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Dynamic Model for Predicting DNBR in PWR during Loss of Flow Accident

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ABSTRACT: Departure from nucleate boiling ratio, (DNBR) is the important factor in the operation of a pressurized water reactor, (PWR) it is of interest to determine how it is affected by variations in the parameters of which it is a function, such as reactor core pressure, coolant inlet temperature, and core flow rate. In this work, a new proposed dynamic model demonstrated by which DNBR can be readily determined and predict in Partial loss of flow accident (PLOFA). For input, boundary conditions are specified relating the time dependent variations of core inlet coolant temperature, system pressure, core heat flux, and coolant flow. The new model predicts the minimum value of DNBRs (MDNBR), and the most parameter from the studied parameters is affected. The new proposed dynamic model has good capability to predict the dynamic performance of the effect of significant parameters on behaviour of the DNBR during partial Loss of Flow Accident PLOFA within period of time. Moreover, the results show that the predicted MDNBR is 1.55. Also the mass flow and the system pressure are directly proportion with DNBR on the hand where DNBR is inversely proportion with fluid temperature and heat flux. There is a good agreement between the results obtained and those published.

KEYWORDS: MDNBR, Dynamic Model, PWR, PLOFA, CHF.

1.INTRODUCTION

The PLOFA is one of the important conditions of reactor coolant system flow down in the design basis accidents. In this condition partial number the reactor coolant pumps stop due to loss of power, and it leads to the partial loss of forced core flow, thereby causing an increase in reactor coolant temperature, and there is a possibility that minimum DNBR limits are exceeded, resulting in partial failure of the fuel rods[1] .

One of the key safety parameters during the transient of pressurized water reactor is the departure from nucleate boiling ratio (DNBR), this ratio is a function of the power level, and the primary conditions (pressure, temperature and mass flow rate) [2]. an alternative technique has been demonstrated in this analysis Which results in a best-estimate calculations of the DNBR and its probability distribution. The desired relationship between MDNBR and rod diameter subject to the constraints of constant specific power and constant enthalpy rise is given in .The rod heat flux is influenced by the changing rod diameter in two ways: by changes in the rod surface area, and changes in linear power for a given rod. With increase the rod diameter is the MDNBR will decrease [3]. A technique has been demonstrated in a best-estimate calculation of the DNBR and its probability distribution. A computer code, COBRA IIIC/MIT, was used to perform the best-estimate calculation. Additional computer runs were made with the code to perform a sensitivity analysis on the code input variables in order to identify significant variables and minimize subsequent computational effort. A pressurized water reactor (PWR) generally operates in the nucleate (sub cooled) boiling regime. The transition from nucleate boiling to the film boiling accompanied by severe reduction of the heat transfer capability can result, however, in a boiling crisis that in the long run can cause fuel clad melting. This type of boiling crisis is called the departure from nucleate boiling (DNB). The DNB can overheat fuel pellet and cladding. DNBR is defined as the ratio of the expected critical heat flux (CHF) to the actual fuel rod heat flux and is used for measuring the DNB phenomena. Therefore, it is very important to predict and monitor MDNBR in the reactor core to prevent boiling

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crisis and cladding melting. By now, lots of researches have been conducted to predict DNBR values [2]. In previous researches DNBR analysis, was performed as a function of a single input variable while all other parameters were kept fixed in normal and transits conditions [4]–[11].

In this research a new Dynamic model is proposed using **Matlab** and basically depends on the equations and relations between DNBR and main sensitive four variables which are suggested by the author of reference [2]. The new proposed dynamic model describes the time-dependent behavior of the core heat flux, core inlet coolant temperature, system pressure, and coolant flow to predict the MDNBR in normal (steady state) and PLOFA transient conditions.

II. THE NEW PROPOSED MODEL

General Description

A proposed Dynamic Model code has been developed to model the steady state and transient thermal hydraulic behaviour of a PWR nuclear reactor core. It is capable of computing the coolant flow and temperature along parallel flow channels the code organization and differ national equation of calculation DNBR with their governing equations that results from in [2] are used and produced differential equations by RengQuta algorithm to increased efficiency for dynamic behaviour

The new proposed dynamic model analysis in the steady state

Pressure, (p), coolant inlet temperature, (T), average mass velocity, (G), and average heat flux, (Q), are variables x_1 , x_2 , x_3 , and x_4 , respectively. The resulting response surface in which represent the new proposed dynamic model is used to predict DNBR at selected combinations of the significant input parameters as prescribed function. The corresponding DNBR is evaluations, {y}. the input variables for reactor system functional relationship between the code input and output are used to building the differential equations of the new proposed dynamic model by equation 1 and their input parameters as shown in tables 1& 2 with time ten second;

$$DNBR \{y\} = 2.7043 + 5.6191 * 10^{-2} x_1 - 1.2256 * 10^{-1} x_2 + 1.4939 * 10^{-1} x_3 - 8.8544 * 10^{-2} x_4 - 1.4075 * 10^{-2} (x_2^2) \quad (1)$$

Where: x^N represents coded variables defined by:

$$x_1 = (\text{Pressure, psia} - 2250.) / 45$$

$$x_2 = (\text{Coolant temp., } ^\circ\text{F} - 552.5) / 5.525$$

$$x_3 = (\text{Mass Flow, lb/hr-ft}^2 - 2.46 \times 10^6) / 1.488 \times 10^5$$

$$x_4 = (\text{Heat Flux, Btu/hr-ft}^2 - 1.898 \times 10^6) / 3.796 \times 10^3$$

Table 1 represented the values of Input Parameters of the new proposed Dynamic Model and Table 2 represented Response Surface Coefficient of Variables Model for DNBR Analysis.

Table 1 Input Parameters [2]

Reactor System Pressure	2250 psia
Coolant Inlet Temperature	552.5°F
Average Mass Velocity	2.48 x 10 ⁶ lb /hr -ft ²
Average Heat Flux	1.898 x 10 ⁵ Btu/hr-ft ²
Initial value of DBNR	2.7043

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Table 2 The Response Surface Coefficient[2]

Coefficient	Variable
5.6191	x_1
-1.2256×10^{-1}	x_2
1.4939×10^{-1}	x_3
8.8544×10^{-2}	x_4
-1.4075×10^{-2}	x_2^2

III. TRANSIENT ANALYSIS

Analysis of the PLOFA transient

For the transients studied, the initial conditions which gave the most limiting steady-state DNBR were the same for each transient and are given in Table 3. These operating conditions produced a steady-state minimum DNBR of 2.7043 then produce transits PLOFA conditions through differs from the normal operation (steady state) by decreasing the flow of coolant with time till reached 35% from the nominal value at the end of run time (10 sec.).

Table 3
Transient Initial Conditions

Reactor Power	100%
Average Heat Flux	1.898×10^5 Btu/hr-ft ²
Inlet Temperature	552.5°F
System Pressure	2250 psia
Coolant Flow	2.244×10^6 lb/hr-ft ²

IV. RESULTS AND DISCUSSION

DNBR Evolution:

Figure (1) shows the variation of the minim DNBR with the time during the partial loss of flow accident. from the figure DNBR decreases with time and the minimum value is 1.55 as shown in figure.

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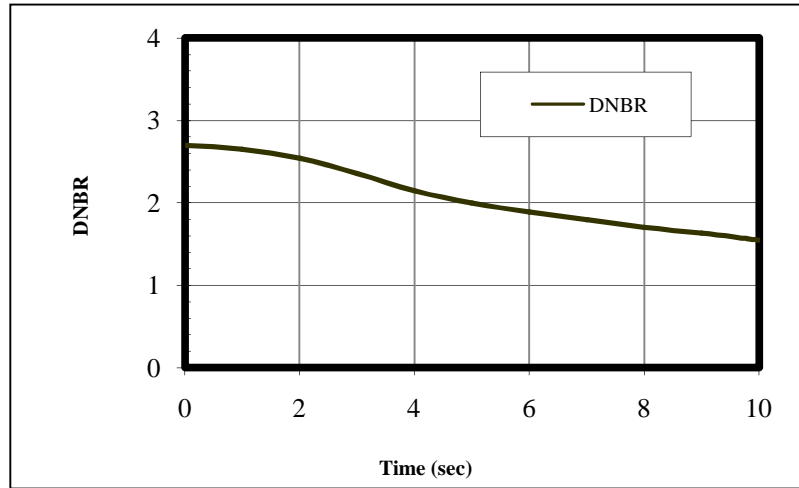


Fig (1) DNBR Evolution

Effect of Mass flow rate on DNBR:

As the loss of flow Scenario the coolant mass flow rate decreasing with time. Figure (2) shows the relation between coolant mass flow and DNBR with time, from this figure DNBR decreasing with the decreasing slowly of mass flow rate for all the run time.

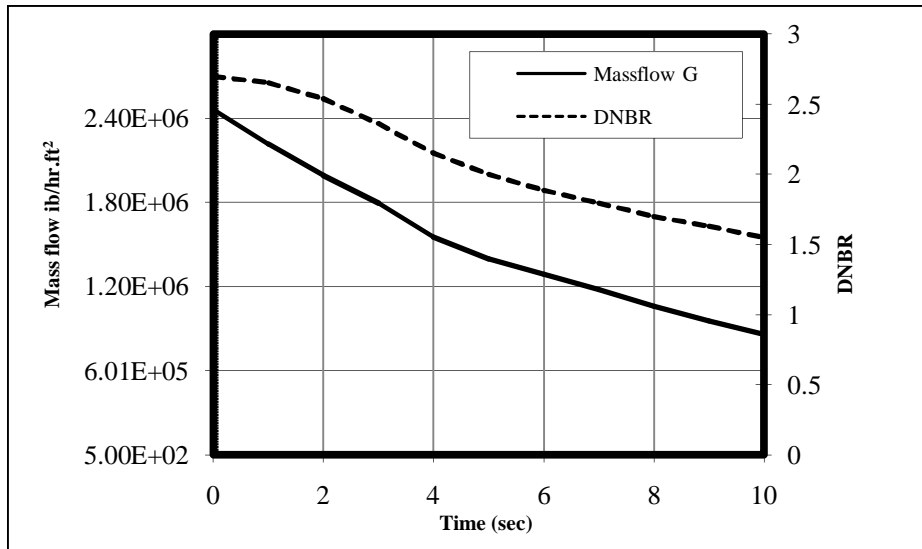


Fig (2) Mass flow & DNBR with time

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The mass flow is directly proportional with DNBR as shown in figure 3.

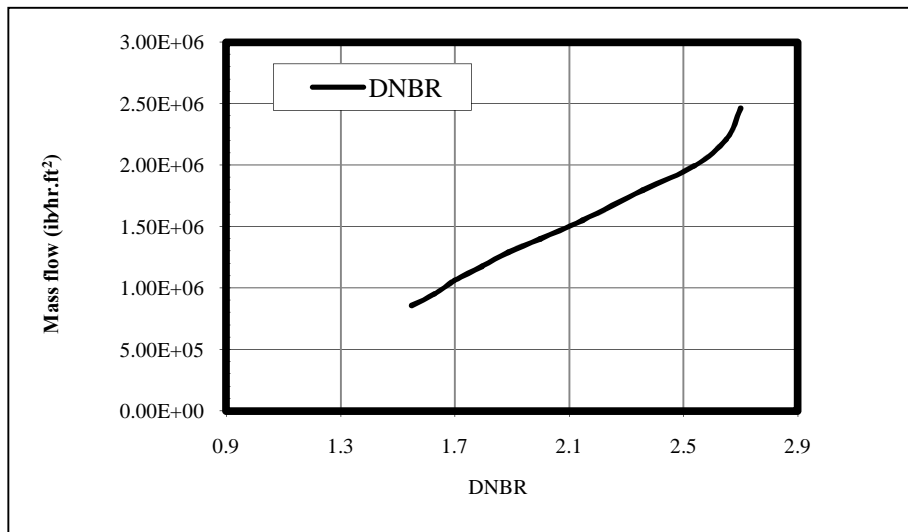


Fig (3) Mass flow rate with DNBR

Effect of Heat flux on DNBR:

Figures (4&5) demonstrate the relation between heat flux (Q) and DNBR with time. From the figure as the partial loss of flow accident Scenario the scram is occurred and heat flux decreasing with the time as shown in fig 4 during the 10 seconds.

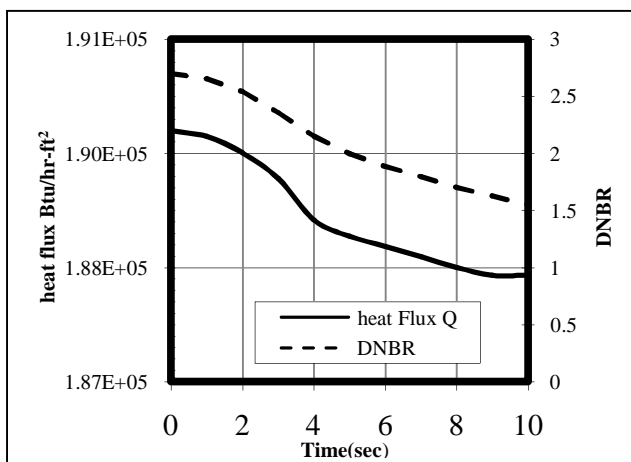


Fig (4) Heat Flux & DNBR with time

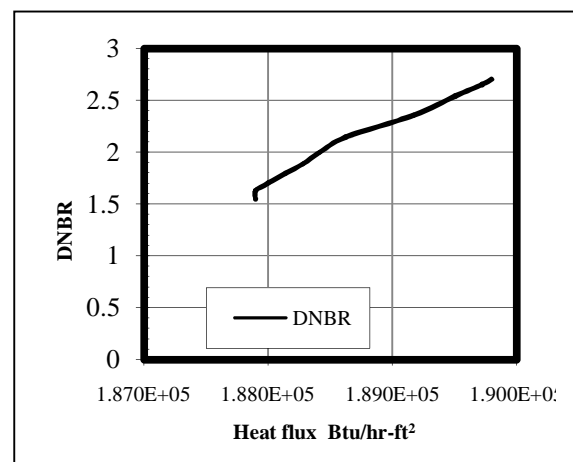


Fig (5) Heat Flux with DNBR

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Effect of Fluid Temperature on DNBR:

Figure (6) shows the relation between fluid temperature and DNBR with time, as the partial loss of flow Scenario after the initiation of loss of flow event the fluid temperature is increased, and from this figure DNBR decreasing with the increase of the fluid temperature. **DNBR** is inversely proportional with The fluid temperature as shown in fig. (7)

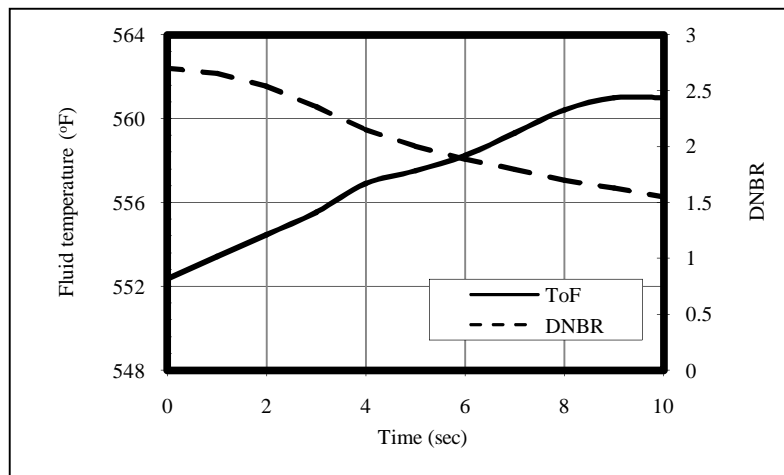


Fig (6) Fluid temperature & DNBR with time

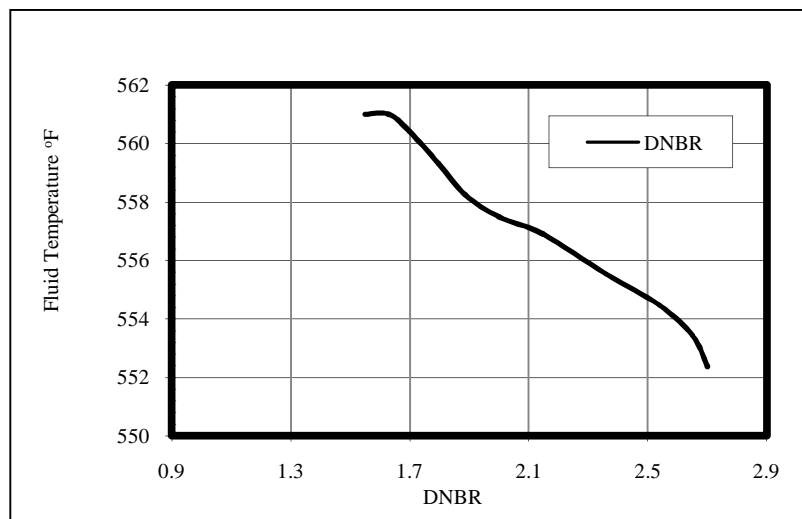


Fig (7) Fluid temperature with DNBR

Effect of system pressure on DNBR:

As the partial loss of flow Scenario the MCPs are cost down, so the system pressure is increased it causes reactor SCRAM due to loss of MCPs. After reactor SCRAM, turbine stop valves are closed as well as the main SGs feed water

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stopped, too. In this way increasing of secondary pressure reaches the set point for SGs SV and they open and start to cycle removing this way residual power from primary circuit so the system pressure decreasing as shown in figure 8. Figure (9) shows the relation between system pressure and DNBR, with time from this figure MDNBR increasing with the increase of the system pressure till 2277 pasi. At 5 sec after that showed that the increase of DNBR with the decreasing of the pressure.

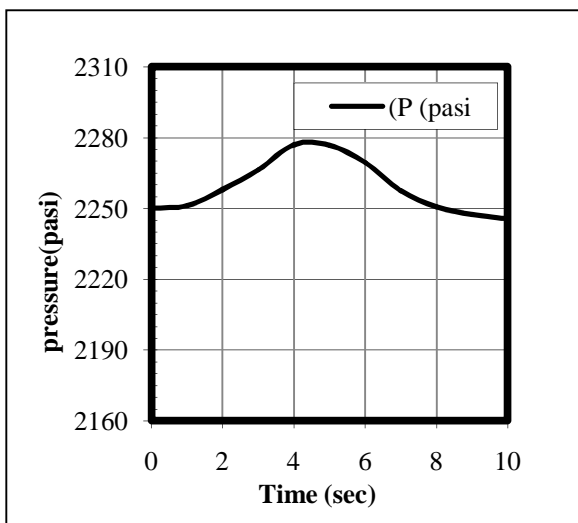


Fig (8) pressure with time

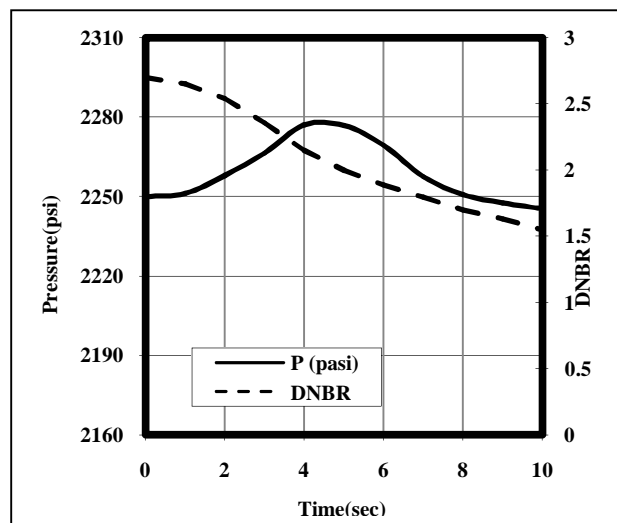


Fig (9) pressure & DNBR with time

V.COMPARISON

MDNBR is compared with the results in reference [3]. The MDNBR results for different correlations are compared in Table 4 during the Partial Loss Of Flow Accident **PLOFA**.

Table 4. [3]

	MacBeth	B&W-2	B-3L	Bowring	EPRI	AECL-UO	present
PLOFA	1.848	1.516	1.589	2.238	3.055	4.753	1.55

VI.CONCLUSION

A new proposed dynamic model is investigated and has good results (ability) to predict dynamic performance of the effect of significant parameters such as core inlet coolant temperature, system pressure, core heat flux, and coolant flow on behavior of the DNBR during steady state and partial Loss of Flow Accident **PLOFA** within period of time. The new proposed dynamic modeling results carried out that the DNBR is directly proportional with the mass flow and is inversely proportional with the fluid temperature. The predicted MDNBR from dynamic model is 1.55. The results of the model are well agreement with comparison with reference [3].

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