ISTC Project #3345

Source Term Assessment at Ex-vessel Stage of Severe Accident

Summary of Technical Report

on the work performed from 01.01.2007 to 31.12.2007

Authorized for unrestricted publication

Federal State Unitary Enterprise “St.Petersburg Research and Design Institute ATOMENERGOPROEKT”
(FSUE SPAEP)
191036, Russia, St.Petersburg, 2nd Sovetskaya street, 9/2a

Project Manager SPAEP Deputy Director for R&D	**Vladimir Bezlepkin Doctor of Science (Power Engineering)**	
First Deputy General Director – Technical Director	**Anatoly Molchanov**	

March 2008

This work is supported financially by ISTC and performed under the contract to the International Science and Technology Center (ISTC), Moscow.

Project number: 3345

Title of the Project: Source Term Assessment at Ex-vessel Stage of Severe Accident

Date of publishing: January 2008

Objectives / scope of work and technical approach / expected results

Project Objectives - theoretical and experimental research of the processes affecting the late phase fission product release to the PWR containment atmosphere at the ex-vessel stage of the hypothetical severe accident with core meltdown.

Scope of Work

Task 1. Assessment of results of severe accident sequences modeling
Task 2. Experimental research on FP release from molten pool/core melt catcher
Task 3. Analytical investigation of fission products release from molten pool or core catcher.
Task 4. Experimental study of aerosols transport processes in the primary circuit equipment
Task 5. Theoretical and computer modeling of aerosol transport in the primary circuit
Task 6. Experimental investigations of containment parameters impact on volatile iodine content and correlation
Task 7. Numerical and theoretical modeling of containment parameters impact on volatile iodine species content and correlation

Technical approach

- Severe accident scenarios for AES-91 with VVER-1000 are analyzed using Russian computer codes and international recommendations to choose the boundary conditions for the experiments. Pre-test and post-test calculations are performed.
- Experiments are carried out for the FP release from the molten pools, for the aerosol transport, for content and proportioning of the volatile iodine species.

Expected results:

- Experimental data and numerical analysis of core melt fission product release.
- Experimental data for the model aerosols and the numerical analysis of the spatial-time patterns of the deposition and resuspension of the aerosol particles.
- Experimental data and numerical analysis on how composition of containment sump solution and sludge affects content and partitioning of volatile iodine species in the containment atmosphere at different temperature, irradiation dose, ambient parameters and coating characteristics.

Obtained results

1. Approaches and models that had been used in the AES-91 with VVER-1000 design were reviewed along with the EUR, NRC and IAEA recommendations for LWR. The main uncertainties of the design estimates of the accident source terms and main factors significantly effecting the source term levels had been identified.

The numerical analysis of the severe accidents both in-containment LOCA and primary-to-secondary leaks had been performed. The following data had been obtained: chemical composition of the upper layer of the molten pool both in-vessel and in the core catcher, medium velocities above the molten pool surface, flow velocities for the emergence gas removal system and for the failed steam generators tubes, fission products transport along the primary circuit. Content of the sump solution and sludge content, temperature, dose rates and containment environment parameters.

Based on the analyses performed the boundary conditions for the experiments had been chosen.

2. Quantitative data had been obtained on release of the uranium oxides, zirconium oxides, and fission products stimulants like SrO, BaO, La_2O_3, CeO_2, Ru and Mo from the molten core during its oxidation from C-70 to C-100 and at different temperature of the pool surface. It is confirmed that corium temperature is the major factor affecting release of the fission products and corium components.

   Analysis of the size distribution of the aerosols, carried out by different techniques, has shown that the primary condensed particles have characteristic size less than 1 μm. Significant difference had been observed for the particles condensed in the inert environment and in case when oxidizer is supplied onto the molten pool surface. During the very process of oxidation, the fraction of fine particles increases, while after corium is oxidized up to C-100, larger particles with characteristics diameters of 11-12.6 μm take significantly increased portion.

   The experimental results obtained can be used for extending the molten pool FP release databases and to validate relevant computer codes.

3. For theoretical predictions of the FP release two models had been developed. Atomic model considers the molten pool as a regular atomic solution with the evaporation process described with the Langmuir model. Molecular model describes the molten pool like the regular molecular solution. Above the solutions there is assumed to be the saturated vapor being in thermodynamic equilibrium with the solution. Vapor is described as an ideal molecular gas. FP release mechanism is the blowing out of the saturated vapors by the gas carrier medium above the corium. Using both models the molten pool FP release is calculated and compared with the experiments EV1 with satisfactory outcome. Molecular model is implemented as a stand-alone computer code.

4. Quantitative data had been obtained on the kinematics parameters of the carrier medium (average velocities, pulsation components of the velocities, pulsation frequencies) in the cylindrical vertical channel with diameter 98 mm. Quantitative data had been obtained to evaluate the deposition rate of the liquid aerosols with diameter ranging from 0.5 to 28 μm in the cylindrical vertical channel at Re range from 10000 to 240000. Quantitative data had been obtained on the particle structure of the flow, including the particles size distribution, particles concentration and sizes variations along the cross-section of the channel and along the flow direction in the cylindrical vertical channel with diameter of 98 mm.

   Aerosol generator had been designed to generate the ammonia chloride particles using the reversible chemical reaction of dissociation-recombination. New experimental setup had been made to investigate the deposition and resuspension of solid aerosols in the cylindrical channels. Quantitative data had been obtained on deposition rate of the ammonia chloride aerosols with size ranging from 0.5 to 10 μm in the vertical channel with diameter of 50 mm at the flow velocities of 20 to 38 m/s. The data on the resuspension of the solid particles at air flow velocities of 65 to 105 m/s had also been obtained. The experimentally observed deposited mass is determined by two processes – deposition and resuspension.

5. Using statistical model for the aerosol dynamics for probability density function, the simplified analytical correlations for the aerosol deposition rate had been obtained taking into account different mechanisms. Generalized formula for the deposition rate determined by the combined effect of the convection type (gravity, convection, thermophoresys, flow twist) and fluctuation type (turbulent and Brownian diffusion) had been developed. Using known correlations for the deposition and resuspension rates of the particles with fixed diameter the dynamic model is used allowing the user to calculate the combined effects of the turbulent deposition and resuspension processes at arbitrary particles size distribution and multi-layered deposition type.
   Software package had been developed for analysis of the viscous incompressible turbulent flows using LES model with the particles moving in the flow under actions of the friction forces, lift forces and stochastic Brownian force. Calculation to experiment comparison confirmed the ability of the developed code to model the turbulent flows in the channels with high Reynolds number and with sufficient accuracy.

6. During thermal oxidation of the iodide-ion in the solution with concentration of 10^{-4} mole/l and with pH 5 (at presence of the boric acid, 10 g/l) the volatile iodide species generation is observed, with the gas phase release being 0.1 – 0.6% at 30-90°C. Increasing pH from 5 to 7 decreases the iodine volatility by a factor of 1.5-2. In case of temperature increase from 60 to 90°C the volatile species release is increased by factor of 2-4. Iodine partitioning coefficients at these conditions are in the range of 200-900. In case the iodide concentration decreases to 1E-5 mole/l, the volatile iodine species release is increased up to 7-11%, while iodide concentration up to 1E-3 mole/l decreases the release down to 0.04-0,14%.
   Quality of water effecting the I_2 release to the gas phase is investigated and it is shown that the possible catalysts of the thermal iodine oxidation are the chloride and organic impurities.
   Under irradiation of the iodide solution in the stainless steel ampoule, the I_2 release to the gas phase is one order of magnitude less compared to the thermal iodide oxidation, while the partitioning coefficient is 1-2 orders of magnitude higher. As the temperature rises and pH goes down, the I_2 release is increased by factor of 5 to 70. At the temperature above 100°C thermal and radiolytic iodide oxidation rates are comparable.
   Effect of the sludge of the iron hydroxide (FeOOH) on the iodine volatility depends on the solution pH and medium temperature. It is assumed that the iodide-ion chemically reacts with the iron hydroxide.

7. Iodine software package for the severe accident analysis had been developed. The code includes: water phase module, pH module, water phase surfaces module, atmosphere module, module for coatings exposed to atmosphere, common block. The computer implementation had been done; pre-test calculations had been made, mathematical model had been proved to be adequate, code had been verified against the experiments carried out within the same project, post-test calculations had been made. Iodine model and the software package can be used in the integral severe accident model.

Keywords:
AES-91, VVER-1000, NUCLEAR REACTOR, SEVERE ACCIDENT, FISSION PRODUCTS, IMITATIORS, CORIUM, CORE MELT, INDUCTION HEATING, OXIDATION DEGREE, AEROSOL, GENERATOR, AMMONIA CHLORIDE, TURBOPHORESYS, DEPOSITION, RESUSPENSION, LES-MODEL, IODINE MODULE, CONTAINMENT, SLUDGE, SUMP, DOSE RATE, CALCULATION, BOUNDARY CONDITIONS, EXPERIMENT.