XA9744604

The proposals on cooperation to foreign centers of science

Thermophysical properties of reactor materials in a broad band of pressure and temperatures realized at normal transient and emergency operation activity of nuclear power plants

(Dr. Vladimir E. Fortov, Academician, Russian Academy of Sciences, Moscow)

Introduction

The basic condition of development of atomic engineering is now ensuring of safety of nuclear power plants (NPP). Only fulfilment of this requirement it is possible to count on support by a public of various countries the programs of development of atomic engineering projects including development and construction of NPP of new generation. In this connection investigations of problems of safety of NPP in particular research of slightly investigated till now processes of occurrence and evolution of severe accidents and the ways of struggle with their consequences acquire the major value.

The full scale experimental research of such accidents is impossible and consequently there is the only one way of physical and mathematical modeling of various stages and processes of accident with development on a final stage an integral numerical code described sequence of events during accident . The solution of this problem is impossible without knowledge of reactor materials properties, parameters and constants described variety of processes.

For the description of thermal behaviour of the nuclear reactor during accident knowledge of termophysical properties of reactor materials such as fuel, structural and cladding materials and coolant is necessary. Until recently the researches of thermophysical properties of these materials were conducted basically in ranges of temperatures and pressures characteristic for normal and transient operational modes of NPP with parameters poorly distinguished on range from nominal. In the world the extensive information about thermophysical properties of reactor materials in these conditions ($T_{max} \leq 1500$ K) is accumulated.

At the same time experience of operation of NPP has shown that study of behaviour of reactor materials and processes which take place at severe accidents conditions with heavy damages of a core (accidents on NPP TMI, Chernobyl) when in result of disturbance of the core cooling and therefore increasing of core temperature the zirconium -steam reaction and the core destruction and melting begins resulted in the danger of destruction of reactor pressure vessel, steam and hydrogen explosions and in the end of containment failure is necessary.

In this connection there are the new problems of research of behaviour of reactor materials their thermophysical, mechanical and other properties, properties of melts of reactor materials and new systems formed in result of core melting and also parameters and constants described various processes (high-temperature zirconium steam reaction, interaction of melts of reactor materials with construction materials, combustion and detonation of hydrogen-air mixtures, and etc.) at extreme conditions ($P \geqslant 10$ MPa, $T \geqslant 3000$ K) characteristic for such accidents.

Now such information or is away, or is unsufficient, uncoordinated and is inconsistent.

The activity on the collecting, analysis and systematization of the literary data on thermophysical properties of reactor materials in the field of increased temperatures - on one hundred of degrees higher than the melting temperature of a material was begun at implementation of the IAEA research program " Thermophysical Properties Data Base for Light and Heavy Water Reactor Materials ". Data collecting on some processes, which take plase during accident (zirconium steam reaction, melts interaction with construction materials) was also begun. At the same time this program was not aimed at research of thermophysics of severe accidents and their consequences. In the program a number of important processes were not considered and on the basis of collecting material recommended values were not developed.

Therefore the research of the listed above properties and processes in the specified above pressures and temperatures range is urgent and also collecting, analysis, and systematization of literary data relating to thermophysics of severe accident and development on this base the reference recommendations are necessary.

Development of the reference recommendations and databases on thermophysical properties of reactor materials (water cooled reactors)

The offered project is directed to boths on ensuring by the necessary data activities, in which thermal behaviour of reactor materials in normal, transient and emergency operation mode of reactors including severe accident are simulated, and on maintenance the calculation and design works on creation of more perfect nuclear reactors of increased safety.

In the High Energy Density Research Center (HEDRC) investigations of thermophysical and mechanical properties of reactor materials in broad range of temperatures and pressures up to extremely high values, which arise at severe accident with core melting, steam and gas explosions and high-speed impact effects on elements of designs of reactor are carried out.

For obtaining the information about properties of substances in the HEDRC the following experimental installations and benches are used:

1. The installation for research of an enthalpy and heats of phase transformations by a method of mixing with heating of a sample by a RF-heating method including levitation heating. T_{max} =3200-3300 K. The error 1 %. Limitations on materials type are not present.
2. Bench of subsecond pulse electrical heating for simultaneous measurement of specific heat, electrical conductivity, emissivity and melting temperatures of electrical conducting materials at temperatures 293-3500 K (speed of heating 10^3-10^4 K/s).

3. Installation for research of thermal conductivity of metals, alloys and composites with electrical heating of a sample (T_{max} =2800-3000 K).
4. Installation with pulse laser heating for research of vapour pressure of materials by a method of a point of boiling (T_{max} =4500 K, P_{max} =1 MPa).
5. Bench of submillisecond pulse electrical heating for research of an enthalpy, electrical conductivity, and phase diagrams of electrical conducting materials (T_{max} =5000 K, *speed of heating* 10^7 - 10^8 *K/s*).

In the HEDRC the work on systematization and generralization of the numerical data is conducted. The Research Center participated in implementation of the IAEA coordinated research program " Thermophysical Properties Data Base for Light and Heavy Water Reactor Materials " and supports communications with the foreign partners - participants of this program (Boris Kidric Institute of Nuclear Sciences (Yugoslavia), Bhabha Atomic Research Center (India), Universitat Stuttgart, IKE (Germany), Nuclear Research Institute (Czech Republic), Institute of Atomic Energy (China)). In the Research Center a databank "IVTANTERMO" is created, which lets to execute:

- calculation and accumulation of the data on thermodynamic properties of substances for a broad interval of temperatures (up to 6000 K);
- the full mutual coordination of all thermodynamic properties including of a thermochemical constants and thermodynamic functions;
- assessment of reliability initial molecular, thermochemical and other constants selected in result of the analysis and of processing of the primary literature and also calculated thermodynamic properties;
- calculation of thermodynamic functions of each particular substance with use of the most exact methods;
- the systematic account of the new information about an initial constants and entering of appropriate consistent changes into a system of the data including recalculation of the tables of thermodynamic properties.

Thermodynamic properties more than 2000 substances together with their compounds with oxygen, hydrogen, halogens, sulfur, nitrogen and carbon are now calculated. There are the thermodynamic properties in a standard condition (P = 0,1 MPa) at temperatures 293-6000 K such important for atomic engineering substances as uranium, zirconium and uranium and zirconium dioxides, water and heavy water, hydrogen, helium, krypton, , xenon, carbon dioxide.

In the HEDRC carring out of research of heat effects of high-temperature phase transformations of refractory substances and compounds is planned. It is supposed also to conduct research of the phase diagrams of refractory substances and compounds (uranium dioxide, reactor alloys). Melting and boiling temperatures of substances, solidus and liquidus temperatures will be determined.

The Research Center has both the literary data and data of own measurements of thermal conductivity, emissivity, enthalpy, specific heat, electrical conductivity, solidus and liquidus temperatures of a zirconium and made in Russia cladding materials produced on the basis of a zirconium with various alloyed additives in solid and liquid states and of stainless steels.

Severe accidents with core melting

In the HEDRC some processes characteristic for severe accidents with loss of coolant and core melting and also ways of struggle with consequences of such accidents are investigated. For the solution of these problems the Research Center disposes unique experimental base:

1. High-temperature installations and benches with various sources of heating: electrical (constant and pulse), high-frequency (8, 60, 440 KHz, 3 MHz), laser and radiation, on which researches of thermophysical properties of metal and oxide materials up to 3000-5000 K, processes of interaction of reactor materials melts (weight of a melt up to 5 kg, temperature up to 3000 K) with structural materials, are conducted.

2. Explosive chamber with volume of 110 m^3 designed on explosion up to 20 kg TNT.

3. Unique spherical explosive chamber with diameter 12 m designed on explosion up to 2000 kg TNT (fig. 1).

4. Benches for research of mechanical properties of materials at impact loading (impactor speed 0,1-6,0 km/s).

5. Bench for steam-zirconium reaction research (T_{max} = 2000- 2300 K, P_{max} = 0,3 MПa) is now constructed, with the help of which it is supposed to execute experimental modeling of destruction process of fuel element claddings arised as result of this reaction. On the basis of the received and literary data it is supposed to conduct computational modeling of this process.

For a number of years in the Research Center the elaboration and research of high-temperature oxide materials (concrete, ceramics) being perspective materials for core melt catcher are conducted.

The Research Center has the data and carries out researches:

- on interaction of a liquid zirconium with zirconium dioxide;

- on thermophysical properties of refractories (concretes, ceramics);

- on thermal stability and strength properties of refractories at temperatures up to 2500 K;

- on interaction of metal and oxide melts with zirconium dioxide concrete and ceramics and other perspective high-temperature oxide materials at temperatures up to 3000 K;

Enthalpy, heat capacity, thermal conductivity, thermal diffusivity, thermal expansion, emissivity, electrical conductivity, melting temperatures of high-temperature oxide materials are investigated.

The researches of physical and chemical processes of interaction of metal and oxide melts of reactor materials with high-temperature oxide materials determination of their erosion are carried out by crucible method with use of laser, high-frequency and radiation heating in an inert and air environment. The products of interaction are analyzed by methods of X-ray analysis, optical and scanning electron microscopy. It is established that at interaction with zirconium dioxide materials the melt of zirconium is the most aggressive among metal melts. The carring out of research of a kinetics of the interaction processes is planned.

In the Research Center the extensive experimental information on equations of state and mechanical properties at impact loading of a number of metals and alloys, ceramic and composite materials is received. Equations of state of substances and oriented on mathematical modeling rheology determined relations are created.

In the Research Center experimental, calculation and theoretical investigations on a problem of hydrogen explosion at NPP are conducted. The conditions of origin and development of hydrogen explosion approximated to the conditions of severe accidents at NPP and the modes of non-stationary combustion capable to initiate the largest loads on elements of construction are studied. The activities are directed on creation of a database and development of packages of the applied programs.

The experimental works are carried out on a number of the installations including the spherical explosive chamber with diameter of 12 m.

The calculation and theoretical researches are directed on study of non-stationary combustion regimes and transition to detonation in conditions, which difficultly to realize in laboratory practice.

The activity actuates study of a kinetics of chemical reactions in hydrogen-air and hydrogen-air -steam mixtures with the purpose of optimization of the scheme of kinetic equations of reaction and its adaptation to the numerical solutions of gasdynamic models, development of models of non-stationary processes taking into account criteria of combustion to detonation transition and

- creation of the computational programs on the basis of developed and verifide models.

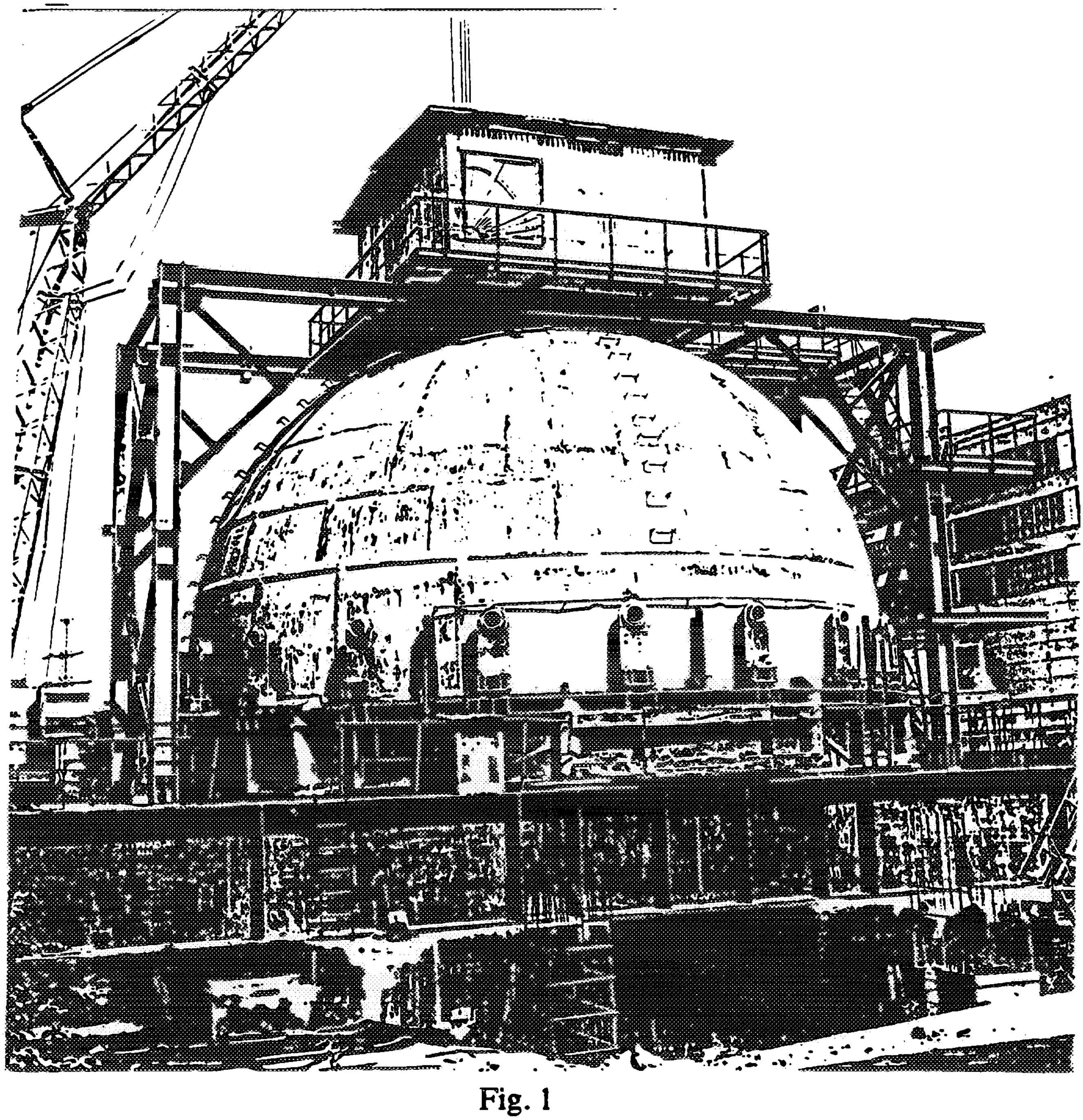

Fig. 1