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Development of model and numerical analysis of cask TC 46 with uranium hexafluoride (UF6) in fire conditions

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Introduction

For providing safety of uranium hexafluoride (UF6) transportation in casks, there is need for appropriate experimental and numerical researches aimed to determine UF6 state in the fire conditions. Temperature and pressure are the basic UF6 parameters of interest in terms of the transportation safety. In total, these parameters allow also to evaluate cask strength.

Because of the known difficulties in arrangement of experimental researches due to high toxicity of UF6, of great importance is development of techniques and computational codes, which would simulate correctly behavior of UF6 and casks in the conditions of fires.

After issue of "Rules of safe transportation of radioactive materials" (TS-R-1) of IAEA in 1996, new requirements (item 630) were included in the part of testing of transportation casks under high-temperature effect without break of protective shell (800 °C for 30 minutes) as a result of an accident. Up to this date, no any full-scale tests have been performed with casks intended for mass transportations of UF6 in the world due to high radiotoxicity and chemical risks. Besides, there are no calculation techniques for numerical study of behavior of TC with UF6 in the fire conditions.

Presently Russian experts from RFNC-VNIIEF developed a state-of-the-art technique, which allows performing numerical researches and justification of safety of transport casks (TC) with UF6 in the fire conditions without need for tests.

Below the authors briefly present the developed technique and the corresponding program complex AJAX- UF6.

Peculiarities of technique

Available information on thermophysical and thermodynamic properties of UF6 has incomplete and fragmentary character that does not correspond often to the thermodynamics requirements. The following fact can be considered as an example. Parameters of UF6 are given in triple point and critical point, and an equation for the “liquid-gas” saturation line, which is not satisfied in these points. The other similar examples can be presented as well.

In the developed technique, relations without these disadvantages are suggested for description of thermophysical and thermodynamic properties of UF6. Moreover, use of the thermodynamics principles allowed to expand the existing UF6 equations of state for the narrow temperature range (around the triple point) up to the critical temperature.

Using elements of the nonequilibrium thermodynamics, relations were obtained, which describe phase transitions for nonequilibrium processes. They helped to develop algorithms for UF6, which take account for melting and solidification, boiling, evaporation, and condensation.

The ratios of volumes, which are occupied by the solid, liquid and gaseous phases, are also changed during the aggregate changes. Density and pressure of the gas phase are changed in the same manner. Also density of the gas phase is growing due to evaporation. It is evident that research of the mentioned processes cannot be correct in essence, if (as it happens sometimes) a cask with UF6 is considered as independent areas of the type “top – bottom”. In the developed technique, a construction is considered as a uniform system consisting of a solid casing and three internal areas, which correspond to aggregate states of UF6 changing in time.

Brief description of program AJAX- UF6.

The program is based on the finite element method, and it allows to take account for the following dependences and processes:

- dependence of thermophysical properties on temperature
- dependence of nonlinear boundary condition on coordinates, time, and temperature in general case
- heat exchange by radiation both in the internal cavities and with the environments
- insolation
- phase and chemical transitions
- heat exchange by convection in the internal cavities with use of engineering approaches.
- calculations of boiling and evaporation processes with taking account for mass transfer between the liquid phase and the gas phase, and absorption or release of energy
- change of geometry as a result of melting, boiling, and evaporation.

Numerical example

Using the program AJAX- UF6, state of cask TC-46 with the external diameter of 1.216 meters was researched. Variants were considered for casing thicknesses of 8 mm and 16 mm and loading of 7500 kg and 5000 kg of UF6. General view of the numerical models of the cask is presented in figure 1.

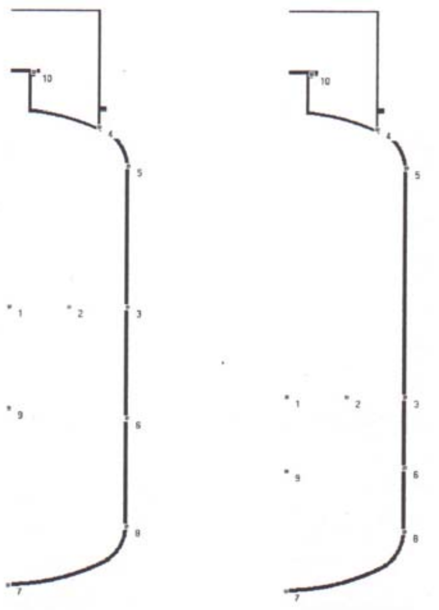


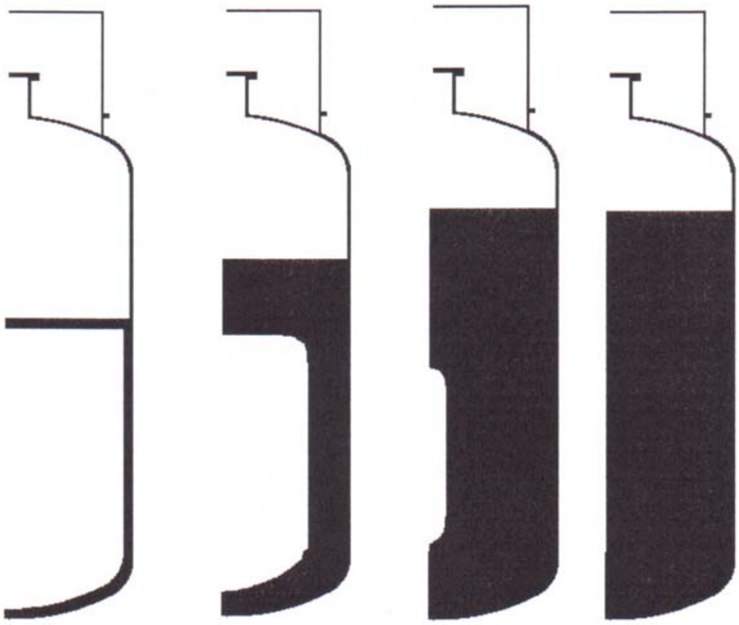
Рисунок 1. Расчетные модели ТУК с загрузкой 7500 кг и 5000 кг

Figure 1. Numerical models of TC with loading of 7500 kg and 5000 kg

In the figure, the points show the places of analysis of calculation results.

As the thermal effect, the authors considered a fire, in accordance with the IAEA requirements, at 800°C for 30 minutes, and with flame emissivity of the fire environment equal to 0.9.

For illustration, figure 2 demonstrates the design geometry for different times.



2 мин. 0.5 часа 2.92 часа 3.52 часа

2 minutes 0.5 hours 2.92 hours 3.52 hours

Figure 2 – Dynamics of uranium hexafluoride melting

Figure 3 presents the dependences of temperatures on time for points shown in figure 1. Figure 4 presents the dependence of pressure on time in the gas cavity.

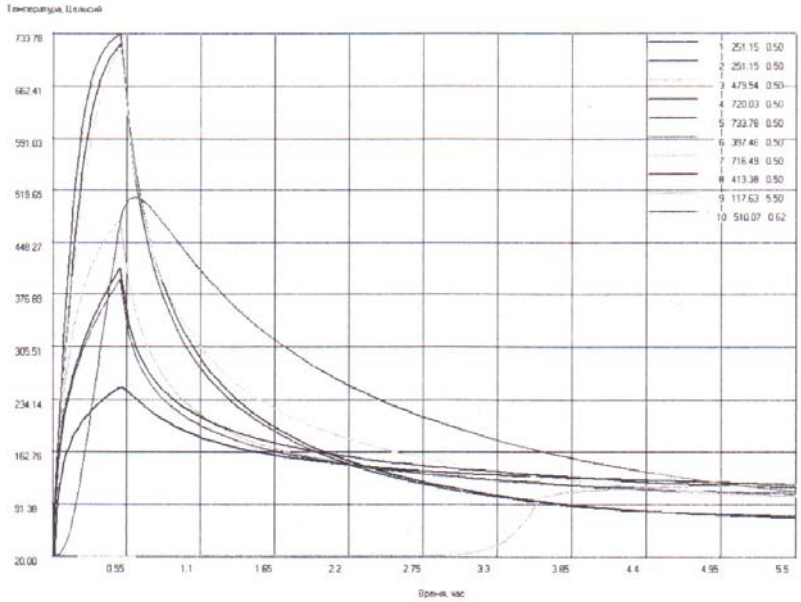


Рисунок 3. Температурные кривые для точек рисунка 1.

Figure 3. Temperature curves for points from figure 1

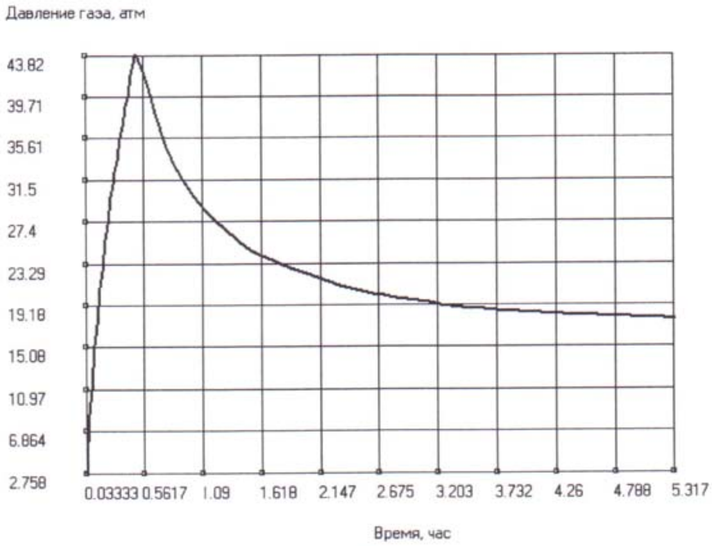


Рисунок 4. Давление в газовой фазе UF6.

Gas pressure, atm

Time, hour

Figure 4. Pressure in UF6 gas phase.

Conclusions

RFNC-VNIIEF experts developed an up-to-date technique, which allows performing numerical researches of thermal state of TC intended for UF6 transportation in the fire conditions. Application of this technique enables to prepare numerical justification of safety for various TC designs, which are used for international and domestic transportations of both depleted and enriched UF6 (TC-46, 48X, 48Y, etc.), without the need for tests.