DPST-65-246

BURNOUT PROGRAM FOR HIGH HEAT FLUX ASSEMBLIES (U)

Westinghouse Savannah River Co.
Savannah River Site
Aiken, South Carolina 29808

This is a Technical Report on the
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Due: ASAP

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

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May 26, 1965

M E M O R A N D U M

TO: E. C. NELSON

FROM: R. H. TOWELL RHT
REACTOR ENGINEERING DIVISION

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INTRODUCTION

The power of high flux fuel assemblies and three-tube drivers planned for future operations is limited by the burnout safety factor (BOSF). In the past, the power of standard production fuel assemblies was limited almost always by one of the hydraulic limits, and in most cases the assemblies operated at powers significantly below that permitted by the BOSF limit.

The burnout conditions for an "ideal" fuel surface have been well established in mockups at SRL and Columbia University. Little experimental data are available on nonidealities (such as local hot spots), although calculated factors are applied to the BOSF to account for certain nonidealities. Because of operation at the BOSF limit, better knowledge is needed of the effects of non-idealities and other factors on heat transfer burnout of fuel surfaces. This memorandum presents a program designed to give a better understanding of BOSF.

SUMMARY

The following program is proposed to improve knowledge of the effects of nonidealities on BOSF limits for SRP fuel assemblies and to define acceptable risks of operation when burnout is limiting:

- Measure and/or analytically determine effects of nonidealities (hot spots and hot channel factors) on burnout heat flux, and develop statistical methods of applying such factors to BOSF limits.
- Measure effects of aluminum surfaces, cosine heat generation, and heating from both surfaces on heat transfer burnout.
- Re-evaluate Technical and Operating Limits on BOSF.
- Evaluate methods of reducing effects of nonidealities in production fuel assemblies (such as by reducing manufacturing tolerances for fuel element fabrication and assembly).

The program will require about three technical man-years at SRL and a test program at Columbia University in FY-1966 and 1967. Tests under the second item above require relatively large-size test sections that exceed the current generating capacity at SRL. Such capacity is available at Columbia University, and it is proposed that $90,000 be made available annually in FY-1966 and FY-1967 for burnout tests at Columbia University. The present program at Columbia University on flow instability ($90,000 in FY-1965) is expected to be completed by the end of this fiscal year.

Preliminary calculations and burnout tests indicate that the above program may lead to potential power increases up to ~30% in high flux and three-tube driver assemblies. Such power gains could be realized only if (1) penalty factors for nonidealities and the Operating Limit on BOSF can be safely reduced and (2) the burnout heat flux is increased by the aluminum surfaces of the fuel.

DISCUSSION

Hot Spots

The hot spot factors used in calculating the BOSF (burnout safety factor) represent departures from an ideal heat transfer surface. An ideal heat transfer surface is defined as one with uniform heating and cooling. Nonidealities in the heating or cooling of the fuel surfaces can cause localized increases in the operating heat flux or decreases in the burnout heat flux. In fuel assemblies, nonidealities are caused by ribs, unbonded areas between the fuel and cladding, nonuniform fuel distribution, neutron flux gradients, restricted coolant passages, and to a lesser extent nonuniform oxide thickness on aluminum clad fuel tubes.

The BOSF of SRP fuel assemblies is computed on the basis of burnout tests on idealized heat transfer surfaces, and the nonidealities of the assemblies (with one exception) are calculated, most of them pessimistically but some optimistically. The single exception is the reduction of the burnout heat flux caused by contact between a rib and the surface of a fuel piece, which was experimentally measured at SRL (DP-562).

Fuel core thickness is held within limits specified both circumferentially and longitudinally, and hot spot factors are applied to the operating heat flux to represent these limits. Fuel segregation, rib upset, and nonbonds are held within specified limits by 300-Area inspection. The limits for these nonidealities are determined on the basis of relaxation calculations of the local heat flux increases and the pessimistic assumption that the burnout heat flux is affected as strongly by these nonidealities as the local peaking of the operating heat flux. Preliminary tests at SRL have shown that, because of their short length or narrow width, these nonidealities affect the burnout heat flux much less strongly than they peak the local operating heat flux.

It was also pessimistically assumed for the first SRP assemblies that nonbonds and fuel segregation occurred on top of each other and at the hottest point of the hottest assembly in a charge. Such nonidealities do not actually occur on every assembly, may occur anywhere on the fuel tube, and are not necessarily associated with each other. With the Mark VIB, the factors for nonbonds and fuel segregation spots were not compounded; any fuel pieces with such a defect is rejected.

Neutron flux gradients cause an increase in the operating power and heat flux on one side of the assembly. The gradients are measured in the PDP and are a function of the fuel-target loading and the reactivity held in the control rods. A hot spot factor is applied to the operating heat flux to account for the flux gradient.

The fuel pieces in an assembly with a neutron flux gradient may bow (because of differential thermal expansion) towards the high power side and restrict the coolant channels on the hot side. The burnout heat flux, which is a function of the coolant velocity and subcooling, may be reduced on the hot side because of reduced coolant flow in the restricted passages as well as the extra heat addition. If it is assumed that the fuel pieces are bowed against the ribs over their length, the increased ΔT and flow reduction in the hot channel can be calculated. However, the increases in ΔT as measured by thermocouple assemblies in the reactor are always less than half of the calculated increase. These measurements indicate that the fuel pieces do not contact the ribs over much of their length. Because the calculated hot channel factor has been shown to be too pessimistic, the worst hot channel factor measured in the instrumented assemblies is used to calculate the burnout heat flux. There is some optimism in using a measured hot channel factor, even if it is the worst value measured, because only a few assemblies are instrumented and there is no assurance that one of these assemblies will have the worst possible combination of all the factors that affect the hot channel factor.

Heat Transfer Burnout of Fuel Elements

The burnout heat flux of fuel elements is predicted from tests of electrically-heated mockups fabricated of stainless steel or 70% Cu-30% Ni alloys. Several of the differences between fuel elements and the mockups may be important in predicting reactor safety. The first of these differences is the material of the heat transfer surface which in the fuel elements is aluminum, not a stainless alloy. Preliminary tests at SRL have indicated that for a given coolant velocity and subcooling, the burnout heat flux may be as much as 20% higher on an aluminum surface than on a stainless surface. If this is true, then the BOSF, which is computed from the correlation of the mockup tests, is low by 20%.

Other differences between the electrical mockups and the fuel elements concern the behavior of the two after local film boiling starts. All the heat transfer burnout tests conducted at SRL and Columbia University* have used heaters with uniform heat generation along the length. Burnout occurred at or very near the effluent end of the heated section with uniform heat generation. With cosine heat generation, as in the fuel assemblies, burnout would occur at a point about 1/3 the heated length from the effluent end.

Because burnout occurs further upstream with cosine generation, the area of the fuel surface in film boiling will be larger than indicated in tests with uniform heat generation. The extent of the film boiling cannot be predicted from tests with uniform heat generation, because the bubbles move downstream with the flow, off the heated surface, and collapse immediately. Tests at SRL indicate that bubbles generated at upstream sites contribute to the burnout process. It is possible then that the extent of local melting may also be greater than indicated by uniform heat generation tests.

Another difference between the mockups and the fuel elements that has not been tested and might affect burnout is the effect of heat transfer from both walls of an annulus. The tests on which the burnout correlation is based were all obtained with only one wall of the annulus heated. Both the three-tube driver and the high flux assemblies have annular coolant passages heated from both walls. It is currently assumed that the burnout heat flux is not affected by heat transfer from the second wall, and the coolant passage is designed so that the coolant temperature rise remains the same for both cases. This is a very reasonable assumption, but it should be experimentally verified.

*Tests at Columbia University on a mockup of the Mark I quatrefoil used cosine heat generation. However, the failure in these tests was due to flow instability, not heat transfer burnout.

Burnout Program

The burnout program concerned with nonidealities is expected to remove uncertainties in their effect on burnout and provide for statistical treatment of the factors that might affect local burnout. The burnout program for nonidealities is as follows:

- Measure the burnout heat flux of those nonidealities where burnout is affected by the short length or narrow width of the hot spot.
- Evaluate the sampling basis for the hot channel factor and apply statistical analysis.
- Obtain statistical data on the magnitude and frequency of nonidealities and develop method of applying such factors to BOSF limits.
- Evaluate methods of reducing effects of nonidealities in production fuel assemblies (such as by reducing manufacturing tolerances for fuel element fabrication and assembly).

The program concerned with heat transfer burnout of fuel elements is expected to determine the effect of the aluminum sheath, the effect of nonuniform aluminum oxide thickness, the behavior of film boiling with cosine heat generation, and the effect of heating both walls of an annulus. This part of the program will require large-size test sections and will be done at Columbia University where sufficient generating capacity is available.

- Measure burnout heat flux on aluminum surfaces with as-extruded and oxidized surfaces (Columbia University at cost of about $60,000 in FY-1966).
- Measure effect of cosine flux shape on burnout and determine behavior of film boiling patch (Columbia University at cost of about $15,000 in FY-1966).
- Measure burnout heat flux of annuli heated from both surfaces (Columbia University at cost of about $15,000 in FY-1966).
- Confirm burnout tests on aluminum surfaces in existing equipment at SRL.

The remaining program is concerned with re-evaluation of the Technical and Operating Limits on BOSF. The limits are an integral part of the experimental and analytical program and must be re-evaluated with information obtained in the above programs so that the risks of operating at the BOSF limit can be defined. The Technical Limit on BOSF is 1.3 to allow for deviations of the burnout data about the correlation. The Operating Limit is currently 1.7. A margin between the two limits is required to allow for accidental power increases, fluctuations in process variables, and uncertainties in monitoring the BOSF. With improved monitoring and protection for accidental power increases, the Operating Limit on BOSF can be reduced to 1.5. Such improvements were made for the High Flux charges, and a TA is currently being prepared by Reactor Technology to reduce the Operating Limit on BOSF to 1.5 for High Flux charges.

Power Increases

Preliminary analysis indicates that the above program may lead to power and productivity gains with high flux and three-tube driver assemblies. The preliminary analysis, which is given in detail in Table I, shows the potential power increases to be about equally divided among the three portions of the program. The total potential power increase is about 40% for both assemblies. However, only part of these power increases can be realized, because the assemblies reach the effluent temperature limit with power increases of about 30%.

The power increases shown in Table I are the results of:

- Using factors interpolated from preliminary tests of nonbonds, fuel segregation spots and streaks, and rib upsets.
- Using the 20% higher burnout heat flux measured in preliminary tests on aluminum surfaces.
- Reducing the Operating Limit on BOSF from 1.7 to 1.5.

RHT/hhh

TABLE I

POTENTIAL POWER INCREASES OF BOSF LIMITED ASSEMBLIES

	High Flux Assembly		Three-Tube Driver	
Power Increase to Reach Effluent Temperature Limit	35%		30%	
Power Increase From Hot Spot Factors (HSF)	13%		10%	
	Design HSF	Expected HSF	Design HSF	Expected HSF
Non Bonds	*1.22	1.02*	**1.22	1.10*
Fuel Segregation	*1.22	1.05*	*1.22	1.05*
Rib Upset	1.06	1.04	1.08	1.05
Core & Assembly Tolerances, Flux Gradients, etc.	1.20	1.20	1.16	1.16
	1.55	1.31	1.53	1.34
Power Increase From Aluminum Surface Effect	15%		15%	
***Power Increase by Reducing the Operating Limit on BOSF From 1.7 to 1.5	10%		10%	
Total Potential Power Increase From Burnout Program	43%		39%	

*Assumed not at same spot on fuel tube.
**Assumed to be same value as High Flux fuel tubes.
***Requires improved monitoring and surveillance of BOSF.

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Power Increase From Aluminum Surface Effect	15%		15%	
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