GENERAL ENGINEERING LABORATORY

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ULTRASONICS FOR RADIOACTIVE DECONTAMINATION

by

G. E. Henry

Report No. 57GL337

November 14, 1957

GENERAL ELECTRIC

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General Engineering Laboratory

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TECHNICAL INFORMATION SERIES

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ULTRASONICS FOR RADIOACTIVE DECONTAMINATION

ABSTRACT Tests have been run to determine in a preliminary fashion whether ultrasonic vibration would be effective in removing mixed radioactive deposits from the inside surface of steel pipes in a heat exchanger. Different frequencies (20 KC/S, 1000 KC/S) have been used at the maximum power levels convenietnly attainable. Different liquids were compared for cleaning effectiveness, with and without ultrasonics

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CONCLUSIONS Mild stirring of water bath at room temperature produced virtually no cleaning effect on the samples. Ultrasonics in water, at room temperature, gave 50% to 80% cleaning (as defined by gamma ray count) in 15 minutes or less. Certain chemical solutions gave moderate cleaning results without ultrasonics; but the effectiveness of these solutions was greatly enhanced by the addition of ultrasonics. It was found, as expected, that the effectiveness of the sound wave depended rather critically on the method of coupling to the work.

INFORMATION PREPARED FOR Knolls Atomic Power Laboratory

TESTS MADE BY G. E. Henry, D. I. Evans

AUTHOR G. E. Henry GE Henry Nov. 14, 1957

COUNTERSIGNED

COMPONENT Electrical Engineering Laboratory

GL-16-C

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INTRODUCTION

This report covers a series of tests performed for the Knolls Atomic Power Laboratory during September and October, 1957. Purpose of the tests was to determine the effectiveness of ultrasonics in radioactive decontamination.

The project was initiated by Frank C. Steiner. A quotation by the General Engineering Laboratory (GL294.017C) in the form of a letter, G. E. Henry to Frank C. Steiner, was submitted on July 31. Authorization to proceed (contract No. NOBS-56405, requisition No. KAPL-G-704) was processed on September 9. The text of this authorization reads:

Conduct Ultrasonic Decontamination tests as follows:

Using contaminated pipe sections furnished by KAPL, the GE Laboratory is to perform a scoping test to establish the feasibility of ultrasonic crud removal. Two methods are to be evaluated.

A. High frequency ultrasonic decontamination at a frequency between 300 and 1000 Kc/SEC.

B. Low frequency magnetrostrivtive decontamination in the range of 20 to 50 Kc/SEC.

The tests are to be carried out with water, "versene" and with a decontamination solution of the following composition:

EDTA (Ethylene Diamine Tetraacetic Acid)	3.5	G/Liter
Hexamethylene Tetramine	1	G/Liter
Sulfamic Acid	25	G/Liter
Hydrazine	5	G/Liter

The tests with water are to precede those with the decontamination solution. General Engineering Laboratory quotation GL-294.017-C and KAPL material request 88837 are by reference made a part of this order.

KAPL Responsibility	FC Steiner
GEL Responsibility	GE Henry
GEL Section Manager	RA Koehler
GEL Department Manager	Dr. JG Hutton

The actual testing was done in Building 37, by G. E. Henry and D.I. Evans, of the Electrical Engineering Laboratory. Measurement equipment and radiation safety devices were supplied by Messrs Harvey Briggs and Robert Zendle, of the Engineering Physics and Analysis Laboratory. These latter designed the overall layout of the experimental arrangement in the Laboratory, and more particularly the arrangement for measuring radioactivity. They checked the assembly for radiation safety, and supervised the handling of specimens through the early stages of the experiment. Technical responsibility for results and conclusions, however, must rest with the author.

EXPERIMENTAL ARRANGEMENT

Test specimens were small chunks of steel pipe, of various shapes, size, and degree of activity. These were furnished by K.A.P.L. They were first sent to Building 258A (control area for radioactive materials in the G.E.L.). Specimens were first rinsed in water and shaken to remove any loosely adhering particles. They were then measured while still wet. Results were as follows:

Specimen	Shape	Milliroentgens/hr
MC-419	fragment	60
MC-420	fragment	60
MC-421	ring	70
MC-422	ring	80

The above readings were taken using a Nuclear-Chicago Ionization Chamber ("Cutie-Pie") Survey Instrument, placed 2" away from the specimens. Instrument was calibrated for Cobalt-60 gamma radiation, but was operated, in this instance, with the Beta shield removed.

Specimens were then removed to Building 37, one by one, as required for carrying out tests. The arrangement in Building 37 for measuring the gamma-ray count is shown in photograph L1-531811. The cylindrical probe is a G. E. Cat. No. 121C196, group one. The transducing element is a sodium iodide crystal having a cross section of 1" by 1.5". The phototube is a 5819 photomultiplier operating at 1050 volts. The system has a resolution down to 5 microseconds.

Probe output is fed to a Tracerlab Inc. Count Rate meter, SC-34A:

Max counting rate:	250 Kilocounts/min
Accuracy:	± 2% of meter reading
Power:	110 volts, 60 c/s, 120 watts

The system as a whole can be characterized by the following:

Sensitivity: about 50 Kilocounts/min per mr/hr.

Plateau: normalizes slope in order of 5 for radium gammas

Resolution loss: less than 1.5% at full scale on all ranges

Probe detects about 10% of all gamma rays entering crystal.

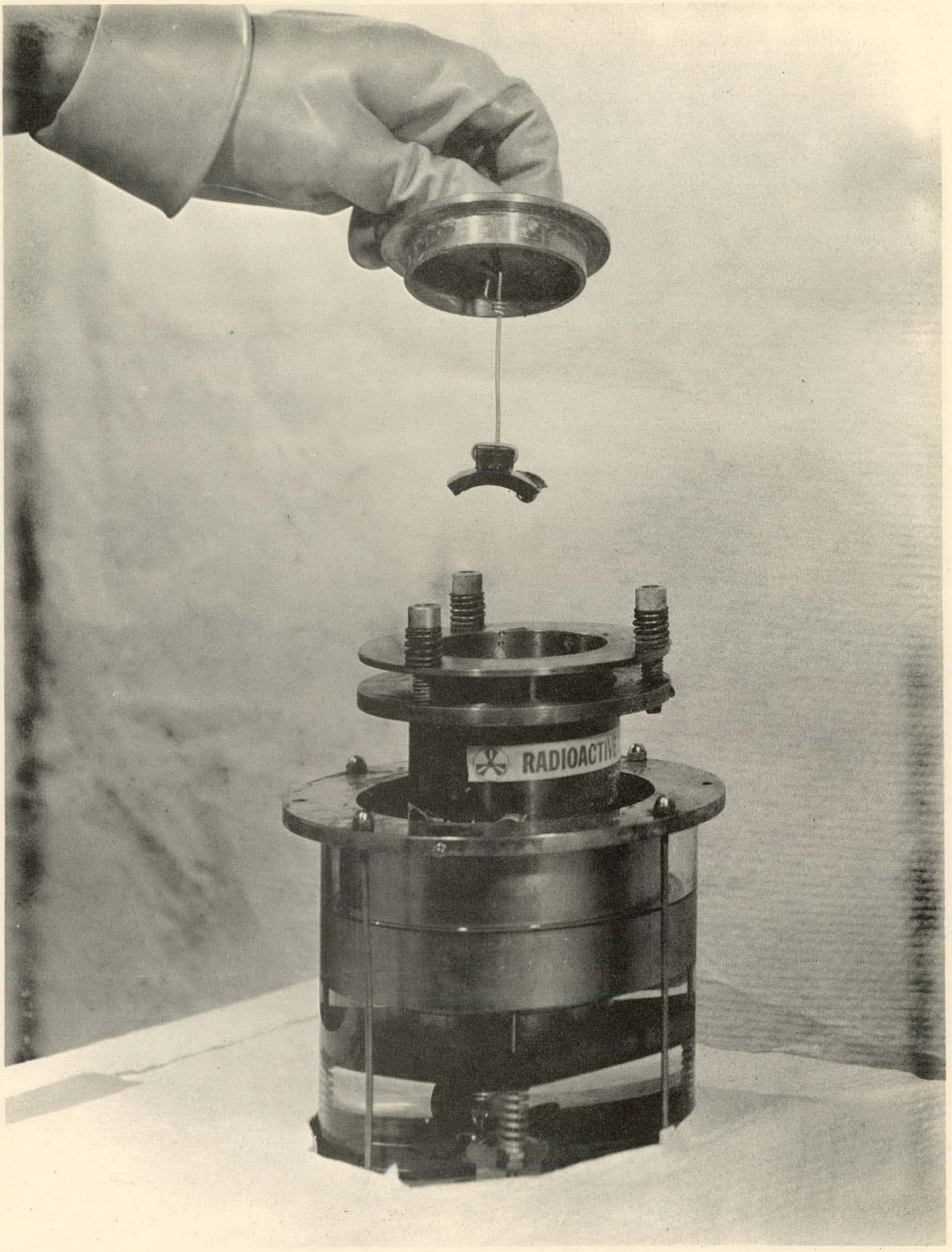
Ultrasonic equipment consisted in two separate and distinct units, operating at two widely separated points in the frequency spectrum.

(1) General Electric Ultrasonic Generator, Cat. No. 866596G3, frequency 1000 KC/second. This machine is fully described elsewhere, as follows:

Bulletin	GEC-544
Instruction Book	GEL-29578D
Reprints	GER-507 GER-613 GER-773

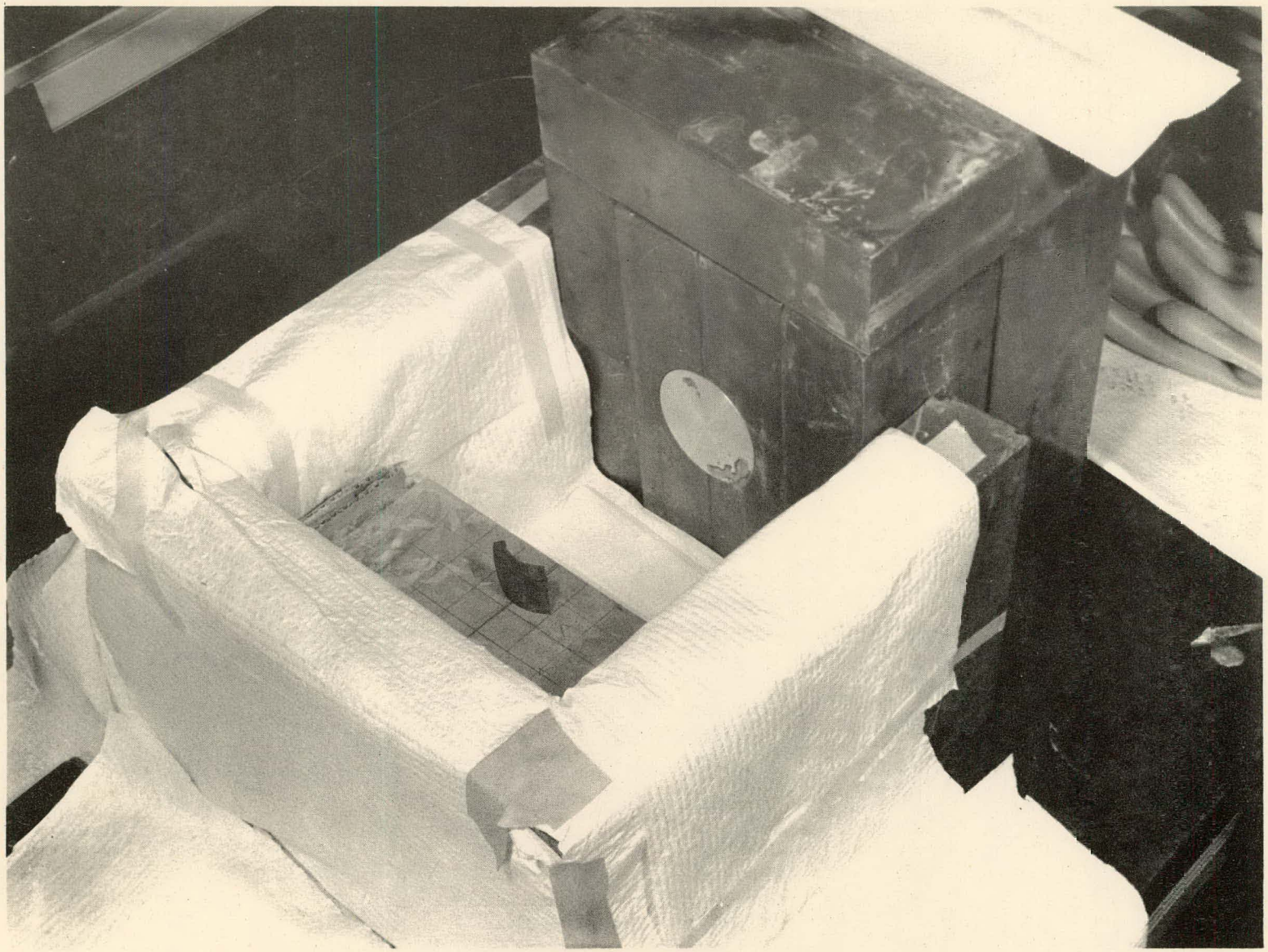
It is a quartz crystal machine, having an output of about 120 watts of sound into the liquid load. Physical arrangement is shown in photograph L1-531808 and in Figure 4-A.

(2) An ultrasonic generator consisting in a magnetostriction transducer (resonant near 20 KC/second) powered by an oscillator-amplifier system built in the Laboratory. The transducer is shown in photograph L1-531809. It consists in a stack of nickel laminae bonded together in the usual way, then brazed to a circular end plate 0.25" thick and 3.5" in diameter. This end plate is the "active face" of the transducer. The stack is of the single-window design, and is supplied with two coils. The D-C coil is energized with 2 to 2.5 amperes of bias current. Transducer was driven with 3 to 4 amps of A.C., at a frequency in the neighborhood of 20 KC/sec. The exact frequency was under the control of the experimenters: the amplifier was fed by a tuned oscillator. In practice, the resonant frequency of the mechanical system (transducer plus load) varies between limits of 19 KC/sec up to 21 KC/sec, depending upon temperature, coupling, and other factors. In all tests, the frequency was continuously varied, by the experimenters, through that part of the range in which resonance appeared to be manifested.



DECONTAMINATION AT 1000 KC/S

Larger cylindrical tank is the transducer assembly of the General Electric Ultrasonic Generator cat. no. 8665966G3. A specially built cylindrical cup, placed in the sound chamber of the transducer assembly, contains the liquid in which cleaning is to be accomplished. The specimen to be cleaned is supported from above by means of a small alnico magnet.



MEASUREMENT OF RADIOACTIVITY

Lead bricks on the right and to the rear shield a scintillation counter from stray radiation and background. Circular end-face of probe is visible in the center. Specimen is located axially in line with probe, about 4" away.

SPECIMEN CLAMPED TO MAGNETOSTRICTOR

Specimen is pressed against the active vibrating face of magnetostrictor by means of stainless steel strap, held by two screws. In use, the assembly is supported from above, with the specimen at the bottom. Assembly is then lowered just far enough into liquid to assure total imersion of the vibrating circular plate to which the specimen is strapped.

TESTS AND RESULTS

Six specimens were available for testing. Of these, only five were used.

It was recognized at the outset that one could hardly hope to conduct the experiment according to a detailed plan or "design", determined in advance. There were too few specimens for a clear-cut statistical approach; also, the lack of uniformity from one specimen to another would have posed a problem had one attempted to apply parallel-control techniques. Instead, it was thought well to try various proceedures with each specimen, beginning with the proceedures deemed easiest and least expensive to apply.

Thus, the general plan was to make the first tests in water only, with and without ultrasonics. It was very quickly discovered that the room-temperature water bath was effective only when ultrasonics was applied. When, after a period of 5 to 20 minutes or thereabouts, the use of ultrasonics in a water bath was found to be yielding a diminished return, recourse was had to other methods.

Both the test proceedures and the results are given in some detail in the notes accompanying the graphs. The count is always expressed in units of thousands per minute. Hence, "a count of 115" means "115 kilocounts per minute".

The cleaning solvents were as follows:

Water (Schenectady Tap Water)

Solution A (Solution of Versene in water; 5 grams of Versene in 500 ml. of water)

Solution B (Special solution, as follows:

EDTA (Ethylene Diamine Tetraacetic Acid)	3.5 grams/liter
Hexamethylene Tetramine	1 gram/liter
Sulfamic Acid	25 grams/liter
Hydrazine	5 grams/liter

Trichlorethylene (Commercial grade)

Solution C (10 grams of "Thanks" detergent in one liter of water)

Figure 1

Specimen MC-419

Notes and Explanations

Specimen MC-419 was a fragment --- actually the fragment shown in the three photographs. It was treated in various liquids, as shown, with and without ultrasonics at 1000 KC/second. No other frequency was used.

Tests were begun on September 13. Initial count, before treatment, was 235 Kilocounts per minute.

F: Specimen exposed to gentle mechanical agitation in water for one minute (shown on graph as two minutes). No ultrasonics. No reduction in count. There was, in fact, a slightly higher count after the rinse: 236 Kilocounts per minute. We attribute this discrepancy to experimental error.

F → G. One minute in water, (same charge as above) with agitation at 1000 KC/second, 110 milliamps plate current. Count dropped from 236 to 167.

G: One minute in a fresh charge of water, gentle stirring, no ultrasonics. No reduction in count.

G → H. One minute in water (same charge as at G), with ultrasonics as before. Count dropped from 167 to 137.

H: One minute in a fresh charge of water, gentle agitation, no ultraconics. No reduction in count.

H → I One minute in water (same charge as at H) with ultrasonics as before. Count dropped from 137 to 120.

I → J Five minutes in water (still the same charge) with ultrasonics as before. Count dropped from 120 to 107.

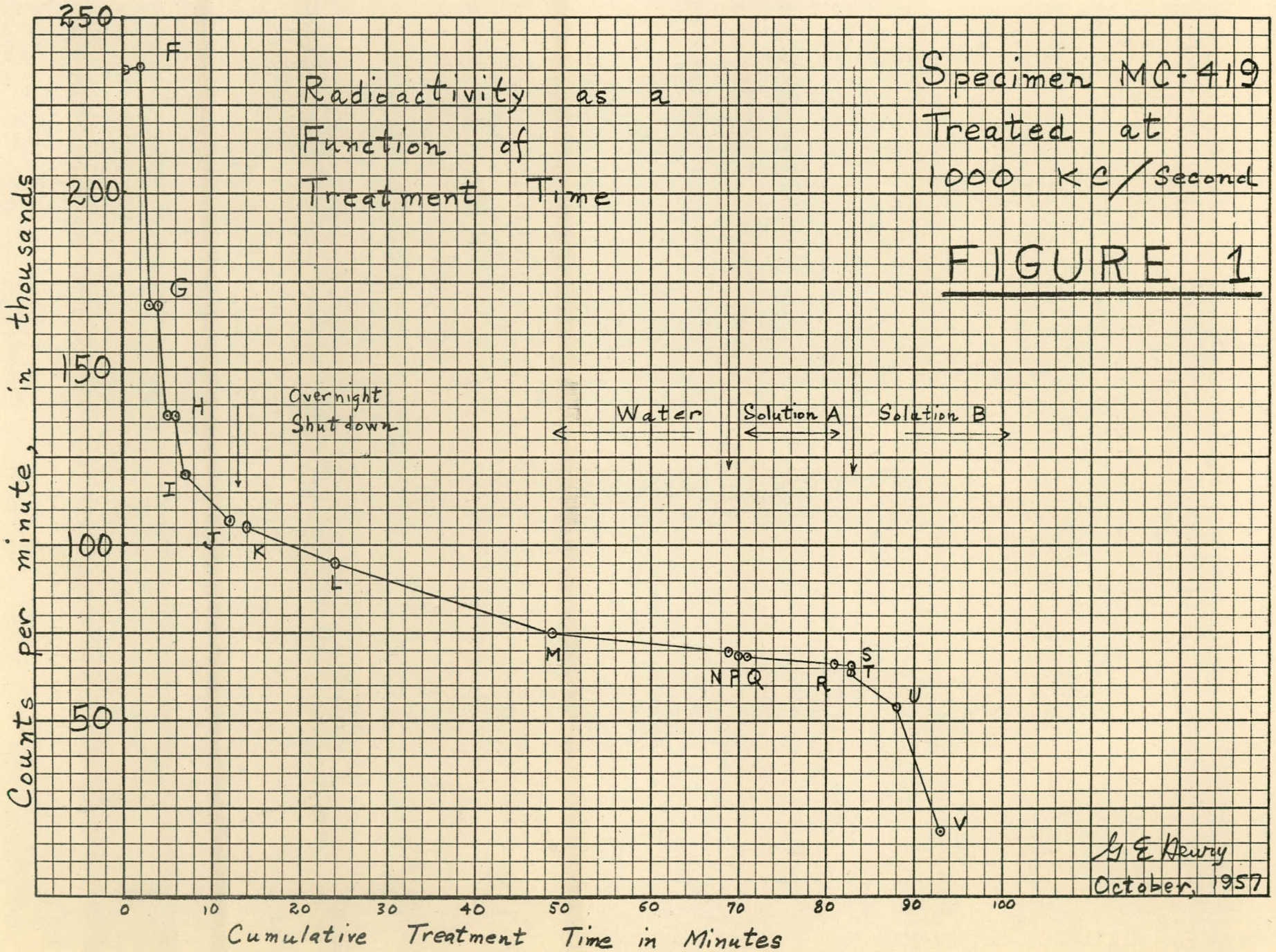
* * *

September 14, 1957

Slight difficulties encountered starting up. A couple of treatment cycles were interrupted almost as soon as they were begun. These false starts were due to failure to allow a proper warm-up time for the ultrasonic generator. After some minutes of warming up, tests were resumed (at point K) without further trouble.

K Count at the beginning of timed tests, 105 Kilocounts per minute.

K → L Ten minutes in ultrasonics as before, with the same charge of water as was put in freshly at the beginning of the day's work. Count reduced from 105 to 95.


Radioactivity as a Function of Treatment Time
Specimen MC-419 Treated at 1000 KC/Second
FIGURE 1
Counts per minute, in thousands
250
200
150
100
50
F
G
H
I
J
K
L
M
N
P
Q
R
S
T
U
V
Overnight Shut down
Water
Solution A
Solution B
0
10
20
30
40
50
60
70
80
90
100
Cumulative Treatment Time in Minutes
G E Kenny
October, 1957

L → M Same charge of water, ultrasonics as before, for 25 minutes. Noticeable temperature rise. Count reduced from 95 to 74.5.

M → N Twenty minutes in ultrasonics, same water, count reduced from 74.5 to 70.0.

In view of diminishing returns, it was decided to switch to a different liquid: Solution A.

N → P Soak sample, one minute in solution A, no ultrasonics. Count reduced, 70 to 69.

P → Q One minute in solution A (same charge) with ultrasonics. No reduction in count.

Q → R Ten minutes in solution A (same charge) with ultrasonics. Count reduced from 69 to 66.5.

R → S Two minutes in solution A, same charge, with ultrasonics. Count reduced from 66.5 to 66.0.

S → T Specimen wiped, while still wet, by paper towel, held in gloved hands. Count reduced from 66 to 64.

Solution A seemed hardly more effective than water. Accordingly, we switched to Solution B.

T → U Specimen soaked for five minutes in Solution B with gentle agitation. Count reduced from 66 to 54.5.

U → V Specimen treated for five minutes in Solution B with ultrasonics as before (1000 KC/second, 110 milliamps plate current). Count reduced from 54.5 to 18.6.

Figure 2

Specimen MC-420

Notes and Explanations

Specimen MC-420 was a fragment very similar to speciman MC-419 in shape, size, and emission characteristics.

Tests were completed in a single day, September 17, 1957.

F: Initial count: 227.5, in thousands of counts per minute.

F → G Specimen was clamped to the face of the magnetostrictor in the manner shown in the photograph. Assembly was dipped in water, gently agitated without ultrasonics, for five minutes. Reduction in count (from 227.5 to 226) was within the experimental error.

G → H Specimen, clamped as before, was now immersed for one minute, while being vibrated by the magnetostrictor. Frequency was slowly varied from 19.5 KC/sec to 21 KC/sec. Count reduced from 226 to 64.

H → I Treatment (G → H) repeated in fresh charge of water. Count reduced from 64 to 54.

I → J Same treatment in same water. Count reduced from 54 to 51.

The sharp reduction in negative slope of the cleaning curve (count vs. time) suggested that a saturation level had been reached, or nearly reached, for ultrasonic cleaning in water. Accordingly, we switched to Versene ---- "Solution A".

J → K Specimen soaked two minutes in Solution A. Mild agitation, no ultrasonics. Change in count (from 51 to 52) can be attributed to experimental error.

K → L One minute, ultrasonics in Solution A; count reduced from 52 to 49.

L → M One minute, ultrasonics in Solution A; count reduced from 49 to 46.

These results appeared to indicate only a marginal advantage for ultrasonics in Solution A as against ultrasonics in plain water. We, therefore, chose to proceed with tests in Solution B.

M → N Five minute soak in Solution B with gentle agitation, no ultrasonics. Count reduced from 46 to 42.5. Slope of curve, however, is less steep than it was in segments (K - L) and (L - M).

N → P Five minutes in Solution B, with ultrasonics as before. Count reduced from 42.5 to 19.5.

Test was terminated at this point. Throughout the above description, for specimen MC-420, the term "ultrasonics" indicates the type of vibration described in the section (G - H).

Note that the time scale for Figure 2 is double the time scale for Figure 1.

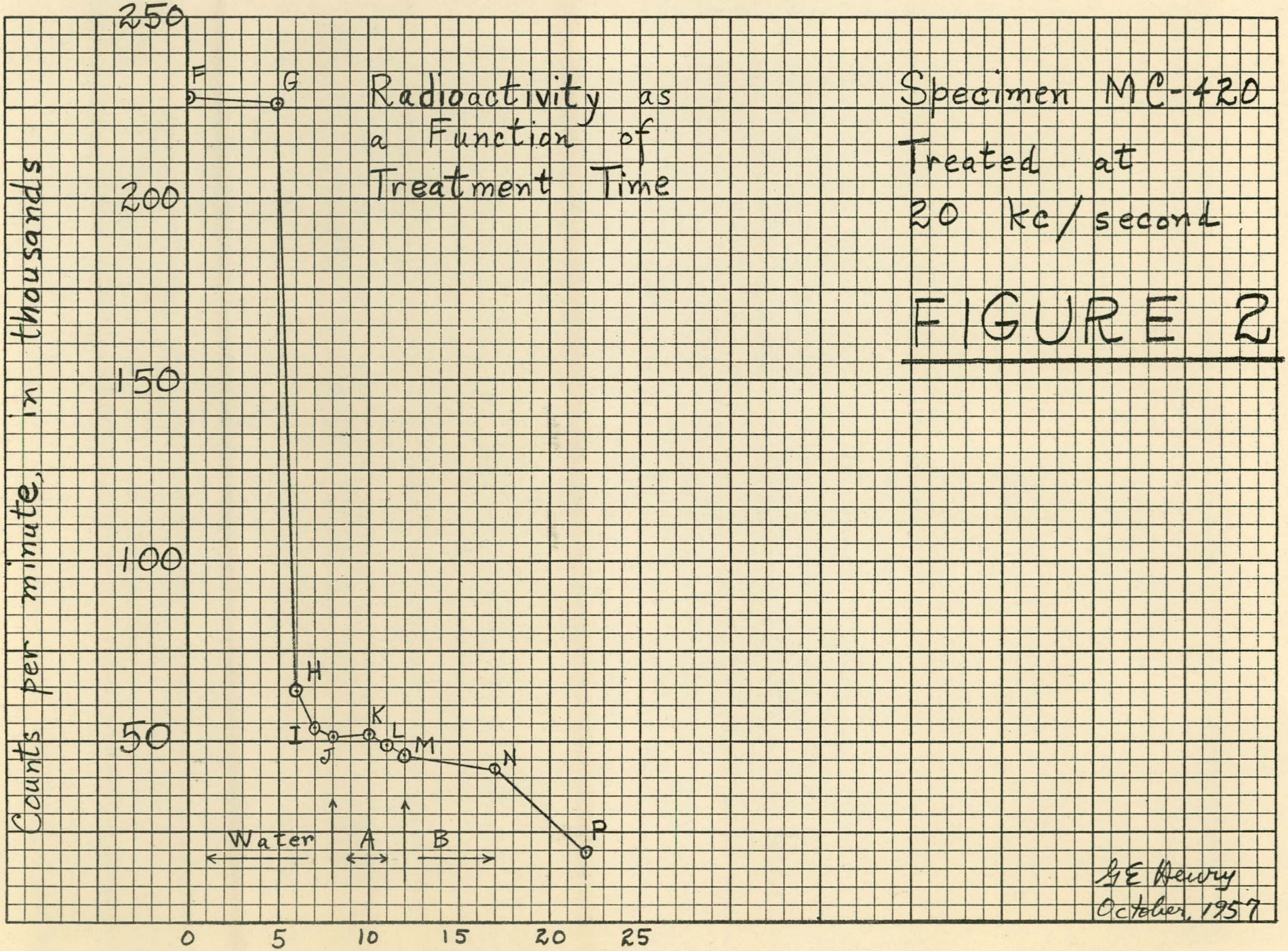

Radioactivity as a Function of Treatment Time
Specimen MC-420 Treated at 20 kc/second
FIGURE 2
Counts per minute, in thousands
250
200
150
100
50
0
5
10
15
20
25
F
G
H
I
J
K
L
M
N
P
Water
A
B
G E Henry
October, 1957

Figure 3

Specimen MC-421

Notes and Explanations

Specimen MC-421 was a ring-segment of steel pipe, having roughly three times the mass of specimen MC-419 or MC-420. The contamination per unit area for this specimen was probably no greater than it was for the previous specimens; but because of its greater area, the total radiation was greater. The scintillation counter probe had accordingly to be backed away from the specimen to reduce the sensitivity of the system. This was done without changing the placement of shielding lead bricks. The probe was merely retracted 25.5 millimeters back into the cylindrical channel.

The test now undertaken aimed to confirm previous results, also aimed to compare the effectiveness of different ways of applying the ultrasonic energy.

Also, an effort was made to guage the extent of experimental error in measuring the count. This was done, in certain cases, by taking four separate readings. The ring would be centered on the same spot each time, but would be rotated through 90 degrees (approximately) after each reading.

F: Initial count, on September 18: 212. (Kilocounts/min.)

F ⟶ G Specimen exposed 30 seconds to ultrasonics (1000 KC/sec) in water, under very unfavorable conditions for cleaning (see figure 4-A) Orientation of specimen was such that the radio-active surface did not lie directly in the sound beam. Such cleaning action as actually took place must have resulted from diffused sound. Count reduced from 213 to 207.

G ⟶ H September 19, specimen placed on the floor of stainless steel cup (see figure 4-B), filled to a depth of two inches with water. Ultrasonic energy (at 20 KC/sec) was imparted to the water by magnetrostrictor dangled from above. There was no physical contact between magnetostrictor and the specimen. The liquid coupling however, is more favorable here than in the previous test, due to the absence of "beam" at the lower frequency. In 30 seconds, count was reduced from 207 to 177.

H ⟶ I Specimen clamped to transducer in the manner shown by Figure 4-C. With this clamping, the ring does not vibrate as a single mass-point. Different motions take place at different points about the circumference. Specimen was immersed in water and vibrated for 30 seconds, then measured in 4 different orientations for residual contamination. Results:

Count	Average Count
152	
155	153
157	
148	

I → J Mild agitation in Solution B, one minute, no ultrasonics.

Count	Average
144	
156	151
151	
152	

J → K Place specimen and transducer in the same relation as for test (G - H) (see figure 4-B), with Solution B instead of water. Total immersion time was 70 seconds. Ultrasonic energy was supplied for 20 seconds during this 70-second period. (Shown on graph as one minute)

Count	Average
142	
147	
144	142
137	

K → L Specimen clamped to transducer, as in (H - I) (figure 4-C). Ultrasonics in solution B, 30 seconds.

Count	Average
113	
113	118
117	
125	

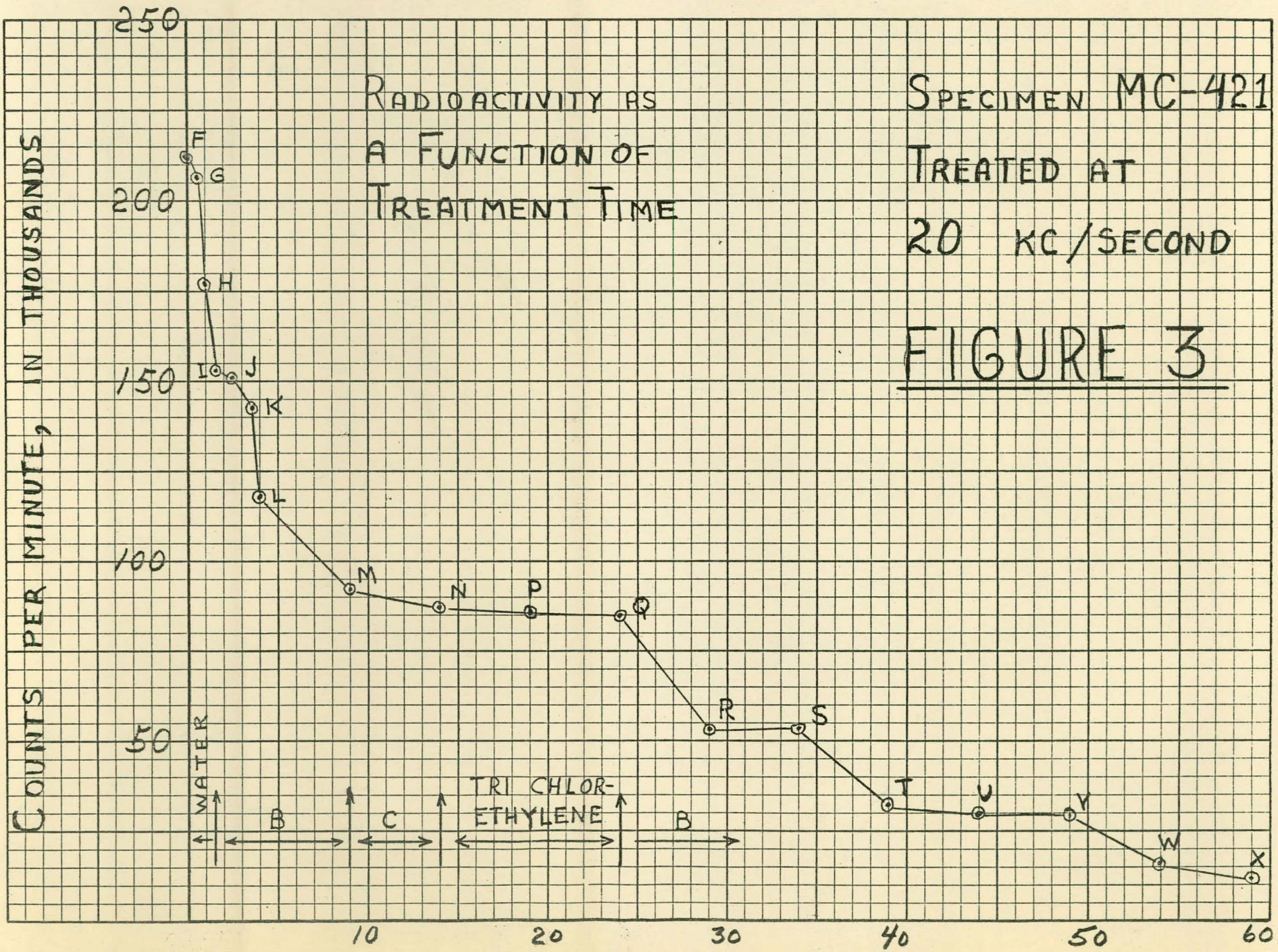
L → M Same as (K - L), but treat for five minutes.

Count	Average
87	
88	92
95	
98	

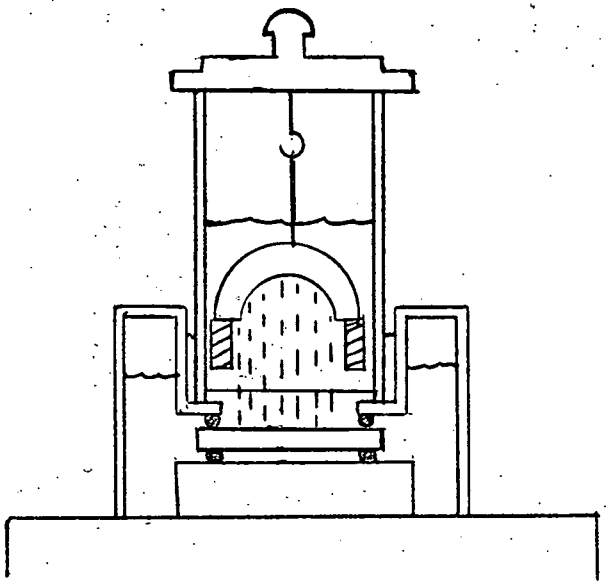
At this point, we theorized that the relatively slow decontamination (compared to results achieved with specimen MC-420) might be due in part to the adhesive tape still clinging to the specimen. Since the tape was apparently unaffected by Solution B, tried other liquids:

M → N Solution C (10 grams of "Thanks", commercial detergent, in one liter of water, heated to 60°C. Specimen clamped to transducer (figure 4-C) vibrated in Solution C for five minutes.

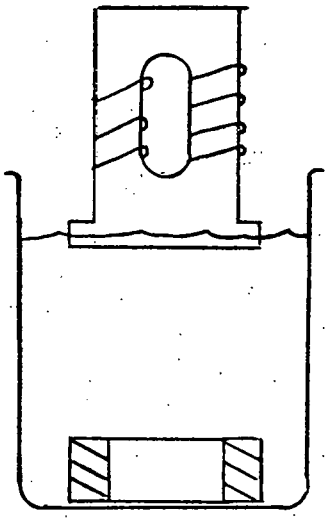
Count	Average
89	
94	87
87	
82	


RADIOACTIVITY AS A FUNCTION OF TREATMENT TIME
SPECIMEN MC-421 TREATED AT 20 KC/SECOND
FIGURE 3
COUNTS PER MINUTE, IN THOUSANDS
250
200
150
100
50
10
20
30
40
50
60
F
G
H
I
J
K
L
M
N
P
Q
R
S
T
U
V
W
X
WATER
B
C
TRI CHLOR-ETHYLENE
B

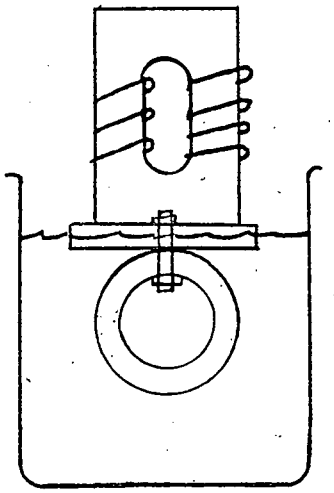
4-A



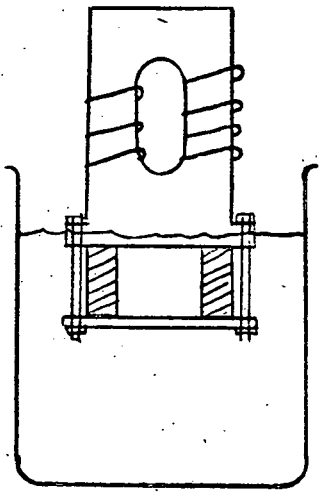
4-B



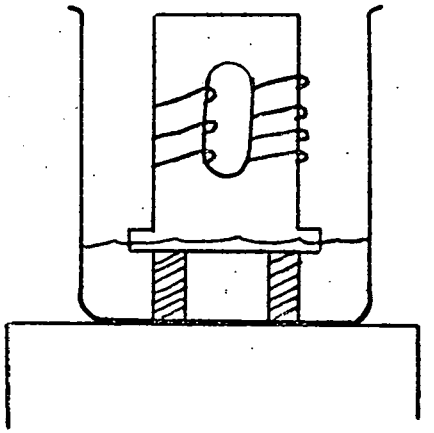
4-C



4-D



4-E



Tape remained stuck to specimen.

N → P Specimen soaked five minutes in hot trichlorethylene (just below boiling). No ultrasonics. Tape was then removed by pulling off with tweezers. Adhesive material remained on specimen.

Count	Average
82	
88	87
94	
84	

P → Q Specimen clamped to transducer (figure 4-C) vibrated for five minutes in hot trichlorethylene.

Count	Average
87	
81	85
82	
91	

The adhesive tape was by now completely removed, but it was apparent that Solution C and the organic solvent were ineffective media for decontamination purposes. Accordingly, we reverted to Solution B.

Q → R Specimen exposed for five minutes to ultrasonics in solution B, with a different clamping arrangement (see figure 4-D). With this clamping arrangement, one can expect the ring to vibrate almost like a single mass point --- all parts moving together in phase.

Count	Average
60	
51	53
53	
50	

R → S Five minutes in a fresh charge of Solution B without ultrasonics

Count	Average
59	
53	54
50	
53	

S → T Using same solution as in (R → S), vibrate for five minutes. Clamping arrangement is the one shown in figure 4-D.

Count	Average
32	
36	32
33	
28	

At this point, we filed off a small burr on the rim of the specimen. This burr, although small, had interferred with proper seating of the ring against the transducer face. Tests were then resumed, using a fresh batch of Solution B, of sub-standard quality. This batch had been prepared by the usual formula, except that the hydrazine was added before the solution was heated. The liquid was of an amber color, and it pH measured 2.00.

T ⟶ U Five minutes, ultrasonics in faulty Solution B, clamping as in figure 4-D.

Count	Average
29	
27	
29	30
35	

U ⟶ V Five minutes, ultrasonics in fresh Solution B, properly prepared. Clamping as in figure 4-D.

Count	Average
33	
29	29
26	
29	

In a final effort to achieve better coupling from magnetostrictor to sample, we adopted the scheme pictured in figure 4-E, wherein no clamping was attempted. All parts merely rested in place by gravity.

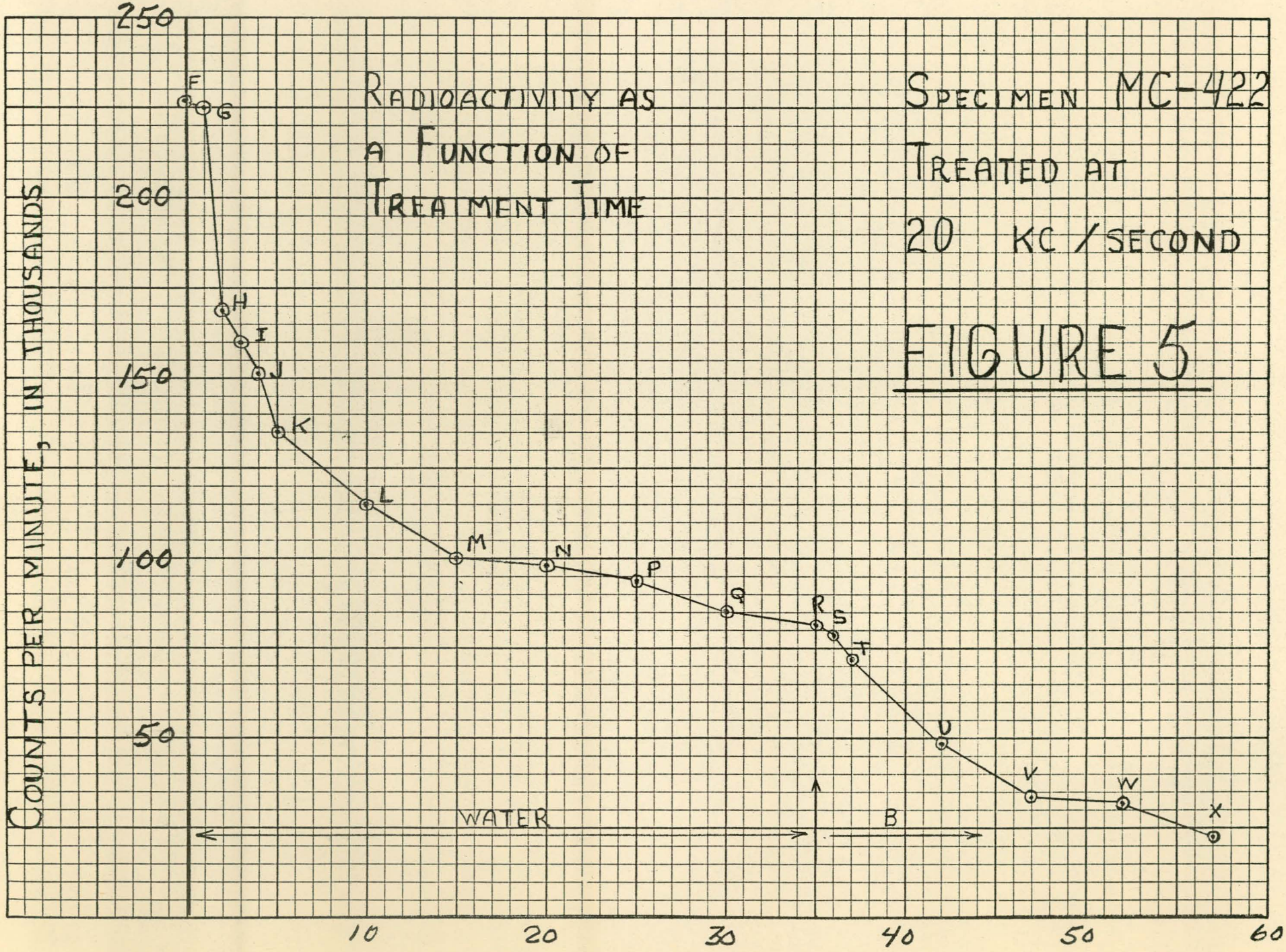
V ⟶ W Five minutes of ultrasonics in solution B, (see figure 4-E)

Count	Average
14.9	
16.5	15.6
17.8	
14.5	

W ⟶ X Repeat of V⟶W in fresh charge of solution B.

9.6	
10.0	10.4
12.0	
9.7	

Test was then regarded as completed.


RADIOACTIVITY AS A FUNCTION OF TREATMENT TIME
SPECIMEN MC-422 TREATED AT 20 KC / SECOND
FIGURE 5
COUNTS PER MINUTE, IN THOUSANDS
250
200
150
100
50
10
20
30
40
50
60
WATER
B
F
G
H
I
J
K
L
M
N
P
Q
R
S
T
U
V
W
X

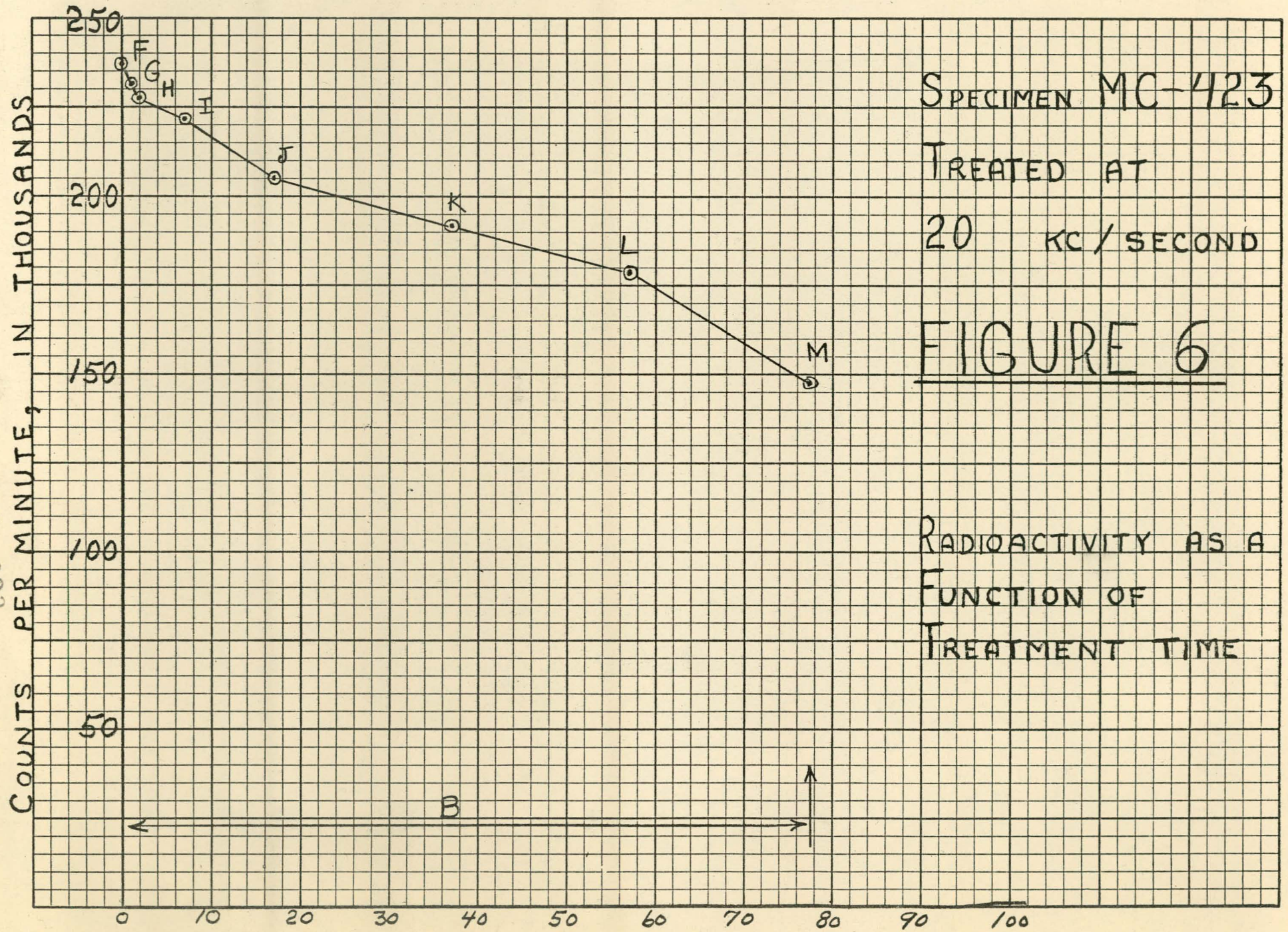

COUNTS PER MINUTE, IN THOUSANDS
250
200
150
100
50
0
10
20
30
40
50
60
70
80
90
100
F
G
H
I
J
K
L
M
B
SPECIMEN MC-423
TREATED AT
20 KC / SECOND
FIGURE 6
RADIOACTIVITY AS A
FUNCTION OF
TREATMENT TIME

Figure 5

Specimen MC-422

Notes and Explanations

Specimen MC-422 was a ring segment similar in shape, size, and activity to MC-421. Before exposing this specimen to any treatment, we first filed a flat spot on the outer surface, thinking we could thus get a better coupling from the ring.

F — Initial count, 227. (Kilocounts/minute)

F → G — One minute, gentle agitation in water. No ultrasonics. Count reduced from 227 to 225.

G → H — One minute in the same water, vibrated at 20 KC/s. Specimen is clamped to the magnetostrictor (see 4-C) with the "flat" of the ring against the transducer end-plate. Count reduced from 225 to 169.

H → I — Same treatment as (G - H) but in a fresh charge of water. Count reduced from 169 to 160.

I → J — Same treatment in same water. Count reduced from 160 to 151.

Results thus far seemed to indicate no special advantage in having the flat spot seated in contact with the transducer end-plate. Accordingly, we rotated the ring through 180° and reclamped. Flat now faced away from transducer.

J → K — One minute at 20 KC/sec in a fresh charge of water. Count reduced from 151 to 135.

K → L → M → N → P → Q → R. A series of treatments, each of five minutes duration, 20 KC/s in water. Ring was rotated some, but was always clamped in the manner shown by figure 4-C. Count was reduced, by slow degrees, to 81.

Such a slow rate of cleaning was thought to be of very marginal interest. We therefore, switched to Solution B.

R → S — One minute in Solution B with gentle agitation, no ultrasonics. Count reduced from 81 to 79.

S → T — One minute in Solution B (same charge), with ultrasonics (20 KC/s). Count reduced, 79 to 72.

T → U — Same solution, five minutes treatment with ultrasonics. Count reduced to 49.

U → V — Same treatment as (T→U). Count reduced to 33.

V → W — Five minute soak in solution B. No ultrasonics. Count reduced to 32.

W → X — Five minutes in solution B with ultrasonics. Count reduced to 23.

Figure 6

Specimen MC-423

Notes and Explanations

Specimen MC-423 was a section of pipe about 3 $\frac{1}{2}$" long, somewhat irregular in shape because of welded or brazed joints. It was subjected to one kind of treatment only: gentle agitation in Solution B, without ultrasonics. The agitation was provided by a simple rotary impeller, driven by an electric motor. All tests were done at room temperature except the last. During the final 20 minute exposure, the solution was heated. During the time of immersion, the temperature rose from 105°F to 167°F.

CONCLUSIONS AND RECOMMENDATIONS

Our main conclusions have already been stated in general terms. In this section we present our findings in greater detail, and cite specific items of evidence to back up general statements.

1. Mild agitation of plain water does not decontaminate (Figure 1, points F, G, and H. Figure 2, F G. Figure 5, F G).

2. Ultrasonic agitation of plain water is highly effective, yielding percentage reductions as follows:

Percent Reduction	Time Required	Evidence
29%	1 min.	Fig. 1, F→G
41%	2 min.	Fig. 1, F→G→H
49%	3 min.	Fig. 1, F→G→H→I
72%	1 min.	Fig. 2, G→H
29%	2 min.	Fig. 3, G→H→I

3. After relatively few minutes of ultrasonic cleaning in plain water, a law of diminishing returns sets in. Progress is slow thereafter.

Slope: Reduction per unit time	Occurring After	Evidence
1% per min.	24 min.	Fig. 1, L→M
0.8% per min.	49 min.	Fig. 1, M→N
6% per min.	2 min.	Fig. 2, I→J
1% per min.	15 min.	Fig. 5, M→ → → R

4. When the above condition has been brought about, further decontamination, at a fast rate, can be accomplished by switching to Solution B.

Slope: Reduction per unit time	Occurring after X minutes of treatment in less potent solvents	Evidence
2% per min.	83 min.	Fig. 1, T→U
2% per min.	12 min.	Fig. 2, M→N
9% per min.	24 min.	Fig. 3, Q→R
7% per min.	35 min.	Fig. 5, R→U

5. When Solution B is used in the manner indicated above (to remove the contamination not previously removed by ultrasonics in water) its effectiveness is enhanced by a factor of about 10, if ultrasonic vibration is provided.

Reduction in count, per unit time:

Without ultrasonics	With ultrasonics	Evidence
2% per min.	20% per min.	Fig. 1
2% per min.	12% per min.	Fig. 2
0% per min.	9% per min.	Fig. 3, Q → R
	15% per min.	Fig. 3, S → T
< 1% per min.	9% per min.	Fig. 5, U → V
	8% per min.	Fig. 5, W → X

The above comparison applies, of course, to the case where the solution remains at room temperature or slightly higher. The effectiveness of this solvent is known, by previous work, to be much greater at higher temperatures.

6. Solution B was by far the most effective of the few liquids in which tests were made. Note in particular that solution A (Versene) did not show up to advantage when used to follow a cleaning cycle of ultrasonics in water. (Figures 1, 2.)

7. Ultrasonics in water, applied at the outset, gives faster cleaning than Solution B without ultrasonics, applied in the same way. (Compare Figures 1, 2, 3, and 5 with Figure 6).

8. The effectiveness of ultrasonics varies considerably with the kind of coupling employed. (Figures 1, 2, 3, 5).

The above conclusions are relevant to the problem of designing a practical system for ultrasonic decontamination of in-service equipment.

In planning such a system, the first question to settle is that of choosing the frequency range and the type of transducer. Our experiment shows ultrasonics to be effective at either of two widely different frequencies, but it also provides an insight into the difficulties of applying high frequency ultrasonics (above 100 KC/sec) to a practical system. Above 100 KC/sec, transducer dimensions are large compared to the wavelength, and the sound wave, accordingly, has a very directional "beam pattern". Surfaces not in the path of the beam are not cleaned. In particular, any surface lying in an acoustic shadow must be expected to remain unaffected by the sound wave. Figure 3 (F→G) and Figure 4-A exemplify this difficulty. Any attempt to utilize this kind of ultrasonics in an actual installation would probably require an arrangement whereby the transducing crystals, placed inside the pipes or tubes, would be moved about to provide a scanning action by their acoustic beams. Such a possibility is not economically attractive.

For low frequency ultrasonics, the outlook is much more favorable. Magnetostriction transducers can be clamped to the outside walls of pipes, tubes, or heat-exchanger wall surfaces. The decontamination effects brought about by such transducers would not be strictly localized, but could be expected to show up, in varying degree, at distances as much as several feet away from the clamping point. Because of the irregular geometry and the uncertainties of a clamp-coupling, the exact range of effectiveness will not be accurately predictable. It seems reasonable, however, to envision a system in which 2" pipes might have flats or bosses

(for clamp-attachment of magnetostrictors) every 2 or 3 feet along their length. It is even conceivable that the magnetostrictors might be permanently attached at these points. More likely, however, would be the demountable coupling arrangement.

To get a rough idea of cost, one might consider a system in which 20 bosses are provided. Four magnetostriction transducers, each having dimensions comparable to the one used in our experiment (3.5" diameter of end plate, 4" - long stack) could be moved from station to station as required. These four magnetostrictors could be provided at a cost of about $500 each. They could be driven simultaneously, in parallel, by a tunable-oscillator amplifier system having an output capacity not less than 1 KW. Such an amplifier should cost not more than $5,000.

If a very large installation were projected, considerable saving would result by going to a rotary A-C power supply. Rotary generators for 10 KC/second are now commercially available. Such generators have sometimes been revamped to run at double speed and generate 20 KC/sec. It is also possible to think of using the 10 KC/s generator at its design speed, building 10 KC/sec. magnetostrictors to match. This approach has many advantages, but also has a noteworthy disadvantage: high audio noise level (disagreeable to personnel.)

In conclusion, it should be noted that a very close control of frequency is not required. Indeed, it is desirable that the frequency vary within reasonable limits, thus providing a variation in output pattern which improves the "coverage" of each individual transducer.

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