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AXIAL SHAPE INDEX FOR BOSF

INTRODUCTION

Minimum burnout safety factor (BOSF) in a fuel assembly is a function of the axial distribution of power as well as total power, temperature, and flow. Axial power distribution is expressed in reactor problems by values of relative power at each of 20 axial layers as derived from TWFM or APM data. Meaningful representation of the axial power distribution, by a single factor is desirable to rapidly analyze fuel power data and optimize operating flux shapes. Empirical factors which have been used to qualitatively define flux shapes - rooftop ratio, maximum-to-average ratio, percent saddle, flattened cosine, etc. - are too vague and imprecise in relation to BOSF. A reliable and consistent means is needed to communicate more meaningful shape information among interested parties in SRL and Reactor Technology Physics and Engineering groups.

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* Calculations for this work were made by R. H. Stephens, Summer Technical Employee in Reactor Technology.

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SUMMARY

An axial shape index (ASI) is developed which represents the effect of axial power distribution on BOSF accurately enough to predict BOSF within ±5% with gross changes in distribution. The index is a simple function of the "n" and "m" values (see Discussion) for any distribution:

$$ASI = (n \cdot m)_{max}$$

For constant conditions of power, temperature, flow, and pressure, BOSF in a fuel assembly is approximately inversely proportional to the ASI:

$$\frac{(BOSF)_1}{(BOSF)_0} \simeq \frac{(ASI)_0}{(ASI)_1}$$

The index is useful because:

- it provides a quantitative relationship between BOSF and axial power distribution alone - without reference to particular fuel assembly conditios,
- it is a simple function of n and m values,
- it is a more accurate indicator of the BOSF - axial shape relationship than are rooftop ratio, maximum-to-average ratio, or percent saddle.

CONCLUSION

It is concluded that either the ASI or the entire flux shape be documented with calculated or reported BOSF, values, in cases where axial shape may be important to BOSF, and reactor power (e.g., SRL Engineering and Physics Technical Manuals starting with Mark 14, Reactor Technology Engineering and Physics memoranda, projections of reactor power performance in advance conceptual fuel types and case studies made by SRL - AOP). If this were done, apparent discrepancies can be more easily identified and resolved by all groups.

DISCUSSION

Background

The method used at SRP to calculate the approach to film boiling in fuel or target assemblies involves the axial power distribution of the particular component in the reactor flux. Reactor flux shapes are subject to considerable variation because of control rod configurations used to meet desired operating objectives. The calculated margin from film boiling varies with the flux shape and component power, but for simplification most quoted performance levels are only defined at one set of operating conditions (often based on the most convenient flux shape available to the calculator). This practice has led to some confusion in identifying differences in performance level and in incentives and goals for axial flux shaping. It is the purpose of this study to clarify the realtionship between BOSF and axial flux shape and to establish a meaningful common language for those involved in fuel and target performance calculations.

Nominal BOSF

Approach to film boiling in heat producing fuel assemblies is expressed by the burnout safety factor (BOSF), which is the minimum ratio of burnout heat flux to operating heat flux at any point in the assembly. Using the applicable burnout heat flux correlation (Reference 1), $BOSF_N$* is expressed by the following equation:

$$BOSF_N = \left(\frac{85{,}300\ (1 + 0.0515V)\ \left[1 + 0.124(T_{sat} - T_{in} - m\ \Delta T) \right]}{(P/A) \cdot n} \right)_{minimum} \qquad (A)$$

P = assembly power, pcu/hr

A = surface area, ft^2

V = mean channel velocity at the burnout site, ft/sec

T_{sat} = saturation temperature at the burnout site, °C

T_{in} = plenum inlet temperature, °C

ΔT = total temperature change of fluid within assembly, °C

n = normalized local heat flux

m = accumulated heat generation

The values n and m are functions of the axial power distribution and nothing else. For a 20-layer distribution, m is approximated at the midpoint of each layer by:

$$m_i = \frac{\sum_{i-1}^{1} n + \sum_{i}^{1} n}{2 \cdot \sum_{20}^{1} n} \qquad (B)$$

For the usual case where values of n are normalized to unity;

$$\sum_{20}^{1} n = 20$$

The DRTFY code uses 50 layers to define flux shapes, but the same relationship for ASI should be equally applicable.

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* The equation is solved for each of the 20 axial layers, using appropriate values for T_{sat}, n, and m at each layer, where n and m vary with the flux shape. $BOSF_N$ is the minimum value over the 20 layers.

To assess the effect on $BOSF_N$ of a change in axial power shape, it has been, in the past, necessary to perform a complete BOSF calculation for the new distribution and compare this BOSF value with the former. As shown by Equation A, $BOSF_N$ is not a simple function of n and m.

Axial Shape Index

A simple, empirical function of n and m for any given axial distribution has been developed which provides a good approximation of the effect of a changed axial distribution on BOSF. The function is called the Axial Shape Index (ASI) and is defined as follows:

$$ASI = (n \cdot m)_{max}$$

As shown by the example in Table I, an axial flux distribution is defined by 20 values of n, the normalized power generation in each layer. A value of m for each layer is calculated by Equation B. The ASI is the maximum of the products of n and m over the 20 layers. It is also of interest that the point of minimum BOSF is generally at the "Index Layer".

Validity of the index was established by calculating* $BOSF_N$'s for several fuel assemblies over a wide range of powers, temperatures, and flows, and for 15 different axial distributions. Table II shows the ranges covered in power and temperature. Table III illustrate the range covered with the 15 axial distributions.

Representative results of the calculations are illustrated in Figure 1. $BOSF_N$ was calculated for each fuel assembly at typical conditions of power, flow, and temperature for each and at each of the 15 axial shapes. The correlation between ASI and $BOSF_N$ is within about ±5%, except for one Mark V-R case with a very extreme axial shape (perfectly flat).

The following relationships are apparent from Figure 1:

$$\frac{(BOSF)_1}{(BOSF)_0} = \left[\frac{(ASI)_0}{(ASI)_1}\right]^X$$

Mark V-R $X = 1.07$

Mark 14 $X = 0.95$

Mark XII-A $X = 0.94$

For general application it can be assumed that X = 1.0 and that BOSF is then inversely proportional to ASI.

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* The DETTY-1 program for the IBM 360 computer was used for BOSF calculations.

Additional confirmation of the validity of the ASI is shown by data in Figure 2 from Mark XII-A operation in the Mixed Lattice - ThO_2 program. $BOSF_N$ was calculated for the limiting Mark XII-A assembly using the maximum channel temperatures and appropriate axial distribution data. Therefore, the only cause for any change in the difference between the operating pads from the Channel Effluent and $BOSF_N$ limits is a change in the axial distribution. The good correlation of the differential pad and ASI shown in Figure 2 indicates validity of the ASI in accounting for the effect on BOSF of axial distribution.

DAW:gvb

REFERENCE

1. "Technical Manual - Effluent Temperature and Surface Heat Flux Limits for Fuel and Target Assemblies", DPSTM-110, June 1966, prepared by W.H. Baker (Secret).

Table I

Typical Evaluation of ASI

Layer	n	m	n · m
1	0.47	.012	
2	0.77	.043	
3	0.96	.086	
4	1.06	.137	
5	1.10	.191	
6	1.10	.247	
7	1.08	.301	
8	1.05	.355	
9	1.04	.407	
10	1.03	.459	
11	1.03	.511	
12	1.04	.563	
13	1.06	.616	.653
14	1.09	.670	.730
15	1.10	.725	.798
16	1.10	.780	.858
17	1.10	.835	.919
18	1.06	.889	.942
19	0.95	.940	.833
20	0.72	.982	.707

Axial Shape Index = $(n \cdot m)_{max}$ = 0.942

Index Layer = 18

Table II

Power and Temperature Ranges Covered in Calculations

Assembly	Power (MW)	Inlet Temperature (°C)
V-R	3 - 5.5	30° - 40°
VI-E	3.5 - 6.5	30° - 45°
XII-A	8 - 11	30° - 40°
14	5 - 8.5	30° - 45°

Table III

Range Covered by Axial Distributions Studied

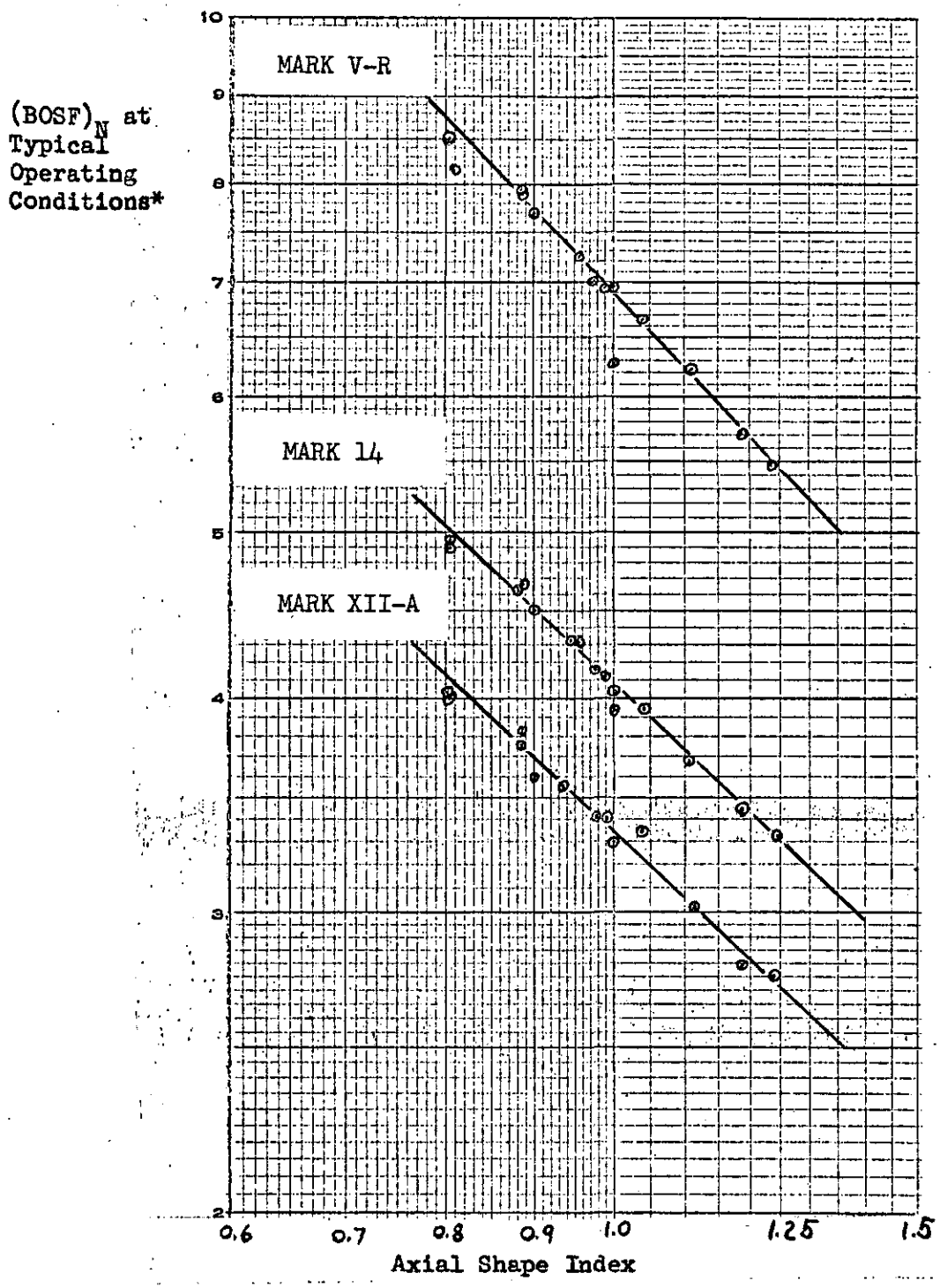
Qmax/Qavg	1.0 - 1.5
RTR	0.5 - 2.2
Percent Saddle	0 - 70%*

* Saddled shapes studies had equal peaks; percent saddle is defined here as:

$$1 - \frac{\text{relative power at either peak}}{\text{minimum relative power between peaks}}$$

Figure 1

$(BOSF)_N$ Versus ASI



* These are not necessarily at comparable reactor conditions for each of the fuel types, so no inference should be made about their relative $BOSF_N$'s.

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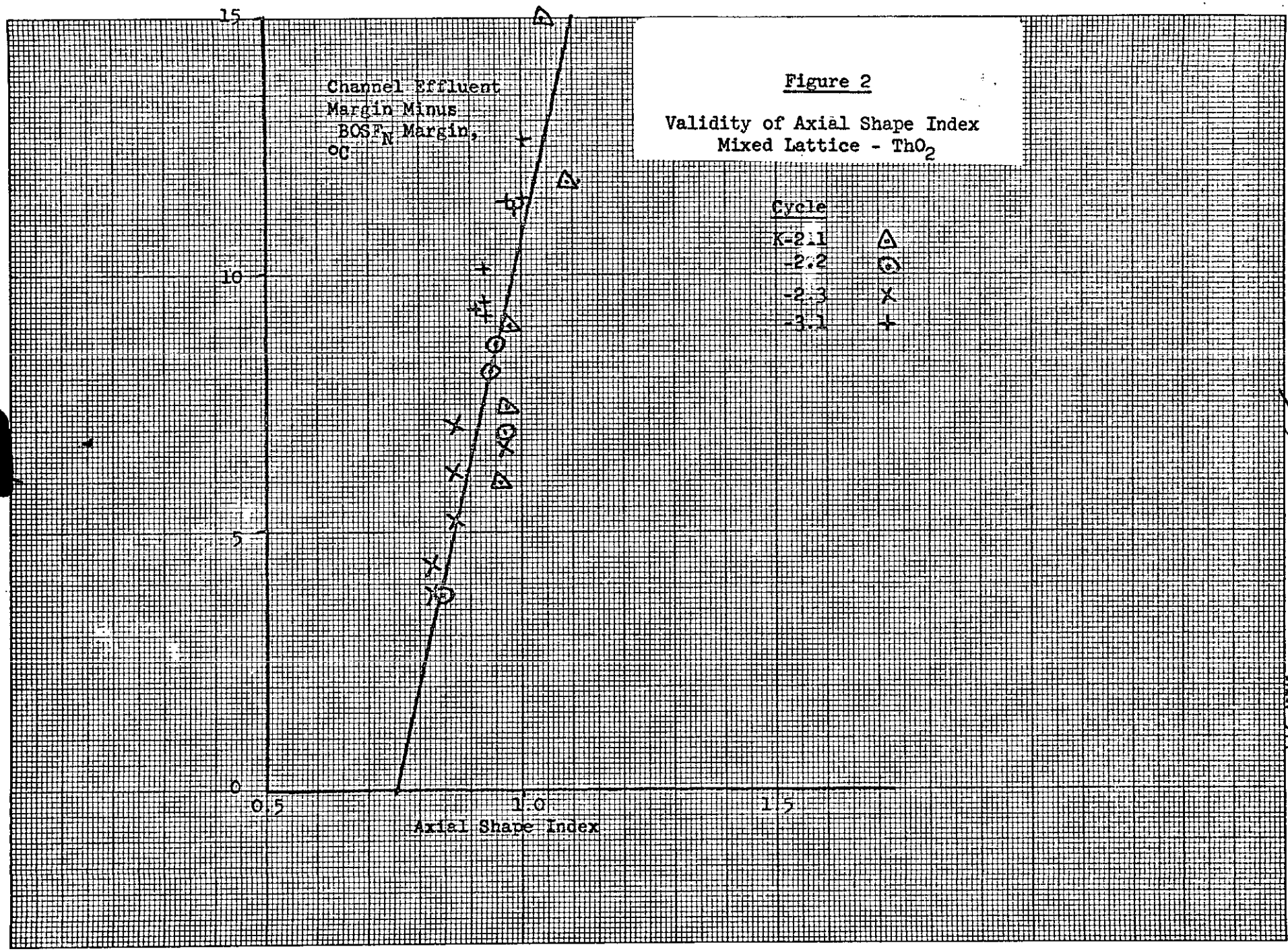

Figure 2

Validity of Axial Shape Index
Mixed Lattice - ThO_2

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