The RBMK reactor Structural Mechanics at the Fast Destruction Phase

L.M.Parafilo, V.N.Korolev, O.Yu.Novoselsky
Institute of Physics&Power Engineering, Obninsk, Russia
Reactor Design Institute of the Power Engineering, Moskow, Russia

Механика структур реактора РБМК на этапе быстрого разрушения

Л.М.Парафило, В.Н.Королев, О.Ю.Новосельский
Физико-энергетический институт, Обнинск, Россия
Научно-исследовательский и конструкторский институт энерготехники, Москва,Россия

АННОТАЦИЯ

На основе описываемого сценария гипотетической аварии с полным разрушением реактора и примыкающих конструкций определены задачи расчетного анализа, основу которого составляют проблемы механики структур. Приводятся результаты решения некоторых задач для случая множественных разрывов труб технологических каналов.

1. The familiar scenarioes of the 4th block Chernobyl NPP accident based mainly on the neutron-physical and thermo-hydraulical components. The scenario could be more trustworthy if structural mechanics would be take into consideration. There are reliable data about reactor remains. It is evident that the inter communications of the structural mechanics and other components (including thermo-chemical) are essential in this case. Following scenario may be considered as an attempt to coordinate the accident's events to put emphasis on the structural mechanics problems. Such a method of analysis will provide more complete description of the accident. This paper is the attempt to resolve same of these problems.

2. Let's divide the accident's scenario into the following stages.

Stage 1. Fast (a few second) reactor's power excursion up to ~200-500% . The were some difference between two sides of the reactor. The pressure in the drum separators was rised to ~115-130%. The runaway because of coolant density drop is most probable. There was local abnormally high power intencity with explosive break of the fuel elements. Part of that fuel mass find themselves on the inner surfaces of the pressure tubes (PT). Other part of dispersed fuel creates the high density suspension.

Stage 1 tasks: fuel's flying away, shaping of the temporal dens fuel structures, axial fuel transport including the transport of lower sub-assembly part, stress-strain state of the PT, in-tube generated shock waves propagation.

Stage 2. Tube rupture as a result of PT overheating. The outcoming mixture of coolant and dispersed fuel form high pressure internal areas near to break places. The core elements are displaced at horizontal and vertical directions. The pressed stack provides the force transfer from high pressure areas to casing, upper and down reactor plates. The casing deform, lift of the upper plate, increasing load on the reactor support construction. Because of the casing compensator rigidity low all reactor structure below upper plate has a chance to move down under force effecting the interior part of the lower plate. The high-temperature flowing mixture reacts with tubes, casing and graphyte. Thickness of these objects decreases, hydrogen is produced.

Stage 2 tasks: estimation of the tube break opportunity, of the coolant flow in the reactor space after that, of the pressure field and displacement of the block-laying, of the forces acting at the plates and casing, of the support structure resistance.

Stage 3. The PTs, the control system (CS) tubes and the reflector coolant tubes breaks would be unevitable if the upper plate is lifted. Because of different conditions these breaks are not simultenous. The initial break location make the upper plate lifting noncomplanery. As a result there will be a localisation of secondary breaks. CS tube breaks may be dangerous because draining of them leads to input ~4β_{eff} positive reactivity. Pressure in the CS circuit is near to barometric pressure, pressure in the reactor space may be essentially more. Low-density vapor from the reactor space will substitute the water in the CS tubes and even to move control rods. A new power rise will be possible, as well as runaway. All this events may coincided with the lower plate moving if the reactor support structure resistant will be unsuffitient.

Stage 3 tasks: the dynamic of tube breaks, flow in the CS circuit, lower plate moving.

Stage 4. There are essential change in the object's topology. The tube breaks cause fast pressure increase. Because of decreasing of the number unrupture tubes the resistance to following rupture is decreased. This process is similar to the chain reaction. The reactor structure is divided: the lower part falls with acceleration more then gravitational one the upper plate take off with a great velocity. The pipelines connected with the upper plate act with the walls of reactor hall and break. Pressure drop between lower and upper parts of the reactor shaft make available ejection of the core elements. The upper plate falls in the free shaft volume. At the stage 4 of the steam-water-H_2 mixture flows from the reactor space through the mounting space to the drum-separator boxes. H_2-explosives in the boxes cause the collapse of the structural construction.

Stage 4 tasks - fracture mechanics: the reactor and upper plate moving, the casing break, the tube breaks above the upper plate, the stack elements ejection from the reactor, structural construction destroying.

3. To solution all these tasks mustbe created new methods and new software. This software will proveded the simultaneous calculations of all principal processes. Some of that problems were solved. There are following modules today:

- thermal model of the core,
- thermo-hydraulic model of the reactor circuits,
- model of the flow, heat transfer and heat transport in the reactor space (in the gap system),
- mechanics structure model of the reactor.

The first two models are connected with point kinetic model of the core and they were jointed to single code, The last two models are separate codes. Joint actions of the codes take by means of file data changing.

The model of flow in the reactor space are based on the hydraulic approximation. The gap system were simulated by connected one-dimension channels system. Main problem was nonlinear hydraulic resistance with factor changing from 10^{-3} to 10^{3} as a nominal value. It is function of blocks displacement and parameter flow changing.

The big displacement of the core elements were demanded to use the nonlinear deformation theory. Because action of the thermo-local load at the shall's elements we were used Shor's nonisothermic plasticity theory that take into account temperature dependence of the material yield stress. Geometrical nonlinearity were accounted for by incremental theory based on Green's deformation increment tensor and on Piola-Kirghoffa's strain tensor. Main digital model was produced reducing from three-dimension model to rod's model. To advanced stages of the deforming these was used variation-difference method based on the discontinuity basis functions.

4. To demonstrate some characteristic of the accidental behaviour and some possibilities of the created codes calculation of the hyphotetical accident to the RBMK core were performed At the middle horizontal cross section at the same time 7 PT were breaked . Flow rate trough each rupture was 30kg/s if pressure in the reactor space at the break point was barometric. The more tha pressure the less the flow rate. The quality of the flow in tube was set 30%. The reactor was in operation mode at full power.

Fig.1 shows the state of the stack at the moment 1 sec after breaks on the central horizontal section. The visible sizes of the gaps here are essentialy increased to visualise the picture. Main peculiarities are here

- the predominantly disturbance expantion along of the main axis,
- the creation of thepressed area around break tubes with high hydraulic resistance,
- fast disturbance expantion to the stack border, contacts with casing.

The fig.2 show the gauge pressure distribution at the central horizontal section. Near the break places the pressure is approximately the same ~2.3 MPa. Next isobaric level is one half as large and so on. The block-laying packing around the break places causes the pressure to be abruptly decreased (fig.3). The results give the possibility to defined the force dynamics acting to the reactor structure, to asses their stress-strain state and integrity.

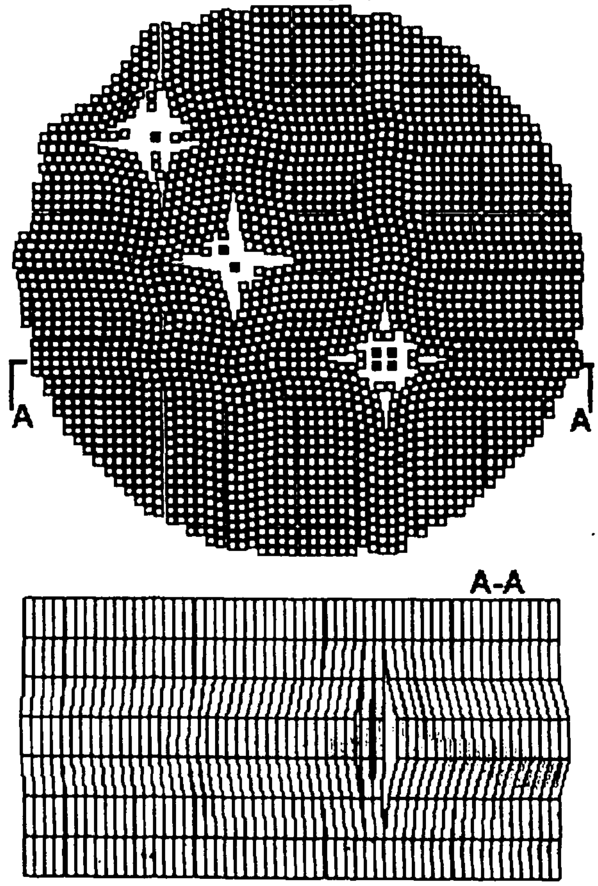

Fig.1. RBMK. Multiply rupture (7units) of the channel tubes. Time = 1s.
▪ - cell with rupture tubes.

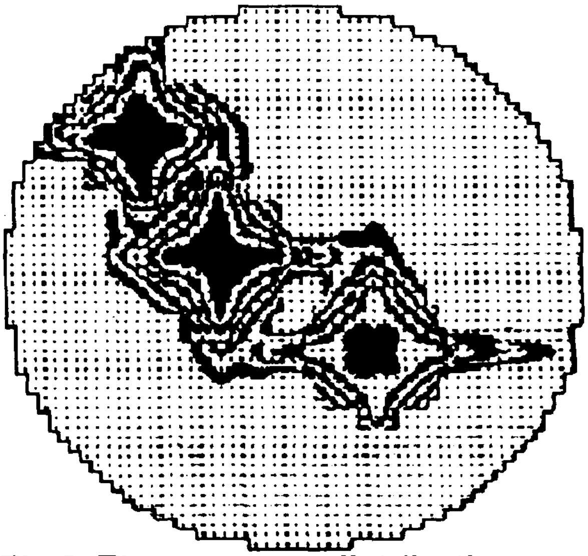

Fig.2. The pressure distribution at the middle horizontal section. Time = 1s. Pmax = 2.4 MPa.

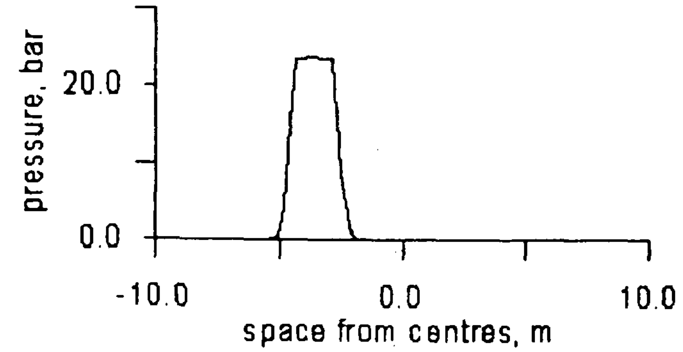

Fig.3. The pressure distribution along main horizontal axis at the fig.2.