Overcoming Thermal Shock Problems in Liquid Targets

by

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Prepared for consideration for presentation and publication at the 2000 Annual Conference of the American Nuclear Society, San Diego, CA, June 2000.

SUMMARY

Short pulse accelerator-driven neutron sources such as the Spallation Neutron Source[1] (SNS) employ high-energy proton beam energy deposition in heavy metal (such as mercury) over microsecond time frames. The interaction of the energetic proton beam with the mercury target leads to very high heating rates in the target. Although the resulting temperature rise is relatively small (a few °C), the rate of temperature rise is enormous (~10^7 °C /s) during the very brief beam pulse (~0.58 μs). The resulting thermal-shock induced compression of the mercury leads to the production of large amplitude pressure waves in the mercury that interact with the walls of the mercury target and the bulk flow field. Safety-related operational concerns exist in two main areas, viz., (1) possible target enclosure failure from impact of thermal shocks on the wall due to its direct heating from the proton beam and the loads transferred from the mercury compression waves, and (2) impact of the compression-cum-rarefaction wave-induced effects such as cavitation bubble emanation and fluid surging. Preliminary stress evaluations indicate stress levels approaching yielding conditions and beyond in select regions of the target. Also, the induction of cavitation (which could assist in attenuation) can also release gases that may accumulate at undesirable locations and impair heat transfer.

Fortunately, powerful approaches also exist which, if properly applied can conclusively mitigate thermal shock issues. One such approach relies on use of scattering centers in the fluid or at wall-liquid interfaces to attain 10 to 100 times attenuation of pressure waves over relatively short distances. Use of such approaches can potentially lead to several benefits such as: (1) controlled elimination/minimization of pressure loads on to structures, (2) ability to minimize material degradation due to mercury attack during pulsations, (3) ability to tailor the proton energy deposition away from the sensitive front window region, and, (4) ability to reduce concerns related to uncontrolled cavitation gas bubbles migrating to undesirable regions.

The general philosophy being addressed for addressing thermal-shock related issues for SNS is “intelligently designing our way out.” To succeed in such a philosophy requires knowledge of one or more key phenomena or mechanisms that provide conclusive and compelling benefits, which, if properly harnessed into the design will automatically address several issues. The general approach is based on use of wave energy attenuation via use of appropriately-configured scattering centers (such as gas-filled low impedance cylinders/spheres, or gas injection) in the bulk or at liquid-structure interface regions.

This paper provides a perspective overview of scoping assessments that demonstrate via simulation the degree of attenuation one may expect with introduction of scattering centers (SCs) modest void fractions in mercury. A companion paper[2] presents experimental confirmation.

The CTH hydrocode[3] (used extensively at ORNL[4,5] for several fluid-structure interaction studies) was employed for these scoping studies. Figure 1 shows a sample problem in which the physics of attenuation using SCs in mercury is demonstrated by considering two cases in a gun-barrel type geometry. In the first case (Case 1), a 10 MPa high pressure zone is created in the mercury at the base region (e.g., via rapid energy deposition as in the SNS target) and the transport of waves upwards is evaluated. For the second case a series of SCs of 2mm in diameter (e.g., gas filled rings) are introduced at several locations to provide for an average void fraction of ~2.5%. As expected, for Case 1 no significant wave energy attenuation takes place. On the other hand, with the addition of scattering centers (Case 2), results shown in Figure 2 for wave energy at three axial locations clearly

demonstrate the power of scattering-induced attenuation. The 10 MPa pressure at the base region is attenuated by close to a factor of 10 a few cm after interaction with the SCs.

The strong attenuation of pressure waves moving through air-water systems is well-known. A dependence is also known to exist on bubble size distribution and the frequency of pressure waves. However, no experimental evidence was found for the role of SCs in mercury filled systems. This aspect was clarified and conclusively demonstrated by recent experiments reported in a companion paper[2] by Kim, Knaff and Taleyarkhan.

The above-mentioned simulation results provide encouragement that judicious use of SCs in liquid target systems will result in large-enough attenuation of thermal shock-related loads. The presentation will describe details of simulations and also present design concepts for incorporation in liquid target systems.

<u>References</u>

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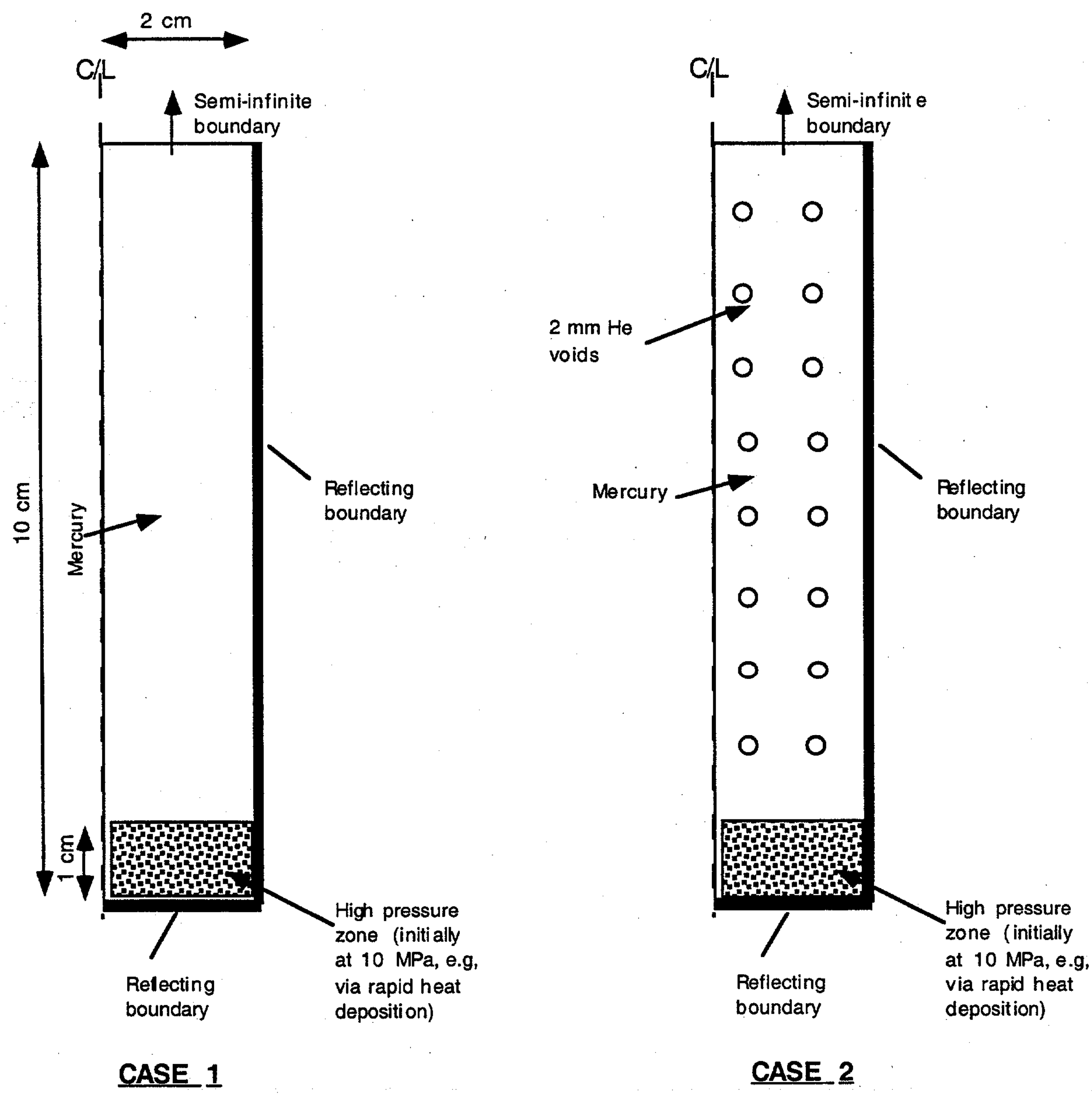

Figure 1. CTH Hydrocode simulations of impact of scattering centers in mercury

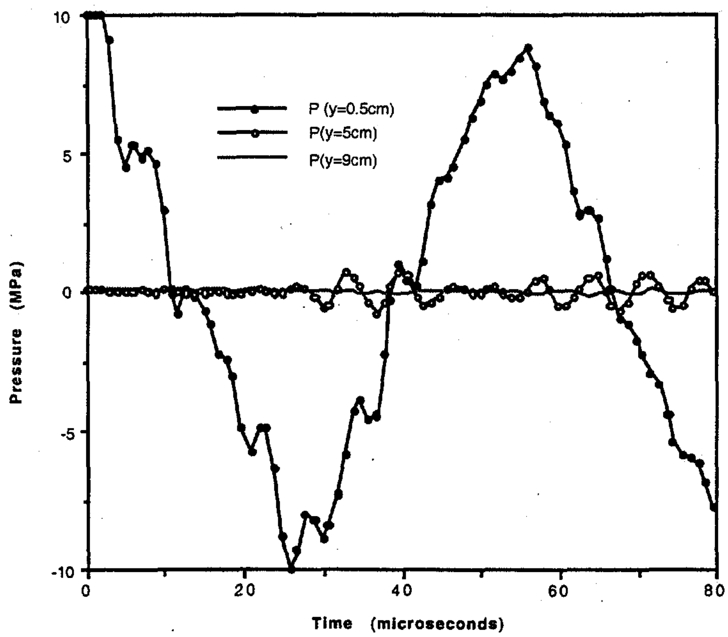

Figure 2. Variation of pressure with axial distance and time - Impact of scattering centers