TRANSCO PRODUCTS INC.

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Postulations of the Range of Fibrous Insulation Debris Size Generated by High Energy Jet Impact

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for

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The use of fibrous insulation to reduce the heat flux into containment buildings has raised questions about its behavior during a loss of coolant accident. If a crack forms in a high pressure piping system or component of the reactor primary system, or if the piping were to become completely severed, then the insulation may be subjected to high energy jets. The impact of the jets on the insulation would produce insulation fiber fragments of various sizes that could be transported to the sump screens of the emergency core cooling system (ECCS). The flow rate of cooling water through the ECCS pumps may be reduced by the accumulated insulation debris. Methods are needed to obtain reasonable estimates of the head loss that might occur during such an accident.

Numerous tests have been conducted on various types of insulation to determine the head loss characteristics of material. The damage to the material has been divided into three general categories according to USNRC-NUREG Guide 1.82.

$0<L/D<3$ (linear) Region I - Total Destruction
$0<R/D<3$ (lateral)

$3<L/D<7$ (linear) Region II - High Levels of Damage $3<R/D<7$ (lateral)

$7<L/D<R_{0.5\ psi}$ (linear) Region III - Dislodgement of Insulation
$7<R/D<R_{0.5\ psi}$ (lateral)

Guidelines are not provided by the USNRC on how the insulation should be prepared to simulate the different effects of destruction on the insulation fibers. Therefore, to simulate "total destruction" that occurs in Region I, the insulation structure is cut into 1/4" squares, and then shredded into even smaller pieces. Larger fragments of 1" x 1" dimension are used to represent the Region II debris and the "as-fabricated" sections are used for Region III debris. This type of testing has shown that head loss across the insulation is sensitive to the size of the fragments, flow rate, thickness and temperature. When dealing with fragments, the smaller sizes tend to arrange themselves more compactly on the screen, which results in a higher head loss. Therefore, the tests have shown that some knowledge of the sizes of the insulation debris is important for estimating the possible head loss following a loss of coolant accident.

It can be theorized, there is a need to determine the distribution size of the fiber debris generated in Region I and, even Region II of the LOCA zones. This is generally addressed by NUREG/CR-3170, which gives a description of the effect of jets impinging on pillows of fibrous insulation Photographs of the damaged insulation debris show clumps of debris in the sizes ranging from 2" to 12", but no quantitative data with respect to exact fiber length and diameter is presented. Other tests on jet impingement conducted at IIT were primarily concerned with the level of damage to the covering of the insulation, rather than the insulation itself, and no data on insulation fiber length was obtained.

In lieu of experimental measurements, reasonable estimates on the range of insulation fiber debris size can be predicated on the understanding of the behavior of turbulent jets. Given the high pressures (100 bars) of the fluids within the primary system piping and components, it is reasonable to assume that a break would produce flow having high Reynolds number turbulent jets. These jets have time averaged (mean flow) and turbulence distributions that will damage the insulation.

We assume the jet develops as either a two-dimensional slit jet, such as the flow from a long narrow crack in the component, or as a round jet from the end of an open pipe. The flow from the crack or small pipe will have a core region where the velocity is uniform and extends about 7 diameters from the break opening. The turbulence level within this core region will be low. Within a few jet diameters, the flow will undergo a transition and become a turbulent jet. The local shear stresses created by the turbulence will break up the insulation into smaller than original length fragments of varying lengths. The core region, transition zone, and turbulent eddies can be seen in the flow visualization photograph in Figure 1 of a round jet.

We then consider the size of the insulation debris generated, as a result of being impacted by the jet flow to be proportional to the size of the energetic eddies in the turbulent jet. It has been well documented, that jets spread linearly, as depicted by the outline in Figure 1. The size of the turbulent eddies also increases as the jet spreads. Thus it is reasonable to expect the insulation debris to be larger when it is generated by jet impact farther downstream from the jet exit. The photograph clearly illustrates a wide range of eddy sizes within the turbulent jet, at any location downstream of the jet exit. The insulation debris size will be determined by the size of the energy containing eddies, which will depend on the location of impact from the jet exit.(Given the insulation fiber length is proportional to the diameter of the eddy, or the diameter of the jet stream, depending on the energy at the location streamwise the insulation fiber is located, at the point it is impacted.) The most energetic eddies will have sizes comparable to the local jet diameter, the spatial integral length scale, λ_T or the mixing scale length, l_m. The least energetic and smallest scale of turbulence prior to the dissipation scale is the Taylor microscale. Although it is known that the Taylor microscale is not strictly a physically meaningful length scale, it does provide a conservative lower bound for the insulation fiber length of the debris.

The consideration for the size of the debris to approximate the scales of turbulence is conservative, as the strength of the insulation fibers and any residual binder is ignored. If the insulation had infinite strength, then no breakage would occur as a result of the jet forces. Recognizing the insulation fiber strength is finite, then there is a streamwise location, where the turbulent forces are equal to the strength of the insulation fiber. On either side of the point of equivalent stresses, fiber breakage "will" or "will not" occur. Considering the size of debris to approximate the scales of turbulence ignores any consideration for the point of equivalent stresses, and considers all fibers along the flow stream to be subject to breakage. This overestimates the amount of fiber to be broken and is thus conservative.

Scales of Debris

The largest scale in the jet should be proportional to the local jet diameter. A common measure of the local jet diameter is two times its half-width, $R_{0.5}$, where the half-width is defined as the radius where the mean velocity is half the centerline speed. According to Hinze, the local jet diameter downstream of the potential core is approximately

$$2 \times R_{0.5}/D = 0.16X/D.$$

Therefore, a round jet impacting insulation at X/D = 10 is expected to produce large fragments about the size of 1.6D.

Intermediate size debris can be estimated in two ways, by using

1) Prandtl's Mixing Length, l_m

and

2) Spatial Integral Scale, Λ_r

The estimate of the size of the mixing length can be found in Hinze (1975)

$$l_m = 0.21R_{0.5}/D$$

Using $R_{0.5}$ = **0.08** X/D, then l_m/D = 0.017 X/D. For a round Jet impacting insulation at X/D=10, we expect to find intermediate size fragments with a size around 17% of the jet exit diameter.

Measurements by Wygnanski and Fiedler (1969) have shown the spatial integral scale to be slightly smaller on axis than in the high shear layers on the sides of the local jet. On axis measurements show Λ_r/D = 0.0385 X/D, compared to off-axis Λ_r = 0.0525 X/D. For impact at X/D = 10, debris sizes will be in the range of 38% to 52% of the jet exit diameter.

The smallest scales before the turbulence is dissipated into heat would be roughly estimated by the Taylor microscale λ. The scale is Reynolds number dependent, and according to Tennekes & Lumley, $\lambda/R = (0.61\ Re_D^{-0.5})X/D$. For a jet Reynolds Number of 10^6 we find $\lambda/D = 2 \times 10^4\ X/D$. Thus at $X/D = 10$ we expect the smallest sizes of turbulence to be 0.002D. These relations predict the possible range of sizes of the turbulence, but do not predict the distribution of debris, i.e., what percentage of insulation debris will be small size compared to the large scale? The small scales of turbulence have the lowest energy, and will not produce much debris. The majority of the turbulence energy is in the large and intermediate sizes, so we expect the majority of the debris to be in those ranges.

Proposed Experiment

Verification of the preceding postulation is possible experimentally, utilizing sections of as-fabricated insulation (with the external covering removed) placed downstream of a high pressure jet. The insulation section would be so fixed to allow the insulation fibers to move unconstrained by the jet stream. The jet stream would be allowed to impact the insulation, and the insulation debris would be collected. Utilizing a system of graduated filters of decreasing % open, the insulation fiber debris would be collected, and the resultant insulation debris fiber length distribution determined. Repeating the test for a number of X/D locations, where X = 1, 2, 3, 5, 7, 10, 20, 30, would allow for the experimental determination of the most-probable debris size, and the standard deviation of sizes. With jet turbulence being responsible for debris formation, then the most probable insulation fiber length will increase linearly as X in X/D increases.

Any head loss test must consider a debris size distribution representative of the debris generated by a pipe break in the primary piping system. Therefore, the head loss tests must incorporate a debris size representative of the debris size distribution determined from the foregoing data collection and analysis, given the procedure produces a debris size distribution representative of that generated by the primary system pipe break. The test discussed above is meant to describe a general approach, not a definitive test procedure.

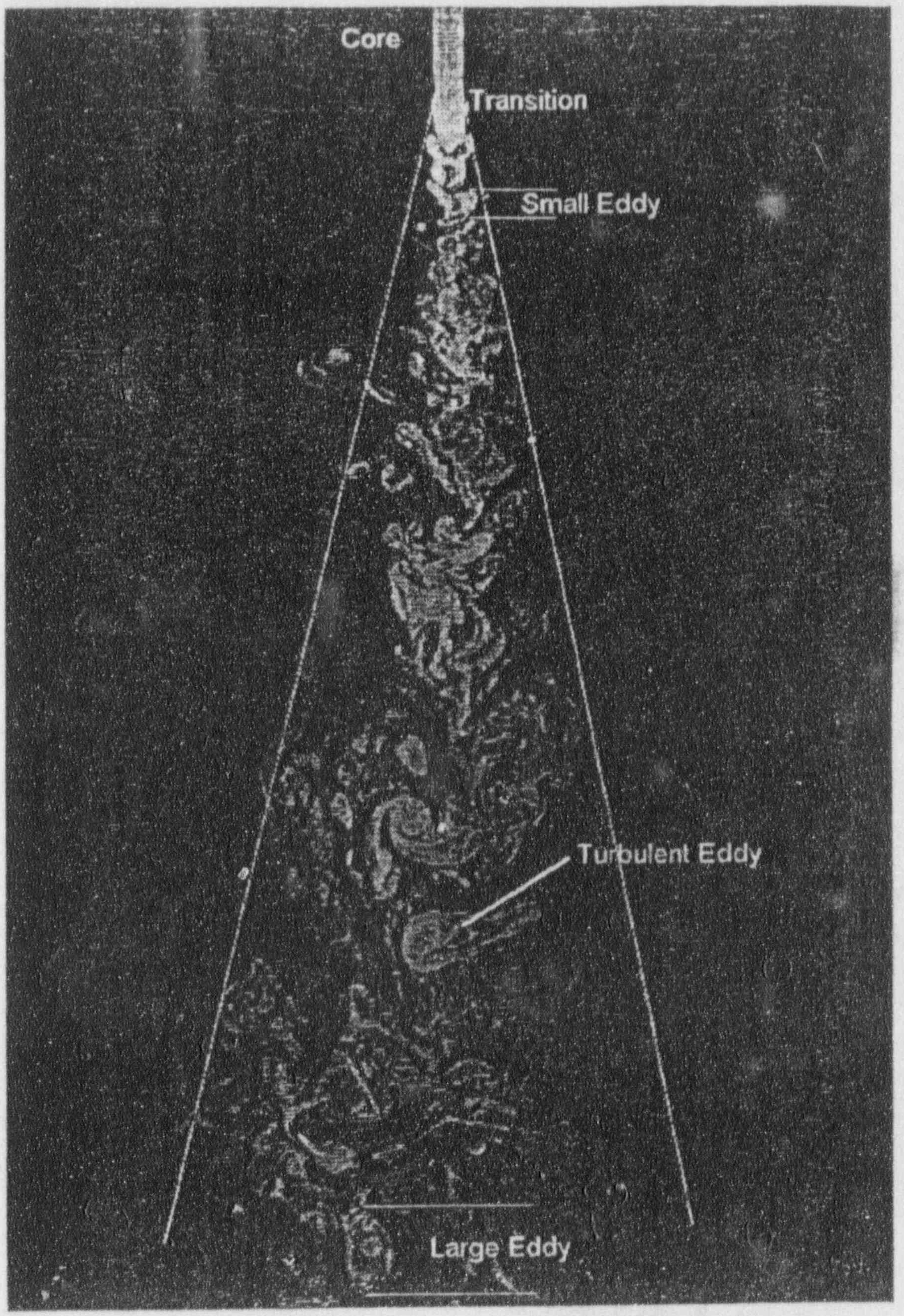

Figure 1 - Flow visualization with a laser light sheet in the center plane of a round jet.
Dimotakis, Lye & Papantoniou, 1981.

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