

# Heavy Ion Beam in Resolution of the Critical Point Problem for Uranium and Uranium Dioxide

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Presently available heavy ion beams (HIB) with duration  $t_{HIB} \sim 100$  ns and energy deposition  $\Delta U \sim 1$  kJ/g could be successfully used for volumetric heating and study of thermophysical properties of warm dense matter (WDM). The basic points of such applications are: (i) careful choice of investigated substance, (ii) proper arrangement of the HIB energy deposition and (iii) proper arrangement of thermophysical measurements. Investigated substance choice should be done under three priorities: (j) great uncertainty in knowledge of its thermophysical properties, (jj) great application importance and (jjj) relevance to fundamental physical problem. Two such examples could be recommended in the field of nuclear safety problems: (1) Uranium critical point location problem [1] and (2) Non-congruent phase transition in uranium-bearing compounds, first of all, in uranium dioxide [2]. Arrangement of the HIB energy deposition and thermophysical measurements should be under three priorities: (#) uniform (as much as possible) state of investigated material and subsequent equality of surface (measured) and bulk (needed) thermodynamic parameters, (##) direct measurement of thermodynamic parameters without intermediate re-calculations via complicated hydrodynamic codes, (###) maximum pre-pulse control of thermodynamic parameters of the sample: energy deposition, chemical composition and initial density control. Present HIB heating of solid homogeneous samples definitely is not uniform because it is too long to be isochoric and too fast to be isobaric. It was proposed previously [3, 4, 1] to use the HIB heating of highly dispersive porous state of investigated material. In this case one could obtain slow and free, quasi-isobaric expansion of each single grain if their hydrodynamic time,  $\tau_d \equiv d/c_s$  ( $d$  – diameter of grain,  $c_s$  sound speed of grain material) is much smaller than  $\tau_{HIB}$ , i.e. if  $\tau_d \ll \tau_{HIB}$ . The main idea of this proposal is to reach the moment of homogeneous state of the sample during this quasi-free expansion (moment “X”). It corresponds to exhausting of the total free inter-grain space during the grain expansion. At this moment quasi-isobaric expansion is finished and one obtains uniform and homogeneous states of investigated material. Then stressed quasi-isochoric expansion is started. This isochoric expansion will be accompanied by a sharp pressure increase (“pressure jump”). The purpose for experiments is to catch this moment of pressure jump. The main advantage is that at this moment one exactly knows the density from porosity and initial density control, and enthalpy from HIB energy deposition control. Together with surface temperature measurements and uniformity of the sample it gives us the value of thermal {or caloric} expansion coefficient  $\alpha_p \equiv (\partial p/\partial T)_p \{(\partial p/\partial U)_p\}$  and heat capacity  $c_p \equiv (\partial H/\partial T)_p \{H \equiv U + PV\}$ . The main question is: which

physical problem could be resolved by measuring the thermal expansion coefficient, vapor pressure and heat capacity at the energy deposition range  $\Delta U \sim 1$  kJ/g. The presently proposed answer is: (A) thermal expansion of liquid uranium at temperature range 1000 – 7000 K and (B) thermal expansion of liquid uranium dioxide (or uranium carbide, and nitride etc.) at temperature range 1000 – 7000 K. High temperature parameters of evaporation for uranium and uranium-bearing compounds, including its critical point location and properties, are of great uncertainty during long time inspite of its extraordinary applied importance in the frame of nuclear safety problems as well as in development of new perspective schemes of nuclear energy devices, for example such as so-called Gas-Core Nuclear Reactor (GCNR) [5, 1].

Uranium critical point location problem [1]. Present estimations of critical temperature vary from  $T_c \sim 6000$  K to  $T_c \sim 14000$  K (!) [1]. As physical explanation of this uncertainty one could expect anomalous behavior of liquid uranium during its 3-5 fold expansion from melting point ( $T = 1400$  K) to critical point. Measurement of thermal expansion and vapor pressure of porous uranium under HIB volumetric heating could resolve this problem and reveal these fundamental physical anomalies.

Non-congruent evaporation in uranium dioxide [2]. Non-congruence (different chemical composition of coexisting phases) leads to non-standard topology of phase boundaries, first of all, vapor pressure, and to completely different properties of critical point in comparison with standard gas-liquid evaporation of simple substance and its critical point. Measurement of thermal expansion, vapor pressure *etc.* of porous uranium dioxide under HIB volumetric heating could confirm or disprove thermodynamic anomalies predicted by theoretical models [1, 2].

## References

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