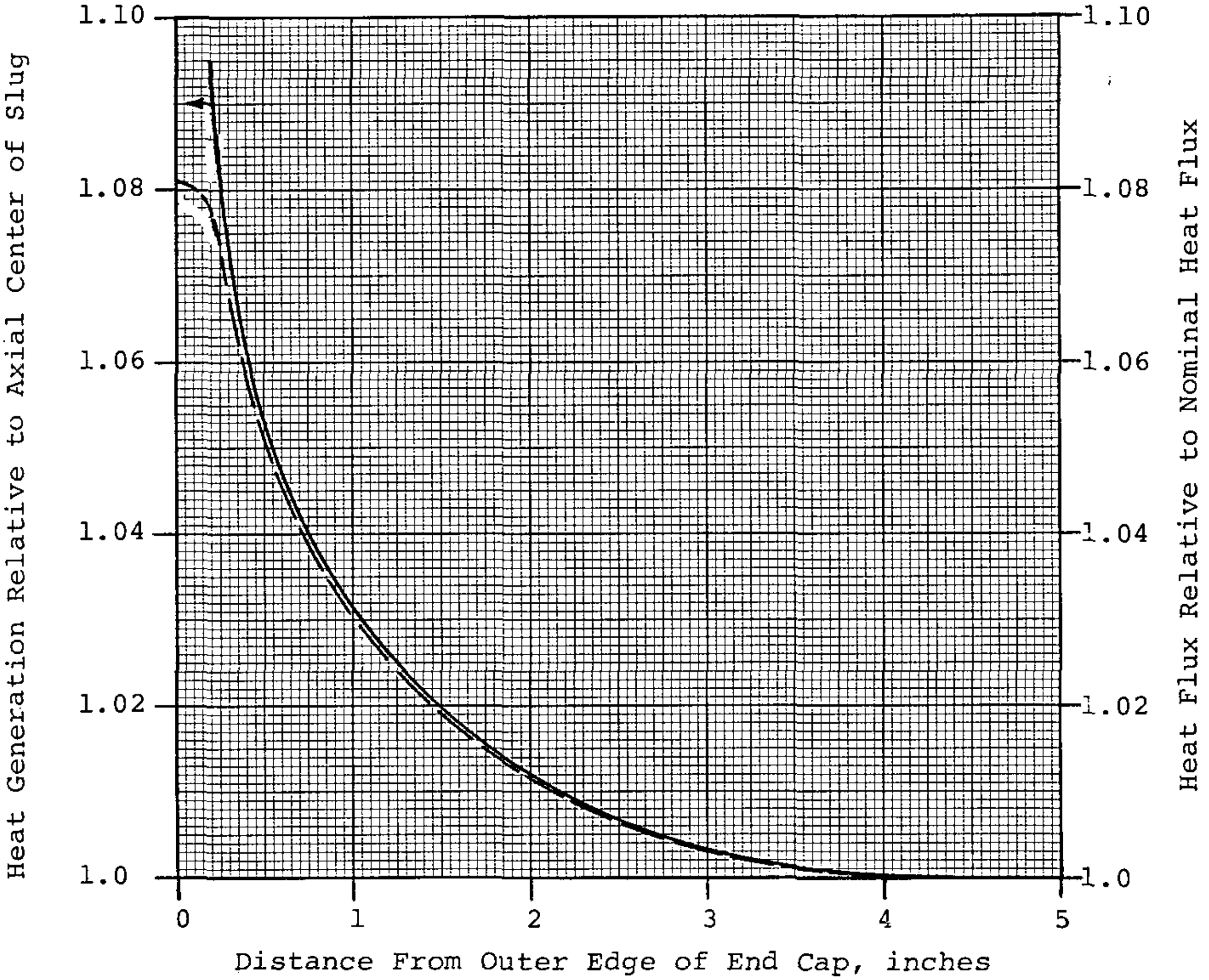


Figure A4. Increased Heat Generation and Heat Flux From the Wilkins Effect for the Inner Surface of the Inner Mark 15 Slug

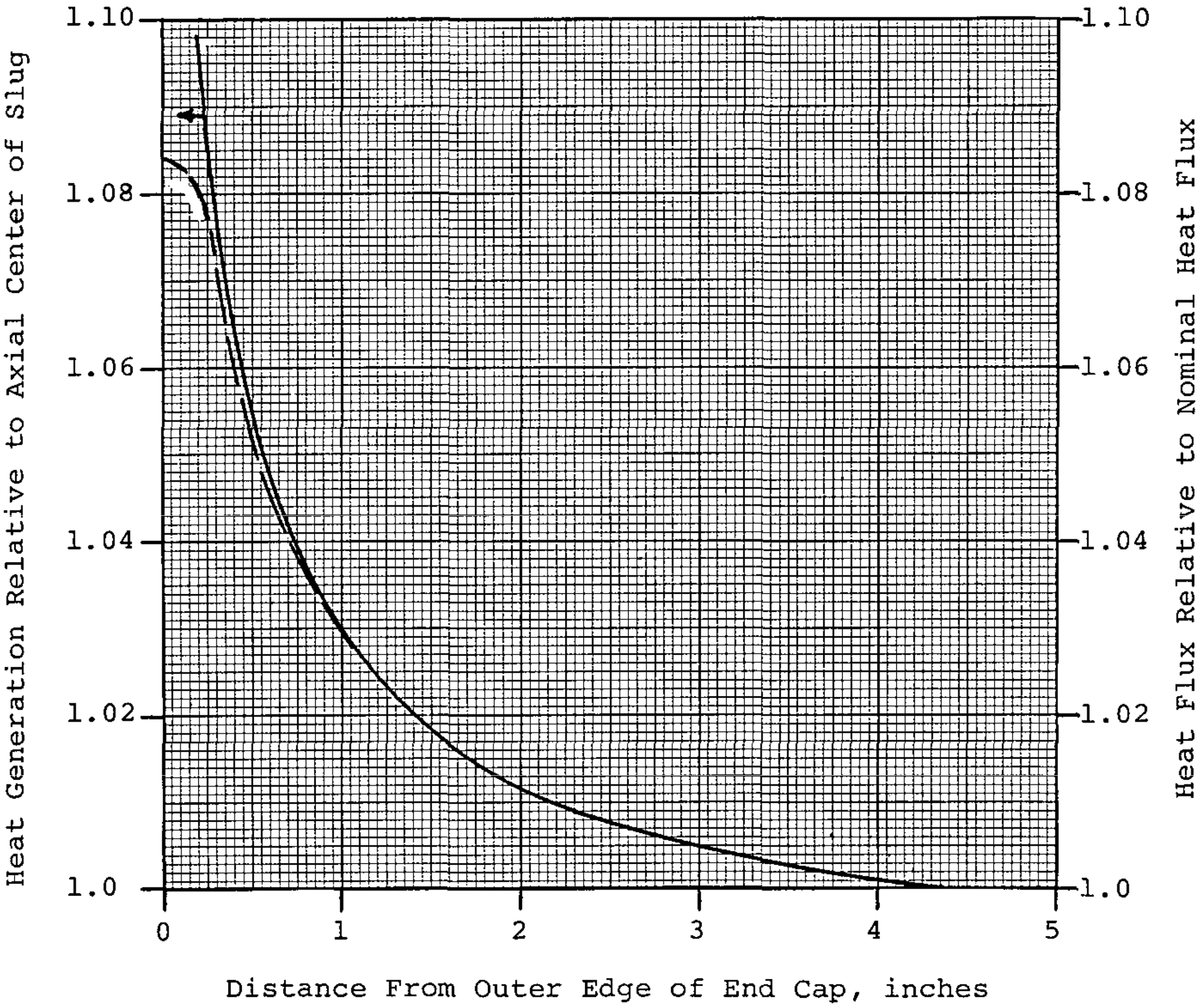


Figure A5. Increased Heat Generation and Heat Flux From the Wilkins Effect For the Outer Surface Of the Inner Mark 15 Slug

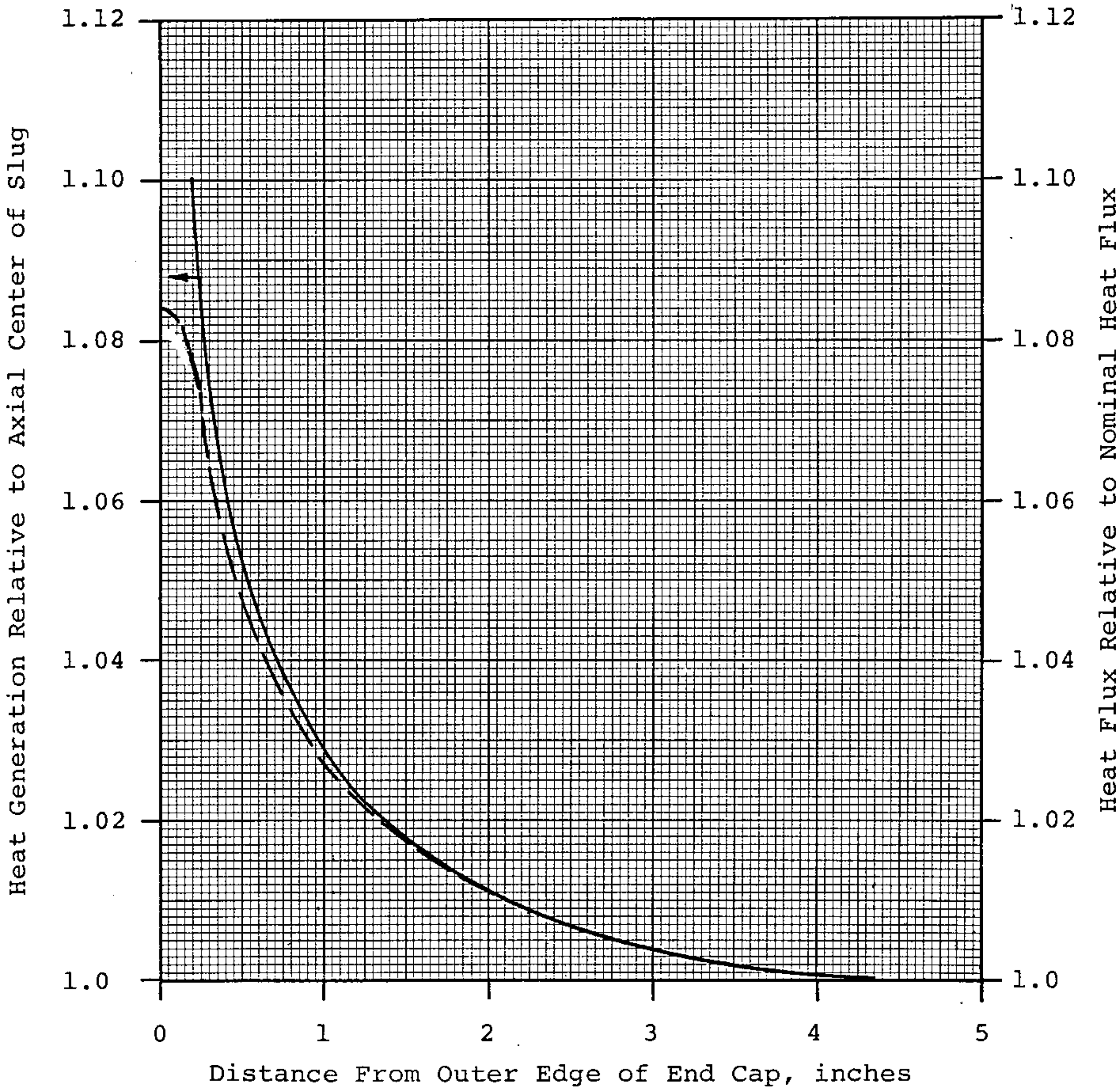


Figure A6. Increased Heat Generation and Heat Flux From the Wilkins Effect for the Inner Surface of the Outer Mark 15 Slug

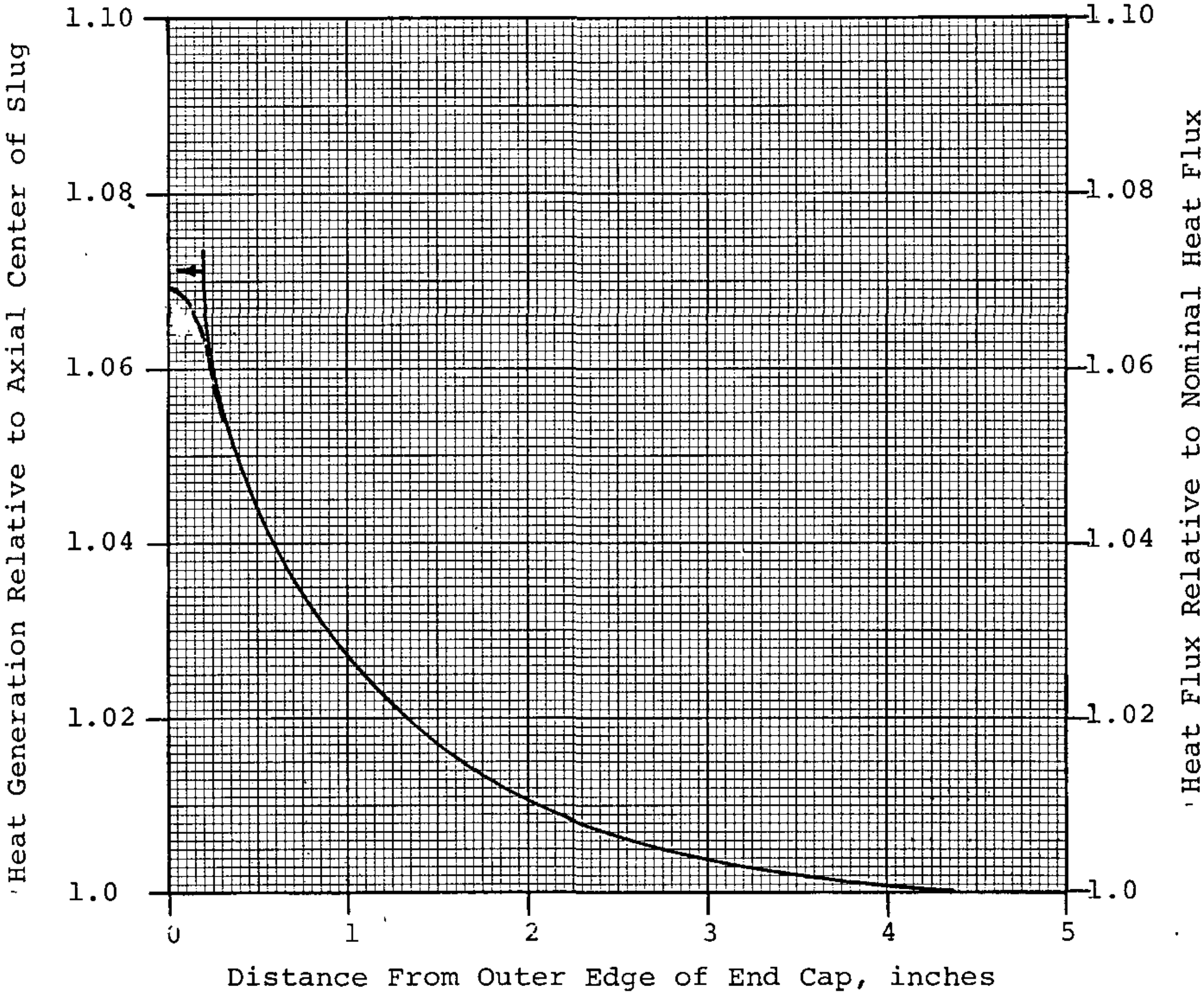


Figure A7. Increased Heat Generation and Heat Flux From the Wilkins Effect For the Outer Surface of the Outer Mark 15 Slug

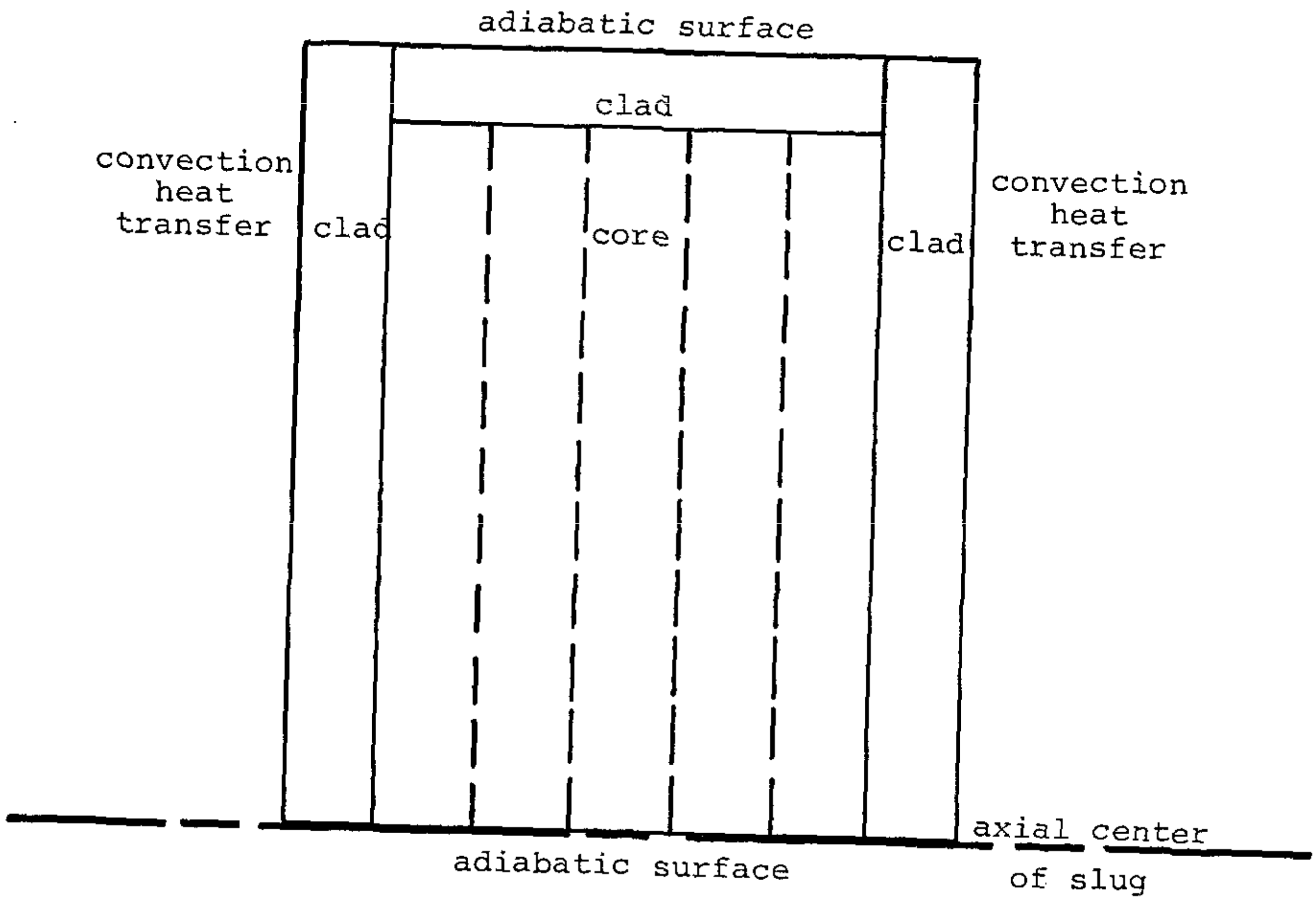


Figure A8. HEATING5 Slug Model

APPENDIX B

Appendix B summarizes all input data associated with tube surface uncertainties for the Mark 15 assembly. These input data are employed by COBAD for doing damage calculations and were placed on records of the form:

5365.INPUT.DITTYBOP.NONIDEAL.M15.?

where the last qualifier indicates the surface. The surface number scheme employed by COBAD is shown on Figure A1 and is cross-referenced below:

Surface Number	Slug	Surface	Qualifier ?
1	outer housing	outer	SUR1-OD
2		inner	SUR2-ID
3	outer fuel	outer	SUR3-OD
4		inner	SUR4-ID
5	inner fuel	outer	SUR5-OD
6		inner	SUR6-ID
7	inner housing	outer	SUR7-OD
8		inner	SUR8-ID

Each uncertainty has allocated to it a group of nonideality factors which affect either or both operating and burnout heat flux through various variables. Thus, each individual nonideality factor of a given uncertainty must be identified by the following descripters:

- The type of distribution function of the uncertainty.
- The specific variable to which the nonideality factor is applied.
- Whether the numerical values of the nonideality range are in fractional form or degrees centigrade.
- The relationship, positive or negative, between the allowance and the nonideality factor.

These descripters, as well as their selected values, are given in Table B1. A summary of the nonideality factors, their extreme values, and their key descripters are given in Table B2 for all eight surfaces.

TABLE B1

KEY INDEX FOR TABLE B2

FACTORS ARE PRINTED IN THEIR DEPENDENT GROUPINGS

NTYPE - TYPE OF DISTRIBUTION OF THE FACTORS IN EACH GROUP
- 1 - CONSTANT
- 2 - UNIFORM
- 3 - NORMAL

NVAR - NUMBER OF THE VARIABLE TO WHICH THE NONIDEALITY IS APPLIED
- 1 - BURNOUT HEAT FLUX
- 2 - VELOCITY
- 3 - SATURATION TEMPERATURE
- 4 - BULK TEMPERATURE RISE
- 5 - OPERATING HEAT FLUX

NDEGPC - KEY NUMBER SPECIFYING WHETHER NONIDEALITY IS PERCENT OR DEGREES CENTIGRADE
- 1 - PERCENT
- 2 - DEGREES CENTIGRADE

NMIN - KEY NUMBER SPECIFYING THE MIN-MAX RELATIONSHIP
- 1 - MINIMUM VALUE OF NONIDEALITY OCCURS WHEN MINIMUM VALUE OF STANDARD NONIDEALITY OCCURS
- 2 - MAXIMUM VALUE OF NONIDEALITY OCCURS WHEN MINIMUM VALUE OF STANDARD NONIDEALITY OCCURS

TABLE B2

TUBE SURFACE UNCERTAINTIES FOR THE MARK 15

SURFACE NUMBER 1

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR

SURFACE NUMBER 2

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR

SURFACE NUMBER 7

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR

SURFACE NUMBER 8

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR

TABLE B2 continued
TUBE SURFACE UNCERTAINTIES FOR THE MARK 15

SURFACE NUMBER 3

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR
1	5			1.04700		HEC
2	5	1	1	0.98000	1.02000	HP
1	5			1.06900		HW
3	5	1	1	0.98300	1.01300	HM
2	2	1	2	0.89300	1.10700	HV
2	4	1	1	0.89000	1.11000	HT
2	5	1	1	0.88000	1.12000	HG
3	2	1	1	0.99000	1.00000	CMX TOTAL FLOW
3	3	2	1	-0.20000	0.00100	CMX TOTAL FLOW
3	2	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.10000	CMX CHANNEL FLOW
3	5	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.20000	CMX PRESSURE
3	4	2	1	-0.50000	0.50000	MPTC
3	5	2	1	-0.50000	0.50000	MPTC
3	4	2	1	-0.10000	0.10000	THERMOHM
3	5	2	1	-0.10000	0.10000	THERMOHM
3	4	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	TIN
3	2	1	1	0.98000	1.02000	ZONE FLOW
3	3	2	1	-1.60000	1.60000	ZONE FLOW
3	5	1	1	0.98000	1.02000	ZONE FLOW
3	2	1	1	0.98000	1.02000	ASSY FLOW
3	5	1	1	0.98000	1.02000	ASSY FLOW
3	2	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.96000	1.04000	APM ACRCY
3	5	1	1	0.96000	1.04000	APM FIT
3	5	1	1	0.98000	1.02000	APM CALC

SURFACE NUMBER 4

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR
1	5			1.04700		HEC
2	5	1	1	0.98000	1.02000	HP
1	5			1.08400		HW
3	5	1	1	0.98300	1.01300	HM
2	2	1	2	0.94400	1.05600	HV
2	4	1	1	0.92300	1.07700	HT
2	5	1	1	0.88000	1.12000	HG
3	2	1	1	0.99000	1.00000	CMX TOTAL FLOW
3	3	2	1	-0.20000	0.00100	CMX TOTAL FLOW
3	2	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.10000	CMX CHANNEL FLOW
3	5	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.20000	CMX PRESSURE
3	4	2	1	-0.50000	0.50000	MPTC
3	5	2	1	-0.50000	0.50000	MPTC
3	4	2	1	-0.10000	0.10000	THERMOHM
3	5	2	1	-0.10000	0.10000	THERMOHM
3	4	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	TIN
3	2	1	1	0.98000	1.02000	ZONE FLOW
3	3	2	1	-1.60000	1.60000	ZONE FLOW
3	5	1	1	0.98000	1.02000	ZONE FLOW
3	2	1	1	0.98000	1.02000	ASSY FLOW
3	5	1	1	0.98000	1.02000	ASSY FLOW
3	2	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.96000	1.04000	APM ACRCY
3	5	1	1	0.96000	1.04000	APM FIT
3	5	1	1	0.98000	1.02000	APM CALC

TABLE B2 continued

TUBE SURFACE UNCERTAINTIES FOR THE MARK 15

SURFACE NUMBER 5

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR
1	5			1.04700		HEC
2	5	1	1	0.98000	1.02000	HP
1	5			1.08400		HW
3	5	1	1	0.98100	1.02500	HM
2	2	1	2	0.94400	1.05600	HV
2	4	1	1	0.92300	1.07700	HT
2	5	1	1	0.88000	1.12000	HG
3	2	1	1	0.99000	1.00000	CMX TOTAL FLOW
3	3	2	1	-0.20000	0.00100	CMX TOTAL FLOW
3	2	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.10000	CMX CHANNEL FLOW
3	5	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.20000	CMX PRESSURE
3	4	2	1	-0.50000	0.50000	MPTC
3	5	2	1	-0.50000	0.50000	MPTC
3	4	2	1	-0.10000	0.10000	THERMOHM
3	5	2	1	-0.10000	0.10000	THERMOHM
3	4	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	TIN
3	2	1	1	0.98000	1.02000	ZONE FLOW
3	3	2	1	-1.60000	1.60000	ZONE FLOW
3	5	1	1	0.98000	1.02000	ZONE FLOW
3	2	1	1	0.98000	1.02000	ASSY FLOW
3	5	1	1	0.98000	1.02000	ASSY FLOW
3	2	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.96000	1.04000	APM ACRCY
3	5	1	1	0.96000	1.04000	APM FIT
3	5	1	1	0.98000	1.02000	APM CALC

SURFACE NUMBER 6

NTYPE	NVAR	NDEGPC	NMIN	BMIN	BMAX	IDENTIFICATION
1	1			0.92000		HCOR
1	5			1.04700		HEC
2	5	1	1	0.98000	1.02000	HP
1	5			1.08100		HW
3	5	1	1	0.98100	1.02500	HM
2	2	1	2	0.92400	1.07600	HV
2	4	1	1	0.95200	1.04800	HT
2	5	1	1	0.88000	1.12000	HG
3	2	1	1	0.99000	1.00000	CMX TOTAL FLOW
3	3	2	1	-0.20000	0.00100	CMX TOTAL FLOW
3	2	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.10000	CMX CHANNEL FLOW
3	5	1	1	0.99000	1.00000	CMX CHANNEL FLOW
3	3	2	1	-0.20000	0.20000	CMX PRESSURE
3	4	2	1	-0.50000	0.50000	MPTC
3	5	2	1	-0.50000	0.50000	MPTC
3	4	2	1	-0.10000	0.10000	THERMOHM
3	5	2	1	-0.10000	0.10000	THERMOHM
3	4	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	ADC CONV
3	5	2	1	-0.10000	0.10000	TIN
3	2	1	1	0.98000	1.02000	ZONE FLOW
3	3	2	1	-1.60000	1.60000	ZONE FLOW
3	5	1	1	0.98000	1.02000	ZONE FLOW
3	2	1	1	0.98000	1.02000	ASSY FLOW
3	5	1	1	0.98000	1.02000	ASSY FLOW
3	2	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.95000	1.05000	CHNL FLOW
3	5	1	1	0.96000	1.04000	APM ACRCY
3	5	1	1	0.96000	1.04000	APM FIT
3	5	1	1	0.98000	1.02000	APM CALC