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LOFT ADVANCED DENSITOMETER ARA

III/L1-4 PREPARATORY TESTS

MASTER

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LOFT TECHNICAL REPORT

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ABSTRACT

A report on the LOFT advanced densitometer lab testing that was conducted at ARA-3 in preparation for the non-nuclear L1-4 blowdown at LOFT is presented. The densitometer uses a pulse height analysis method for determining PWR coolant fluid chordal average density. The average density of the coolant fluid along the Cs-137 gamma beam path is determined by measuring the uncollided flux count rate in a Cs-137 photopeak and knowing the LOFT primary coolant hot leg piping geometry. This is an application of a gamma densitometer technique which processes discrete pulses and with no pulse pile-up or integration taking place. Time sampling of the piping and fluid attenuated Cs-137 spectrum provides the data which is related to the changing coolant fluid density as a function of time.

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SUMMARY

LOFT advanced densitometer preparatory L1-4 test has been completed at ARA-3. This test included: (1) the set-up and checkout of the nuclear spectroscopy modules to be used in the multichannel scaling (MCS) mode for PC-2, "C Beam" densitometer data acquisition, and (2) the use of an experimental test section of LOFT primary coolant hot leg pipe to simulate the LOFT densitometer geometry. This test section of pipe had an OD of 14.0 inches and an ID of 11.18 inches. A 44 Curie, Cs-137 source was used for the gamma ray photon flux.

The densitometer that has been tested uses pulse height analysis, energy discrimination principles so that the uncollided flux count rates from "source" and "background" gamma radiation emitters can be separated. It is essential to the coolant fluid chordal average density measurement that the "background" gamma radiation count rate can be subtracted from the total "source" plus "background" count rate, as only the "source" gamma radiation count rate is proportional to the coolant fluid density. The nuclear series of Loss of Coolant Experiments (LOCE) at LOFT will have both "source" and "background" gamma radiation sources. For the non-nuclear series of LOCEs that has been conducted at LOFT so far, an integrating current mode densitometer has been used. Since current mode operation does not distinguish between "source" and "background" radiation a different technique for the nuclear LOCE test is required.

The metal and water path of 3.932 and 7.062 inches respectively for the lab tests were identical to the primary coolant hot leg "C Beam" densitometer detector at LOFT. (See Figures 1 and 3 for a comparison of the LOFT and ARA-3 "C Beam" geometries.) The detector consisted of a Bicron model 2M2 [2 x 2 NaI (Tl) crystal] and a RCA 6342A photomultiplier tube. The signal conditioning modules used were an Ortec model 276 preamplifier and Ortec model 460 amplifier. With this geometry and detector combination, uncollided Cs-137 gamma beam flux count rates of 6273 counts/sec with the pipe empty and 1256 counts/sec with the pipe full were measured and correspond to densities of 0.0752 #/ft³ (air) and 62.43 #/ft³ (water). The statistical accuracy of the pipe empty count rate is 1.3% and the statistical accuracy of the pipe full count rate is 2.8%.

Using these data points as the calibration of the measurement system, intermediate stratified water heights in the pipe test section were measured by the count rate technique and compared to measured water height values throughout the 0. to 7.062 inch pipe ID range.

The data sampling time was reduced to 0.1 sec for MCS mode data acquisition (the limiting factor being the data output rate of a 110 cps paper tape punch). The pulse output of the main amplifier was passed through a single channel analyzer whose window width was set at levels to pass full width at tenth maximum (FWTM) pulses, plus and minus 20 channels, so that only the photopeak counts were processed.

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1.0 INTRODUCTION

Loft Advanced Densitometer testing was conducted at ARA-3 in preparation for the L1-4 non-nuclear blowdown.

The tests at ARA-3 consisted of (1) modifying the LOFT PC-2, "C Beam" detector cask for additional shielding and more collimation, (2) setting up the modified cask in the "C Beam" geometry with a test section of the LOFT Primary coolant hot leg piping, and (3) using nuclear spectroscopy electronics in the pulse mode to discretely determine gamma radiation count rates as a function of the water path length in the LOFT pipe.

Hence the ARA-3 tests involved making single phase path length measurements to determine the suitability of using the pulse height analysis and counting techniques proposed for chordal average density measurements during L1-4.

This report documents the ARA-3 PC-2 "C Beam" densitometer test set-up, including the pulse height analysis electronics used and the calculations made to compare experimental results with theoretical predictions.

2.0 PURPOSE

The purpose of the ARA-3/L1-4 LOFT Advanced Densitometer tests was to (1) verify the feasibility of the pulse height analysis technique and (2) specifically investigate its application to a two phase steam/water density measurement using an on line analog background subtraction method to separate the peak count rate signal from high background radiation noise.

3.0 CALCULATIONS

3.1 "C Beam" Geometry Calculations

3.1.1 LOFT primary coolant hot leg piping dimensions

OD = 14.0 in.

ID = 11.18 in.

3.1.2 Metal and fluid path lengths

5.1.2.1 Physical measurements

$D_o = 35.56 \text{ cm (14.0 in.)}$

$D_i = 28.397 \text{ cm (11.18 in.)}$

LOFT Advanced Densitometer
L1-4/ARA 3 Test Data
LOFT Primary Coolant, Hot Leg
Piping, PC-2, "C-Beam" Geometry

Figure 1

$$R = 57.785 \text{ cm (22.75 in.)}$$

$$D_s = 22.86 \text{ cm (9.0 in.)}$$

$$\theta = 22.117^\circ (22^\circ 7')$$

$$D_o + D_s = 58.42 \text{ cm}$$

$$\sin \theta = .376$$

$$\sin^2 \theta = .142$$

3.1.2.2 Fluid path length

$$x_f = [D_i^2 - (D_o + D_s)^2 \sin^2 \theta]^{1/2}$$

$$x_f = 17.938 \text{ cm (7.062 in.)}$$

3.1.2.3 Metal path length

$$x_m = [D_o^2 - (D_o + D_s)^2 \sin^2 \theta]^{1/2}$$

$$-x_f$$

$$x_m = 9.988 \text{ cm (3.932 in.)}$$

3.1.2.4 Air path length

$$x_a = R - [D_o^2 - (D_o + D_s)^2 \sin^2 \theta]^{1/2}$$

$$x_a = 29.859 \text{ cm (11.756 in.)}$$

3.1.3 Calculations for ARA 3, "C Beam" geometry

The decrease in intensity of radiation as it passes through an absorber is given by

$$I = I_o e^{-\left(\frac{\mu}{\rho}\right) (\rho) (x)}.$$

I = intensity after the absorber

I_o = Intensity before the absorber

LOFT Advanced Densitometer
 L1-4/ARA 3 Test Data
 ARA 3, "C Beam" Geometry
 Diametral Offset

Figure 2

LOFT Advanced Densitometer
L1-4/ARA 3 Test Data
ARA 3, "C Beam" Geometry

Figure 3

$\frac{\mu}{\rho}$ = mass attenuation coefficient

ρ = absorber density

x = absorber thickness

The intensity before the absorber, I_0 , is further defined by

$$I_0 = \frac{\epsilon \gamma A_D S}{4\pi r^2}$$

where

ϵ = photoelectric efficiency; probability of a photon emitted by the source giving a pulse recorded in the photopeak.

γ = percentage of total disintegration of that is gamma radiation

A_D = exposed surface area of the detector (non-shielded area)

S = total number of disintegrations per second due to the source ($S = \text{no. Curies} \times 3.7 \times 10^{10}$)

r = source to detector distance

Therefore the radiation intensity equation can be written

$$I = \frac{\epsilon \gamma A_D S}{4\pi r^2} e^{-\left(\frac{\mu}{\rho}\right)(\rho)(x)}$$

If the exponent of the exponential term is defined as η and it is recognized that it is the sum of the products of the pipe, fluid and air mass attenuation, density, and absorber thickness terms or

$$\begin{aligned}\eta &= \Sigma \left(\frac{\mu}{\rho}\right)(\rho)(x), \\ &= \left(\frac{\mu}{\rho}\right)_m(\rho)_m(x)_m + \left(\frac{\mu}{\rho}\right)_f(\rho)_f(x)_f + \left(\frac{\mu}{\rho}\right)_a(\rho)_a(x)_a\end{aligned}$$

The subscripts "m," "f," and "a" relate to metal, fluid and air respectively, then the complete radiation intensity equation for the LOFT pipe ARA-3 tests becomes

$$I = \frac{\epsilon \gamma A_D S}{4 \pi r^2} e^{-\left[\left(\frac{\mu}{\rho}\right)_m(\rho)_m(x)_m + \left(\frac{\mu}{\rho}\right)_f(\rho)_f(x)_f + \left(\frac{\mu}{\rho}\right)_a(\rho)_a(x)_a\right]}$$

Since Cesium-137 is being used for the source, the following absorber constants are being used.

$$\left(\frac{\mu}{\rho}\right)_m = 0.0729 \text{ Iron}$$

$$(\rho)_m = 7.83 \text{ g/cm}^3 \text{ Steel (1\% carbon)}$$

$$(x)_m = 9.987 \text{ cm (3.932")}$$

$$\left(\frac{\mu}{\rho}\right)_f = (.0895) \text{ Water}$$

$$(\rho)_f = 1.0$$

$$(x)_f = 17.938 \text{ cm (9.062")}$$

$$\left(\frac{\mu}{\rho}\right)_a = (.0805) \text{ Air}$$

$$(\rho)_a = .001205$$

$$(x)_a = 47.838 \text{ cm (18.834")}$$

In addition to the attenuation due to metal, water and air, tungsten shims can be inserted into the beam path for calibration purposes. These calibration shims simulate density changes in the fluid medium going from water to steam conditions. The two shims are nominally 7/16 and 1/16 inches thick and provide a 18% and 77% of full scale calibration. The beam attenuation due to these shims is given below.

$$\eta_s = \left(\frac{\mu}{\rho}\right)_s (\rho)_s (x)_s$$

for large shim.

$$\begin{aligned}\eta_s &= (.1021)(170 \text{ g/cm}^3) (1.150 \text{ cm}) \\ &= 1.196\end{aligned}$$

for small shim.

$$\begin{aligned}\eta_s &= (.1021) (17.0 \text{ g/cm}^3) (0.159 \text{ cm}) \\ &= .276\end{aligned}$$

for both shims used simultaneously in the beam path.

$$\begin{aligned}\eta_a &= (.1021) (17.0 \text{ g/cm}^3) (1.309 \text{ cm}) \\ &= 2.272\end{aligned}$$

Using all of the values that are a function of the gamma source energy (Cs-137 gamma energy equals 0.662 Mev) and the physical constants of the test set the attenuated beam count rates are calculated.

$$I = I_o e^{-\eta} = \frac{\epsilon \gamma S A_D}{4 \pi r^2} e^{-\eta}$$

Calculating just the initial count rate due to the source.

$$\begin{aligned}
 I_o &= \frac{\epsilon \gamma S A_D}{4 \pi r^2} \\
 &= (.24) (.93) (44 \text{ Ci} \times 3.7 \times 10^{10} \frac{\text{disintegration/sec}}{\text{Ci}}) \times \\
 &\quad (.317 \text{ cm}^2) \times \left(\frac{1}{4(3.14)(70.3 \text{ cm})^2} \right) \\
 &= 1.85 \times 10^6 \frac{\text{disintegrations}}{\text{sec}} \quad \text{or} \quad \frac{\text{counts}}{\text{sec}}
 \end{aligned}$$

Recalling that the metal, fluid and air path lengths for the ARA-3/L1-4 geometry were

$$x_m = 9.947 \text{ cm}$$

$$x_f = 17.978 \text{ cm}$$

$$x_a = 42.401 \text{ cm.}$$

The calculated count rates for the pipe empty condition are

<u>Shims</u>	<u>I_{Calc}</u>
None	6295
Small	4792
Large	838
Both	620.

The calculated count rates for the pipe full with 59°F, 15°C water are

<u>Shims</u>	<u>I_{Calc}</u>
None	1263
Small	967
Large	173
Both	131.

Figures 4, 5, 6, and 7 are photographs of the actual test setup at ARA-III. Shown are the source, LOFT pipe, and detector cask geometry.

Overall View of ARA 3
Loft Advanced Densitometer
Test Configuration

Figure 4

LTR-141-72

LOFT PC-2 "C beam" geometry
detector, piping offset

LOFT Pc-2, "C Beam" Geometry,
Detector, Piping Diametral Offset

Figure 6

LTR-141-72

Densitometer Detector Cask
Lead Shield Insert

Figure 7

Loft Advanced Densitometer
Detector Cask, Collimator Housing
and Shim Drive Mechanism

4.0 DATA ACQUISITION

Figure 8 is a block diagram of the instrumentation used to acquire the experimental data.

The nuclear spectroscopy modules are standard off-the-shelf NIM modules, and the output devices are standard units.

5.0 ANALYSIS OF DATA

7.1 General

Figure 9 is a table of the log of the calculated count rates and the experimental count rates for the PC-2 "C Beam" geometry.

With the small shim inserted into the beam path, the measured count rate was only 75-85% of the calculated count rate for both the empty and full conditions.

Interestingly, this ratio changes as the large shim and then both shims are inserted. This leads to the question: why one shim varies the ratio but the other does not.

This phenomenon is presently being investigated for a physical and/or statistical explanation. Because the large shim causes a significant change in the ratio, it is thought that possibly the additional attenuation caused by the shim makes the interaction phenomenon no longer "RARE" with a correspondingly low probability. Hence the implicit Poisson statistic assumptions in the radiation attenuation equation

$$I = I_0 e^{-\eta}$$

would no longer be valid.

Figure 8

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LOFT ADVANCED DENSITOMETER
L1-4/AFA 3 Test Data Pc-2,
"C Beam" Geometry Instrumentation

LOFT ARA-III/L1-4 TEST RESULTS

	Shims	I_{Calc}	I_{exp}	I_{exp}/I_{calc}
<u>PIPE EMPTY</u>	None	6292	4761	.76
	Small	4792	3645	.76
	Large	838	837	1.0
	Both	620	666	1.07
<u>PIPE FULL</u>	None	1263	1033	.82
	Small	967	803	.83
	Large	173	201	1.16
	Both	131	161	1.23

Figure 9

If the measured count rate to the calculated count rate was in error but constant, then it could be concluded that there was a bias error in the calculations. But since this ratio varies a more indepth explanation needs to be found.

5.2 PHA Data Analysis

Figure 10 is a plot of the Cs-137 spectrum after the beam has been attenuated going through the pipe.

Figure 11 is a plot of the Cs-137 spectrum for the pipe empty condition and shows the effect that inserting shims has on the count rate in the photo peak.

The object of the densitometer measurement is to relate the count rate data to the fluid density.

At ARA-3, neither the density of the fluid, nor the flow regime could be varied, so all testing was done with cold water and a stratified flow regime. The count rate was varied by changing the water path length rather than the fluid density. (The relation of the fluid path length to the count rate was handled in an identical manner to the fluid density as both are exponents to the exponential in the photon attenuation equation.)

$$I = I_0 e^{-[(\frac{\mu}{\rho})_m(\rho)_m(x)_m + (\frac{\mu}{\rho})_f(\rho)_f(x)_f]}$$

where the air attenuation term has been neglected because it is negligible compared to the metal and water attenuation. Rewriting these equation and regrouping terms yields

$$\frac{I}{I_0 e^{-(\frac{\mu}{\rho})_m(\rho)_m(x)_m}} = e^{-(\frac{\mu}{\rho})_f(\rho)_f(x)_f}$$

Taking the natural log of both sides gives

$$\frac{\ln(I/I_0)}{-(\frac{\mu}{\rho})_m(\rho)_m(x)_m} = -(\frac{\mu}{\rho})_f(\rho)_f(x)_f$$

And letting

$$\eta_m = (\frac{\mu}{\rho})_m(\rho)_m(x)_m$$

$$\frac{\ln(I/I_0)}{-\eta_m} = -(\frac{\mu}{\rho})_f(\rho)_f(x)_f$$

LOFT ADVANCED DENSITOMETER
 L1-4/ARA 3 Test Data
 Cs-137 Spectrum Taken on LOFT Pipe

Figure 11

LOFT ADVANCED DENSITOMETER
L1-4/ARA 3 Test Data Effect
of Calibration Shims on Photopeak

This equation gives a direct relationship between the count rate and the fluid mass attenuation, density, and path length terms. For actual operation of the densitometer on the LOFT primary coolant system, the fluid mass attenuation is essentially constant over the steam-water range. The path over which the measurement is made is the chordal path and is also constant. This leaves as the only unknown the fluid density along the chordal path.

Hence

$$\frac{\ln(I/I_0)}{(-\eta_m)(-)(\frac{\mu}{\rho})_f(x)_f} = (\rho)_f$$

It must be remembered that the fluid density, $(\rho)_f$, is really the average fluid density along the chordal path and not a point density nor a constant along the entire path.

For the ARA 3 tests, this average fluid density was not made, but the actual beam water path length was made with the water density being constant. The equivalent equation relating the count rate to the water path length becomes:

$$\frac{\ln(I/I_0)}{(-\eta_m)(-)(\frac{\mu}{\rho})_f(\rho)_f} = (x)_f$$

This relationship was used to analyze the water height data.

See Figure 12 for the plot of count rate versus water height.

5.3 MCS Data Analysis

The majority of ARA 3 tests were run with the multichanger analyzer in the pulse height analysis mode so that the number of counts in a particular energy window was acquired. Because the analyzer must determine the peak amplitude of the input pulse to know which slot it belongs in, the PHA mode is "slow". In fact the TN1700 analyzer is limited to a minimum 1.0 sec spectrum data acquisition.

LOFT ADVANCED DENSITOMETER
 L2-4/ARA 3 Test Data
 Ln of Count Rate vs.
 Water Height (PHA Mode Operation)

Figure 12

Considering Nyquist sampling theory, which states that under ideal conditions (infinite rolloff filters and interval centering in the sampling window), the sampling rate must be twice the maximum frequency of interest. A 0.1 sec spectrum data acquisition would have a frequency response of 0.5 Hz which is too slow for the LOFT test requirement.

To speed up the data acquisition process operating, the analyzer in the multichannel scaling mode becomes necessary. In the MCS mode there is no pulse amplitude determination, but if the pulse is of sufficient amplitude to fall in a given window it is counted. Hence, the analyzer operating in this mode can acquire data samples at a much faster rate. In fact, the sampling rate of the analyzer was limited by the rate at which the data could be outputted to a storage device. A block diagram of the instrumentation used in the MCS mode is shown in Figure 13.

The window was set at FWTM plus and minus 20 channels, so that any pulse with an amplitude in the photopeak could be counted. This is the count rate which is related to the water path length.

MCS data relating count rate to water height is shown in Figures 14, 15, and 16.

6.0 DETECTOR CASK MODIFICATIONS

The present LOFT densitometer detector casks use a 3/4 in. diameter collimation hole to limit the count rate of the attenuated beam through the pipe. See Figure 17.

In order to keep the analyzer dead time to less than 20%, it was necessary to reduce the collimator hole size from 3/4 in. to 1/4 in. in diameter. To accomplish this a tungsten insert was placed in the collimator hole in the detector cask. Also, to provide additional attenuation against the unwanted uncollimated photons, a non concentric lead shield insert was also placed in the detector cask. This provided an additional 3/4 in. lead shielding in the forward direction and 1/8 in the backward direction. See Figures 18 and 6.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The LOFT advanced densitometer tests at ARA 3 substantiated the proposal that the primary coolant fluid density measurements taken during blowdown could be made using pulse height analysis nuclear spectroscopy techniques. This method is a prime candidate to make the measurement when LOFT goes nuclear and when there is a substantial nuclear background.

Using energy or pulse amplitude discrimination, a selected portion of the energy spectrum can be analyzed with the exclusion of unwanted portions. Although none of the testing done at ARA 3 included this nuclear background, the methods used would be the same but with the important consideration of handling a higher count rate, and having to subtract the background count rate from the photo peak count rate.

With this in mind, a number of the aspects of making a coolant fluid density measurement in a nuclear environment need further study. These include: (1) increasing the pulse throughout rate handling capabilities of the conditioning and processing electronics to improve the counting statistics, which determine the maximum theoretical accuracy of the measurement; (2) an extensive analysis of the overall measurement accuracy of the energy discrimination technique, including not only the statistical counting accuracy, but also the acquisition, storage, and reduction electronics accuracies; and (3) an extensive analysis of how the chordal average density relates to the flow regime interpretations, since it is the total cross sectional density which leads to the determination of the heat transfer characteristics of the coolant.

An in-depth study of the measurement accuracy is important in the selection of the optimum energy source, as electronics accuracy is as important as statistical accuracy. This is important in determining future density measurements at LOFT.

Figure 13

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LOFT ADVANCED DENSITOMETER
L2-4/ARA 3 Test Data
Instrumentation "MCS" Mode Operation

LOFT ADVANCED DENSITOMETER
 L1-4/ARA 3 Test Data
 Ln of Count Rate vs.
 Water Height (MCS Mode Operation)

Figure 14

Figure 15

INEL-A-3032

LOFT ADVANCED DENSITOMETER
L1-4/ARA 3 Test Data Count Rate
vs. Time (MCS Mode Operation),

Pipe Empty

Figure 16

INEL-A-3034

LOFT ADVANCED DENSITOMETER
L1-4/ARA 3 Test Data Count Rate
vs. Time (MCS Mode Operation),
Pipe Full

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LOFT, PC-2, "C BEAM" GEOMETRY

COUNT RATES * AS FUNCTION

OF COLLIMATOR HOLE SIZE

PIPE CONDITION

<u>Collimator Hole Dia.</u>	<u>Empty</u>	<u>Full</u> (Hot water)	<u>Full</u> (Cold Water)
3/4	57199	18480	11424
1/2	25467	8228	5086
1/4	6367	2057	1272
1/8	1587	513	317

* These values are calculated for the actual LOFT MTA PC-2, "C Beam" and not the ARA-III, "C Beam" geometry.

LOFT ADVANCED DENSITOMETER
L1-4/ARA 3 Test Data
Calibration Shims and Lead
Sleeve Insert for PC-2, "C Beam"
Detector Cask Assembly

Figure 18

Calibration shims & lead sleeve
for detector cask assy.

INEL-A-3042

REFERENCES

1. Evans, R. D., "The Atomic Nucleus", McGraw-Hill, 1955
2. NSRDS-NBS29, "Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV_x", 1969
3. Swierkowski, S. P., "A Feasibility Study and Prototype Design of a NaI Gamma-Ray Densitometer for Use in LOFT", Lawrence Livermore Laboratory UCID - 17365, 1977
4. Stephens, A. G., "Determination of Flow Regime Characteristics of Photon Attenuation", 1975
5. Fenyres, E. and Haiman, O., "The Physical Principles of Nuclear Radiation Measurements", Academic Press, 1969