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P. W. R. PROTECTION SYSTEM

PRESENT STATUS AND IMPROVEMENTS

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INTRODUCTION

The purpose of the protection system is to insure that ANS condition II events will not result in fuel rod failures and that condition III or IV will only result in limited release of radioactivity.

In order to satisfy the above criteria, the following design bases have been established for the protection system design :

- Departure from nucleate boiling (DNB) is not expected during condition II events. This is met by limiting the minimum departure from nucleate boiling ratio (DNBR) to 1.3.

  This ratio is a function of the power level, of the primary conditions (pressure, temperature) and of the power distribution.

- Fuel melting is not expected during condition II events. This is met by limiting the local overpower to a given value. Local overpower is a function of the power level and of the power distribution.

- Specific criteria have to be met for the LOCA accident.

PRESENT PROTECTION SYSTEM : ΔT SYSTEM

The core protection impose limits on important design variables, which in turn are translatable into limits on related process variables.

For a given flow rate, these limits can be related to the following process variables : core thermal power, coolant temperature and pressure, and core axial flux difference (ΔI).

The thermal overpower and overtemperature trips respond to unacceptable conditions in all or some of these variables.

The ΔT overpower system protects the core against overpower conditions (fuel melting).

The ΔT overtemperature system protects the core against DNB.

Trip is initiated when the power level (primary temperature increase ΔT measurement) equals a power limit (ΔT trip set point) which is function of primary conditions (temperature and pressure) and a parameter (axial power difference = ΔI) which is significant of the core power distribution.

ΔI is measured by four two sections excore detectors.

NUCLEAR CALCULATIONS

The spatial power distribution has two components :

. the radial power distribution,
. and the axial power distribution.

A synthesis of these two components leads to a tridimentional power distribution and the validity of this method has been verified through many incore flux map with an accuracy of 5 % on total power peaking factor (F_Q^T) and 4 % on Enthalpy rise hot channel factor ($F_{\Delta H}$).

. Radial power distributions are mainly function of fuel burnup distribution, burnable poison loading pattern and presence or absence of full length control rods in each horizontal plane. The effects of power level, xenon samarium and moderator density are taken into account but these are quite small.

- Axial power distributions are largely under control of the operator through the control rods motion and are also function of burnup, xenon and moderator density distributions. Axial power distributions are characterized by a parameter called Axialoffset (AO) defined as :

$$AO = \frac{P_t - P_b}{P_t + P_b}$$

where P_t and P_b are respectively power generation in top and bottom halves of the core. Axial offset is measured continuously by means of 4 excore detectors and used by the operator to control axial power distributions. Therefore, nuclear design calculations have to correlate this parameter (AO) with the two parameters : F_Q^T and $F_{\Delta H}$.

- Calculations are performed first for normal operation including normal transients like load follow situations with different power ramp, power escalations at maximum speed. Beginning, middle and end of cycles conditions and different histories of operation are assumed in the calculations.

The results are synthesized from axial calculations combined with radial factors appropriate for rodded and unrodded planes, taken into account uncertainties and engineering factors.

The envelope drawn over the calculated points represent an upper bound envelope on local power density versus core elevation during normal operation. This envelope is an input to the LOCA analysis which must satisfy the corresponding safety criteria. Otherwise, a feedback is made on control strategie. Figure 1 illustrates such typical envelope with a maximum at 2.35 relative power.

. Starting from previous normal conditions of operation, we simulate class II events, mainly control rod malfunction and operator errors. Total peaking factors (F_Q^T) obtained are then plotted versus A.O. and determine a flyspeck like illustrated in figure 2 where is drawn an envelope showing a plateau at a typical value of 2.69 relative power.

The peak linear power being limited to 18 kw/ft by design consideration (well below the melting temperature occuring at a linear power density of 22 kw/ft) it is possible to determine from the previous envelope, for each value of axial offset, what maximum power can be allowed without exceeding the above criteria, leading to a limitation of core power versus AO typically illustrated on figure 3. In all cases, the total core power is limited to 118 % nominal power giving enough flexibility to plant operation.

- From previous synthesis calculations performed on normal operation and class II events, envelope of $F_{\Delta H}$ can be drawn function of core power level taking into account the control rod bank insertion, typically

$$F_{\Delta H} < 1.55 \left[1 + 0.2(1 - P)\right]$$

All the axial power distributions are then used in DNB calculations in order to correlate DNBR with AO parameter.

CALCULATIONAL BASIS FOR ΔT TRIP SETPOINTS

ΔT overtemperature trip setpoint

Trip setpoints are calculated on a two step sequence.

- In the first step, ΔT limits which correspond to the DNBR design limit (typically 1.3) are calculated as a function of the coolant temperature and pressure assuming a fixed reference core power distribution :

  The reference axial power distribution is a chopped cosine with a peak to average value F^N_Z of 1.55 (typical value for 3 loop plants).

  The radial peaking factor, $F^N_{\Delta H}$ will obey the following equation :

  $$F^N_{\Delta H} = 1.55 \left[1 + 0.2 (1 - P)\right]$$

  P = power level.

  Line segments are obtained in a plane ΔT, T (average temperature) for different pressures. Trip setpoint can then be calculated assuming a linear approximation of these limits :

  $$\Delta T_{limit} = K_1 - K_2 T + K_3 p$$

- In the second step, the appropriateness of the reference power distribution is checked and a compensating term is derived which accounts for core power distributions more severe with respect to DNB than the reference core power distribution. This compensating term is a linear function of ΔI.

  The final equation of the trip setpoint can be represented by :

  $$\Delta T_{limit} = K_1 - K_2 T + K_3 p - f(\Delta I)$$

./.

The compensating term is determined by the following procedure :

- for each power shape generated by Nuclear calculations, the power level that gives a minimum DNBR of 1.3 is calculated.
- calculations are performed assuming coolant conditions (temperature, pressure) situated on the DNB limits which are calculated during the first step.

ΔT overpower trip setpoint

Nuclear calculations indicate that a power limit of 118 % can be accurate in a given band of ΔI. Outside of this band, power limit is decreased using a compensating term which is a linear function of ΔI. Trip set point can be represented by the following equation :

$$\Delta T_{limit} = K_4 - K_5 T - f' (\Delta I)$$

The temperature dependance results from the fact that thermal power is not precisely proportional to ΔT due to coolant density and heat capacity effects.

PROTECTION SYSTEM IMPROVEMENTS

- The use of envelope power distribution results in a significant loss of plant availability and operability. In particular, for each ΔI value, the most pessimistic power distribution is used to determine a compensating term in the ΔT protections.

  The improvements which are described later are made possible by the use of :

  . multisection excore detectors which allow a better knowledge of the axial power distribution

  . microprocessors which are able to deal with fairly sophisticated algorithms with a sufficiently short-response time.

- DNBR and KW/ft trips involve microprocessor calculations of current plant operating conditions based on inputs from the following plant sensors :

  . primary temperature detectors

  . primary pressure detectors

  . rod position indicators for radial power distribution

  . multi-section excore detectors for axial power distribution. The FRA 6-sections excore instrumentation is described later

  . primary pump speed measurement for normalized core flow rate

- This new system is such that the actual power distribution is used to determine the DNBR. Thus it is possible to take benefit from favourable power shape when this is the case. It enhances the level of safety in the sense that through the use of a more accurate instrumentation it allows the protection system to automatically include the effect of adverse power shapes much more effectively than before. It improves the manoeuvrability of the plant since some operational transients are feasible with the new system, although they are impossible with the classical system because of the simplistic way the power distribution is taken into account.

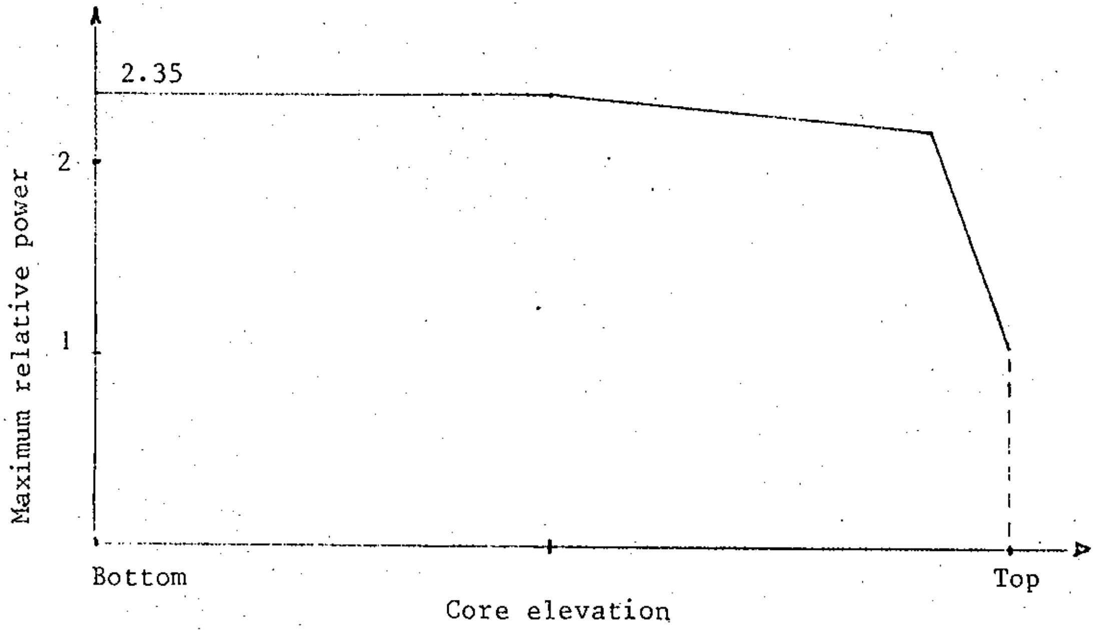

Figure 1 - Maximum linear power versus core elevation during normal operation.

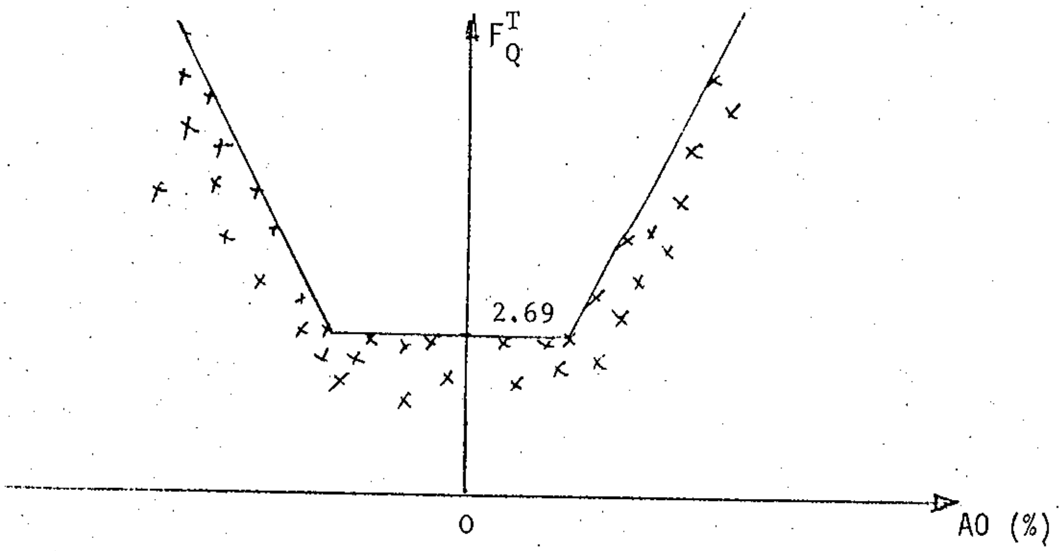

Figure 2 - Maximum linear power versus AO during normal operation and class II events.

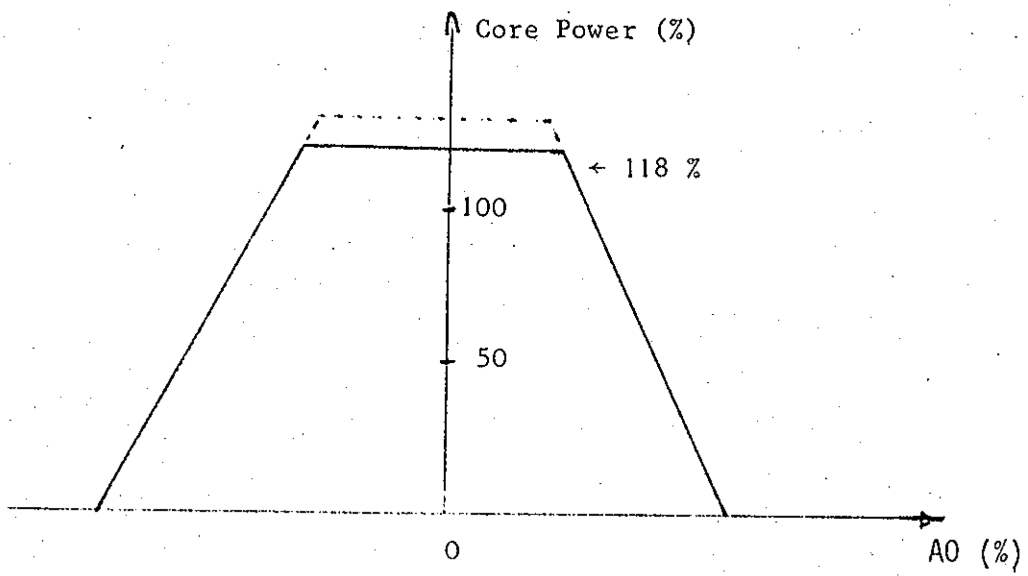

Figure 3 - Maximum core power versus AO.