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SAVANNAH RIVER LABORATORY

DPST-86-385

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April 14, 1986

MEMORANDUM

TO: C. E. AHLFELD, 773-A

FROM: T. E. BRITT, 773-41A TEB

NATURAL CONVECTION BURNOUT HEAT FLUX LIMIT FOR CONTROL RODS

INTRODUCTION

Technical Standard 105-3.05, Safety Circuits, does not require the Septifoil Supply Header Pressure Very Low safety circuit for current charges. This document develops a new requirement for this circuit based on the burnout heat flux of a control rod under natural convective cooling. Specifically, the Septifoil Supply Header Pressure Very Low safety circuit will be required whenever the calculated control rod operating heat flux exceeds 155,000 pcu/ft^2-hr.

DISCUSSION

The Septifoil Supply Header Pressure Very Low safety circuit is designed to provide protection against loss of control rod cooling. Under forced convective flow, film boiling burnout is the only mechanism identified by which a control rod can be overheated (Reference 1). To protect against this situation, the maximum control rod operating heat flux is restricted to a value no greater than 2/3 of the minimum forced convection burnout heat flux (Reference 2). However, if this safety circuit is bypassed or becomes inoperable, then a loss of forced convective flow may go unnoticed. The cooling regime in the septifoil would shift from forced to natural convection. Under natural convective flow, the heat flux of the control rods could exceed the natural convection burnout heat flux and damage the control rods (see Table I). Consequently, Technical Standard 3.05 is being revised to provide a margin of protection to prevent damage to the control rods in this situation. The basis for the new requirement is described below.

BASIS FOR NATURAL CONVECTION BURNOUT HEAT FLUX

A minimum burnout heat flux of 233,000 pcu/ft^2-hr is used as the basis for the operating heat flux limit applied to the Septifoil Supply Header Pressure Very Low safety circuit. The minimum burnout heat flux for a control rod under natural convective cooling was determined experimentally using an "L" septifoil (Reference 3). This value confirmed the results of earlier calculations (a natural convective burnout heat flux of 250,000 pcu/ft^2-hr) based on "L" septifoil (Reference 4). The current "J" septifoil and the "L" septifoil used in the experiments and calculations are very similar in design and the burnout heat flux values determined from the "L" septifoil experiments are applicable to the "J" septifoil (Reference 4).

BASIS FOR NATURAL CONVECTION OPERATING HEAT FLUX

The operating limits placed on control and safety rods undergoing forced convective cooling are designed to prevent the onset of film boiling burnout. The limits include a pad to account for uncertainties in calculating the control rod operating heat flux, to provide protection against overheating resulting for any of the incidents listed in DPST-110, Effluent Temperatures and BOSFN Limits for Fuel and Target Assemblies and Reactor Effluent Temperature Limits, and for uncertainties in the determination of the burnout heat flux (References 5, 6, and 7). Application of these uncertainties results in a restriction of the operating heat flux to a value no greater than 2/3 the minimum burnout heat flux (Reference 8). In the case of natural convective cooling, the same protection required under forced convective cooling is also required. The most significant challenge to control rod cooling under forced or natural convection would occur during incident "b" (a single rod withdrawal) or incident "c" (a gang rod withdrawal). These incidents can increase the control rod heat flux by a factor at least five times greater than any other incident described in DPSTM-110 (see Table II). In either incident "b" or "c", the heat flux could increase by as much as 25%. This alone would require restricting the control rod heat flux to a value no greater than 75% of the minimum burnout heat flux. This potential flux increase coupled with the uncertainties in calculating the operating heat flux and determining the burnout heat flux require a limit on the maximum operating heat flux when the septifoil supply header pressure safety circuit is bypassed or inoperable to protect against exceeding the natural convection burnout heat flux. To accomplish this, the above uncertainties are applied as was done for the forced convection limit and a factor of 2/3 results. This factor is consistent with the establishment of the operating heat flux for control, safety, and insert rods in DPST-105-2.09 and is conservative (Reference 6). Table I shows the burnout heat flux for forced and natural convection cooled control rods and the maximum allowable operating heat flux limits.

IMPACT OF LIMIT ON REACTOR OPERATION

Under currently operating charges, the highest calculated control rod operating heat flux is less than the limit developed in this document. Therefore, no impact on current reactor operation is expected. Even in the event of a localized (incident "b") or reactor (incident "c") power increase and the unnoticed loss of septifoil cooling, the accumulative effect on the control rod heat flux of current charges is well below the burnout heat flux during natural convection.

It must be noted that reactor power has increased substantially in the past 5 years. Future charges could increase the operating heat flux of control rods to the extent that failure to maintain the Septifoil Supply Header Pressure Very Low safety circuit could substantially increase the risk of control rod damage. As reactor power is increased, the potential of a simultaneous failure of septifoil cooling and occurrence of incident "b" or "c" must be reviewed carefully.

TABLE I
Control Rod Heat Flux

CONDITION	MINIMUM BURNOUT HEAT FLUX	MAXIMUM OPERATING HEAT FLUX
Forced Convection	440,000 pcu/ft^2-hr	293,000 pcu/ft^2-hr
Natural Convection	233,000 pcu/ft^2-hr	155,000 pcu/ft^2-hr*

* Applicable when the Septifoil Supply Header Pressure Very Low Safety Circuit is bypassed or inoperable.

TABLE II*

Effect of Postulated Reactor Incidents
Incidents on Control Rod Burnout Margin

Incidents	Transient Effect on Control Rod Burnout Margin
a. Slow, uniform flow reduction in a fuel coolant channel to the set point of the rod reversal (no rod reversal).	None.
b. Local power increase (single rod withdrawal.	Operating heat flux could increase by as much as 25%. The maximum expected power overshoot is 25%**.
c. Reactor power increase (gang rod withdrawal).	Operating heat flux could increase by as much as 25%. The maximum expected power overshoot is 25%**.
d. Reduction in heavy water flow (AC power loss).	Insignificant effect. Flow decrease is slow (initially 5% per sec); power decreases rapidly after 1.7 seconds.
e. Sudden reduction in heavy water flow (pump shaft break).	Insignificant effect.
f. Sudden reduction in H_2O flow in one header.	No effect.
g-1. Slow reduction in blanket gas pressure.	Burnout heat flux could decrease by as much as 2% from a 1 to 2°C reduction in subcooling.
g-2. Sudden reduction of blanket gas pressure.	Burnout heat flux could decrease by as much as 5% from a reduction in subcooling of 5°C.
h. Uniform flow reduction in one assembly to the scram set point (no scram).	None.

* Reference 6.
** Based on survey of Reactor Incident calculations (Reference 6).

REFERENCES

1. S. D. Harris, Flow Instability in Forced Convection Cooled Septifoils-Type J, DPST-72-496, October 24, 1972.

2. D. H. Knoebel, Heat Flux Limits for Control Rods, DPST-69-343, May 9, 1969.

3. H. W. Hodges, Burnout Heat Flux for Control Cooled by Natural Convection, DPST-73-456.

4. S. Mirshak, Control Rods Cooled by Natural Convection, DPST-72-59-54, March 6, 1972.

5. H. P. Olson, Heat Flux Limits for Control and Safety Rods, DPST-72-400, December 1, 1972.

6. H. P. Olson, Control and Safety Rod Cooling for Savannah River Plant Reactors, DPSTSY-100-3, October 1974.

7. Safety Rod, Control Rod, and Insert Rod Heat Generation, DPST-105-2.09, (In Review).

8. Technical, Transient Protection, and Confinement Protection Limits for SRP Reactors, (Rev. 21), DPSTM-110, July, 1984.