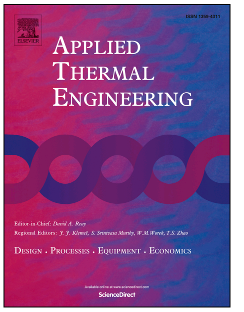

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Masataka Mochizuki, Randeep Singh, Thang Nguyen, Tien Nguyen

PII: S1359-4311(14)00552-3

DOI: 10.1016/j.applthermaleng.2014.07.004

Reference: ATE 5779

To appear in: *Applied Thermal Engineering*

Received Date: 27 March 2012

Revised Date: 30 June 2014

Accepted Date: 3 July 2014

Please cite this article as: M. Mochizuki, R. Singh, T. Nguyen, T. Nguyen, Heat Pipe Based Passive Emergency Core Cooling System For Safe Shutdown Of Nuclear Power Reactor, *Applied Thermal Engineering* (2014), doi: 10.1016/j.applthermaleng.2014.07.004.

HEAT PIPE BASED PASSIVE EMERGENCY CORE COOLING SYSTEM FOR SAFE SHUTDOWN OF NUCLEAR POWER REACTOR

Masataka Mochizuki, Randeep Singh*, Thang Nguyen, Tien Nguyen
Thermal Technology Division, Fujikura Ltd.,
1-5-1, Kiba, Koto-ku, Tokyo 135-8512, Japan
Phone: +81-3-5606-1174, Fax: +81-3-5606-1514,
*randeep.singh@jp.fujikura.com,

ABSTRACT
On March 11th, 2011, a natural disaster created by earthquakes and Tsunami caused a serious potential of nuclear reactor meltdown in Fukushima due to the failure of Emergency Core Cooling System (ECCS) powered by diesel generators. In this paper, heat pipe based ECCS has been proposed for nuclear power plants. The designed loop type heat pipe ECCS is composed of cylindrical evaporator with 62 vertical tubes, each 150 mm diameter and 6 m length, mounted around the circumference of nuclear fuel assembly and 21 m x 10 m x 5 m naturally cooled finned condenser installed outside the primary containment. Heat pipe with overall thermal resistance of 1.44 x 10^{-5} ºC/W will be able to reduce reactor temperature from initial working temperature of 282 ºC to below 250 ºC within 7 hours. The overall ECCS also includes feed water flooding of the core using elevated water tank for initial 10 minutes which will accelerate cooling of the core, replenish core coolant during loss of coolant accident and avoids heat transfer crisis phenomena during heat pipe start-up process. The proposed heat pipe system will operate in fully passive mode with high runtime reliability and therefore provide safer environment to nuclear power plants.

KEY WORDS: *Nuclear Power Reactor, ECCS, Loop type heat pipe, BWR, PWR, Leidenfrost phenomenon*

1. INTRODUCTION

Nuclear power has the potential to support the electric energy needs of the growing population. Nuclear energy share in global electricity production is growing fast due to its high energy density, advanced reactor technology, low greenhouse gas emissions, ease of installation and plant expansion. In nuclear power plants, kinetic energy produced by the nuclear fission of the radioactive material (usually uranium-235 or plutonium-239) is converted to heat and thereby to useful electrical power. Nuclear fission provides very high density energy, for example one kg of U-235 can produce 3 million times of energy generated by equivalent mass of coal. Japan has total of 54 nuclear power reactors with total electric power capacity of 49 GW (30% of country's demand) and there is proposal for 19 new reactors with total capacity of 13 GW to be built in the near future.

Two most commonly used reactors in nuclear power plants are pressurized water reactor (PWR) and boiling water reactor (BWR). PWR pumps high pressure coolant (water) to the reactor core to extract energy from the nuclear fission reaction. The hot water is then passed through the steam generator where it heats up the secondary coolant and produce steam which is passed through turbine to generate electricity. Unlike PWR, in BWR the steam (~ 282 °C) is generated in the nuclear core that is directly used to drive the turbine. In case of an accident, BWR is more susceptible to radiation leak than PWR, due to direct utilisation of the contaminated steam in the turbine located outside the primary containment. The BWR containment consists of drywell that houses reactor with related cooling system and wet well or suppression pool. The suppression pool contains water charge for core cooling during emergency reactor shutdown and for dumping excess heat (nuclear reaction control) during reactor operation. Fig. 1 presents the schematic of the BWR based nuclear power plant showing reactor vessel with fuel and control rods assemblies, turbine and generator arrangement, sea water cooled condenser, suppression pool and, most importantly, electrically driven ECCS with pumps. Nuclear power plants normally use sea water for cooling purpose. In case of any malfunctioning, the nuclear reactors are automatically shut down by using control rod mechanism. After shutdown, the ECCS is required to transfer and dissipate the residual heat from the core and maintain reactor temperature within safer limits (≤ 100 ºC) i.e. below reactor operating temperature (282 °C). It should be noted that reactor with lower temperature will have lower rate of fission reaction and thus will be more safe against lack of cooling accident. The ECCS, which is activated after reactor shutdown, typically uses diesel