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Design of Dedicated Nuclear Desalination System - Low pressure Inherent heat sink Nuclear Desalination plant: LIND

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1. Introduction

This study is for developing a dedicated nuclear desalination system equipped with highly passive safety features. The target site of the project is Abu Dhabi Emirate in UAE. Low pressure Inherent heat sink Nuclear Desalination plant (LIND) adopts the several innovative design concepts: 1) Use of low pressure operation (1-3bar) due to a dedicated nuclear desalination plant; 2) Use of a pool-type reactor to have a large water reservoir; 3) Use of square ring type fuel loading to maintain the cladding maximum temperature below the criterion even in accident scenario; 4) Use of SiC as control rod wall, baffle, guide tube, cladding etc. to allow high temperature of that components for decay heat removal; 5) Use of SiC as cladding to permit CHF during worst transients and eliminate H2 explosion [1]; 6) Underground design of a reactor to eliminate concrete wall surrounding a steel containment; 7) Use of reactor cavity for ex-vessel cooling; 8) Use of steel containment to effectively remove decay heat through radiation and air convection; 9) Use of In-Containment Refueling Water Storage Tank (IRWST) & Desalted Water Storage Tank (DWST) as water storage for safety injection purpose.

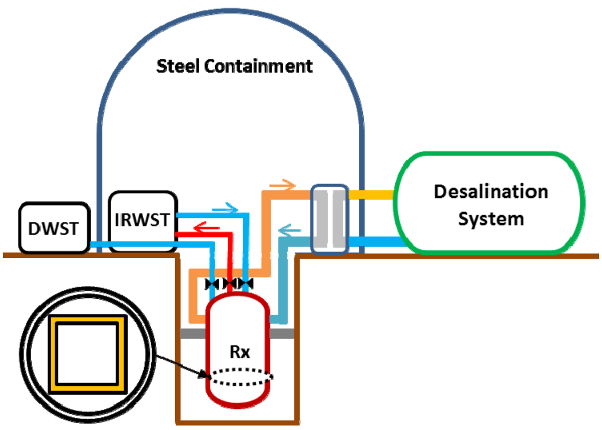

Fig. 1. Schematic diagram of LIND

2. Scoping Analysis Results

The key characteristic of LIND is to have enough decay heat removal capability without any safety system. Initial high level decay heat can be removed by water in a reactor vessel. After drying out of the water in the reactor vessel, reactor core faces no water condition and decay heat level is low. That low level decay heat can be removed by radiation, convection and/or condensation from the core to reactor vessel wall, to containment wall, to environment. The capability is checked in scoping analysis for the total loss of coolant accident. Below table shows basic design parameters which are used in scoping analysis.

Table I: LIND system basic design parameters

Core parameters			Fuel parameters			Containment parameters		
Q_{LIND}	200	MWth	$D_{cladding}$	0.0104394	m	H	20	m
P_{LIND}	0.3	MPa	Pitch	0.012852	m	D	15	m
A_{core}	2.17	m^2	$A_{f,channel}$	7.95804E-05	m	t (thickness)	1	cm
D_{core}	3.11	m	$L_{fuel,LIND}$	3.81	m	$L_{C,eff}$	27.5	m
R_{core}	1.555	m	N_{fuel}	13123		A_{Cw}	1295.9	m^2
D_{Rx}	4.91	m	$q'_{core,LIND}$	4	kW/m	V_C	4417.9	m^3
R_{Rx}	2.46	m	$q_{core,LIND}$	15.24	kW	σ_C	5.67E-08	W/K^4m^2
$H_{Chimnley}$	7.62	m	$q''_{core,LIND}$	134.03	kW/m^2	ε_C	0.8	
$H_{Rx,vertical}$	13.43	m	$\sigma_{cladding}$	5.67E-08	W/K^4m^2	fin effect	1	
$L_{Rx,eff}$	18.34	m	$\varepsilon_{cladding}$	0.8		$T_{air,normal}$	50	deg.C
V_{Rx}	316.3	m^3				$P_{air,normal}$	0.1	MPa
$V_{total,NSSS}$	347.9	m^3				ρ_{air}	1.078612	kg/m^3
$M_{water,NSSS}$	324175	kg						
$A_{Rx,wall}$	282.9	m^2						
σ_{Rx}	5.67E-08	W/K^4m^2						
ε_{Rx}	0.8							

2.1 LIND system thermal-hydraulics analysis in accident case

We assumed the total loss of coolant accident as the worst accident case. We considered decay heat removal capability by radiation, convection and/or condensation 1) from the core to reactor vessel wall, 2) from reactor vessel wall to mixture in containment, and 3) from containment to environment. Pressure and temperature conditions of the design requirements were checked.

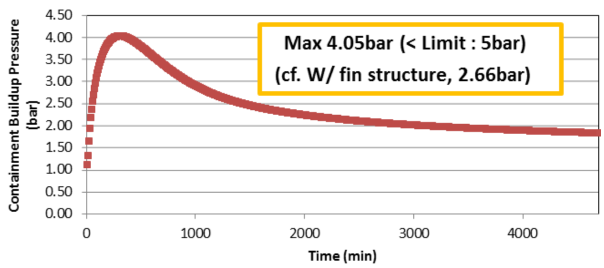

Fig. 2. Containment pressure buildup history

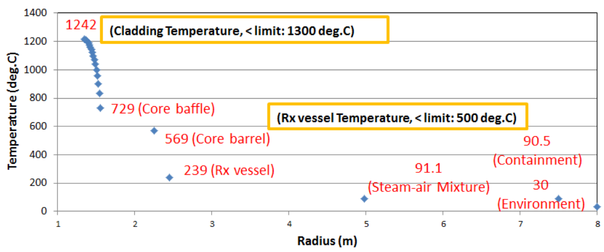

Fig. 3. Temperature distribution in LIND system

Fig. 2 and 3 show the main results. Containment pressure buildup is important in the initial stage of decay heat removal by water in reactor vessel. Temperature distribution is obtained for no water condition right after drying out of the water in the reactor vessel because at that time temperature distribution of LIND system is the highest. Maximum containment pressure, cladding temperature and reactor vessel temperature satisfy each criterion. As a result, the reactor core can be passively cooled down and decay heat (0.89MWth, 0.45% of Total Power) can be removed safely without any active safety system in the total loss of coolant accident scenario.

2.2 Reactor core thermal-hydraulics analysis in normal operation

Fig. 4 and 5 show axial temperature of fuel center & surface, temperature of cladding inner & outer surfaces, and bulk temperature of coolant, as functions of distance along a coolant channel. Because of uncertainty of gap conductance between fuel and cladding, and thermal conductivity of fuel and cladding, we consider two extreme cases. The temperature lower bound conditions assume 1) no gap between fuel and cladding due to fuel expansion and 2) no irradiated fuel and cladding. In those conditions we can get the lowest axial temperature distribution. The temperature upper bound conditions assume 1) gap filled with 1atm helium at room temperature (25 deg.C) and 2) irradiated fuel and cladding. In those conditions the highest axial temperature distribution can be obtained. This temperature information is utilized in the reactor core neutronics analysis.

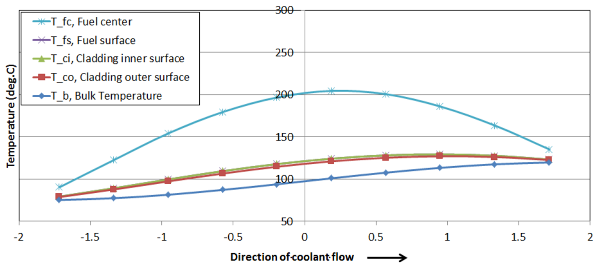

Fig. 4. Core axial temperature distribution in lower bound condition

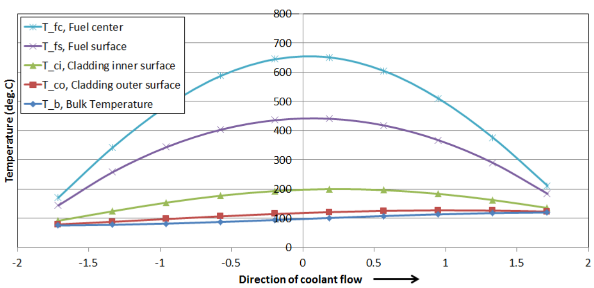

Fig. 5 Core axial temperature distribution in upper bound condition

2.3 Reactor core neutronics analysis in normal operation

For neutronics analysis, we used the MCNP code which is widely used for complex geometry and continuous-energy problems. MCNP input for 1/8 core is shown in Fig. 6.

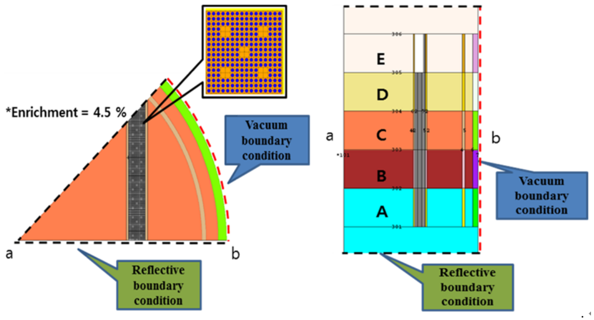

Fig. 6. Horizontal cut (left) and vertical cut (right) of 1/8 LIND core

Under the two bound conditions, we generated cross section data to consider Doppler broadening effect using the NJOY code and then performed depletion calculation for 1/8 core using the MONTEBURNS code. The cycle length of both lower and upper bound conditions is around 1000 days. Burnup curves were also obtained under lower and upper bound conditions. The maximum discharge burnup is around 10 GWd/MTU and it occurs in the same node B for the two conditions. The average discharge burnup is 8.19 GWd/MTU for upper bound condition and 9.01 GWd/MTU for lower bound condition.

3. Conclusions

In scoping analysis, the current LIND design satisfies the several thermal-hydraulics and neutronics design requirements. In thermal-hydraulics analysis, the reactor core can be passively cooled down even in the worst accident case. Decay heat can be removed safely without any active safety system (1D calculation). So, LIND has inherent safety feature. However, for precise analysis, we need to do CFD analysis in the near future. In reactor core neutronics analysis, the cycle length of LIND core is estimated to be around 1000 days under 200 MWth. However, the maximum discharge burnup is around 10 GWd/MTU, which is quite lower than that of conventional PWR.

REFERENCES

[1] D. M. Carpenter, Assessment of innovative fuel designs for high performance light water reactors, Masters Thesis, MIT, 2006.