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A MECHANISTIC ANALYSIS OF LOFT PULSED-NEUTRON-ACTIVATION DATA*

by

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Pulsed Neutron Activation (PNA) is a technique for measuring mass-weighted flow velocities without perturbing the flow.[1-4] In this paper, we combine Monte Carlo PNA tagging and Monte Carlo detection calculations of the irradiated fluid with the transport of the irradiated fluid to predict the time spectrum in a PNA measurement. This mechanistic method has been used to analyze recent LOFT PNA measurements of single-phase water flowing in a 14-in (0.35 m) schedule 160 steel pipe.

Two sets of LOFT PNA data from the L3-7 test, blocks 24 and 26, were analyzed. Blocks 24 and 26 are measurements in which the PNA neutron generators were pulsed respectively at 80 and 100 minutes after the start of the blowdown transient. A linear background was fitted by least squares to the PNA time spectrum data in the regions on either side of the PNA peak. The experimental time spectra for these two blocks, corrected for background, are shown as histograms in Figs. 1 and 2.

A mechanistic analysis was developed to interpret the LOFT data. As described previously, [5] Monte Carlo calculations were carried out to determine the initial ^{16}N concentration in seven axial regions near the PNA source(s). Monte Carlo calculations were also done to determine the detector response to ^{16}N in another seven axial regions near the detector position. The turbulent single-phase flow theory of G.I. Taylor [6] was used to transport the irradiated fluid from the source region to the detector region. The time spectrum of the detector counting rate was then generated assuming: (i) uniform initial ^{16}N concentration in each axial source region and,(ii) constant liquid mean velocity. The radioactive decay of the ^{16}N was also included.

The width of the calculated time spectrum depends on the Taylor dispersion coefficient κ, given by [6]: $\kappa = K R \sqrt{\tau_0/\rho}$, where R is the radius of the pipe, τ_0 is the shear stress at the wall, ρ is the fluid density, $\bar{u}$ is the mean flow velocity and K is an empirical constant which, for fully developed conditions, Taylor found equal to 10.1. By varying the empirical constant K and the mean velocity $\bar{u}$, a good fit can be obtained to the LOFT data.

Figure 1 shows the block 26 experimental data and three calculated spectra with $\bar{u} = 0.37$ m/s and for K equal to 10.1 (the "classical" Taylor value), 2.8 and 1.4. The area under each calculated spectrum was normalized to the area under the experimental peak. A value of K of 1.4 appears to fit the experimental data. Figure 2 shows the experimental time spectrum for block 24 and a fit to the data with $\bar{u} = 0.37$ m/s and K = 1.4.

These LOFT data are fitted with a dispersion coefficient which is smaller than that obtained by Taylor. The classical Taylor theory assumes fully-developed radial mixing within each axial section for L/D ratios ≥ 50, whereas the PNA geometry at LOFT has an L/D ratio of ≈ 5.4. W. Gill and co-workers have shown that for short L/D ratios, smaller dispersion coefficients are obtained in single-phase laminar flows, [7-10] and turbulent film flows. [11] They discuss the fact that at short distances from the injection, the transverse eddy diffusion inhibits longitudinal dispersion. Thus, it is not surprising that the LOFT PNA data can be fitted with a small dispersion coefficient.

The L3-7 single-phase LOFT PNA measurements can be fitted with the mechanistic method which includes axial dispersion of the induced ^{16}N activity, axial response of the detector and a turbulent single-phase Taylor theory with an empirical dispersion coefficient. This method has two significant advantages: (i) all the data can be utilized in determining the "best fit", and, (ii) the model to which the data is being fit can readily be tested by either "eyeball" comparison between calculated and experimental data or by a goodness-of-fit statistical criterion. A good fit to all counting data lends confidence to the accuracy of the deduced mass-weighted velocity, as well as giving some information on the flow regime during the LOFT test.

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FIGURE CAPTIONS

Figure 1. Comparison of LOFT L3-7 test, block 26 PNA time spectrum data (histograms) with time spectra calculated with a mean flow velocity of $\bar{u}$ = 0.37 m/s and three different dispersion coefficients. The experimental LOFT data were summed over 0.2-s-wide time channels. The error bars represent one standard deviation counting statistical uncertainties.

Figure 2. PNA LOFT L3-7 test, block 24 (histograms) and a mechanistic method fit with $\bar{u}$ = 0.37 m/s and $\kappa = 1.4\ R \sqrt{\tau_0/\rho}$. The experimental LOFT data were summed over 0.2-s-wide time channels. The error bars represent one standard deviation statistical uncertainties.

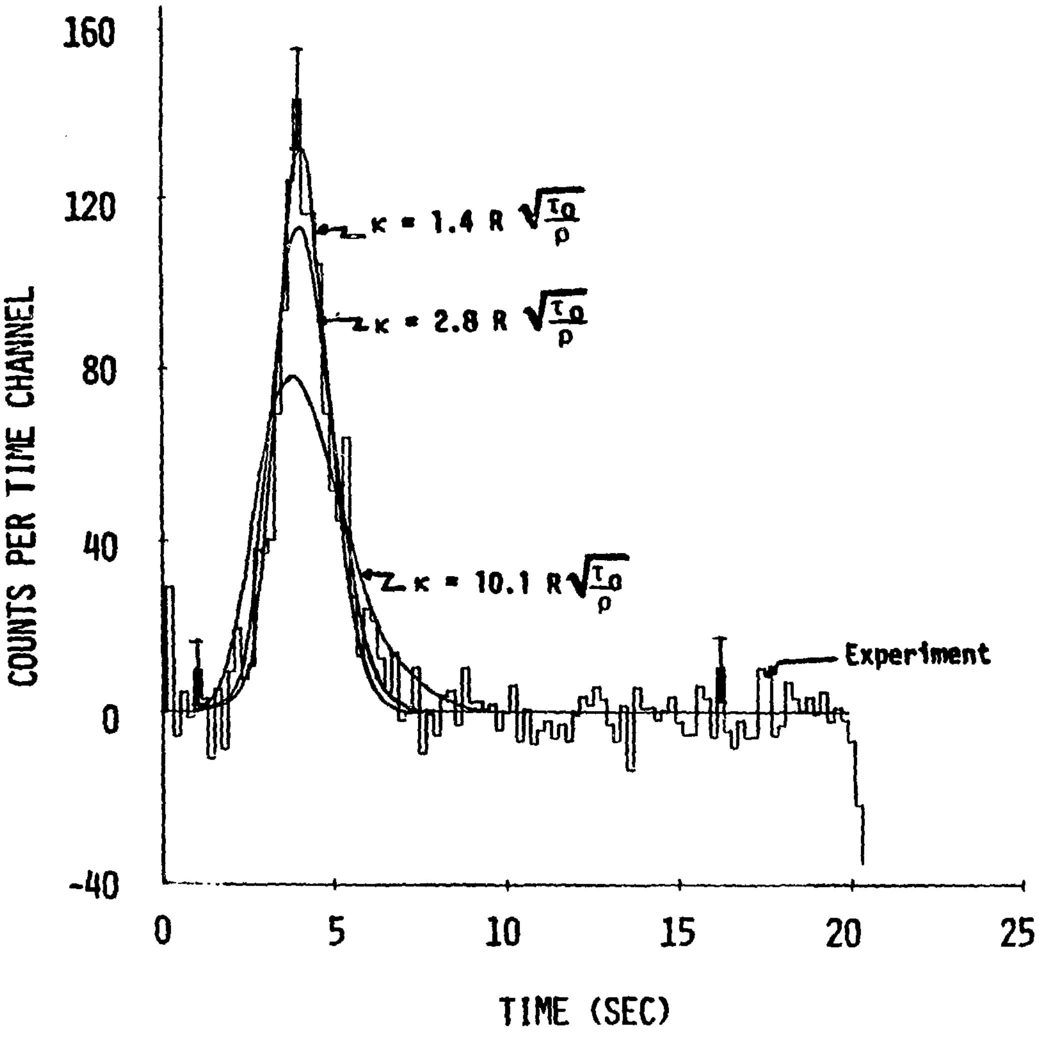
160
120
80
40
0
-40
COUNTS PER TIME CHANNEL
0
5
10
15
20
25
TIME (SEC)
$\kappa = 1.4\ R\sqrt{\frac{\tau_0}{\rho}}$
$\kappa = 2.8\ R\sqrt{\frac{\tau_0}{\rho}}$
$\kappa = 10.1\ R\sqrt{\frac{\tau_0}{\rho}}$
Experiment

Figure 1

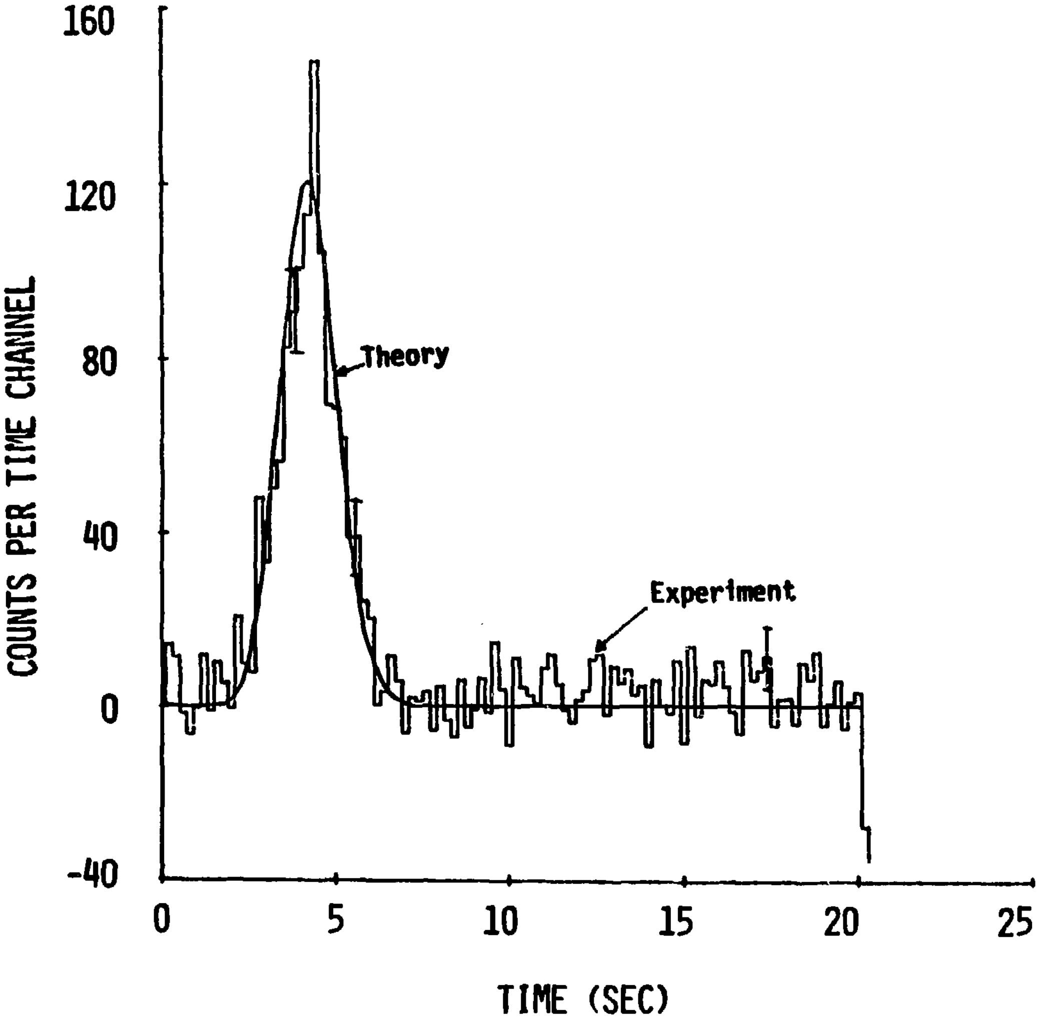
160
120
80
40
0
-40
COUNTS PER TIME CHANNEL
0
5
10
15
20
25
TIME (SEC)
Theory
Experiment

Figure 2