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Fuel Fragmentation and Pressure Waves Generation in Conditions of Reactors Reactivity Initiated Accidents.

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Фрагментация топлива и генерация волн давления в условиях реактивностных аварий реакторов

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***Аннотация**.. Предложена модель диспергирования расплавленного ядерного топлива и генерации волн давления (паровой взрыв) при динамическом разрушении твэла в условиях RIA. Предсказания модели сравниваются с экспериментальными данными. Показана возможность использования развитой модели для расчета этих явлений в условиях реального эксперимента без введения свободных параметров.*

Severe reactivity initiated accidents (RIA) of reactors are connected with fuel rods failure under powerful neutron flash. Dynamic fuel rods failure mechanism under pulse energy deposition was considered in work [1]. After rods failure during fuel - coolant interaction fuel disintegration and pressure pulses generation (vapour explosion) take place which may lead to the destruction of the reactor structure. In this work theoretical approach for the sequential description of fuel fragmentation and vapour explosion at RIA conditions is proposed.

Fuel fragmentation model is based on the mechanism of generation and growth of instabilities on the surface of scattering particles due to tangential instability [2]. Such approach was used in [3] for calculation of fragmented fuel particles size distribution at RIA conditions. In the basis of this approach lies the assumption that square occupied by instabilities with a given size d is proportional to the increment of their growth I(d). In this case we get the following expression for mass change of the particles with size d broken away from the disintegrating drop:

$$\dot{m}(d) = \rho_2 d I^2(d) S_0 / \int_{d_{min}}^{d_{max}} I(x)dx$$

where S_0 - square of the surface from which particles break away occurs, d_{min} and d_{max} - minimum and maximum sizes of breaking away particles which are changing during the braking and fragmentation of the pattern drop.

In work [3] it was assumed that d_{max} is strictly connected with pattern drop size. In such approach it was managed to satisfactory describe particle size distribution functions obtained in [4] for various experimental conditions. Moreover correlations between different parameters were established which allowed to recreate the distribution function actually with use of the sole parameter - fuel rod internal pressure at a failure moment. This pressure can be calculated in terms of the model proposed in [1]. Reliability of this approach is demonstrated at fig. 1 where calculated distribution (particles relative mass with size greater than given) is compared with the experimental data from [5]. It is seen that measured particles size distribution can be satisfactory described without free parameters. Particularly good agreement is observed in the region of small particles. Just this region is most significant for further analysis of vapour explosion and particles throw in the environment.

Naturally for very large pattern drops the value of d_{max} is defined most probably not by their size but by the competition between instabilities modes. It seems reasonable to assume that d_{max} is proportional to d_{min}. Such situation occurs in the case of molten fuel release into coolant [6]. In this experiments series such parameters as melt mass, initial pressure, coolant temperature were varied. The results of our calculations are compared with the experimental data on fig. 2. One can see a good agreement in all the region of d change. Minimum to maximum size ratio is in the interval 25 - 37 for all experiments.

In the work [7] state equation for hot particles - coolant mixture was proposed. Generally speaking this equation is four - component: hot particles, non - equilibrium vapour forming at their surface, coolant, equilibrium vapour (if present in coolant). Main feature of this state equation is taking into account the temperature local non - equilibrium near the hot particle. Change of the non- equilibrium vapour mass share m_2 is connected with forming of the vapour film around hot particles. The main approach of this model is the assumption that the vapour increase rate depends only on the current pressure and mass share of non - equilibrium vapour. This approach can be presented by the following expression:

$$\frac{dm_2}{dt} = f(m_2, P)$$

This equation allows to use the solution of film growth under constant pressure for determination of function $f(m_2,P)$.

This state equation was used for numerical simulation of pressure pulses generation after fuel rods failure under pulse energy deposition [4]. Corresponding particles mean diameter was calculated in terms of above mentioned particles size distribution. This parameter comes into the function $f(m_2,P)$ and is one of the most important for the vapour explosion intensity.

Let us define a conversion ratio as ratio of coolant mechanical energy to energy released in fuel during the flash. Fig. 3 presents conversion ratios obtained in [4] and calculated ones in terms of the proposed model for various experimental conditions. The deflection in the region of large particles may be caused by underestimation of heat and partial evaporation of coolant during the fuel rod disintegration.

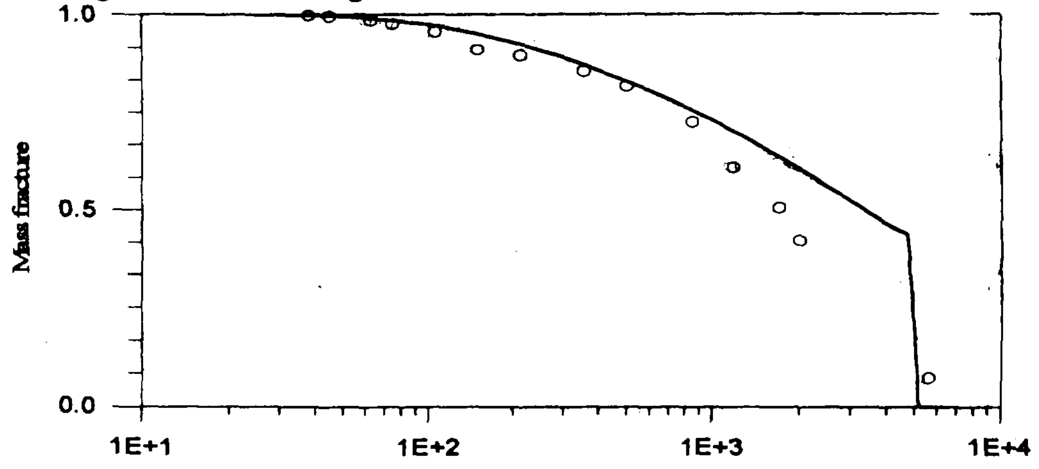

Fig 1. Particle size distribution for RIA-ST experiments.
Circles - experiments, lines - calculation

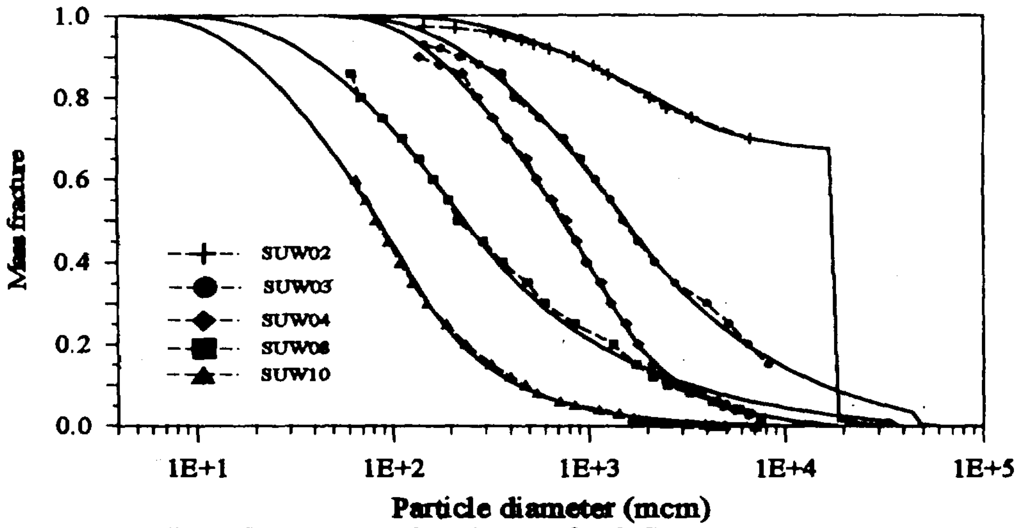

Fig 2. Particle size distribution for SUW experiments.
Dashed lines - experiments, Solid lines - calculation.

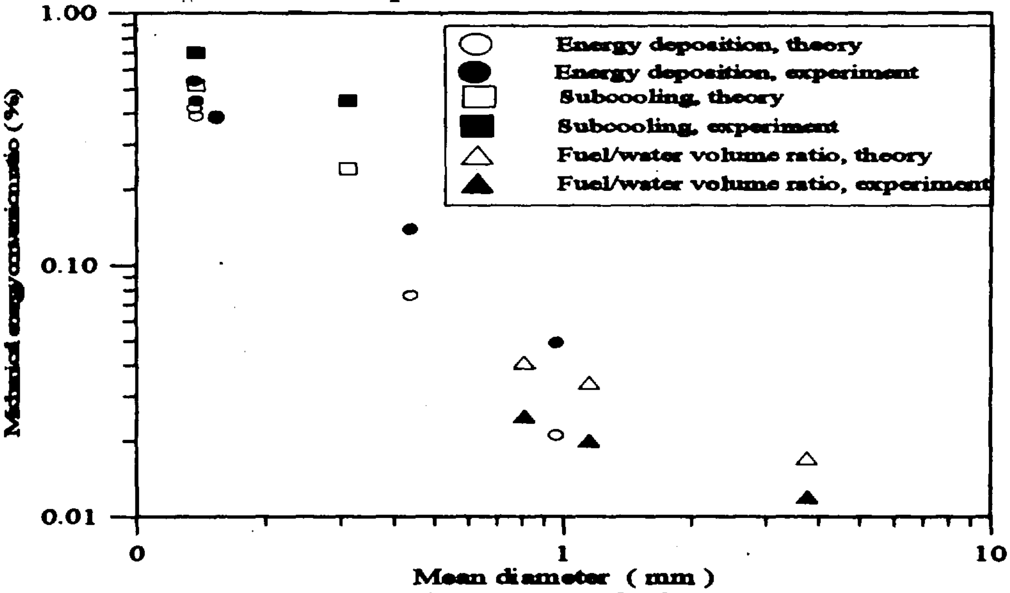

Fig 3. Comparison of experimental [4] and calculated mechanical energy conversion ratio.

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