Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

A GENERATION IV NUCLEAR POWER PLANT NAUTRAL CIRCULATION SYSTEM DESIGN FOR EMERGENCY COOLING

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Abstract: While the current Generation II and III nuclear power plant designs provide economically competitive electricity supplies in many countries, further advances in nuclear energy system design are pursued as Generation IV systems. Goals of Gen-IV (Generation IV) systems are mainly high economical competitiveness, enhanced safety, sustainability including waste minimization, and proliferation-resistance. Almost 100 different concepts and ideas were suggested from researchers in over ten countries. They are proposed as the future energy systems to meet the goals. In this paper, one of the most substantial elements, a Gen-IV nuclear reactors emergency cooling system design has been described by natural circulation using decay heat after reactor shutdown at state of loss of cooling severe accident.

Keywords: Gen-IV, Nuclear Power Plant, Emergency Cooling, Natural Circulation

1. INTORDUCTION

During the last 10 years, emergency cooling systems for the prevention of Generation IV (Gen IV) nuclear power plant (NPP) severe accident have been developed. As one of the technical solution of this problem, natural circulation effect is being developed using 10% of reactor core decay heat as state of emergency reactor showdown by loss of flow accident.

Liquid metal coolant has been selected as a type of Gen IV nuclear power plant primary coolant due to heat removal capability. Conservation of liquid metal natural circulation driving force and mass flow rate under reactor shutdown condition needs thermal balance control system between core and heat exchangers. And to control this system, several procedures have been performed. (Y.C. Kim at al., 1997)

2. APPROACH

2.1 Derivation of System Design Function.

Firstly, base on the conceptual design of Lead-cooled 850MWt Gen IV nuclear reactor was adopted to calculate natural circulation on 10% of decay heat of full power in loss of flow accident. Generally, natural circulation capability is very important condition for accident-tolerance (OECD-NEA Nuclear Science Committee, 2007).

Secondly, NPP's primary system natural circulation capability analysis has been performed using one-dimensional mass conservation, momentum conservation and energy conservation under single liquid metal phase (Hyong Won Lee, 2007).

As a result of analysis, emergency cooling control system analytic method has been derived by using steady state governs equation of one-dimensional natural circulation (Equation 1).

$$u_0 = \left\{ \frac{\beta \dfrac{\dot{q}_0 l_0}{\rho C_p} \left(\dfrac{a_{s0}}{a_i} \right) l_h}{\dfrac{1}{2g} \sum \dfrac{K_i}{A_i^2}} \right\}^{1/3}$$

$$u_{\min} < u_0 < u_{\max}$$

Equation 1: Derived natural circulation flow control function

2.2 *Evaluation of System Design Function.*

To evaluate derived natural circulation analytic control function, firstly, 3D CAD mock-up (Fig. 1) of natural circulation system had been developed to make system geometry for simulation.

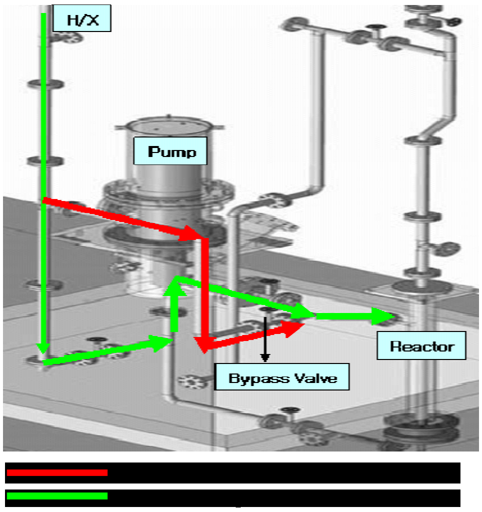

Fig. 1. 3D CAD Mock-up for Natural Circulation System Design

Mock-up has two flows. One is forced circulation line for normal operation (Green Line on Fig. 1) and the other red line is bypass line for natural circulation. Using two flow paths, liquid metal natural circulation phenomenon can be simulated by one dimensional simulation code.

Secondly, mock-up system had been simulated from 3D CAD geometry (Fig. 1) at 14kWt and 19.9kWt core power scaled down from 10% decay heat of 850MWt.

Forced circulation had been operated during 500sec, at 3.3kg/sec flow. Then pump stopped and bypass valve was opened at 500sec. then system flow vibrated to 1000sec and steady state of natural circulation started at about 1000sec flow (Fig. 2).

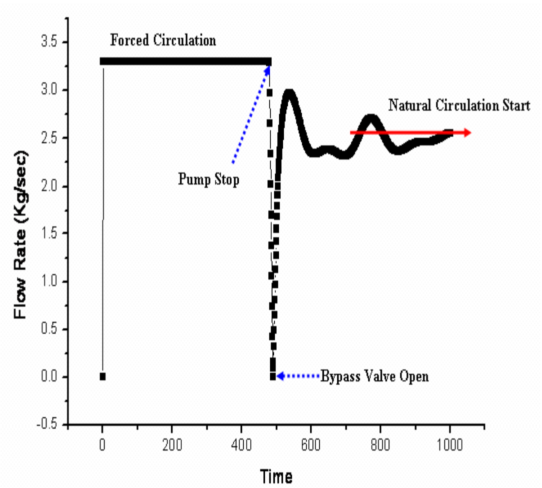

Fig. 2. Numerical natural circulation simulation result at 14kWt mock-up scaled down core power.

3. CONCLUSION

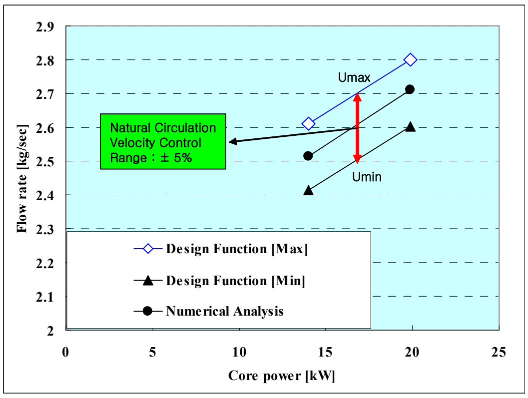

Fig. 3. Natural circulation flow rate comparison between numerical analysis and design function based on minimum and maximum total pressure loss error boundary.

As a result of natural circulation control function minimum and maximum flow rate boundary, analytical natural circulation control function has about 5% error that is directly related total pressure loss error (Fig. 3). Therefore, reducing pressure loss coefficient error boundary is faster and easier to control thermodynamic nuclear system stable using control algorithm for Gen IV nuclear power plant loss of flow accident.

NOMENCLATURE

a	Flow area
a_s	Wall cross sectional area
A	Non-dimensional area
c_p	Solid heat capacity
g	Acceleration due to gravity
K	Pressure loss coefficient
l_h	Length of hot fluid section
$\dot{q}$	Heat generation in heated rod
u	Natural circulation velocity
ρ	Density of Pb-Bi
i	i th section
o	Reference constant
r	Representative variable
s	Solid

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