論文の内容の要旨

Dissertation Abstract

論文題目 Title: Experimental and Numerical Investigation of Thermal Stratification by Direct Contact Condensation of Steam in Pressure Suppression Pool

(圧力抑制室における直接接触凝縮に起因する温度成層化現象に関する研究)

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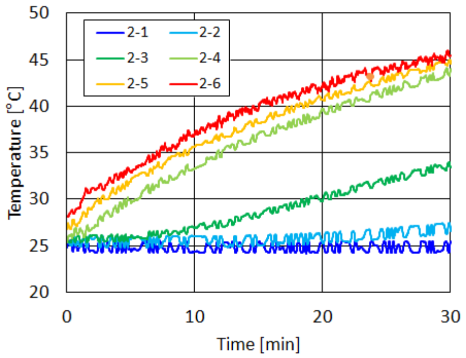
Fukushima-Daiichi accident is one of the design based accidents with extreme natural event, an exceptional strong earthquake accompanied by a colossal tsunami. Long duration station black out (SBO) happened by damaged AC electric power and got flooded emergency diesel engines. Although the reactors were cooled by Reactor Core Isolation Cooling System (RCIC) after reactor isolation in unit 2 and 3, RCIC malfunctioned by unconfirmed reasons, the reactor vessel water level decreased, fuel rods were damaged, and those situations leaded to severe accidents such as hydrogen explosion and radioactive matter release. With RCIC malfunction, the pressure in suppression pool (SP) increased higher than expected. In this research, the reason of abnormal pressure increase in SP is investigated in the viewpoint of thermal stratification phenomenon.

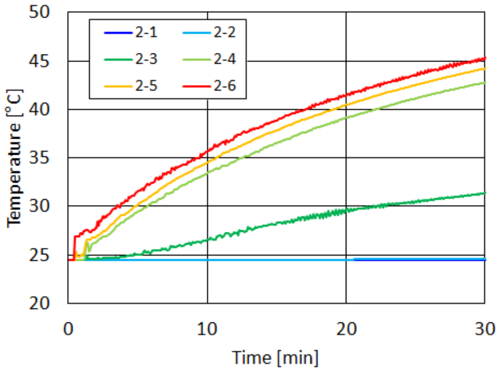
To understand unexpected pressure increase of SP in Fukushima accident and give useful information to LWRs designers for nuclear safety, downsized 2D SP was designed and experiments were carried out. This research is carried out to understand thermal stratification in SP experimentally and analytically and to predict the thermal stratification by single phase CFD code. Because of complicated phenomena depending on DCC (Direct Contact Condensation) regimes and the difficulties of accurate momentum calculation from two phase simulation, single phase model is selected and additional heat and momentum models are investigated.

At oscillatory interface regime, temperature distribution and velocity field around steam injection pipe were obtained. To measure momentum from condensation interface, the oscillating frequency and the amplitude were investigated and the regime between oscillatory interface and external chugging was found. To simulate thermal stratification, volumetric heat and momentum source model was chosen and CDCC was obtained from validation of the code with experiments. This code was validated with downsized torus experiment and the time of thermal stratification formation was obtained with good agreement with experiments as shown in Fig.1.

To investigate thermal stratification criteria by non-dimensional parameter, Richardson number for DCC was calculated with steam bubble visualization data. There are three regions regarding to thermal stratification as in Table1; (1) unconditional thermal stratification region, (2) conditional thermal stratification region and (3) Mixing region. In conditional thermal stratification region, DCC regime is important to predict the feasibility of thermal stratification and the regime depends on steam mass flux, subcooling and steam injection pipe inner diameter.



(a) Experiment



(b) CFD

Fig.1 Temperature profiles on the SP center in case 4 (ECEB regime)

Table.1 Criteria of thermal stratification by DCC

Region	Condition	j_m [kg/m2s]	DCC Regime
Unconditional Thermal Stratification	$2 < Ri_{DCC}$ High	$j_m < 5$	Oscillatory Interface, Transitional area
		$j_m > 5$	Any regime (L is large)
Conditional Thermal Stratification	$0.1 < Ri_{DCC} < 2$ Low	$j_m < 5$	Transitional area, ECEB
		$j_m > 5$	ECDB, ECEB, Oscillatory Bubble
No Thermal Stratification (Mixing)	$Ri_{DCC} < 0.1$ Extremely Low		