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FINAL LEAK SIZING FOR LLTR SERIES II TEST A-3
AND RESULTS FROM SUPPORTING TESTS IN THE SONAR RIG

by

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FINAL LEAK SIZING FOR LLTR SERIES II TEST A-3

I. INTRODUCTION

The objective of LLTR Series II Test A-3 is to obtain data on leak propagation resulting from sodium-water reaction wastage damage. A small leak in the order of 10^{-3} lb/sec could cause a larger secondary leak in a nearby tube by wastage. The second larger leak could cause additional tube leaks of somewhat larger size until total leakage with associated sodium-water reactions becomes sufficient to cause the termination of the process by actuation of the pressure relief and blowdown systems.

In a previous letter (Reference 1), an initial size of 40 mils, providing a water leak rate of about 0.1 lb/sec, was recommended for Test A-3. However, this recommendation was tentative because the wastage data used in the leak size selection was obtained at 1 bar sodium pressure, whereas, the LLTR Series II tests will be run at about 10 bar pressure. The 40 mil hole would represent either a self-enlarged initial leak or a small secondary leak.

The higher sodium pressure at 10 bar will compress both the steam and hydrogen around a small sodium-water leak and increase the densities in both gases. As a result, it was envisioned that the wastage areas generated and the penetration rates of a given water leak into sodium would be significantly different at elevated sodium pressures as opposed to the available data obtained at atmospheric pressure.

Since no wastage data existed at the 10 bar sodium pressure, a series of tests were conducted utilizing the GE SONAR test rig. All of the tests were to be run under LLTR Series II Test A-3 conditions, which are:

A. Water pressure at leak site = 1700 psia
B. Sodium temperature = 580°F
C. Sodium pressure = 10 bar (145 psia)
D. Target tube = 0.625" O.D. x 0.109" wall
E. Target tube material = 2-1/4 Cr-1Mo

The description of the SONAR Test Rig can be found from Reference 2. The planned SONAR tests were described in Reference 3.

II. SUMMARY OF SONAR WASTAGE TESTS

A. Test Operations

The SONAR wastage tests are summarized in Table 1. Tests 1-7 were essentially the same as described in Reference 3. During the course of testing, the need for additional tests was identified as described below.

Tests No. 1 to No. 6 were conducted using a short 19-tube bundle arrangement. For the cases of 28, 20, 30 mils hole diameter, extensive self-enlargement occurred. Evaluation showed that a choked flow condition occurred inside the 1/8" supply tube and the short 5/8" injector tube. Thus, the water injection rate was determined by the size of 1/8" tubing instead of injection hole size as intended. Because of the low water pressure inside the injector tube, self-enlargement occurred. For Test No. 5, even though the test time was limited to 20 seconds, the self-enlargement still occurred. Test No. 7 was not conducted due to inability of the test system to handle the large quantity of water required for penetration of the target tube.

In an attempt to correct this condition of excessive pressure loss up-steam of the injection hole caused by expansion into the test chamber, a new water injection system was set up which connected the 1/8" tubing to the injector, bypassing the test chamber (5/8" tube). Tests 2, 3, and 6 were rerun using the new injection design. They are designated as Tests 8, 9, and 10 in Table 1.

However, even with the new water injection system design, the water pressure upstream of the hole was still found to be about 1000 psia instead of 1700 psia as required at LLTR Series II tests. This happened due to high friction losses in the 1/8" tubing. A fundamental design change to the SONAR Test Rig would have been required in order to correct the pressure loss problem. This design change would have been to increase the supply tube size

Table 1. Test Matrix for SONAR Wastage Tests

Test No.	Predicted Leak Size (Lbs/Sec)	D, Hole Diam. (Mils)	Spacing L (Inches)	L/D	L/R
1	0.0082	13.50	0.595	44	88
2	0.037	28.0	1.315	47	94
3	0.020	20.0	0.595	30	60
4	0.012	14.5	0.595	41	82
5[a]	0.037	28.0	1.315	47	94
6	0.05	30.0	0.595	20	40
7	0.025	21.90	1.315	60	120
8[b]	0.037	28.0	1.315	47	94
9[b]	0.020	20.0	0.595	30	60
10[b]	0.05	30.0	0.595	20	40
11[c]	0.0082	13.5	0.648	48	96
12[c]	0.0082	13.5	0.405	30	60
13[c]	0.0082	13.5	0.27	20	40

Notes:
(a) Leak injection time not to exceed 20 seconds to eliminate self-wastage
(b) New water injection system
(c) Supplemental tests

from 1/8" to 1/4". In addition, major changes would have been required in the venting system. This would require additional safety analysis as well as Site Safety Committee approval. Due to the urgent need for timely data to help support the Test A-3 size selection, it was decided the best approach was to conduct a set of supplemental tests, using the correct upstream pressure of 1700 psia, restricting the leak size to 15 mils or less (to obviate the pressure loss problem) and varying the L/D ratio in the same manner as Test 8, 9, and 10. These supplementary tests are designated as Tests 11, 12, and 13 in Table 1 and utilized a 13.5 mil injection hole which was expected to create an upstream water pressure around 1700 psia. These tests would determine if water pressure had a significant effect on penetration rate over an L/D range of 20-48.

B. Test Results

As shown in Figure 1, the SONAR tests showed higher penetration rates at 10 bar sodium pressure than the previously published "mean" line water injection data (Reference 4). However, the SONAR test data falls within the scatter band for the 1 bar data and thus this indicated difference is believed to be not significant. Test No. 8 was run under the desired water injection pressure of 1700 psia for a hole size of 13.5 mils. Compared with Test No. 11 for the same L/D ratio, it appears that water injection pressure does not have significant effect for this particular L/D ratio. Although Tests No. 12 and 13 were intended to be run at the desired water injection pressure of 1700 psia for a hole size of 13.5 mils, the actual water injection pressure was around 1200 psia instead due to facility design limit. It is not clear whether that is what caused the wide discrepancy between Tests No. 9 and 12. Tests No. 10 and 13 have close agreement. For the purpose of evaluating Test A-3 scenarios in the subsequent sections of this report, the SONAR test data representing LLTR test conditions are utilized.

It was also found from the SONAR tests that the maximum penetration rate occurs at a L/D ratio of $\sim$30 as shown on Figure 1. This is also the same maximum wastage point for steam injection data. Although two test data points

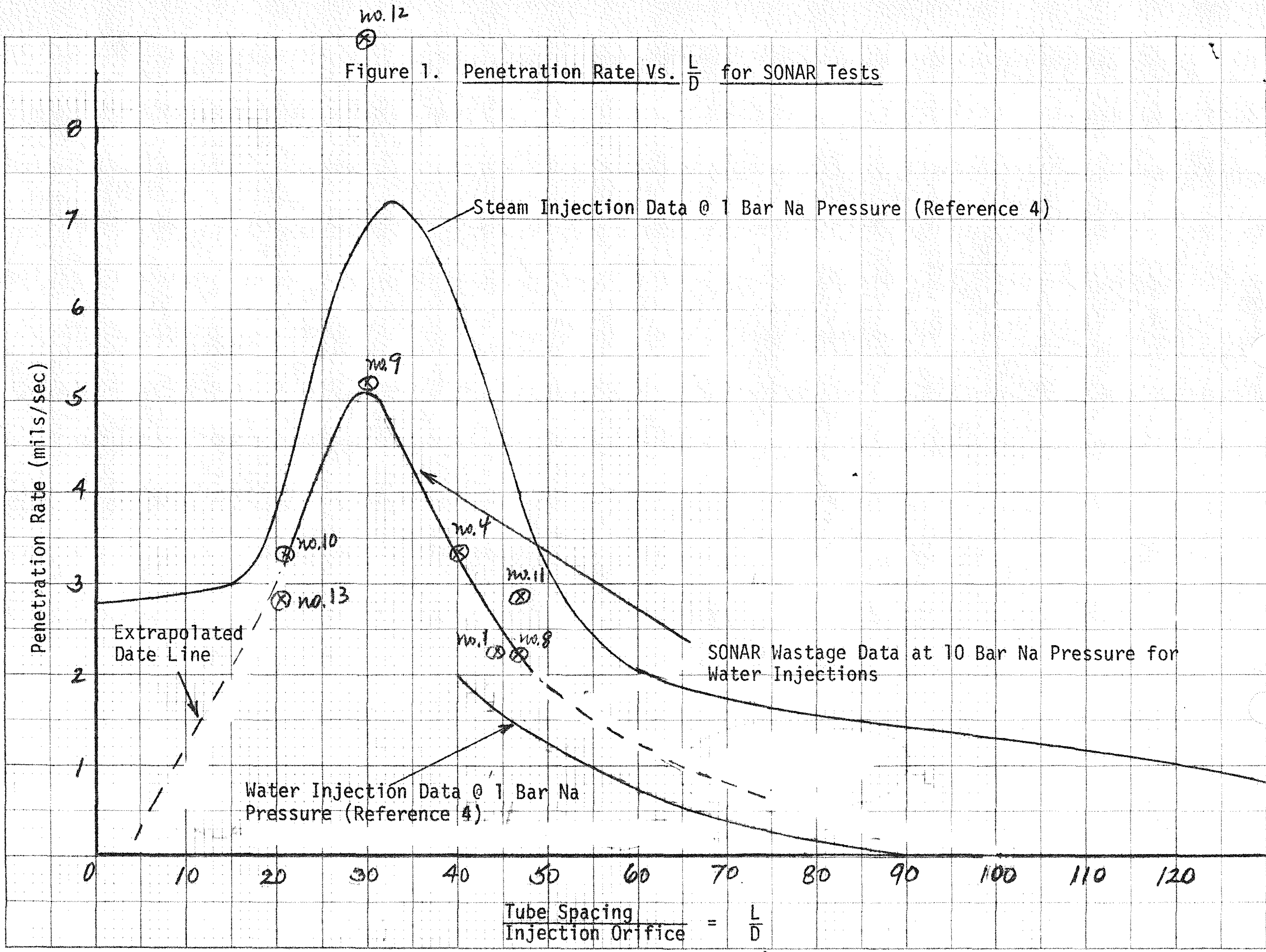

Figure 1. Penetration Rate Vs. $\frac{L}{D}$ for SONAR Tests

at this L/D ratio of 30 were created from the SONAR test results, the slower penetration rate (Test No. 9) will be used in building the scenario for Test A-3 for conservatism.

As shown on Figure 2, the preliminary results for wastage hole sizes show some agreement with the Russian data at atmospheric sodium pressure (Reference 5) for ratios of spacing-to-target tube/orifice radius below 40. However, large discrepancy occurs for the ratios greater than 60. It should be noted that the wastage hole size data from SONAR tests is defined as the wastage hole size as measured on the outer diameter of the target tube. Whether the discrepancy between the Russian and SONAR test data is due to sodium pressure effect or differences in measurement technique is not known at this time. It should be noted that the Russian data is for penetration of thin foils.

III. TEST A-3 CONSIDERATIONS

A. Leak Size Criteria

The desired initial leak size for Test A-3 should be chosen such that the worst damage situation can be simulated. The worst damage situation can be defined as the case where most steam tubes are damaged or where the largest quantity of water has been injected if the same number of tubes is damaged.

The geometry of the leak as well as the leak size is an important factor in determining the leak size for Test A-3. A second row tube is favored over the first row (adjacent) tube as the target tube since there would be less interference of the primary jet on the secondary jet produced from the target tube. Secondly, by aiming the primary jet slightly off normal ($\sim$1-2°) with respect to the target tube, the secondary jet could play on adjacent tubes without interference from the primary jet. Therefore, the desired initial leak size for Test A-3 will be selected based on the following criteria:

1. The initial size chosen should be such that it represents either a self-enlargement hole size (after an initiating small leak in the range of 10^{-4} - 10^{-6} lb/sec becomes self-enlarged) or the impingement hole size on an adjacent tube caused by a small primary leak in the order of 10^{-3} lb/sec, whichever is smaller.

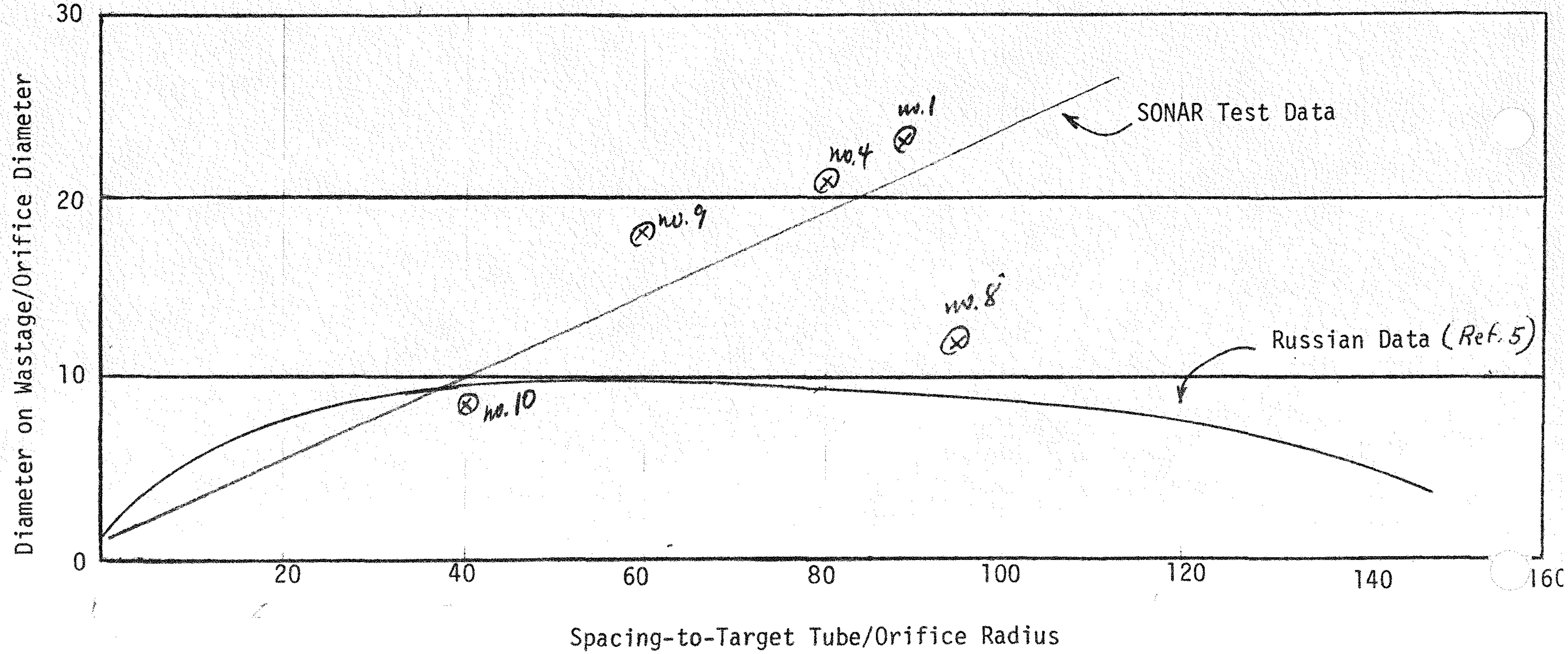

Figure 2 - SONAR Test Data on Wastage Sizes

2. The leak should cause the maximum penetration rate of the target tube so that failure of this tube occurs early, thereby maximizing the time available within the constraints of the LLTR test setup for consequent damage to additional tubes.

B. Leak Size Selection

It is postulated that an initial hole size of 40 mils would create the "worst case" condition for Test A-3 within the constraints specified above based on following rationale:

1. A significant number of impingement tests at CRBRP conditions are reported in the Appendix of Reference 6. These tests are of direct impingement onto CRBRP 2-1/4 Cr-1Mo tubing at a spacing of 0.595 inch, the CRBRP spacing to an adjacent tube. Three water injections (at 580°F sodium temperature) are reported. The diameters of the penetrations, measured at the tubing O.D., were 250, 310, and 380 mils. Fourteen injections were made at low temperature steam conditions (600-650°F). For these, the penetration diameter ranged from 90 to 380 mils. The actual diameter of the secondary leak when it burst through cannot be predicted, although it must be less than the outer penetration diameter. A 40 mil hole is considered to be on the small end of the range of secondary leaks.

A 40 mil hole is typical of initial leaks that have enlarged by self-wastage. This statement is supported by the data presented in References 7 and 8. The post-test (enlarged) hole diameters are not directly reported but can be determined approximately from the 8x magnification photos presented for each test specimen. One self-wastage test (No. 359) was conducted at water conditions (580°F). The hole was initially 0.15 mils diameter and enlarged to ∿26 mils diameter. Three tests (Nos. 334, 339, and 345) were conducted at sodium temperatures of 600 to 650°F. Finally, enlarged diameters were approximately 23, 35, and 65 mils. An additional nine tests were run at 850-900°F temperatures; enlarged diameters ranged from 25 to 80 mils. These thirteen tests are tabulated in Table 2. Similar test results have been reported by the French (Reference 9).

Table 2 - SELF-WASTAGE HOLE DIAMETER TEST DATA

Test No.	Temp °F	Initial Leak Rate (lb/sec)	Initial Equivalent Hole Dia. (mils)	Enlarged Hole Size (mils)
313	860	7×10^{-6}	0.7	70
320	860	2.2×10^{-4}	3.9	112 (outside), 28 (inside)
322	860	1×10^{-4}	2.6	38x75
323	860	1×10^{-4}	2.6	50
324	860	5.5×10^{-6}	0.6	50x75
334	650	3.3×10^{-5}	1.5	50x75
335	860	1.4×10^{-6}	0.3	50x87
336	860	3.7×10^{-5}	1.5	25
339	600	3×10^{-6}	0.2	23
340	900	7.5×10^{-5}	2.2	62
342	900	6.7×10^{-5}	2.1	80
345	650	1.6×10^{-5}	0.3	35
359	580	1.3×10^{-6}	0.15	26

2. The initiating leak of 40 mils in the LLTI will have the maximum burn-through rate in the production of a secondary leak for the tube in the second row. As shown on Figure 1, at an L/D of 30 (L is 1.315 inch for the tube spacing between the injection point and the tube in the second row while D is 40 mils), the penetration rate is at a maximum of about 5 mils/sec. This will penetrate the tube in the second row by wastage in a minimum time period of about 21 seconds.

It should be noted that for any other initial hole size, the penetration time for the tube in the second row is longer than for the 40 mil case. It is possible that the rupture disc would burst prematurely before the tube in the second row is penetrated if hole sizes much different than 40 mils were utilized. For example, an 80 mil hole would burn through a target tube in about 70 seconds; however, the rupture disc would burst in about 60 seconds for the 80 mil hole.

Another factor is if the aiming direction is off the center by an angle (1-2°) on the tube in the second row as proposed above in order to avoid collision of the jets between the initial leak and that from the tube in the second row, the penetration rate will be slower in direct proportion to the amount of angle off the center. Supporting experimental data for this effect were shown in Reference 4. For 1-2° aiming angle which corresponds to 10-20° impact angle, the penetration rate is reduced by 10-20% over a direct, normal jet. Therefore, it is imperative that a maximum penetration rate be utilized in order to penetrate at least one tube within the given test time if the initial leak is aiming off the center by an angle on the tube in the second row.

3. Based on the predicted jet flame region for an initial hole size of 40 mils as shown on Figure 3, it is highly probable that adjacent Tube Nos. 1, 2, and 3 may be penetrated or damaged within the given test time in addition to the target tube in the second row.

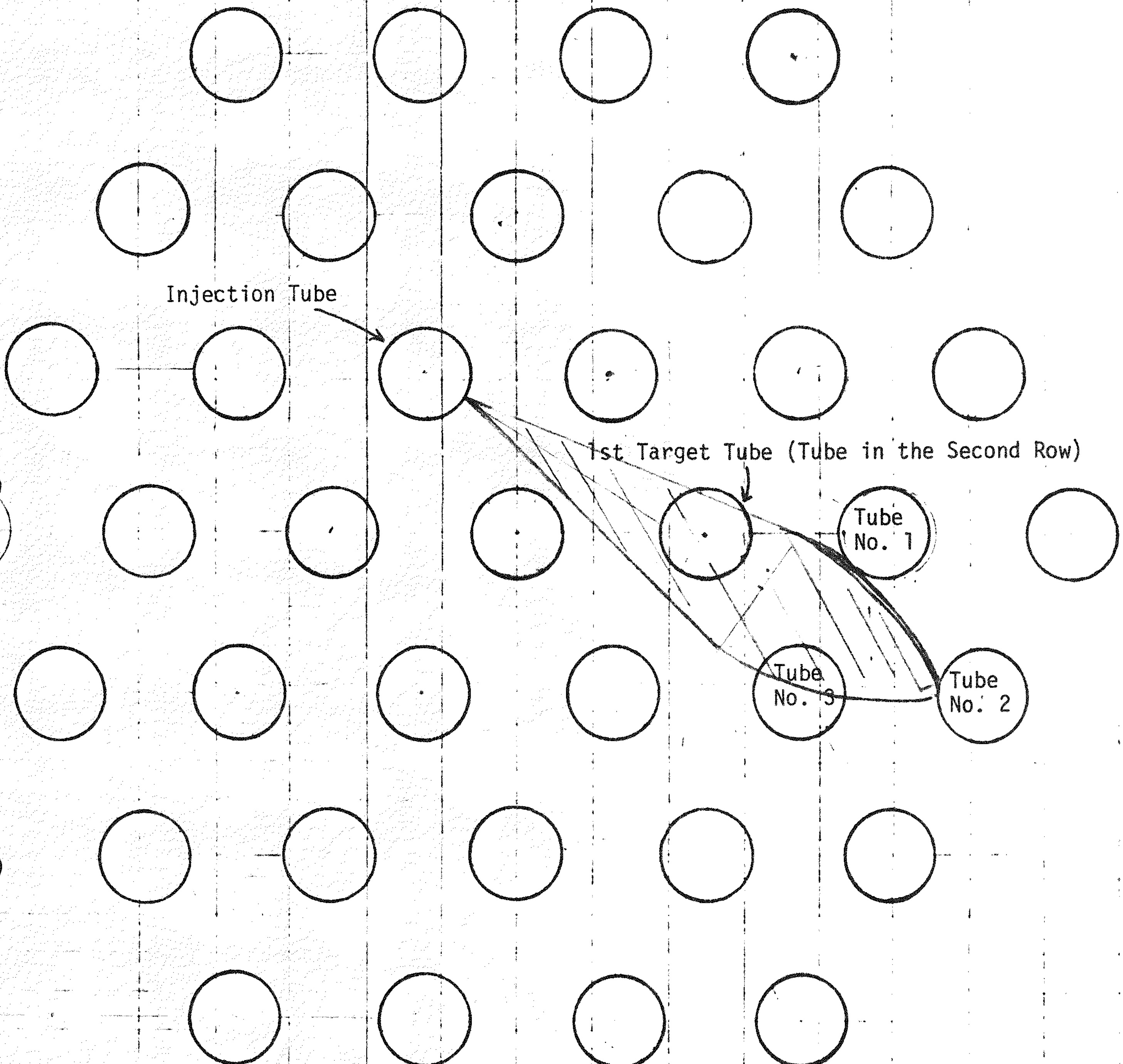

Figure 3 - PREDICTED JET FLUME FOR A HOLE SIZE OF 40 MILS

It should be noted that for the Test A-3, the sodium is filled only to the inlet nozzle in the LLTV test vessel. Thus, the running time is greatly extended than the previous Test A-2 because of the larger volume available for pressurization before activation of the rupture disc.

C. Conclusions and Recommendations

As discussed in Section B, a 40 mil hole (∿0.1 lb/sec of water) represents a typical self-wastage hole that could be suddenly produced from small leaks in the 10^{-4} to 10^{-6} range which are difficult to detect. It also represents the low end of the range of secondary leaks produced by impingement wastage. This size hole would produce the maximum penetration rate through the target tube in the second row and would be expected to damage neighboring tubes either by its own jet flame action or by jet flame action from the target tube. The target tube would be penetrated before the LLTR rupture tube is activated. Accordingly, a 40 mil hole, aimed at a tube in the second row is recommended for Test A-3.

The simulated secondary leak will be produced by drilling a 0.04 inch hole in a tubular insert to be installed in the LLID rupture tube. The wall thickness of this tubular insert will be greater than 0.02 inches to insure that the simulated secondary leak will not undergo any significant self-enlargement during the approximately 21 seconds estimated time before penetration of a simulated "tertiary" tube.

ACKNOWLEDGEMENT

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