REACTIVITY INSERTION ACCIDENT ANALYSIS OF POWER UPGRADED TEHRAN RESEARCH REACTOR

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ABSTRACT

This paper reports the using of the PARET computer code for determining the response of the Tehran Research Reactor (TRR) upgraded core to the ramp reactivity insertion of $1.5/0.5s. This ramp reactivity insertion has been analyzed in two cases; without any scram and with overpower scram conditions. The results show that the maximum clad surface temperature during this reactivity insertion without any scram is increased up to 248C. This value is adequately below the melting point of aluminum alloy (630C). Therefore, the upgraded core of TRR shows a margin of about 382C for the reactivity insertion accident of $1.5/0.5s.

1 INTRODUCTION

Recently, the preliminary results due to a study to investigate the feasibility of raising the power of TRR have been presented [1]. According to that work, from the thermal-hydraulic point of view, the power of the TRR for the equilibrium core configuration consisting of 27 fuel elements (FE) may be upgraded up to 7.5 MW. Power upgrading of TRR can be achieved without any changing of the reactor structure and building while the control valve is just fully opened to provide an increased total flow rate of around 800 m^3/hr through the core.

The second step of the upgrading program of the TRR is considering the transient conditions of upgraded core. Here we report the reactivity insertion accident analysis by using the PARET computer code. At first in order to verify the reliability of our PARET code results, we have considered an IAEA benchmark reactivity transient problem. Then the reactivity insertion transient of TRR upgraded core has been analysed.

2 SUMMARY DESCRIPTION OF PARET CODE [2]

The analysis carried out in PARET is based on an evolution of the coupled, hydrodynamic, and nuclear effects in the core. The PARET model consists of a water-cooled core represented by a maximum of four fuel elements and associated coolant channels. Thus, the core can be divided into four or fewer regions, each having different power generation, coolant mass flow rate, hydraulic parameters etc, and each represented by a single fuel pin or plate, plus its associated coolant channel. A transient problem is forced through specification of externally inserted reactivity versus time, or average core power versus time. The program embodies detailed heat transfer calculation, continuous reactivity feedback, and hydrodynamic calculations allowing for coolant flow reversal.

Heat transfer in each fuel element is computed on the basis of one dimensional conduction solution in each of up to a maximum of 21 axial sections. Local heat generation is determined from the calculated or specified core average power level and spatial weighting factors. PARET employs empirical convective heat transfer correlation in estimating the rate of heat transfer at the clad-coolant interface. This transfer may take place by natural or forced convection, nucleate, transition, or stable film boiling. The hydrodynamics calculations are based on a one dimensional, modified Momentum Integral Model (HTM) in which equations representing the law of conservation of mass, momentum, and energy are solved in each coolant channel at each time node. The solution to this equation yields the pressure drop across the core, as well as point-wise fluid enthalpies, and mass flow rate along the length of each channel.

The power behaviour of the reactor is either specified as a function of time or is determined through a numerical solution of the point reactor kinetics equation. Solution of these equations is affected subsequent to an estimation of the reactivity feedback from time zero up to the time node under consideration. The feedback reactivity is calculated as the sum of that feedback through the mechanisms of fuel rod expansion, moderator density effects, and temperature effects in the fuel.

The major item of input to the code include the following: physical dimensions and geometry of the reactor system; fluid flow parameters, such as pressure loss coefficients; initial system pressure; thermal properties of the fuel element materials and thermal expansion coefficient of the clad as a function of temperature; channel pressure drop or inlet mass flow rate of the coolant to the channels as function of time; enthalpy of the inlet moderator; certain boiling parameters; delayed neutron information; point-to-average neutron flux rations; reactivity coefficients; initial power level; externally inserted reactivity or core level as a function of time.

Computer output includes elapsed reactor time and current time step increment, core power and total energy generated during the transient, current reactivity and reactivity feedback. Also, at each axial node point, the output includes moderator temperature, mass velocity, void fraction and flow regime (e.g., liquid, nucleate boiling, etc.); fuel center, fuel surface and clad surface temperatures, surface heat flux, burnout ratio, local pressure and total pressure drop across channel. Printout is affected by time nodes (N), where N is selected by the user.

PARET was designed for use in predicting the course of nondestructive reactivity accidents in small reactor cores. Therefore, it is not applicable to either destructive excursions or situations in which there is a space-time effect in the neutron flux.

3 DESCRIPTION OF THE BENCHMARK TRANSIENT

The 10 MW IAEA reactor for the benchmark transients is the same reactor model used for the neutronic benchmark computations [3]. But with the central flux trap of water replaced by a block of aluminum with a 5.0cm square hole containing water to generate more realistic radial and local power peaking factors for these required computations. The main initial conditions are:

Burn up: Beginning of life

Radial peaking factor: 1.4

Axial peaking factor: 1.5

Engineering factor: 1.2

Overpower factor: 1.2

Initial Reactor Power: 10^{-6} MW

Flow Rate of Coolant: 1000 m^3/hr

Coolant Inlet temperature: 38 C

Coolant Inlet Pressure: 1.7bar

Fuel Thermal Conductivity: 50W/m K.

The considered transient for the IAEA benchmark reactor is as follows:

Ramp reactivity transient, where $1.5 is inserted in 0.5 seconds without any scram conditions.

4 THE DESCRIPTION OF SELECTED TRANSIENTS OF THE TRR UPGRADED CORE

In order to analyse the dynamic behaviour of the fuel element of the upgraded core under the reactivity insertion accidents, we have considered the equilibrium core configuration with 27 low enriched uranium (LEU) FE (consisting of 22 standard fuel elements and 5 control fuel elements). In addition, in our analysis the following initial conditions are selected conservatively as needed for the PARET code [4-5]:

Initial Reactor Power: 10^{-6} MW

Flow Rate of Coolant: 800 m^3/hr

Coolant Inlet Temperature: 38C

Coolant Inlet Pressure: 1.7bar

Fuel Thermal Conductivity: 50W/m K

Aluminum Thermal Conductivity: 180W/mK

Void Fraction Parameter: 1.13

Effective Delayed Neutron Fraction: 8.13537E-3

Prompt Neutron Generation Time: 4.52782E-5.

We have considered the two following accidental scenarios for the upgraded core with same above initial conditions:

Ramp reactivity transient $1.5/0.5 sec. without any scram conditions.

Ramp reactivity transient $1.5/0.5 sec. with an overpower scram trip set at 8MW with a time delay of 25msec before initiation of the control blade insertion. The reactivity of fully inserted control rods is considered to be -$10.

These initial conditions are the same as those used to analyse the LEU fuel transients of 10MW benchmark IAEA reactor in the Research Reactor Core Conversion Guidebook [3]. The case 1 was also considered to study the transients of TRR core with the nominal power 10 MW [5].

5 RESULTS

Table 1 shows a comparison of results obtained by us, by using PARET code, with those given in Ref. [3] relevant to the reactivity transient specified for the benchmark 10 MW IAEA research reactor. Then the transient responses of the TRR upgraded core expressed as time evolution of reactivity, core peak power, temperatures and minimum to onset of nucleate boiling ratio (MDNBR) to the ramp reactivity insertion of $1.5/0.5s with and without scram are shown in Figures (1-4) and (5-8), respectively.

6 CONCLUSION

According to the results given in the present report, the maximum clad surface temperature during the considered transients is increased up to 248C due to the reactivity insertion of $1.5/0.5s without any scrams (see Figure 7). This value is substantially below the melting point of aluminum alloy (630C). Therefore, the upgraded core of TRR shows a margin of about 382C for the reactivity insertion accident of $1.5/0.5s.

REFERENCES

[1] Nuclear Research Center, AEOI, "Power Upgrading of Tehran Research Reactor", Dec. 2002.

[2] Obenchain, C. F., "PARET- A program for the Analysis of Reactor Transients,"IDO-17282, Jan. 1969.

[3] "Research Reactor Core Conversion Guidebook-Vol. 3: Analytical Verification", IAEA-TECDOC-643, Apr. 1992.

[4] Zaker, M, Annals of Nuclear Energy 30, 2002.

[5] Safety Analysis Report of TRR, AEOI, 2002.

Table 1- Comparison of the reactivity transient Results for the Benchmark 10MW Reactor

Parameter	Given in Ref. [3]	The Present Analysis
Peak Power (MW)	282	284
Time of Peak, t_m (Sec)	0.622	0.617
Energy to t_m (MWs)	5.52	5.58
Clad Temp. at t_m ($^{\circ}C$)	181	175
Peak Clad Temp. ($^{\circ}C$)	263	258
Time to Peak Clad Temp. (Sec)	0.643	0.637
Outlet Temp. at 0.8 s ($^{\circ}C$)	101	105

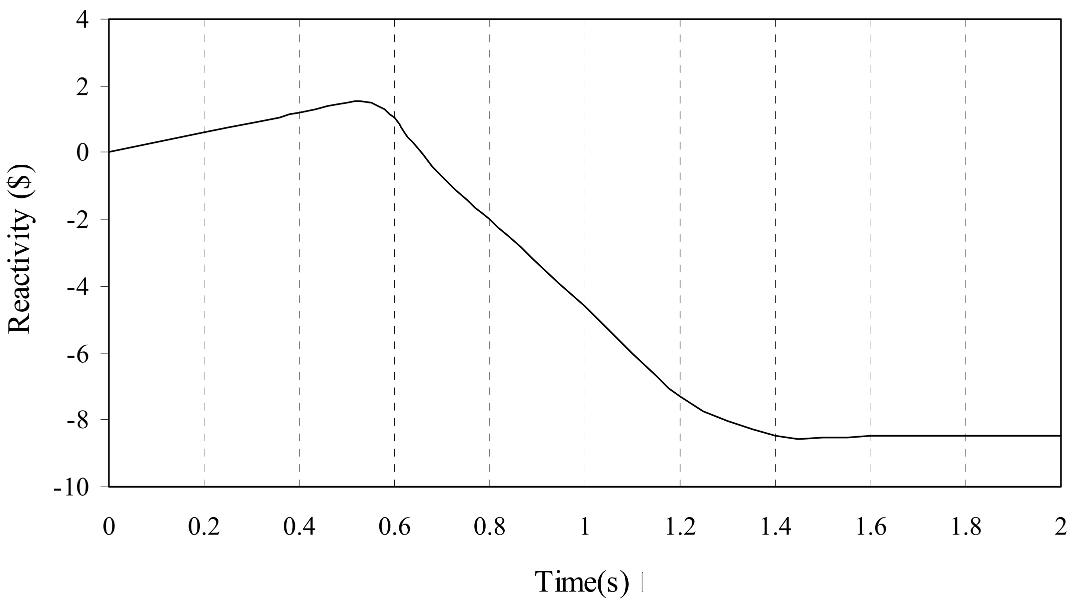

Figure 1- Reactivity Transient for the Reactivity Insertion=1.5$/0.5 Sec
With Scram

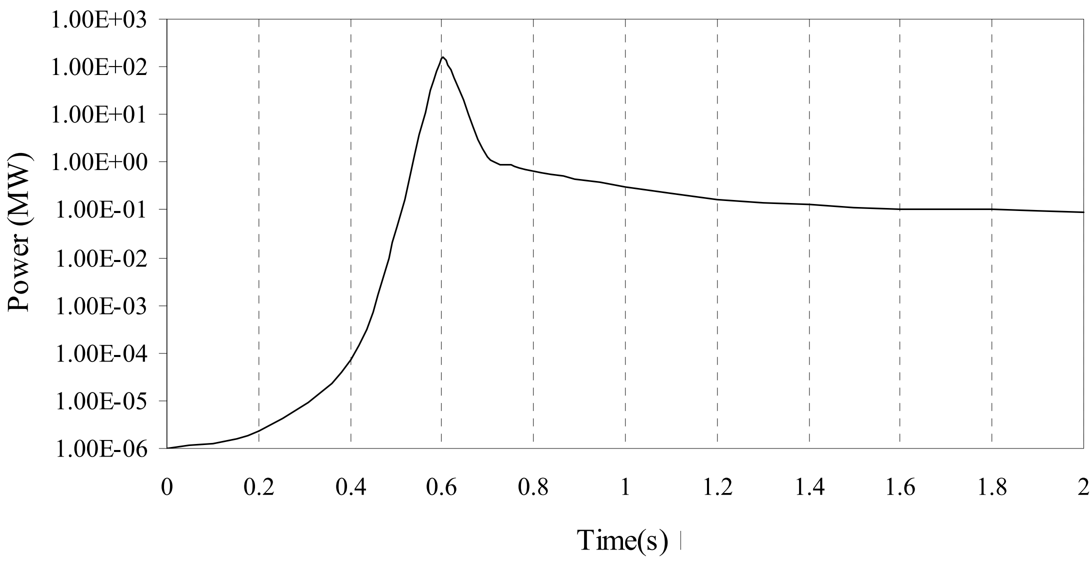

Figure 2- Power Transient for the Reactivity Insertion=1.5$/0.5 Sec
With Scram

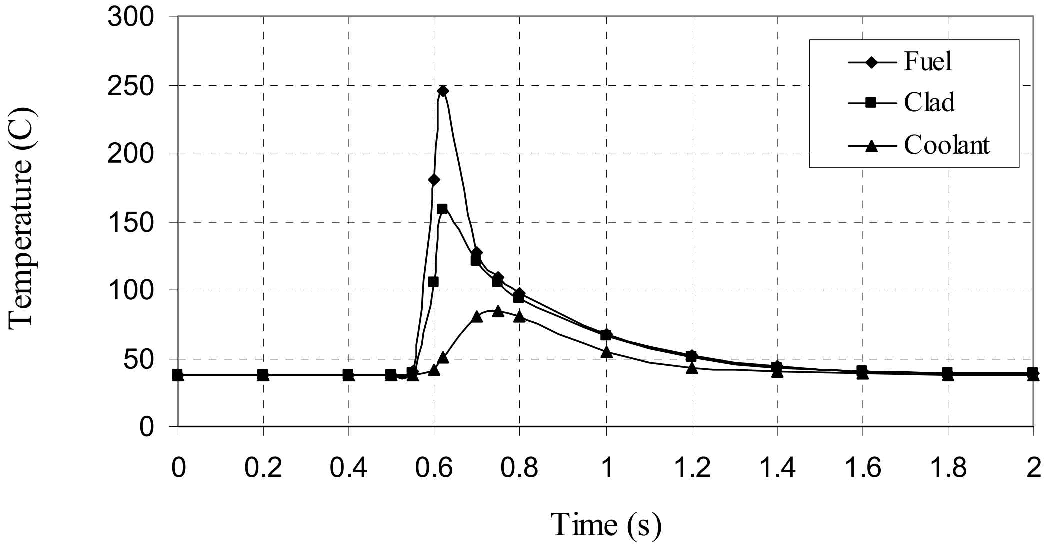

Figure 3- Peak Fuel, clad and coolant temperature transients for the Reactivity Insertion=1.5$/0.5 Sec With Scram

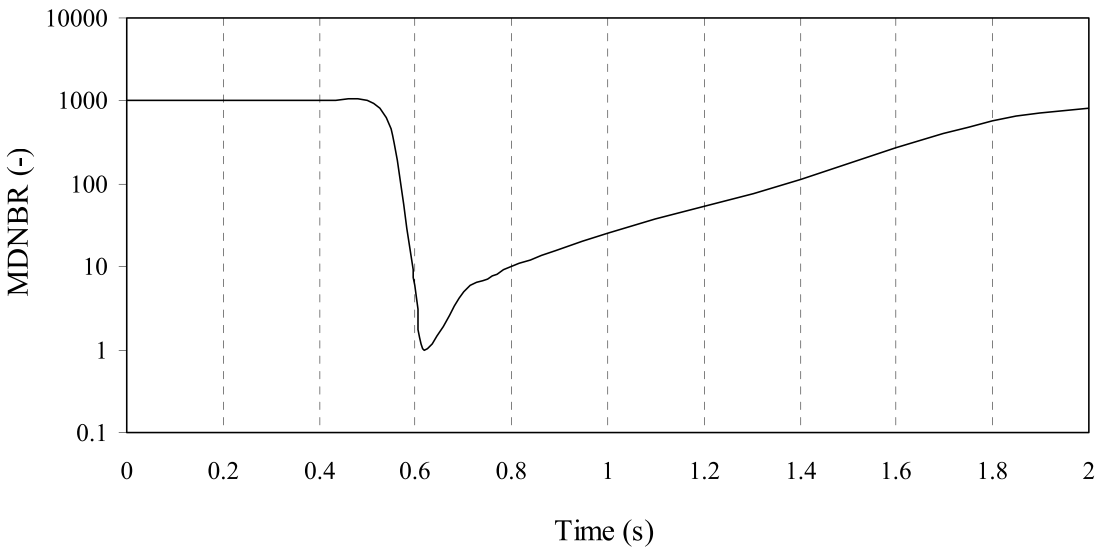

Figure 4- MDNBR Transient for the Reactivity Insertion=1.5$/0.5 Sec With Scram

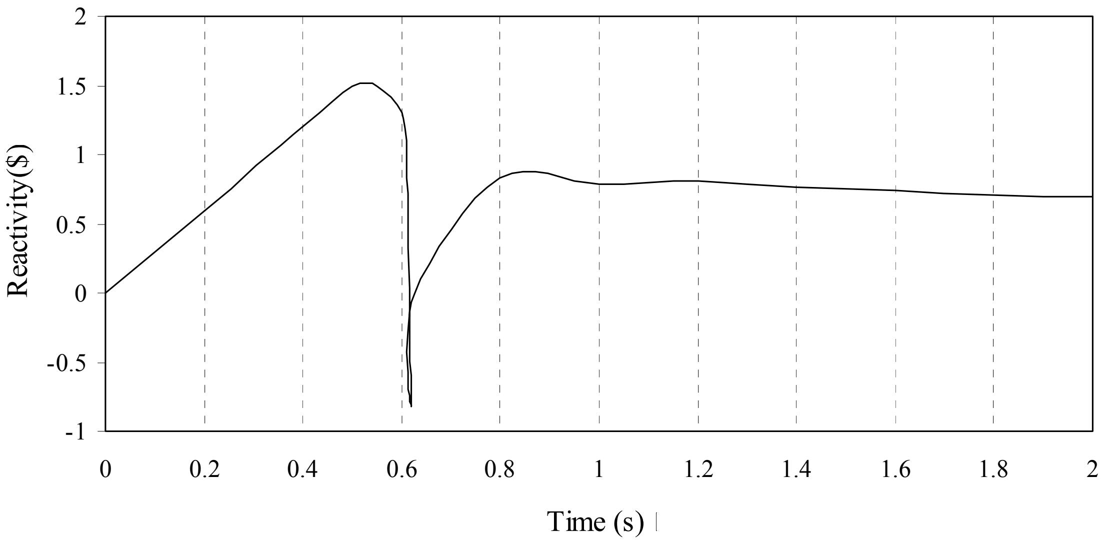

Figure 5 - Reactivity Transient for the Reactivity Insertion=1.5$/0.5 Sec
Without Scram

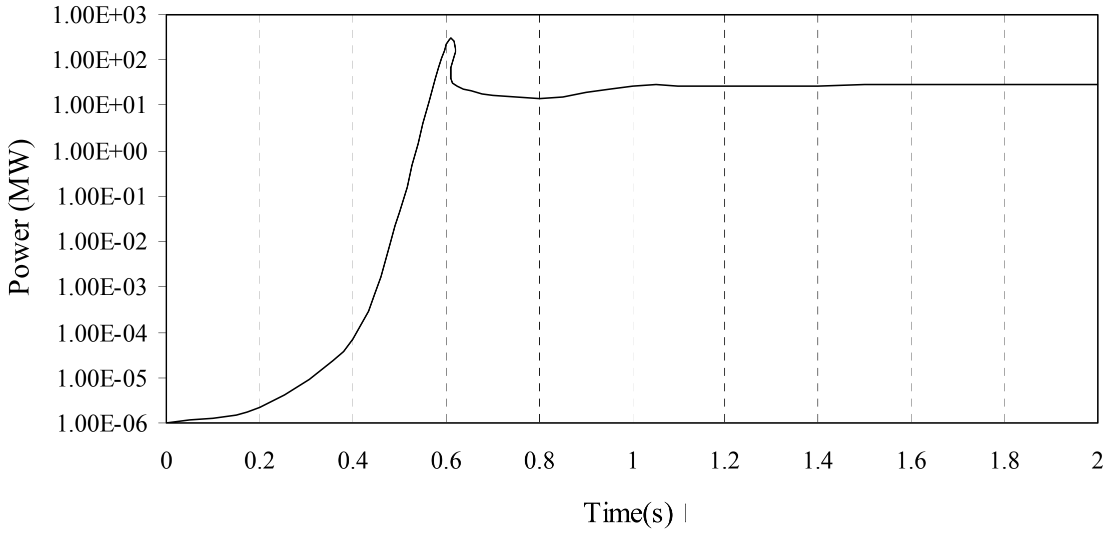

Figure 6 - Power Transient for the Reactivity Insertion=1.5$/0.5 Sec
Without Scram

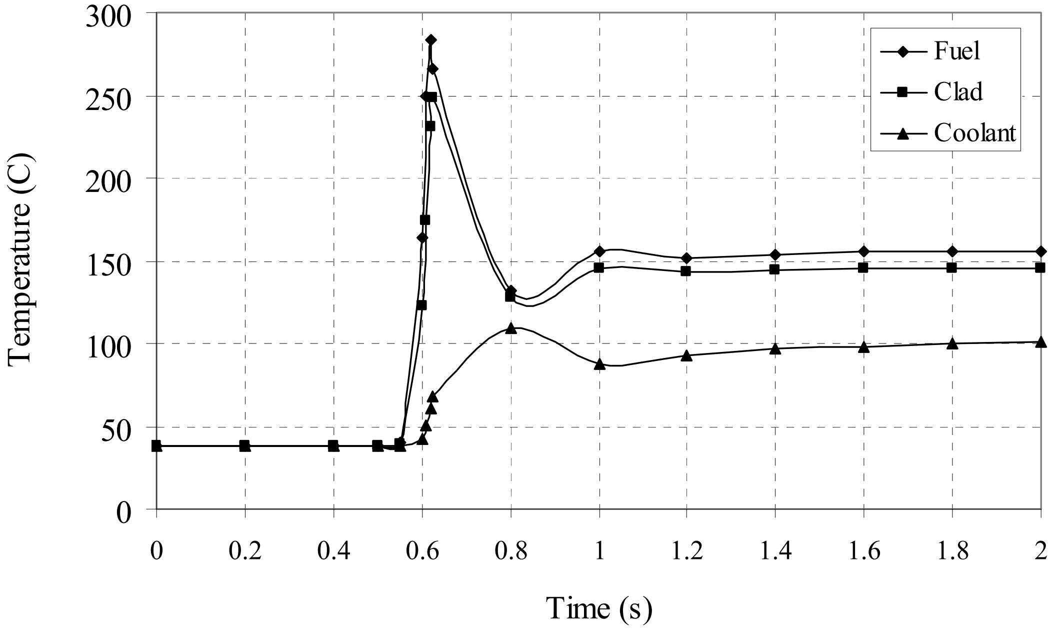

Figure 7 - Peak Fuel, clad and coolant temperature transients for the Reactivity Insertion=1.5$/0.5 Sec With Scram

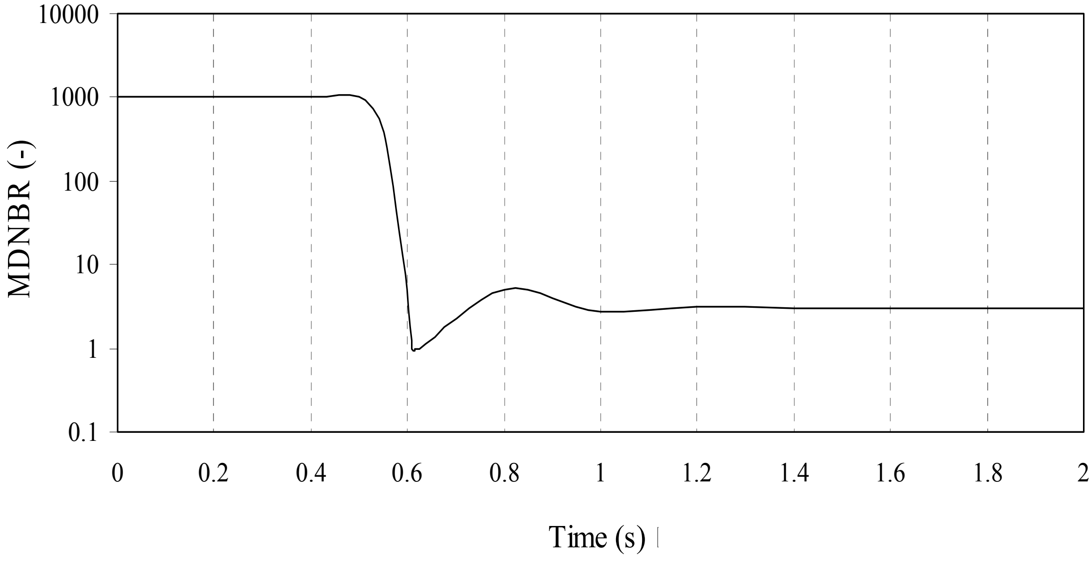

Figure 8 - MDNBR Transient for the Reactivity Insertion=1.5$/0.5 Sec Without Scram