Preliminary Analysis of Ex-Vessel Steam Explosion using TEXAS-V code for APR1400

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1. Introduction

The purpose of this study is to explore input development and the audit calculation using TEXAS-V code for ex-vessel steam explosion for a flooded reactor cavity of APR1400.

TEXAS computational models are one of the simplified tools for simulations of fuel-coolant interaction during mixing, triggering and explosion phase.[1] The models of TEXAS code were validated by performing the fundamental experimental investigation in the KROTOS facility at JRC, Ispra. The experiments such as KROTOS and FARO experiment are aimed at providing benchmark data to examine the effect of fuel-coolant initial conditions and mixing on explosion energetics with alumina and prototypical core material.[1]

2. Methods and Results

The key element in the TEXAS code is a transient liquid particle fragmentation model based on Rayleigh-Taylor instabilities for the mixing phase.[1,2] This fragmentation model includes a dynamic pressure deformation mechanism, which predicts the liquid particle transient fragment size. The TEXAS code also includes an explosive fragmentation model.

TEXAS-V has simplified computational model to analyze the steam explosion phenomena and is used to simulate the selected international experimental data of SERENA project.

Studying the computational model against the selected experimental data is part of OECD/SERENA research project. The purpose of this research is to pursue a collective understanding of the fundamental physics of steam explosion phenomena, which is necessary to predict the steam explosion load on a reactor scale and to identify the shortcomings of the existing models and experimental data[3,4]. TEXAS computational model for the steam explosion phenomena should be able to describe multiphase, multi-dimensional and multi-component phenomena at different length scales.

The calculation procedure consists of two steps; input development and base case calculation.

2.1 TEXAS-V Input preparation for Flooded Reactor Cavity

The TEXAS-V input[5,6,7] produced for the flooded reactor cavity of APR1400 has 35 nodes for simulation of flooded cavity: 28 nodes(0.4m) are for the vessel and 7 nodes(1m) are to cover the upper vapor region. The void fraction and melt fraction in each region are initialized to match the test configuration and condition. Coherent jet of uniform melt is released to the cavity in 17^{th} node(6.41m). The released location of melt jet is selected over the node boundary due to the error of TEXAS-V[5]. The initial condition of fluid temperature and vapor pressure are 304K and 0.2MPa for reactor cavity. The initial properties of ceramic melt jet when only small localized opening exist for the base case calculation are summarized in Table 1 and the sensitivity study of properties will be performed. The selected model for the code calculation is shown in Table 2.

Table 1. Properties of melt jet

Thermal Properties	Unit	Value
Melting Temperature	K	3000
Density	kg/m^3	8450
Thermal conductivity	W/m-K	5.3
Specific heat	kJ/kg-K	0.51
Viscosity	mPa-s	5.3
Surface tension	N/m	0.45
Emissivity	-	0.86
Break size	m	0.2
Velocity	m/s	5

2.2 Base case calculation and Analysis Results

The fragmentation melt mass is 217kg during mixing mode. The $225m^2$ of surface area and mean diameter of jet particle after mixing calculation can be seen in Figure 1. The melt jet from node 17 is reached 4m height from the reactor cavity floor about 0.86sec after. Jet velocity is slower as the jet approaches the bottom area of the vessel because the larger trailing particles are catching up on the smaller leading particles.

Table 2. Input Variables of TEXAS-V code

Parameter	Value and Description
NBREAK	1, No. of independent leading particles
IFRAGMIX	1, hydrodynamic fragmentation
IENTRY	1, coherent jet entry mode
IENTRY2	0, trailing edge model
ALPHA	100, constant in F-factor for explosion
ALPHAS	0.3, cut-off void fraction in F-factor
TFRAGLIMT	0.001, fuel fragmentation time interval
RFRAG	0.5E-4, initially estimated size of fragmented particles

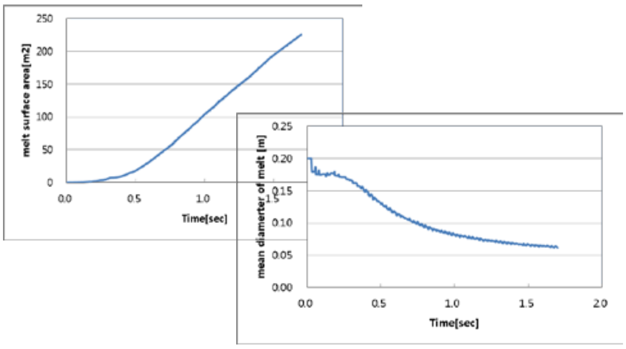

Figure 1. Surface area and mean diameter of melt jet

Figure 2 shows a series of computed pressure distributions for the simulation at various times. In this simulation the double pressure pulse was produced near the reactor bottom nodes, which is assumed that thermal energy is still being released. Superposing the various interacting pressure waves obviously leads to the creation of peaks and troughs. The maximum pressure load is about 37MPa.

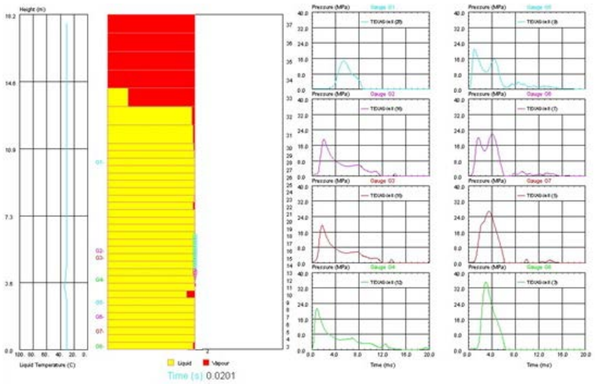

Figure 2. Nodalization and pressure load

The conversion ratio is defined as coolant kinetic energy over internal energy of the fragmented fuel and the maximum conversion ratio is almost 3.77%.

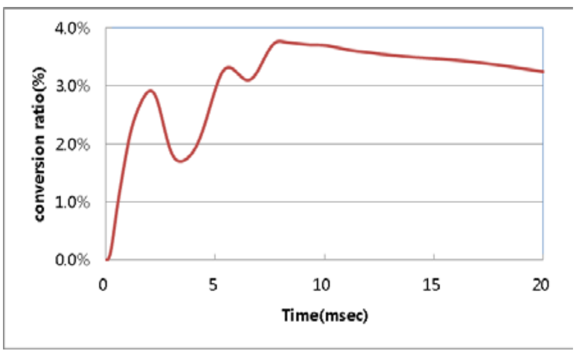

Figure 3. Pressure distribution at each node.

3. Conclusions

TEXAS-V code used in this study was to analyze and predict the ex-vessel steam explosion for a reactor scale. The input deck to simulate the flooded reactor cavity of APR1400 is developed and base case calculation is performed. This study will provide a base for further study. The code will be of use for the evaluation and sensitivity study of ex-vessel steam explosion for ERVC strategy in the future studies.

Analysis result of this study is similar to the result of other study.[8] Through this study, it is found that TEXAS-V could be the used as a tool for predicting the steam explosion load on a reactor scale, as fast running computer code. In addition, TEXAS-V code could be to evaluate the impact of various uncertainties, which are not clearly understood yet, to provide a conservative envelope for the steam explosion.

ACKNOWLEDGMENTS

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