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BNWL-B-71
PART II

RADIOLOGICAL CONSIDERATIONS OF OPENING THE COLUMBIA RIVER FOR PUBLIC ACCESS UPSTREAM FROM 100-F AREA
PART II

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Occupational And Environmental Safety Department

This report is intended primarily for internal use by the sponsoring organization and Battelle-Northwest.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

INTRODUCTION

At the request of the Richland Operations Office of the United States Atomic Energy Commission, a study of radiological conditions on and along the Columbia River from Ringold to 100-F Area was performed in the fall of 1969. The completed study, which furnished radiological information prerequisite to deciding whether that portion of the river should be opened for public access,[1] was transmitted to the Atomic Energy Commission on December 29, 1969. In January 1970, a similar study was requested concerning the portion of the river upstream from 100-F Area. The document "Radiological Considerations Of Opening The Columbia River For Public Access Upstream From 100-F Area," BNWL-B-71 Part I, summarizes that study. Part II contains detailed descriptions, observations, and calculations related to the study. Nearly all the data described in this document were obtained with KE and N reactors in service. The shutdown of these reactors, KE in particular, virtually eliminates the river, its fish, game, and wildfowl, and its shoreline as sources of radiation exposure.

DISCUSSION

DESCRIPTION

Columbia River

Much of the river above 100-F Area is quite shallow at low flow rates. In certain areas which have no discernible channel, such as near the upper end of Locke Island, motorboat passage upstream is nearly impossible at the lowest flow rates. Shorelines are generally very rocky, but contain occasional coves or short beaches of silt or fine, silty sand. Shoreline rocks are mostly coated with silt or algae.

The main attractions of this portion of the river (Figures 1 through 22) appear to be hunting, fishing, and searching for artifacts. Although upland gamebirds are generally scarce, migratory waterfowl are fairly abundant along the lower portion of this stretch of the river. Panfish are abundant in or

(Continued on page 25)

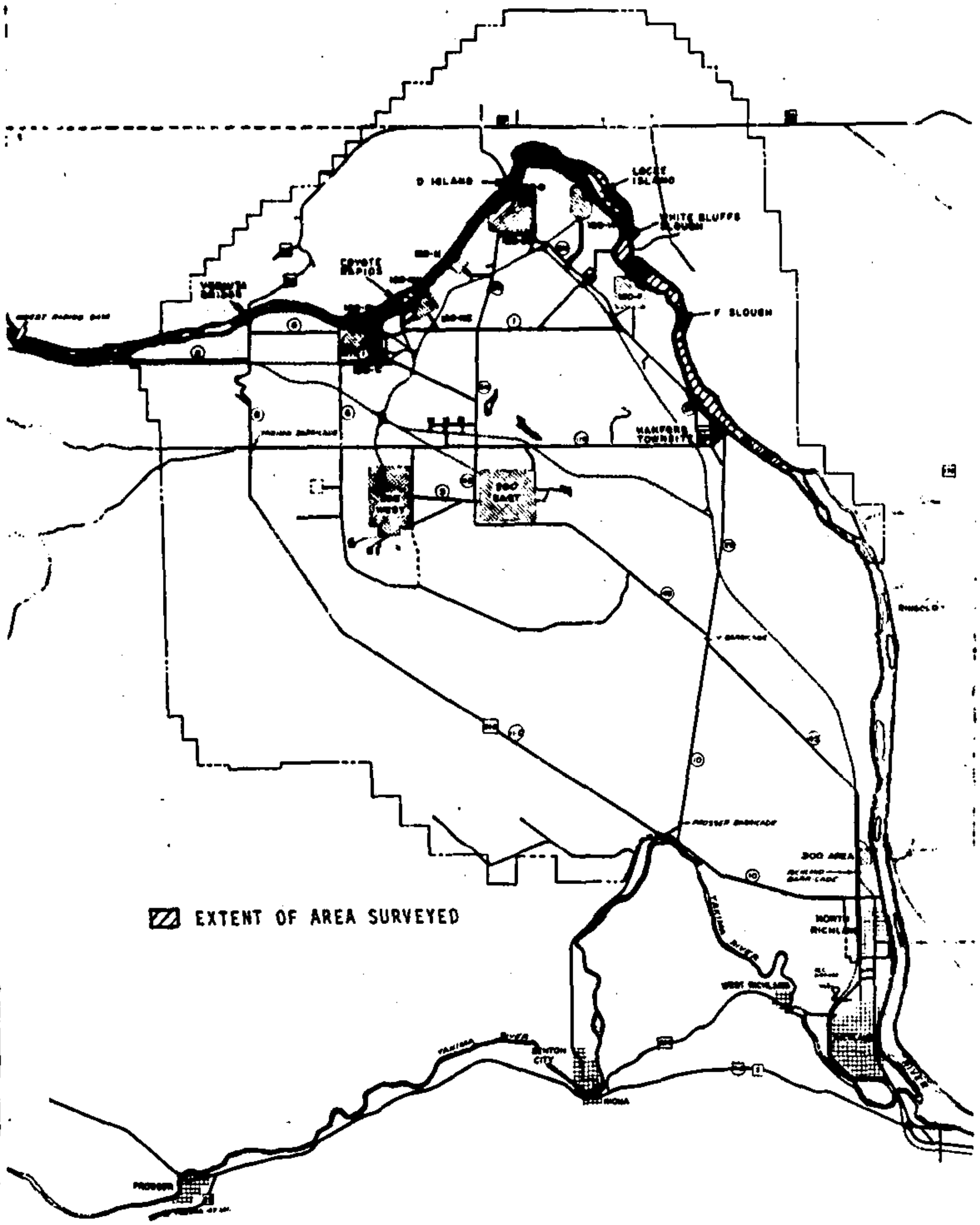

Figure 1. Portion Of The River Surveyed And Its Relation To The Hanford Environs

LEGEND FOR AERIAL PHOTOGRAPHS

(Figures 2-22)

[367]	River Mile
IIIIIIII	Approximate Boundary Of The Foot Survey
[16]	Road Monitor Measurement (μR/hr)
(2)	Shoreline Survey, And Mud And Foam Sample Location (See Figures 4-17)
[10]	Riverbank Spring Location (See Figures 4, 6, 7, 21, and 22)
⟨8⟩	100 Area Radioactivity Location (See Figures 4, 6, 7, 8, 9, 12, 13, 15, 16, and 17)
(Owl)	Location Of Great Horned Owl Pellets (See Figures 5, 10, 11, and 17)
[H.I.P.]	Abandoned Hanford Irrigation Project Pump Station (See Figure 5)

NOTE: Aerial photographs were taken on June 4, 1970 from an altitude of 7500 feet above MSL at an average river flow rate of 230,000 cfs.

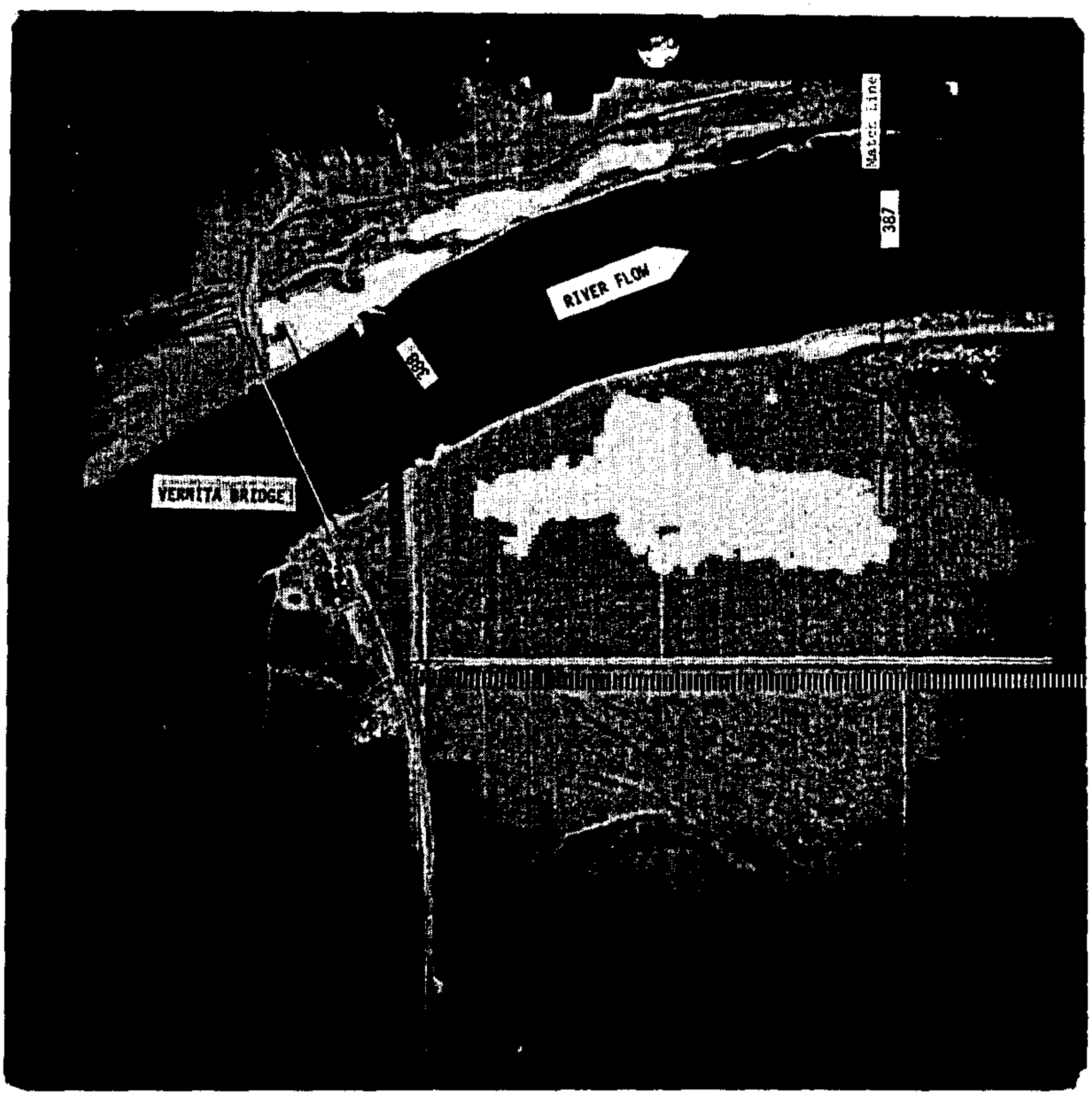

FIGURE 2

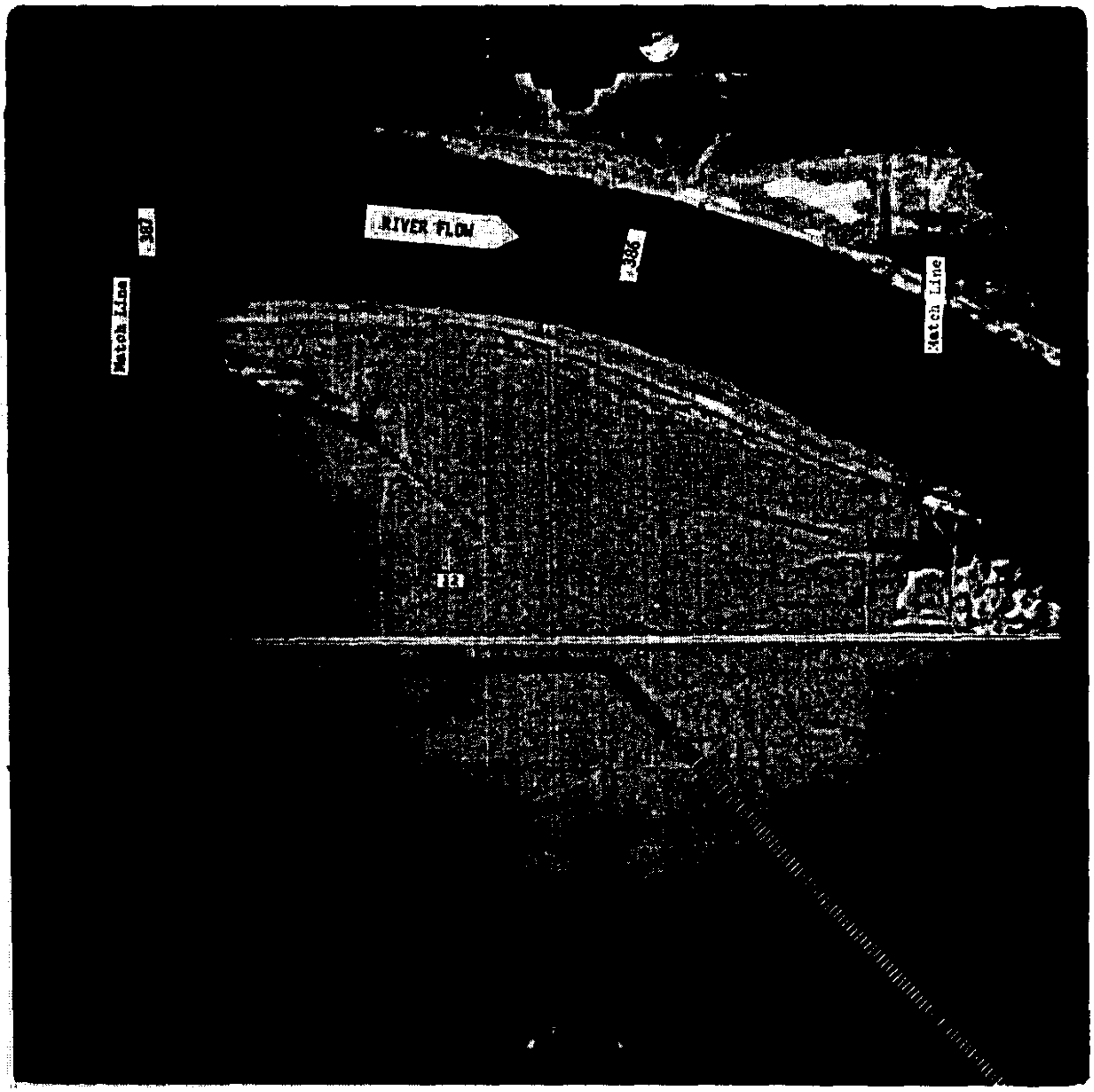

FIGURE 3

FIGURE 4

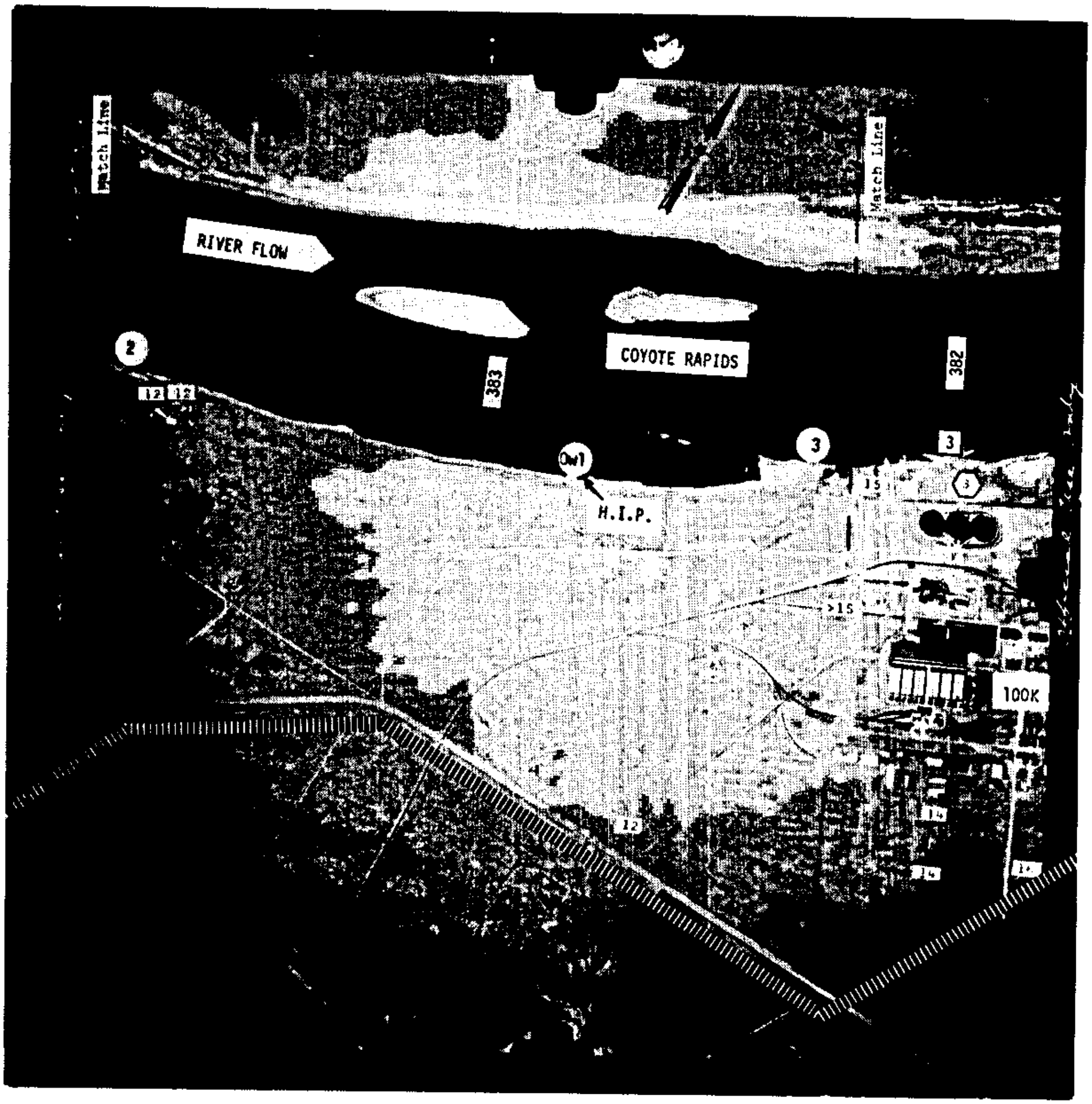
Match Line
Match Line
RIVER FLOW
COYOTE RAPIDS
383
382
2
3
3
Ow1
H.I.P.
12
12
12
15
>15
100K

FIGURE 5

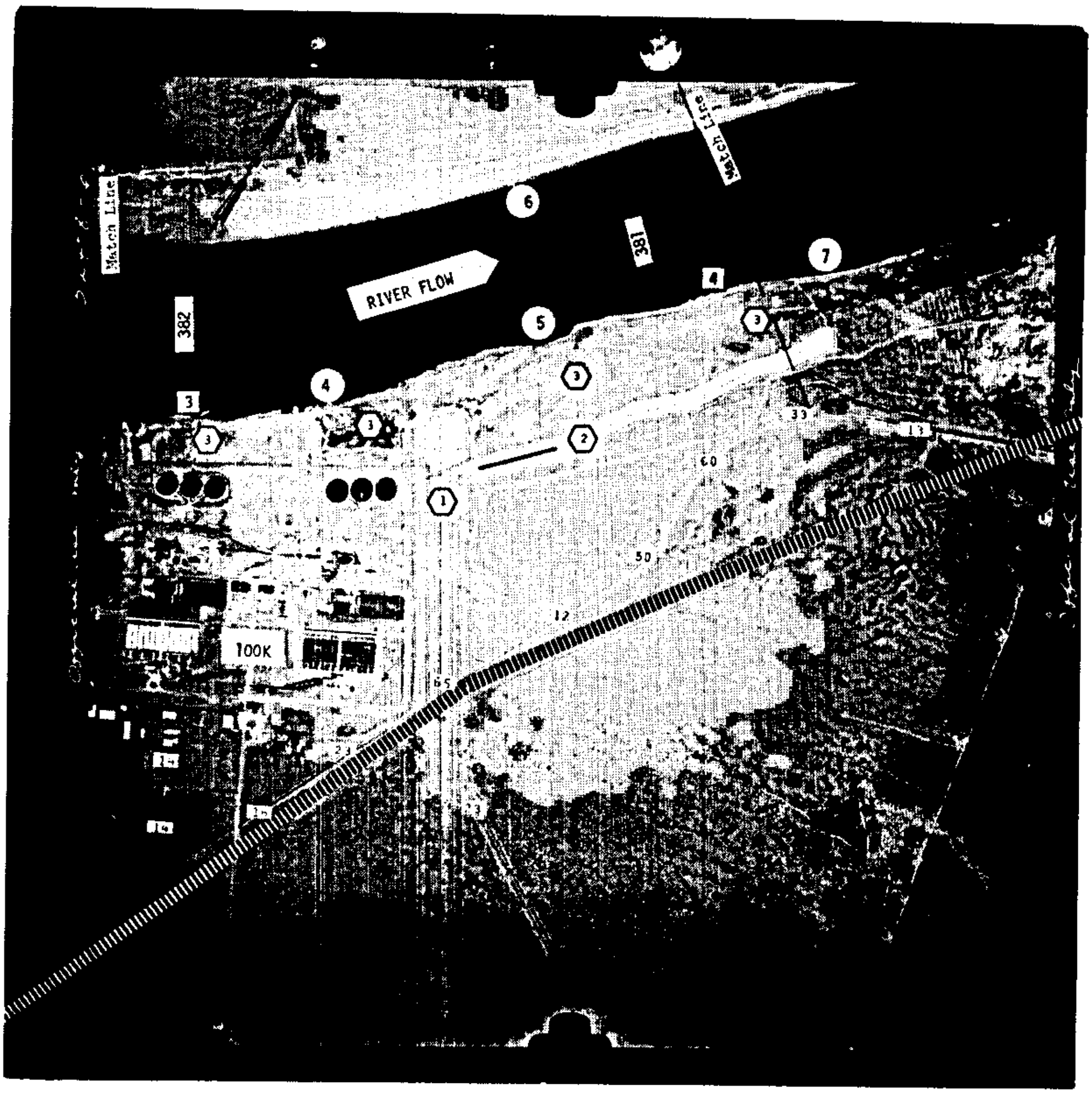

FIGURE 6

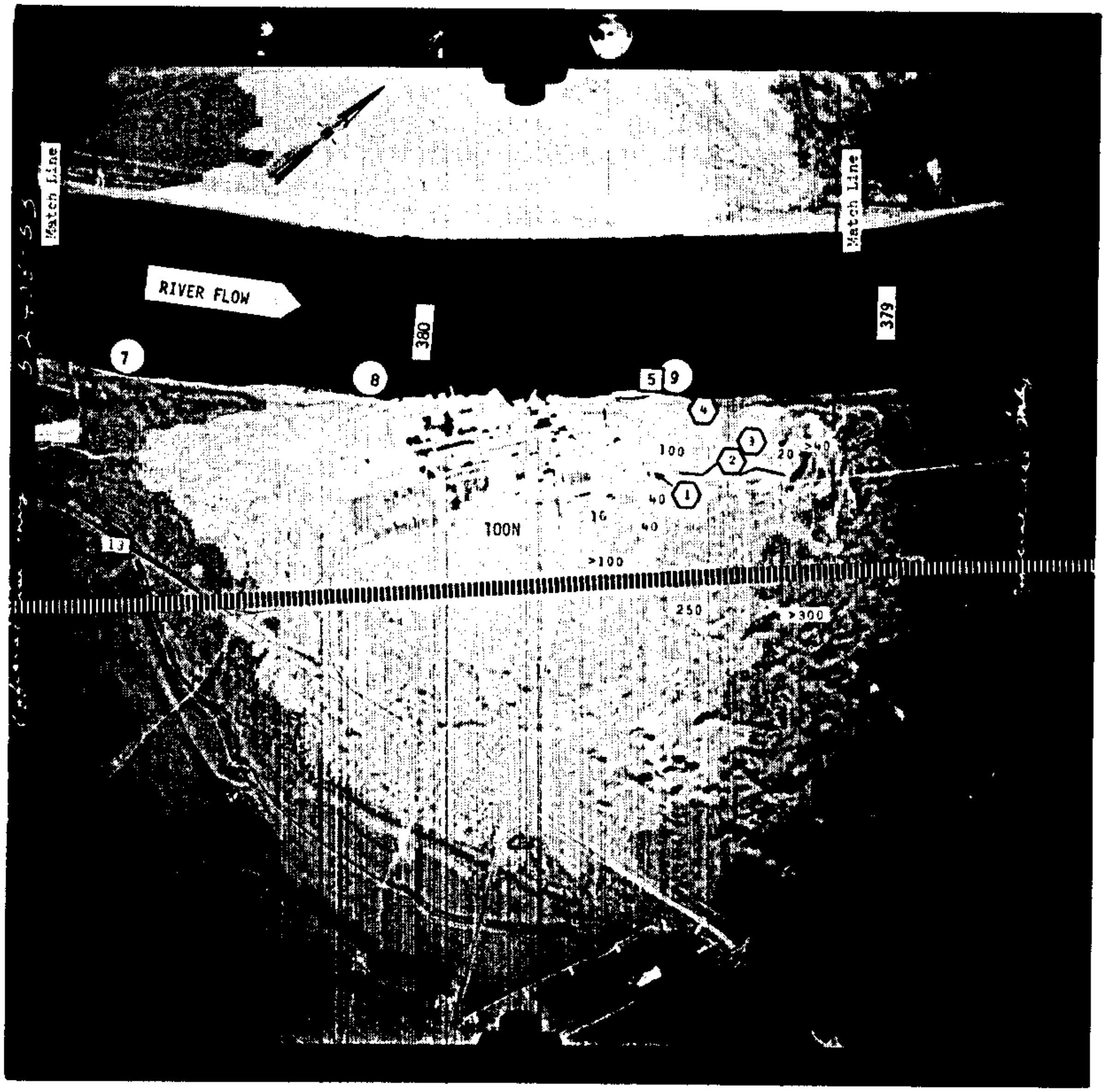
Match Line
Match Line
RIVER FLOW
380
379
7
8
5
9
4
3
2
1
100
20
40
40
100N
16
40
>100
13
250
>300

FIGURE 7

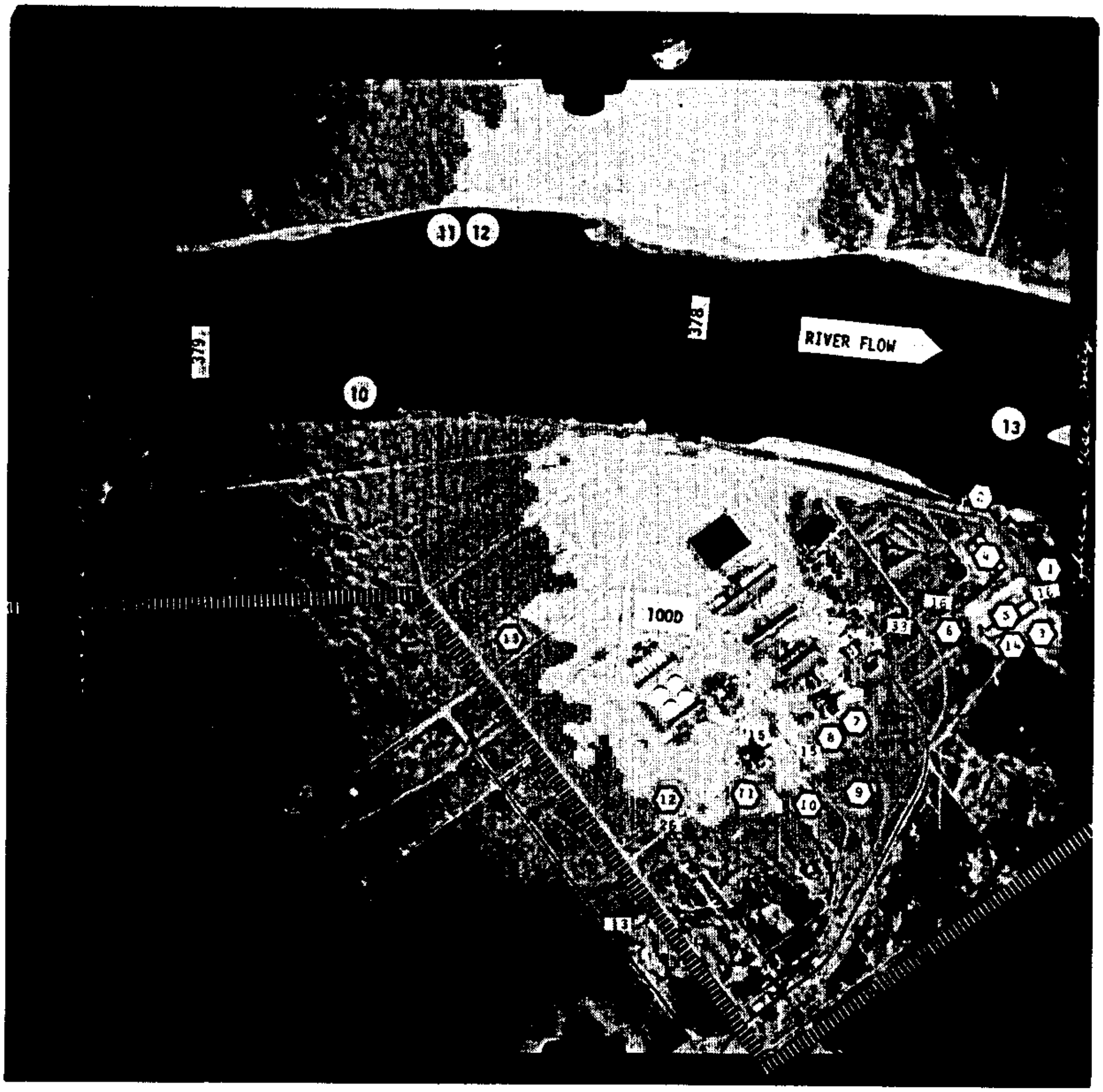

FIGURE 8


Match Line
24
22
23
376
20
RIVER FLOW
19
377
D ISLAND
14
21
13
17
16
26
18
15
Match Line

FIGURE 9

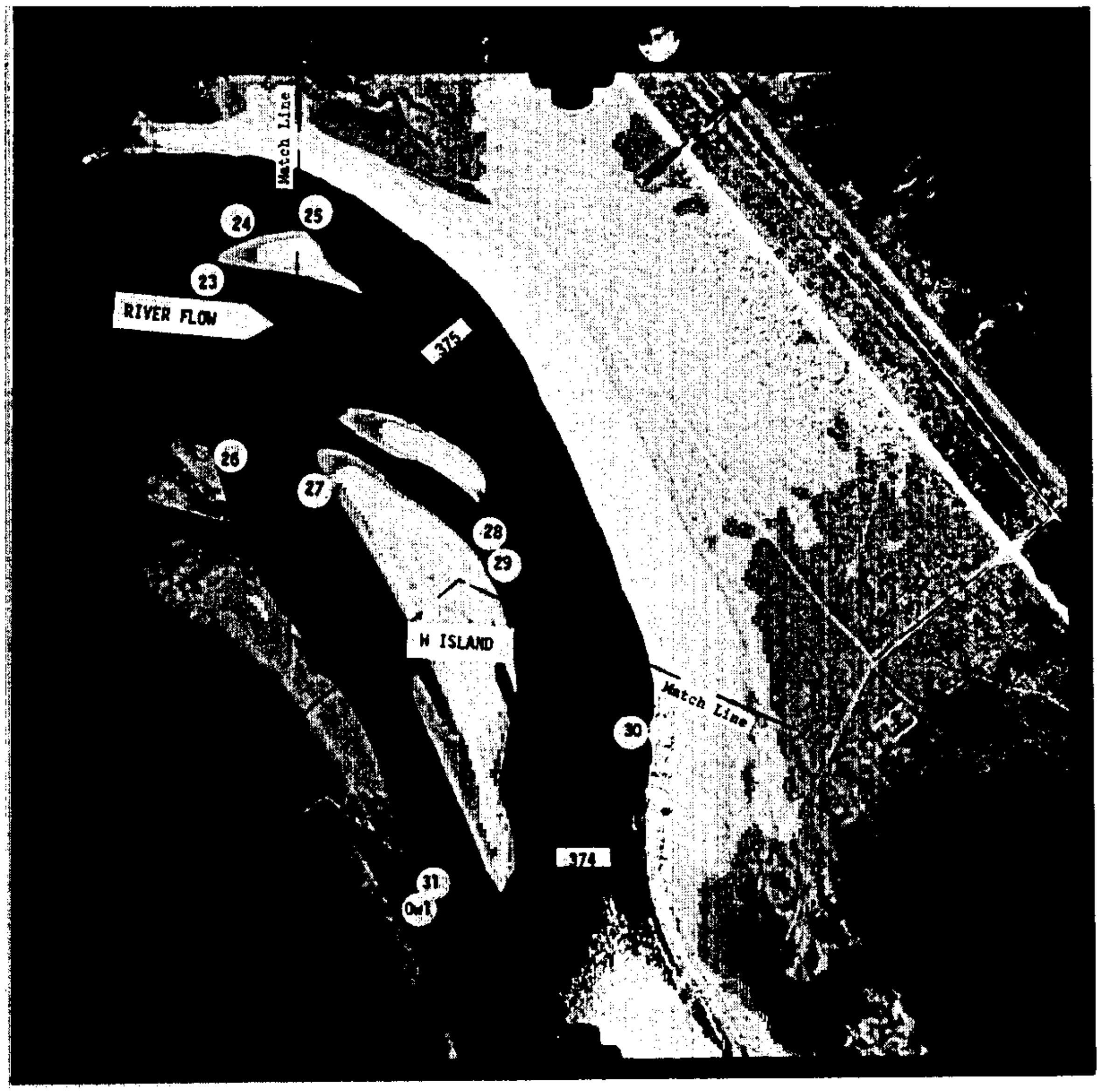
Match Line
24
25
23
RIVER FLOW
375
26
27
28
29
H ISLAND
Match Line
30
374
31
Owl

FIGURE 10


H ISLAND
Match Line
30
374
31
Ow1
RIVER FLOW
Match Line
32
35
36
33
34
373
37
100H
LOCKE ISLAND
38
39

FIGURE 11

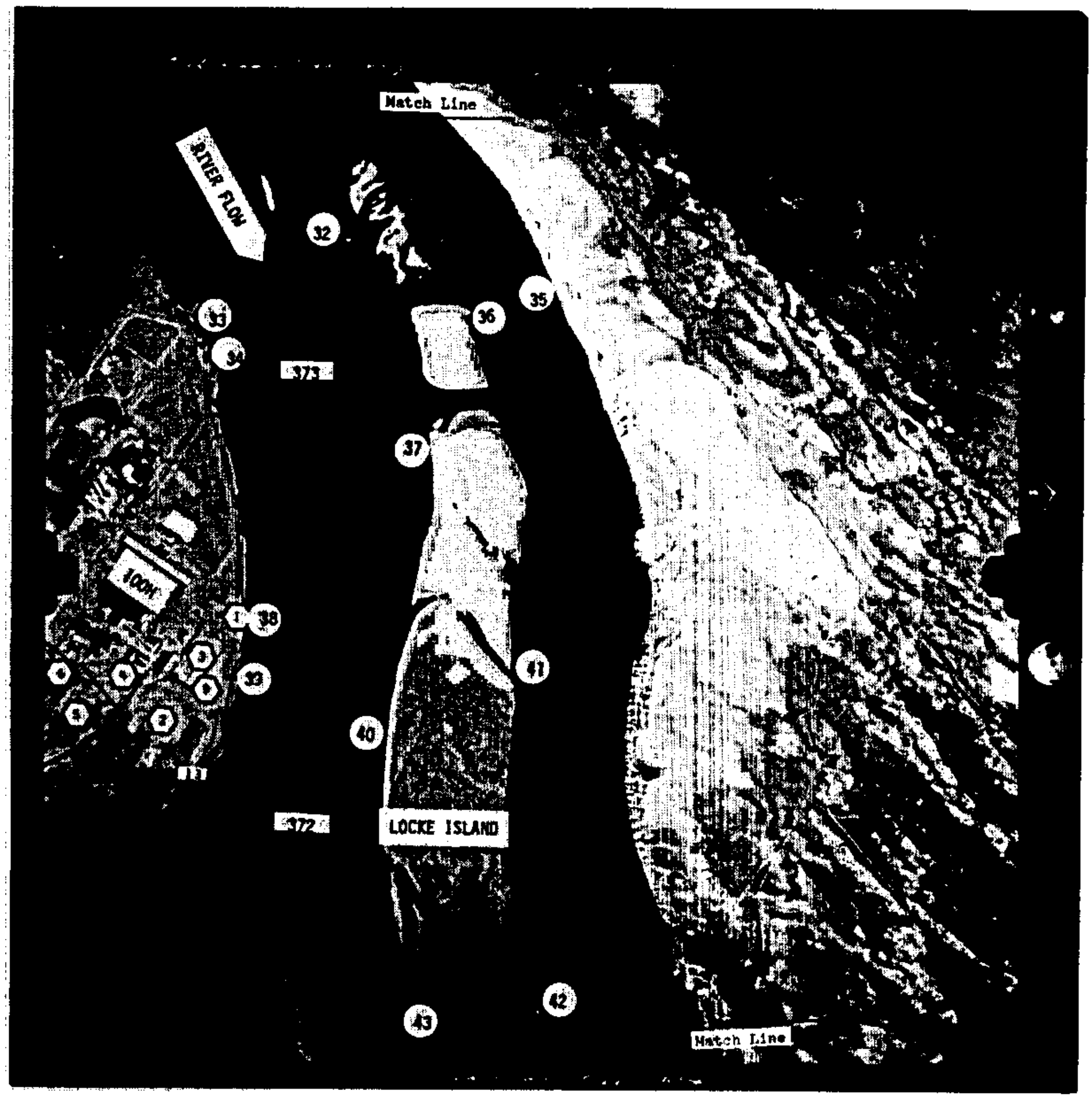
Match Line
RIVER FLOW
32
33
34
35
36
373
37
100H
38
39
40
41
372
LOCKE ISLAND
42
43
Match Line

FIGURE 12

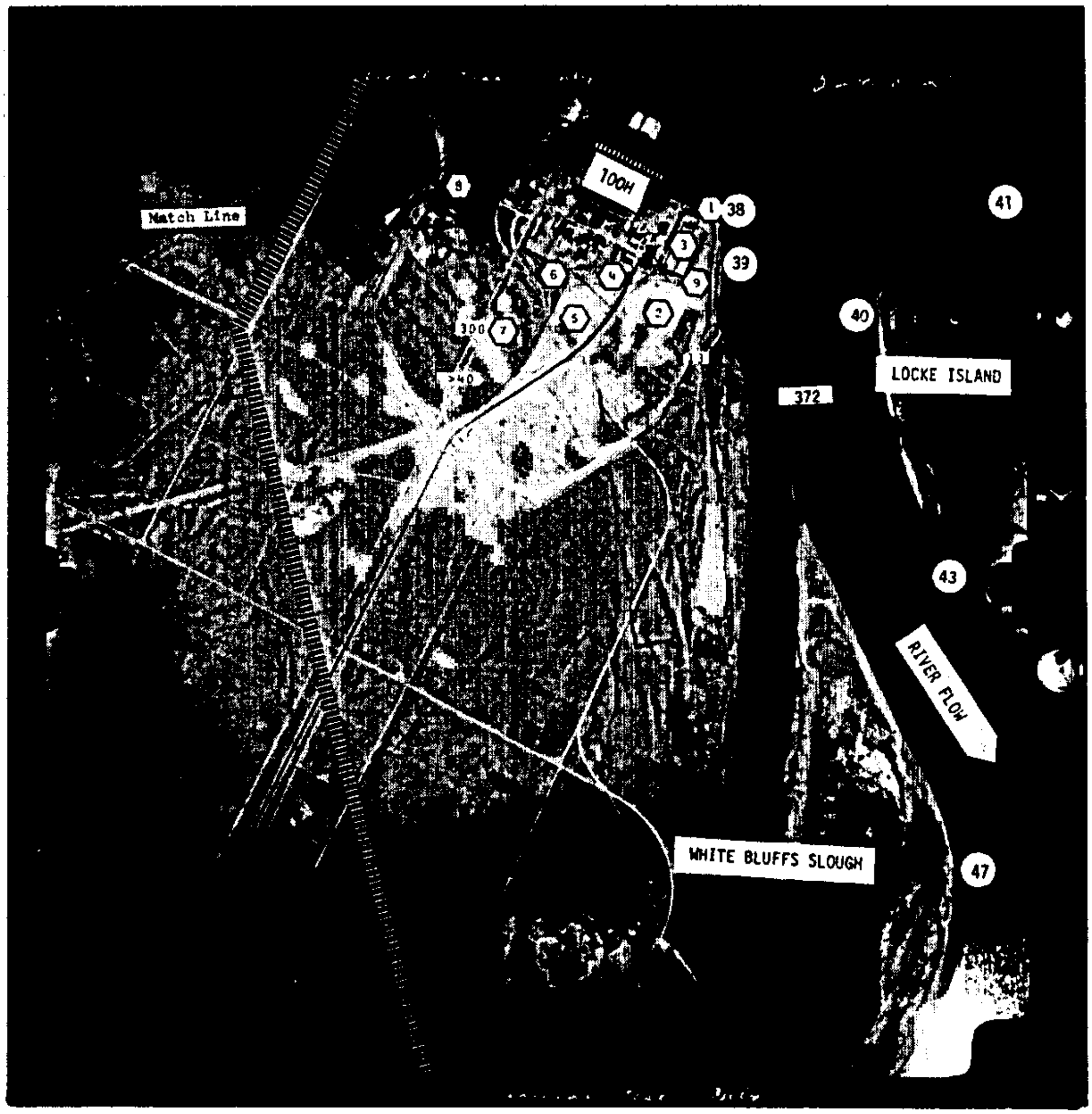
Match Line
100H
1
38
3
39
6
4
9
5
2
7
100
8
>40
372
41
40
LOCKE ISLAND
43
RIVER FLOW
WHITE BLUFFS SLOUGH
47

FIGURE 13

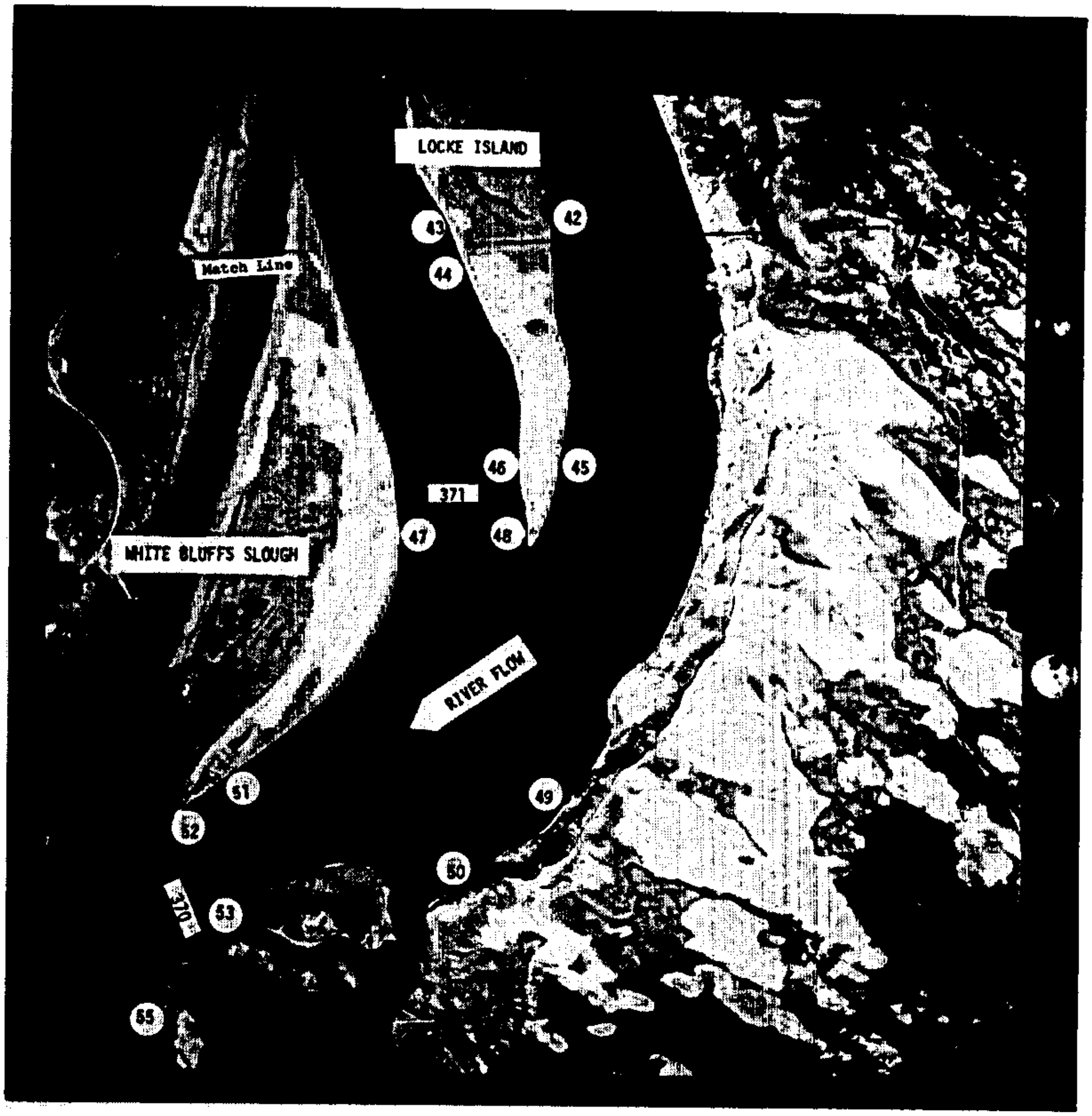
LOCKE ISLAND
Match Line
WHITE BLUFFS SLOUGH
RIVER FLOW
371
370
42
43
44
45
46
47
48
49
50
51
52
53
55

FIGURE 14

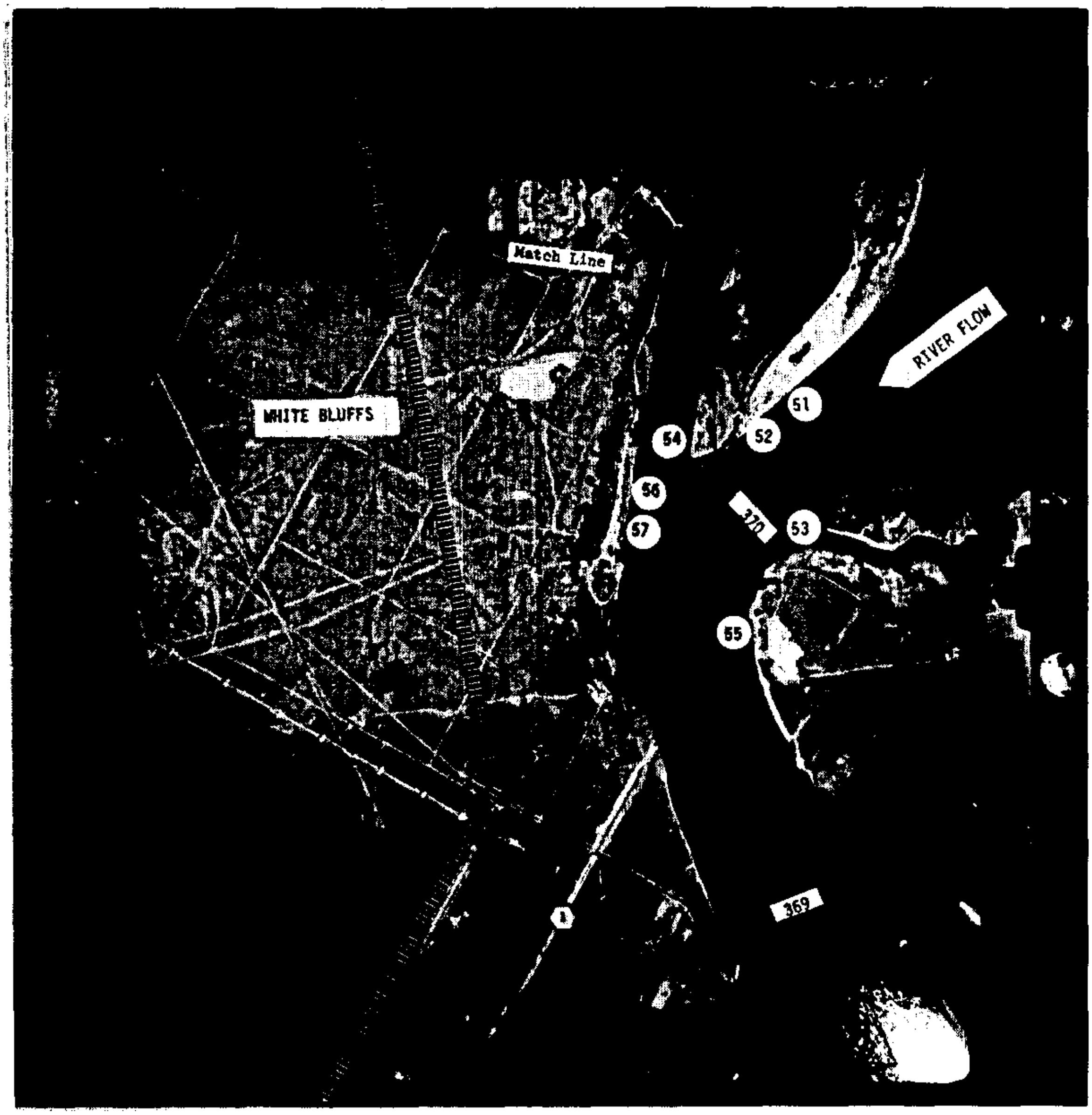

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

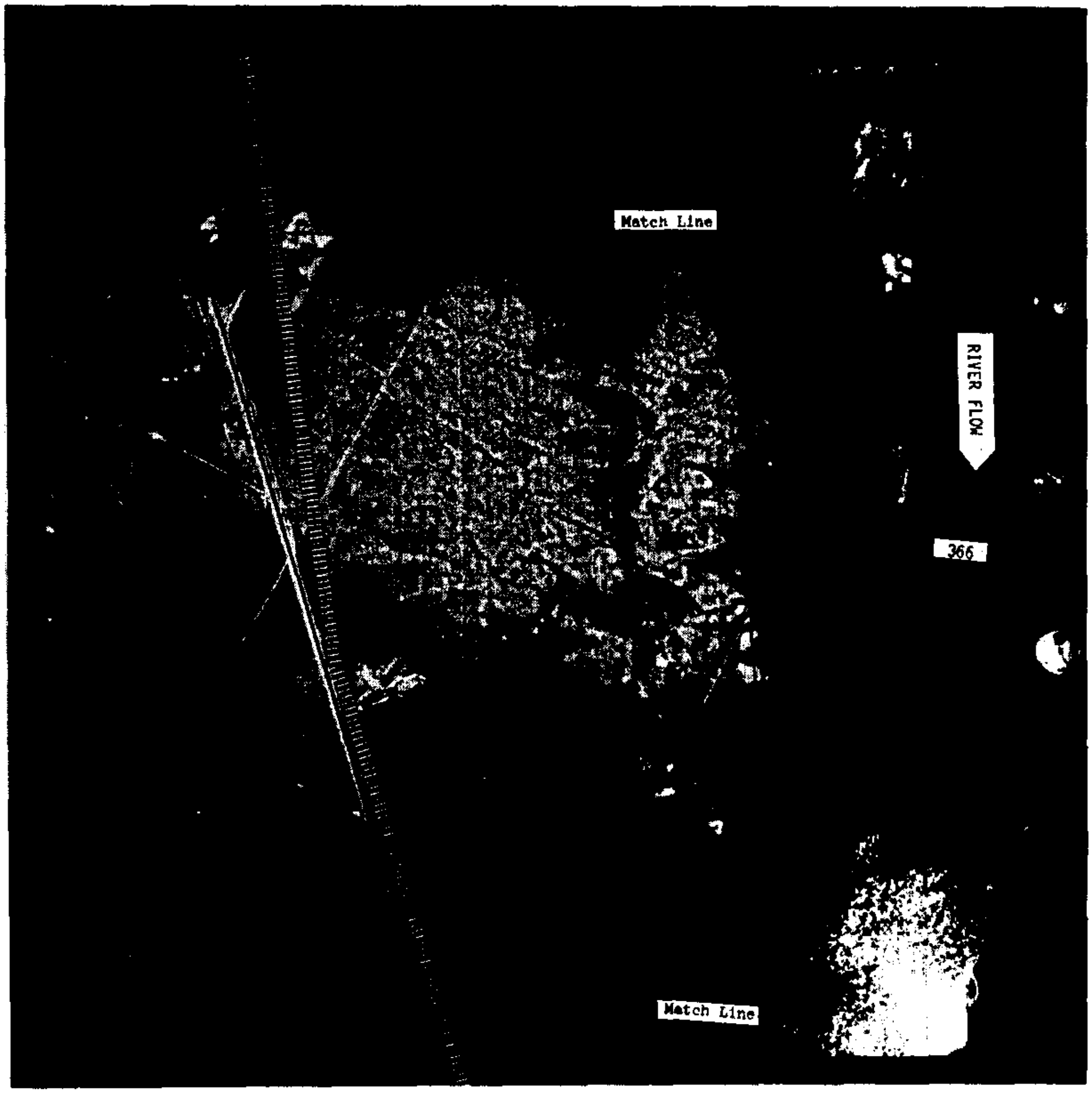

FIGURE 19

FIGURE 20

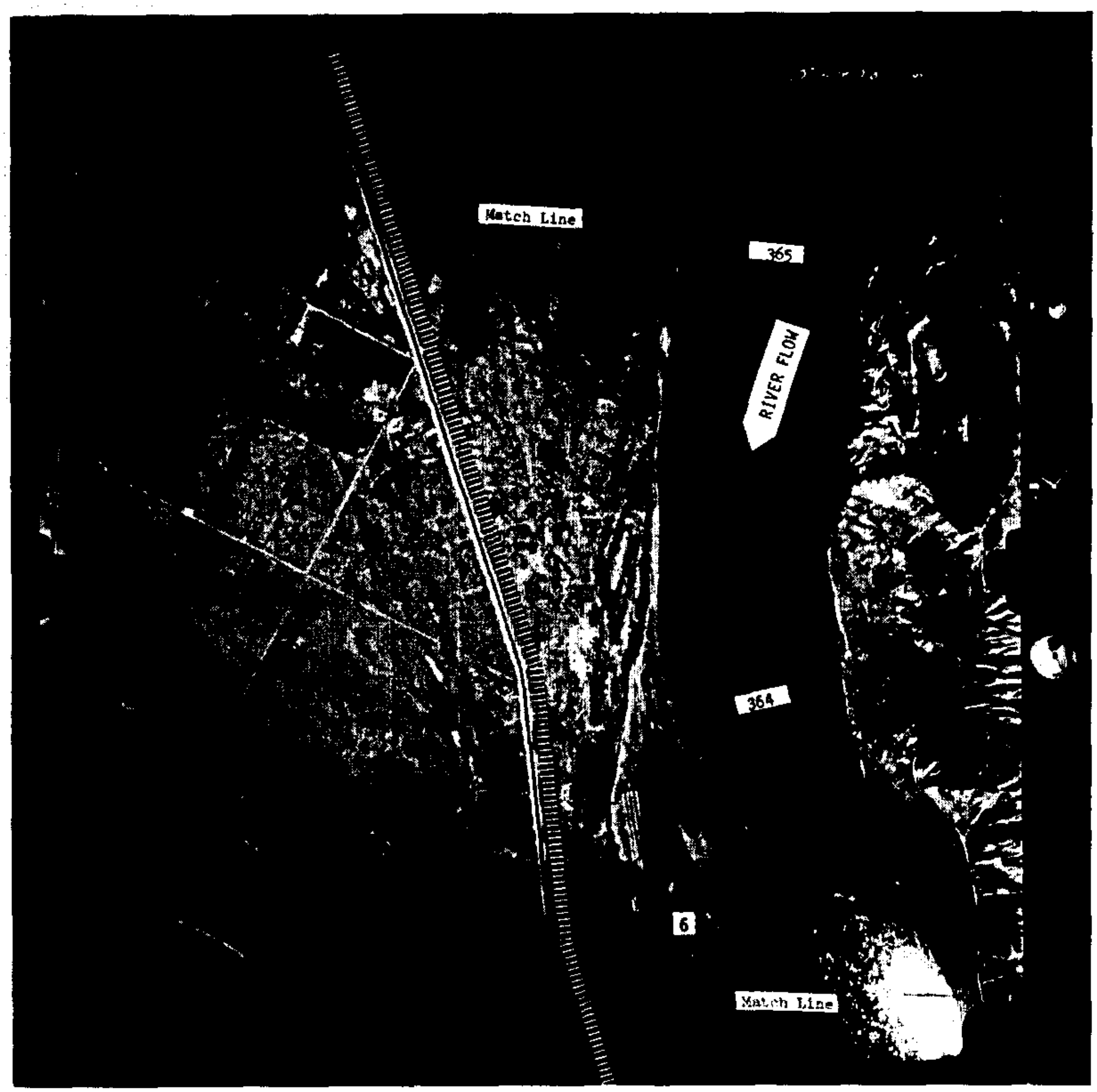

FIGURE 21

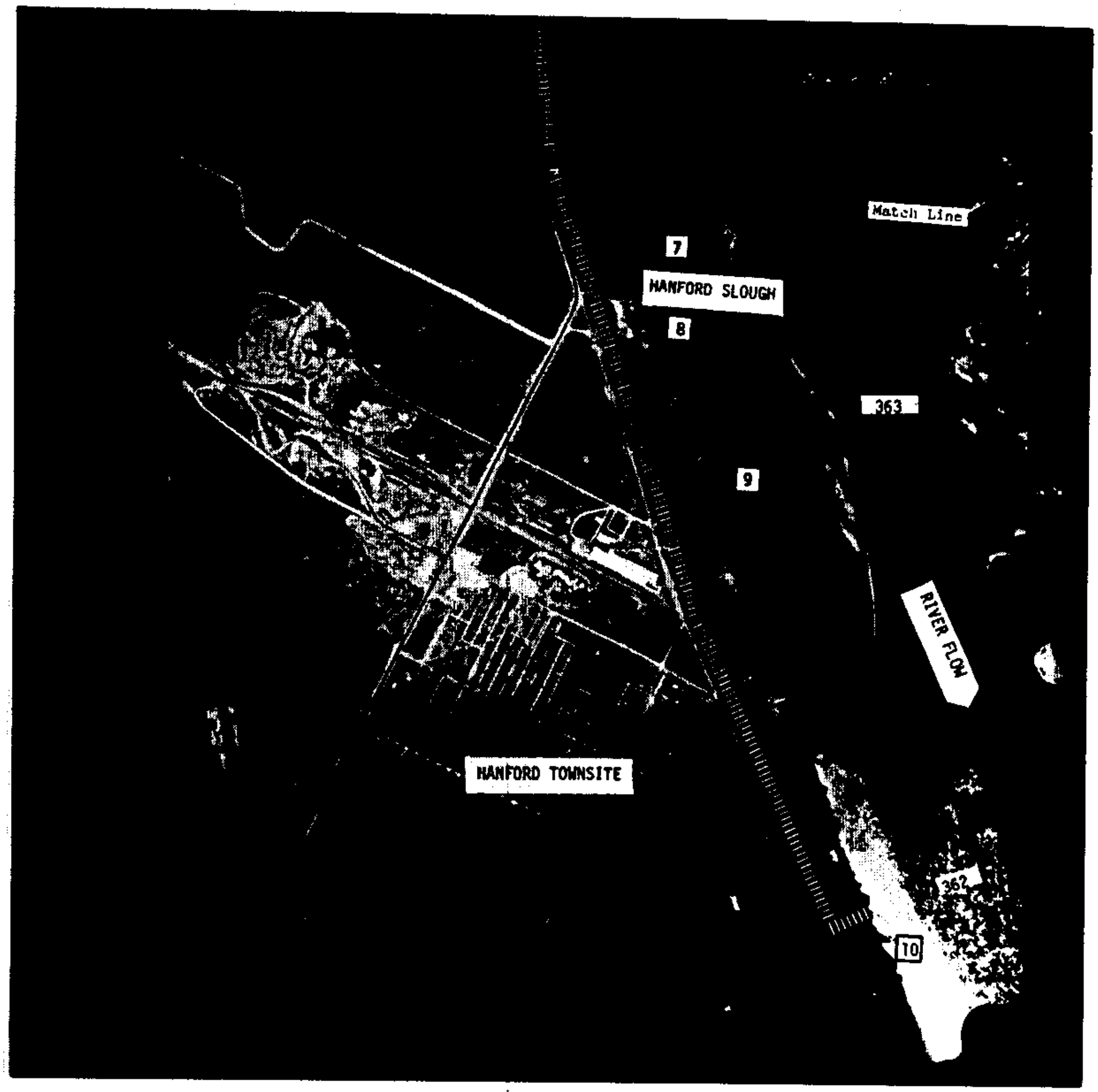
Match Line
7
HANFORD SLOUGH
8
363
9
RIVER FLOW
HANFORD TOWNSITE
362
10

FIGURE 22

near the sloughs, and the river should provide good steelhead fishing. Shallow water, swift current, and unappealing terrain make this portion of the river an unlikely location for water-skiing, swimming, or picnicking. However, the fact that it has been closed for so many years undoubtedly will attract many people for those purposes. Such use should drop off rapidly as the river, which is quite treacherous at low water, takes its toll of equipment. Steelheading from both boat and shore will draw many avid fishermen, who will quickly become familiar with the river and will proceed to spend many days of steelheading each year. Artifact hunting is expected to be another important activity.

Waterborne radionuclides originating at 100-K and 100-N Areas disperse and move slowly across the river, generally reaching the far shore downstream from D Island. Thorough mixing does not occur for many miles--at least as far as 100-F Area. As the river rises and falls, it removes and deposits contaminated algae and other debris unpredictably, such that spotty contamination can be found from time to time along the shoreline. Generally, however, shoreline contamination is reasonably uniform, the greatest variation probably resulting from the decay of short-lived radionuclides with transport downstream. The flow time of the water from 100-K to 100-F Area ranges from about three and one half hours at high flow rates to six hours at low flow rates.

The Far Shore*

The far shore throughout much of this area is not very attractive. Downstream from H Island the shore is dominated by high bluffs. The land upstream becomes more gentle, but is quite desolate.

The Plant Shore*

Having at one time been populated, the plant shore is a little more attractive than the far shore. Although years without water have reduced

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* *The term "far shore" as used in this document means the left bank. "Plant shore" means the right bank (i.e., the one on which the 100 Areas are located).*

once-cultivated land to cheat grass and Russian thistle, trees still find enough water to grow and provide cover for game and gamebirds in the lowlands near the river. Numerous domestic and irrigation wells at old farmsteads and townsites are a safety, though not radiological, hazard.

Radioactivity In And Around The 100 Areas

Since it is possible, even likely, that persons using this stretch of the river would enter the 100 Areas for one reason or another, radiological aspects of such entry should be considered in determining whether or how to open the river for public access. Outside the existing exclusion area fences, accessible* radioactivity is virtually nonexistent in most locations, but is significant in some others (e.g., the 100-N and K trenches). Accessible radioactivity ranges from large masses of slightly contaminated soil (less than 2 nCi/g)**, once contaminated by reactor effluent leakage, and from highly radioactive materials contained in cribs and burial grounds covered by several feet of soil, to significant and easily accessible contamination and radiation fields in currently used burial grounds and other disposal sites. In general, slightly contaminated soil is of little concern. Buried, higher level radioactivity also would be of little concern if the material were to remain buried. However, it would be no great task to either inadvertently or intentionally dig through the covering soil to reach material that could deliver a significant radiation dose.

This section considers, area by area, this radiological aspect of opening the river. It should be understood that the following does not comprise a complete list of 100 Area radiation sources. Rather, it shows the nature and

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* *As used here, the term "accessible" does not mean uncovered or unposted. Rather, it means reachable, either by accident or intent, by persons using the river.*

** *A concentration of 2 nCi/g has been used at Hanford as an unconditional release limit. This value is believed to have been obtained from the International Atomic Energy Agency's definition of "radioactive material" as ".... any material of which the specific activity is greater than 0.002 μCi/g."(2)*

to a degree the extent of 100 Area sources that might be of concern in the event of public access. It includes only those sources located outside of existing exclusion or area perimeter fences.

100-F*

Except for the exclusion area and those locations presently in use by Battelle-Northwest's Biology Department, the termination of 100-F disposal sites is generally assumed complete. The following comments are coded to Figures 15-17.

1. The "Lewis Canal" contains mainly ^{60}Co and $^{152,154}Eu$ in concentrations ranging from about 100 nCi/g at the upper end, where it received effluents from 105-F, to less than 2 nCi/g north of the road at Hanford coordinate N-82200. From its upper end to the road at N-80400, 3 to 4 feet of dirt fill was used to cover concentrations ranging generally from 4 to 40 nCi/g. This portion of the canal was then posted as a Radiation Zone. Between the roads at N-80400 and N-82200, the bottom of the canal was plowed to reduce concentrations ranging generally from 2 to 4 nCi/g. After plowing, the bottom of the canal was covered with 3 to 4 feet of dirt and the canal was then released. North of the road at N-82200, since concentrations were less than 2 nCi/g, the canal was covered with 3 to 4 feet of dirt and released. The Lewis Canal does not seem to present a significant hazard.

2. The side walls of the 1904 outfall structure carried small amounts of ^{60}Co, $^{152,154}Eu$, and possibly some ^{90}Sr and ^{137}Cs. Contact exposure rates of several mR/hr were once accessible. However, the structure has now been buried and is not believed to be of radiological significance.

3. Large masses of soil were slightly contaminated by reactor effluent leakage in the area of the 107 Basin and between the basin and the

* *References 3 and 4.*

river. Radioactivity concentrations in this soil are believed not to exceed 2 nCi/g, and the soil should not be radiologically significant.

4. The 107 Retention Basin has been filled with soil to cover radioactivity, primarily ^{60}Co and $^{152,154}Eu$, in the sludge on the bottom and on the side walls. Some piping contaminated up to about 25,000 c/m on inner surfaces remains accessible, and is marked as being radioactive.

5. The rupture effluent trench and flume are covered with 4 to 20 feet of soil. Accessible radioactivity concentrations in the soil should not exceed 2 nCi/g.

6. The underground effluent lines leading from the 105 Building to the 107 Basin are not considered significant in this study, since it is unlikely they could be entered and since external exposure rates probably do not exceed 10 mR/hr. However, radiation levels of several mR/hr are accessible at the surface of above-ground effluent lines, which are presently posted as Radiation Zones.

7. Just outside the south fence of the exclusion area is a French drain, once used for the disposal of wastes from dummy decontamination, where significant quantities of ^{60}Co, $^{152,154}Eu$, and other shorter-lived radionuclides accumulated underground.

8. The 1608 Trench south of the exclusion area fence was backfilled with about 20 feet of dirt in 1965. The maximum GM count rate obtained in this trench prior to backfilling was about 30,000 c/m, probably corresponding to an exposure rate of less than 10 mR/hr. This trench is not considered a significant source of exposure to the public.

9. The ball-washer crib, which contains waste from the decontamination of boron-steel balls, was backfilled in 1953 with several feet of soil. In the spring of 1970, count rates measured near the surface of the ground were generally 100 to 200 c/m.

10. The Number 3 Burial Ground, once called the "Minor Construction Burial Ground," probably contains much ^{60}Co in irradiated metal reactor components. This terminated burial ground has been permanently posted. In the spring of 1970, count rates measured near the surface of the ground were generally 100 to 200 c/m.

11. The Number 2 Burial Ground has been terminated and permanently posted. However, in the spring of 1970, perfs and other components measuring up to 50 mrad/hr were found on the ground in this area.

12. Portions of the Number 1 Burial Ground have been terminated and permanently posted. However, part of this burial ground is still being used by Biology and is maintained as a Radiation Zone.

13. Liquid effluents containing small quantities of ^{90}Sr and much smaller quantities of plutonium flow from dog kennels and swine pens to the leaching trench. The inventory of ^{90}Sr in the trench is estimated to be less than 15 curies, much of which is probably dispersed through the soil beneath the trench. The trench is still in use and maintained as a Radiation Zone.

14. Sawdust and other solids removed from the dog kennels and swine pens have been deposited outside the old perimeter road east of the 188 Ash Disposal Basin. While these solids, which contain an estimated 15 curies of ^{90}Sr, have been covered with dirt, this contamination must be considered quite accessible, since the fence is not a barrier and since GM readings of several thousand c/m are frequently encountered.

15. Some years ago, six small (1/1000 acre) plots near 1705-F were irrigated with reactor effluent. Recent analysis of soil removed from these plots showed barely measurable radioactivity of plant origin, primarily ^{152}Eu. These plots present no radiological hazard.

16. Beginning about 15 years ago, cereal grains, alfalfa, and other crops were grown in small (1/1000 acre) plots containing known amounts of radioactive material. Six plots contained 5.5 mCi each and six

contained 1 mCi each of ^{90}Sr. In 1962, 10 mCi each of ^{137}Cs was added to the 12 plots. The plots are enclosed by a hardware cloth fence, the top of the enclosure also being covered. Recent analysis of a soil sample obtained from one of the plots showed a ^{90}Sr concentration of 5 nCi/g and a ^{137}Cs concentration of 10 nCi/g.

A 100-F Area radiation survey performed in the spring of 1970 showed that count rates measured near the surface of the ground with GM survey instruments were generally 100 to 300 c/m, these rates hardly being distinguishable from normal background. However, count rates greater than this were found in a few areas. The most significant such findings were in the Number 1 and Number 2 Burial Grounds.

100-H*

Except for the exclusion area, the termination of 100-H disposal sites is nearly complete. The following comments coded to Figures 11-13 concern the major locations of importance from the standpoint of this study.

1. The slightly contaminated 1904 Outfall structure has been filled with soil and presents no radiological hazard.

2. In 1965, exposure rates in the bottom of the rupture effluent trench south of the 107 Basin were about 10 mR/hr, primarily from ^{65}Zn, but also from ^{60}Co and $^{152,154}Eu$. The trench, backfilled to a depth of 10 feet or more, should be of little radiological significance.

3. The 107 Retention Basin has been partially filled with soil to cover radioactivity, primarily ^{60}Co and $^{152,154}Eu$, in the sludge on the bottom and on the side walls. Exposure rates up to several mR/hr and surface contamination levels of several thousand c/m, as measured by GM survey instrument, have been mostly covered by backfilled soil.

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* *References 3 and 4.*

4. Internally contaminated underground effluent lines do not present a significant hazard, although exposure rates of several mR/hr can be found near junction boxes.

5. The construction burial ground located south of the present exclusion area is not believed to contain any radioactive material and is therefore of no radiological significance.

6. A trench located outside the exclusion area fence to the south of the 105 Building possibly contains some radioactivity from reactor effluent. However, it has been well covered and is believed to be of little radiological significance.

7. Although it has been permanently posted, the Number 1 Burial Ground contains accessible exposure rates greater than 1 mR/hr.

8. The Number 2 Burial Ground has been terminated and permanently posted.

9. The French drain located east of the 1717-H Central Maintenance Shops probably contains some ^{60}Co and $^{152,154}Eu$, and possibly a little ^{90}Sr and ^{137}Cs.

A 100-H Area radiation survey performed in the spring of 1970 showed that count rates measured near the surface of the ground with GM survey instruments were generally 100 to 200 c/m, these rates hardly being distinguishable from normal background. However, count rates greater than this were found in a few locations. The most significant of these seem to be the Number 1 Burial Ground, in which small pieces of irradiated metal have been discovered on the surface of the ground, and the 107 Basin. Junction boxes along the effluent lines and the French drain east of 1717-H also seem significant from the standpoint of this study.

100-DDR*

Since 100-D and DR have been on standby status, burial grounds and

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* *References 3 and 5.*

effluent basins have been kept available for reactivation. Little effort has been put into the termination of burial grounds and the covering of contamination. The following comments coded to Figures 8 and 9 concern major locations of importance from the standpoint of this study.

1. A large mass of soil has been contaminated by reactor effluent leakage in the immediate vicinity of the 107 Basins and the effluent lines, and between 107-D and the river. This contamination consists mainly of ^{60}Co, $^{152,154}Eu$, and possibly some long-lived radionuclides such as ^{90}Sr and ^{137}Cs.

2. The 1904-D and DR Outfall structures still remain uncovered. The 1904-D Outfall is still in use for the disposal of D Area process wastes. Exposure rates up to 5 mR/hr are still present at contact with interior surfaces.

3. The effluent disposal trench located east of the 107-DR Basin received 20,000 gpm of reactor effluent for several months during an effluent disposal experiment. As at the other reactor sites, contamination in this trench is fairly low level, consisting mainly of ^{60}Co and $^{152,154}Eu$. The trench has been backfilled to a depth of 15 feet and is a posted Radiation Zone.

4. The 107-D Retention Basin has been filled with 4 to 10 feet of soil to cover radioactivity in the sludge on the bottom. Radioactivity on the side walls has been fixed with asphalt, but otherwise has not been covered. Exposure rates up to several mR/hr are accessible in and around 107-D.

5. A shallow layer of dirt has been placed in the 107-DR Basin to leave it available for reactivation, if needed. Exposure rates are similar to those found in the 107-D Basin.

6. Underground effluent lines are not of radiological significance unless entered, which would be difficult. However, some effluent structures, such as a six-inch diameter vent stack for the effluent lines located near the railroad track south of 107-DR, provide accessible contami-

nation and exposure rates of several mR/hr. A sizable area from about this point northward toward the 107-D Basin remains a posted Radiation Zone.

7. A liquid waste crib outside the exclusion area east of 105-D was used for the disposal of dummy decontamination wastes containing mainly ^{60}Co and probably some $^{152,154}Eu$. This location presently is a posted Radiation Zone.

8. South of the dummy decontamination crib is a solid waste burial ground containing VSR thimbles, covered with 2 to 6 feet of soil. A significant amount of activated metal containing mainly ^{60}Co is buried in this posted Radiation Zone.

9. East of the VSR thimble burial ground lies a construction burial ground, posted as a Radiation Zone, containing slightly contaminated metallic structural members and other equipment used by construction forces.

10. South of the construction burial ground and east of 105-DR lies the Number 3 Burial Ground, which was used until 1967 for the disposal of 100-D and DR solid wastes. This burial ground is not terminated but is a posted Radiation Zone.

11. Southeast of 105-DR is buried sludge from the 1955 cleanout of the 105-DR Basin. This burial site is marked off by a chain, but is not posted. Remaining contamination probably consists of a small amount of ^{90}Sr and ^{137}Cs.

12. The Number 1 Burial Ground, which lies outside the current exclusion area fence south of 105-DR, has been terminated and is permanently posted.

13. The Number 2 Burial Ground, which was used until about two years ago for 100-N reactor waste, has been retired and is a posted Radiation Zone, but has not yet been permanently posted.

14. Sludge removed from 107-DR Retention Basins in 1953 was buried in a slit trench and covered with six feet of soil. The concentration

of radionuclides in this sludge is believed to be very low, mainly ^{60}Co.

A 100-DDR Area radiation survey performed in the spring of 1970 showed that count rates measured near the surface of the ground with GM survey instruments were generally 100 to 400 c/m. However, count rates greater than this were found in many locations, the most significant being the 107 Basins, other effluent systems and structures, and the burial grounds.

100-BC*

Since the 100-BC Area reactors are on standby, only one burial ground and one 107 Basin have been terminated. Surface contamination and significant external radiation levels can be found in the Radiation Zones from 105-C northward to the river. Many accessible areas at 100-BC have not been adequately prepared from a radiological standpoint to permit uncontrolled access. While from the standpoint of this study there are numerous accessible locations or items of raidological significance, only a few, coded to Figure 4, are listed below.

1. The 105-C Solid Waste Burial Ground, while permanently posted for termination, contains spots where the soil covering is inadequate as evidenced by signficant radiation levels. Efforts are being made to correct this situation.

2. The 105-B Solid Waste Burial Ground is being used presently for 100-N Area waste. This active burial ground contains both surface contamination and significant radiation levels.

3. East of 105-B lie several construction burial grounds. The major radionuclide contained here is probably ^{60}Co.

4. The Ball 3X Burial Ground contains sizable quantities of ^{60}Co.

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* *References 3 and 6.*

5. Large masses of soil contaminated by reactor effluent leakage exist in the areas of the 107 Basins, between the basins and the river, and southward from the 107-C Basins toward the railroad tracks. Close to the effluent lines the radioactivity concentrations in the soil exceed 2 nCi/g, mainly ^{60}Co, ^{65}Zn, and $^{152,154}Eu$.

6. East of 105-B lies the 105-B Storage Basin Trench. This trench, which probably contains small quantities of ^{60}Co and ^{152}Eu, has been backfilled to a depth of about six feet.

7. The C Effluent Trench is being used for underground disposal of 100-BC process waste water, primarily storage basin overflow. Contamination levels of several thousand counts per minute and exposure rates of several mR/hr can be found on the rocks in this trench, which at one time was flooded with reactor effluent.

8. The B Effluent Trench, which contained mainly ^{60}Co, ^{65}Zn, and $^{152,154}Eu$, has been backfilled to a depth of about 15 feet.

9. Sludge from the 107 Basins containing primarily ^{60}Co, ^{65}Zn, and $^{152,154}Eu$, was buried in this location to a depth of about six feet.

10. The 105-C Overflow Pluto Crib, although probably not containing a great deal of radioactivity, is uncovered and still posted as a Radiation Zone.

11. The 107-CW Retention Basin has been filled with approximately two feet of dirt. The side walls were hosed down but were not covered with dirt or painted. Exposure rates near the side walls might reach 20 mR/hr. The 107-CE Basin is about half filled with dirt. Side wall exposure rates are generally less than 10 mR/hr.

12. The 107-B Retention Basin has been filled to a depth of about two feet. As with the 107-C Basins the side walls were hosed down to remove loose contamination, but were not covered. Significant contamination levels and exposure rates to several mR/hr are accessible.

13. Junction boxes and other such structures, generally in the vicinity of the 107 Basins, provide accessible contaminated surfaces and exposure rates to several mR/hr.

14. The 1904-B and C Outfall structures have been filled and present no radiological hazard.

Radiation surveys performed at 100-BC in the spring and fall of 1970 showed that count rates measured near the surface of the ground with GM survey instruments were generally 100 to 300 c/m, these rates hardly being distinguishable from normal background. However, count rates greater than this were found in a few locations. The most significant findings were in the burial grounds, one of which is still in use. The 107 Basins and associated effluent systems also contain significant surface contamination and external radiation levels.

100-N and 100-K*

So far this section has concerned areas whose radiological significance from the standpoint of this study results at least partly from the removal of area perimeter fences, which once would have prevented access by the public. The remaining areas, 100-N and 100-K, present a slightly different situation, since fences have not been removed. At 100-N, liquid waste empties into a rock-filled crib (Item 1, Figure 7) and then overflows into a trench (Item 2). Significant contamination levels may be found among the rocks in the crib; exposure rates near the surface of the crib typically are on the order of 5 mR/hr, but can reach 100 mR/hr at the inlet. The trench, which is approximately one third of a mile long, is covered by a wire screen supported several feet above the water level in order to prevent access by waterfowl and animals. Exposure rates at the screen are typically 5 to 20 mR/hr. While the screen is effective for waterfowl and for all but very small animals, such as mice, it was not intended to prevent human access to a potentially hazardous area.

* *References 3 and 6.*

Falling into the trench could subject a person to fairly high exposure rates and certainly to high levels of contamination. Large masses of soil slightly contaminated by reactor effluent leakage and by seepage from the crib and trench exist between the exclusion area, crib, and trench, and the river (Item 3). Radioactively contaminated water from the crib flows underground and emerges as springs near the river shoreline (Item 4).

At 100-K Area solid waste is retained inside the exclusion area fence except in one location, a small posted burial ground (Item 1, Figure 6) located between the main burial ground and the liquid waste basin. A short distance north of this burial ground is the head end of the liquid waste trench, which runs northeast for about 0.8 mile (Item 2). Only the first section of the trench, about 1000 feet, is presently in use, the remainder being dammed off and partially backfilled. The portion of the K Trench presently in use is covered with a wire screen not intended to support the weight of a person. As at 100-N, a significant radiological hazard exists because of the possibility of falling through the screen into the trench. As at the other sites, a large mass of contaminated soil (Item 3) exists between the exclusion area and the river and between the trench and the river. While the concentrations are generally quite low, this area contains many spots having concentrations that probably well exceed 2 nCi/g.

OBSERVATIONS AND DATA

Shoreline Exposure Rates

Radiation exposure of persons along the shoreline of the Columbia is an important aspect of this study. Gamma exposure to the gonads or whole body of a standing person and beta exposure to the skin of a person lying or sitting on the shoreline are of major interest. Gamma exposure rates are measured three feet above the shoreline with a 40-liter ionization chamber[7] to estimate dose rate to the gonads of a person standing on the shoreline. Surveys for beta activity are conducted with GM survey instruments to locate particulate contamination that might lead to significant skin exposure.

The measurement of shoreline gamma exposure rates is a part of the routine environmental surveillance program. Until recent years, however, most shoreline measurements were made below Ringold,[8] because the public did not have access generally to the shoreline upstream from that point. In January 1970, a number of new routine shoreline exposure rate locations were established between Ringold and Vernita in order to provide information for this study. The averages of those 1970 data are shown in Table I. Annual averages for locations routinely surveyed during 1967, 1968, and 1969 are also included to show that shoreline exposure rates generally have decreased at the measurement locations. As expected, the greatest decrease occurred in 1970 following the shutdown of K-West. As a result of this decrease, the highest average in 1970 (i.e., on D Island) is not greatly different from the 1967, 1968, and 1969 averages at Powerline Crossing, which has been open to the public for many years. The 1970 column shows some uniformity of average shoreline exposure rates with distance downstream, except for a few island locations such as at river miles 377.4 IP, 373.4 IP, and 367.0 IF. Another interesting observation from 1970 average data is that the far shore exposure rate peaked at Hanford, 19 miles downstream from K-East.

During 1970, three special shoreline surveys were made for purposes of this study. The locations of these special shoreline surveys are shown in Figures 4-17. On January 31 and February 1 a survey was made from above 100-BC to below 100-F. This survey represents essentially a "two operating K reactor" situation. On May 26 another shoreline survey was performed, this time from above 100-K to below 100-F. These data probably represent something less than the radiation levels expected with one K reactor operating, since the extended shutdown during the winter and spring undoubtedly reduced the shoreline concentration of some of the longer-lived radionuclides. On October 3 another survey was performed from above 100-K to below 100-F. The results of this survey probably are more typical of what one would find with a single K reactor operating and the river flow rate low. Another special survey, intended for July or August, when the flow rate was low, the water warm, and the river at its maximum use, was never made, due at first to scheduling problems and then to an extended shutdown of the KE reactor. Results

Table I

Summary Of Routine Measurements Along
The Columbia River Shoreline - 1967 Through 1970

Average Of Shoreline Exposure Rates
At 3 Feet Above The Ground*

μR/hr

Location	River** Mile	1967	1968	1969	1970
Vernita†	388.0 P	(18)	(15)	(13)	(18)Jan-April 14 Aug-Dec
Above 181 KW	382.5 P	--	--	--	20
Below 181 KE	381.5 P	--	--	--	99
Below 181 KE	381.0 F	--	--	--	16
Below N Trench	379.7 P	--	--	--	59
Below 100 N	379.0 P	--	--	--	59
Above 181 D	378.4 F	--	--	--	20
D Island	377.4 IP	--	--	--	140
E Island	375.8 IF	--	--	--	40
Locke Island	373.4 IP	--	--	--	100
Locke Island	371.1 IP	--	--	--	43
White Bluffs Ferry	369.7 P	200	160	75	64
White Bluffs Ferry	368.8 F	84	64	56	25
Upper End 100-F Slough	368.3 P	--	--	--	64
100-F Slough	367.0 IF	--	--	--	110
Hanford	362.0 P	110	130	88	71
Hanford	362.0 F	88	130	100	59
Savage Island	359.1 F	--	--	--	44
Ringold	355.7 IP	--	--	--	68
Ringold	354.7 F	63	78	45	36
Powerline Crossing	350.4 P	120	150	110	51
Powerline Crossing	350.4 F	130	120	72	38
Byers Landing	345.2 F	57	80	63	44
300 Area	344.5 P	88	82	60	--
Richland	340.5 P	(31)††	(54)	(26)	(20)Jan-April [17]Aug-Dec

* *From weekly surveys when in parentheses and from semiweekly when in brackets. Otherwise, from monthly surveys. Data from May through July excluded.*

** *P-Plant shore, F-Far shore, IP-Plant shore of island, IF-Far shore of island.*

† *Surveys made near Vernita Bridge (plant shore), except from July, 1968 to December, 1969 when made at the Priest Rapids Dam gauge station.*

†† *Average of weekly data at Sacajawea Park (~13 miles downstream of Richland).*

of these surveys are tabulated in Table II. Exposure rates measured during these surveys are plotted in Figure 23 along with those from three earlier surveys[1,9] for comparison.

It should be pointed out here that shoreline exposure rates are somewhat unpredictable, since they depend not only on reactor operating conditions but also on river flow conditions. Abnormally high shoreline exposure rates sometimes experienced during the spring have been attributed to seasonal increases in Columbia River concentrations of stable ^{56}Mn and other nuclides that become activated upon passage through the reactor. Also, scouring of the river bottom at high flow rates can resuspend particulate material which might then be redeposited upon the shoreline. Even in a day's time, due to normal fluctuations in releases from Priest Rapids Dam, the river can deposit and then remove radioactive particulates.

Shoreline Mud And Foam

During the February 1, 1970 shoreline survey, mud and foam samples were collected from 10 locations which, because of spotty contamination detected by the GM survey or because of unusual exposure rates measured with 40-liter chambers, were expected to contain greater-than-normal concentrations of unnatural radionuclides. The locations from which these samples were collected are identified in Table III by numbers corresponding to the shoreline survey locations found in Table II and in Figures 9 through 15. Using a 3 inch by 3 inch NaI spectrometer, it was apparent that most of the activity was attributable to ^{60}Co and to ^{46}Sc+^{65}Zn. (No attempt was made to resolve the ^{46}Sc and ^{65}Zn photopeaks. Instead, the estimated activity associated with the 1.12 MeV photopeak is simply labeled ^{46}Sc+^{65}Zn.)

Interestingly, Table III shows no consistent correlation between any of the four types of measurement. The only apparently valid trend in these four types of measurement is the downstream increase in ^{46}Sc+^{65}Zn concentration in mud, a trend which has been observed in bottom sediments farther downstream by others.[10] No efforts have been made to verify or explain this apparent trend. Probably the only important conclusion to draw from this table is

(Continued on page 50)

Location*		Columbia River Mile	Date	Time	Shoreline 40-1(3') μR/hr	Shoreline GM (Surface) c/m	Approx. River Flow Rate (cfs)	Remarks
P	1	384.6	2/1/70	0735	38	400	43,000	Large uncontaminated pipe on shore; muddy cobbles.
F	2	383.8	2/1/70	0745	--	400	43,000	Large boulders, muddy cobbles
P	3	382.3	1/31/70	0830	40	250	45,000	Rocky shoreline above H boat launch
			2/1/70	0750	25	-	43,000	
			5/26/70	1025	12	150	210,000	Grassy, fairly level shoreline. Wind from NW.
			10/3/70	0950	22	75-100	40,000	
P	4	381.7	2/1/70	0755	290	4,500	43,000	Just below down-river 107 basin; calm, effluent vapors drifting downstream; muddy cobbles
			5/26/70	1020	37	100	210,000	Wind from NW.
			10/3/70	1015	220	3,200	40,000	Possibly seeing some effect of effluent vapor plume. Slippery boulders.
P	5	381.3	2/1/70	0725	--	1500-3000	43,000	Muddy cobbles
F	6	381.2	2/1/70	0805	72	<100	42,000	Rocky, large boulders; dried algae on rocks
			5/26/70	1035	12	150-200	210,000	Grassy, flat shoreline. Some boulders.
			10/3/70	0955	24	100	40,000	Rocky shoreline.
P	7	380.6	1/31/70	0930	95	1500-1800	45,000	Orange marker #30, far end of H rupture trench
			2/1/70	0810	97	2,000	42,000	Large, muddy cobbles
			5/26/70	1030	22	100	210,000	Orange marker #30.
			10/3/70	1040	240	400-600	40,000	Muddy cobbles.
F	8	380.1	2/1/70	0745	--	1500-3000	43,000	Just above H Forebay
			10/3/70	1050	52	300-550	40,000	Muddy, small cobbles

* P - Plant shore, F - Far shore, IP - Plant shore of island, IF - Far shore of island

Table II

Summary Of Special Shoreline Survey Data

P	9	379.4	2/1/70	0815	115	2,000	43,000	Small cobbles; just below 100-N Met Tower and sign #36
			5/26/70	1045	28	150	210,000	Very steep bank.
			10/3/70	1100	52	300-900	40,000	Fairly clean cobbles. Good water.
P	10	378.7	2/1/70	0810	--	1,300	43,000	Steep shoreline, cobbles
			10/3/70	1107	10	400-550	40,000	Red 41
F	11	378.5	2/1/70	0825	13	<100	43,000	Rocks, boulders; dried algae on rocks
			5/26/70	1055	11	100-150	210,000	Grassy, flat, some boulders. Near telephone line and shack.
			10/3/70	1018	10	100	40,000	Just upstream from Bureau Of Reclamation ponding breakthrough.
F	12	378.4	2/1/70	0825	--	150	45,000	Muddy cobbles
			10/3/70	1028	17	150	40,000	Just downstream from Bureau Of Reclamation ponding breakthrough.
IP	13	377.4	2/1/70	0845	--	1000-1500(F)	45,000	Upper end of Island; large expanse of cobbles
						2500-3000(P) (20,000)* 5000		Vent pipes; hot spot found in exposed effluent line
			5/26/70	1100	31	400	210,000	Rocky shoreline. Foam and debris in a cove measured up to 51 μR/hr and 2000 c/m.
			10/3/70	1105	100	900-2000	40,000	"D" Island.
IF	14	377.1	2/1/70	0845	--	2000-3000 (7,500)	45,000	Hot spot on foam; F.S. near center of island in a moist cove
			5/26/70	1115	51	1,000	210,000	Sandy cove. Foam and debris.
			10/3/70	1113	140	1200-1500	40,000	"D" Island. Cobbles.
P	15	377.2	2/1/70	0825	210	4,000	45,000	DR outfall; some steam from rocky shoreline
			5/26/70	1057	22	200	210,000	
			10/3/70	1123	14	600-700	40,000	At dead tree. Steep bank. Fairly clean cobbles. About 100 yards upstream from rusty upwelling (when "D" operated) above the D outfall line (i.e., between 1904D and river)

* Numbers in () are hot spots.

IP	16	377.1	2/1/70	0840	350	2000-5000	45,000	Lower end of D Island; several hundred yards upriver of overhead power line
			5/26/70	1108	56	400-600	210,000	
			10/3/70	1055	130	1800-2000	40,000	Hot spot (6000 c/m) at wet line.
I	17	377.0	2/1/70	0845	64	1000-2000	45,000	Downstream end of D Island; muddy cobbles
			2/1/70	0900	--	1500-3000	45,000	Sandy area, nice beach
			10/3/70	1120	140	2000-2500	40,000	Hot spot (6000 c/m). Sandy shoreline.
P	18	376.9	2/1/70	0940	--	1,500	43,000	Potential hunting area; large cobbles at shoreline, diminishing in size with distance from shoreline. In grassy area above daily wet line.
			5/26/70	1118	27	250	210,000	Old shoreline survey marker-metal stake. Upstream end of slough.
			10/3/70	1134	32	700-800	40,000	
F	19	376.7	2/1/70	0845	45	<100	45,000	Steep bank, cobbles, swift current; barrel high on bank; stiff wind from northwest
			5/26/70	1135	10	150-250	210,000	Sandy gravel shoreline. Steep bank.
			10/3/70	1135	27	200-300	40,000	Good shoreline.
F	20	376.5	2/1/70	1000	--	400-500	42,000	Rocky shoreline, sand dunes above; old shack up on bank
						150		Above daily wet line; mussel shells and arrowhead chips
			10/3/70	1220	26	250-300	40,000	Shack. Deep water. Steep shoreline.
P	21	376.3	2/1/70	0920	190	2,000	43,000	Rocky, some slime.
			5/26/70	1135	37	400	210,000	Foam measured up to 81 μR/hr and 2000 c/m
			10/3/70	1143	82	800	40,000	Much good water in this area below "D" Island.
F	22	376.0	2/1/70	1015	--	200-1600	42,000	Good sandy shoreline; fast current except close to shore in cove; good water skiing; three live head of cattle; strong wind from north.
			5/26/70	1145	12	150-200	210,000	Sandy shoreline, fast current.
			10/3/70	1230	42	250-300	40,000	Good sandy shoreline.

I P	23	375.8	2/1/70	0925	41	2000-4000	43,000	Rocky; plant side of "E" island
			5/26/70	1145	33	200	210,000	Old shoreline survey marker-metal stake.
			10/3/70	1258	130	1100-1200	40,000	
I F	24	375.7	1/31/70	1015	150	1500-2000	49,000	Flat, rocky shoreline, shallow water
			2/1/70	0935	30	1800-2000	43,000	Far Side of "E" Island
			10/3/70	1235	100	700-750	40,000	Gravel, fast current.
I F	25	375.5	2/1/70	1035	--	1500-2000	42,000	Small, clean pebbles, some sand back from shore.
			5/26/70	1150	11	200-250	210,000	Rocky, gravel shoreline. Fast current.
			10/3/70	1242	57	500-600	40,000	Gravel, fast current.
P	26	375.4	2/1/70	0935	170	3,000	43,000	All rocky, no water flow, somewhat flat above shoreline; swift current, deep enough for boat access.
			5/26/70	1157	18	100	210,000	Slough filled with water. Good picnic and waterski area.
			10/3/70	1245	67	200-1000	40,000	Rocky, fairly steep bank. Very swift current.
I P	27	375.2	2/1/70	0940	270	1000-2000	43,000	Cobbles.
			5/26/70	1240	28	200-250	210,000	Large herd of deer on island.
I F	28	374.7	2/1/70	1050	--	2000-2500	42,000	F.S. cove of island; count rate dropped off rapidly about 100 feet from shore where terrain was grassy
			5/26/70	1205	19	200-300	210,000	Rocky shoreline. Shallow water.
			10/3/70	1312	74	400-500	40,000	Gradually sloping, rocky shoreline.
I F	29	374.6	2/1/70	0955	36	1500-2000	43,000	Flat, rocky shoreline; lots of dried algae on rocks.
			5/26/70	1210	12	200-250	210,000	Rocky, gently sloping shoreline.
			10/3/70	1317	100	750-800	40,000	Gradually sloping, rocky shoreline.
F	30	374.2	2/1/70	1010	62	500	43,000	Landslide area; rocky, boulders.
			5/26/70	1220	16	200-250	210,000	Landslide area. Mud and clay.
			10/3/70	1327	30	350-375	40,000	Steep bank. Rocky.

P	31	373.9	2/1/70	0945	270	4000	43,000	Below trees on bank; some moist sand and rocks
				1110	--	3500 2000	42,000	In sandy cove; potential boat access
			5/26/70	1300	24	100	210,000	Very steep bank. Fast current.
			10/3/70	1250	92	350-800	40,000	Muddy cobbles.
IP	32	373.3	1/31/70	1115	115	1200-1500	48,000	All rocky shoreline
			2/1/70	0955	115	400-2000	42,000	
			5/26/70	--	--	--	210,000	Struck rocks. Unable to survey this point.
P	33	373.1	2/1/70	1000	150	2000	42,000	Sandy, sheltered, easy boat access
			5/26/70	1315	29	100	210,000	Sandy shoreline just upstream of H forebay.
			10/3/70	1300	145	500-2000	40,000	Sandy cove above H forebay.
P	34	373.0	2/1/70	1130	--	500-2000	40,000	Sand bar in H forebay; some depressions similar to those observed at Hanford Ferry Landing during October 10, 1969 survey. Good water skiing and swimming.
			5/26/70	--	--	--	210,000	H forebay sandbar submerged. Thus, no survey.
			10/3/70	1308	200	2000-3000	40,000	Sampled foam from H forebay bar.
F	35	373.1	2/1/70	1025	60	600-700	42,000	Muddy, rocky, fast current.
			5/26/70	1310	14	200-250	210,000	Muddy, steep bank.
			10/3/70	1350	30	300-400	40,000	Steep, rocky.
IF	36	373.1	2/1/70	1300	--	1000-2000	42,000	Far shore of Locke Island; muddy cobbles, some debris.
			5/26/70	1230	10	200-250	210,000	Rocks and sand.
			10/3/70	1340	57	600-650	40,000	Rocky
IP	37	372.9	2/1/70	1020	97	1500-2000	42,000	Large expanse of small pebbles.
				1300	--	500-2000	42,000	1500-2000 on downstream tip of peninsula.
						400		Sandy in channel on island side of peninsula.
						400-1000		Large expanse of small pebbles; some scum (up to 1800 c/m) along shoreline
			5/26/70	--	--	--	210,000	Small island adjacent to Locke Island was submerged.

P	38	372.4	2/1/70	1335	--	1000-2000	42,000	H outfall; concrete ramp.
P	39	372.3	2/1/70	1050	170	2000	43,000	Rocky shoreline about 200 yards downstream of H outfall
			5/26/70	1355	23	100	210,000	Steep, rocky shoreline.
			10/3/70	1325	145	350-600	40,000	Fairly clean cobbles.
IP	40	372.2	2/1/70	1035	270	2000	43,000	Rocky; some algae on rocks at water line
			5/26/70	1401	23	100	210,000	
			10/3/70	1333	200	400-600	40,000	Fairly clean cobbles.
IF	41	372.4	2/1/70	1100	--	1500	43,000	Rocky, shallow water.
			5/26/70	1320	16	250-600	210,000	Muddy, steep bank. Foam.
			10/3/70	1407	49	400-500	40,000	Rocky, shallow, difficult access.
IF	42	371.6	2/1/70	1355	--	1000-1500	43,000	Far shore of Island; muddy cobbles, very shallow.
			10/3/70	1418	46	350-400	40,000	Rocky, shallow.
IP	43	371.5	2/1/70	1100	145	1500-3000	42,000	Muddy rocks; somewhat sheltered
			5/26/70	1408	21	100	210,000	Muddy, steep bank.
IP	44	371.4	2/1/70	1400	--	600-1500	43,000	Pebbles at shoreline, sandy at wet line (250 c/m), fairly steep bank; possible water skiing.
						150-200		On top of island.
			10/3/70	1340	220	500-600	40,000	Gently sloping, muddy, rocky shoreline.
IF	45	371.1	2/1/70	1435	--	200-600	43,000	Sandy shoreline.
			5/26/70	1355	12	250-300	210,000	Sandy shoreline. Some foam.
			10/3/70	1425	40	250-300	40,000	Sandy shoreline.
IP	46	371.1	2/1/70	1410	--	600-1500	43,000	Rocky.
			5/26/70	1415	27	100	210,000	Rocky shoreline. Good landing spot. Deep water.
P	47	370.9	1/31/70	1145	79	600-1200	46,000	Rocky, steep bank.
			2/1/70	1220	115	1500	42,000	Rocky, steep bank.
			5/26/70	1420	22	50	210,000	Cobbles.
			10/3/70	1356	165	200-300	40,000	Steep, clean rock

IP	48	370.9	2/1/70	1120	170	800	43,000	Sandy, good boat and water ski access
			5/26/70	1410	12	250-300	210,000	Sandy shoreline.
			10/3/70	1350	165	400	40,000	
F	49	370.5	2/1/70	1250	75	500-600	43,000	Flat shoreline, rocks and mud
			5/26/70	1415	12	250-300	210,000	Muddy sand. Flat shoreline. Some vegetation.
			10/3/70	1437	26	150-200	40,000	Muddy, fairly flat shoreline.
F	50	370.4	2/1/70	1300	83	400	43,000	Flat, mud and sand.
			5/26/70	1425	51	350-1000	210,000	Flat, grassy shoreline 350-400 c/m. Foam 1000 c/m and 51 μR/hr.
			10/3/70	1444	49	300-400	40,000	Muddy shoreline.
P	51	370.2	2/1/70	1330	120	1000	43,000	Flat, sandy shoreline; calm, good swimming and water skiing area
			5/26/70	1427	21	100	210,000	
			10/3/70	1405	235	500-600	40,000	
P	52	370.1	2/1/70	1230	170	1000 (2500)	42,000	Muddy; hot spot in drainage area of cove.
			5/26/70	1433	21	100	210,000	Cove not apparent, due to high water.
			10/3/70	1412	215	400	40,000	Good sandy shoreline. Strip about 2000 c/m 10 feet above shoreline. Good water. Calm.
F	53	370.0	2/1/70	1445	--	500-1000	43,000	Muddy cove.
			5/26/70	1435	<10	250-300	210,000	Muddy, grassy bank.
			10/3/70	1453	52	300-325	40,000	
P	54	370.0	2/1/70	1300	97	800-1000	42,000	Muddy, rocky; sandy back from shoreline.
			5/26/70	1439	27	100	210,000	Water very high. Muddy.
			10/3/70	1423	270	500-600	40,000	Muddy shoreline and slough. Slough shallow. Probably good waterfowl hunting.
F	55	369.8	2/1/70	1315	68	400-2000	43,000	Muddy cobbles, some sand, steep bank.
			5/26/70	1440	13	250-300	210,000	Sandy, grassy bank.
			10/3/70	1458	35	250-300	40,000	

P	56	369.9	2/1/70	1250	97	1000	41,000	Muddy cobbles.
			5/26/70	--	--	--	210,000	Water very high. Did not survey.
			10/3/70	1430	325	300-700	40,000	
P	57	369.8	1/31/70	1210	210	1600-2200	44,000	Muddy cobbles about 100 feet up-
			2/1/70	1305	130	1500-2000	40,000	stream of White Bluffs Ferry Landing
			5/26/70	1447	23	100	210,000	Cobbles.
			10/3/70	1515	67	300-500	40,000	
F	58	368.5	1/31/70	1230	95	700-1100	44,000	Rocky, below lone juniper tree.
			2/1/70	1330	115	400-600	40,000	Rocky, below lone juniper tree.
			5/26/70	1445	12	250	210,000	Small gravel. About 10 feet below juniper tree.
			10/3/70	1457	135	200-300	40,000	Below lone juniper. Steep, rocky.
P	59	368.4	2/1/70	1315	190	1500-2000	40,000	Rocky, fairly steep bank.
			5/26/70	1455	14	250-300	210,000	Rocky, steep bank. Foam and debris in water.
			10/3/70	1447	260	500-600	40,000	

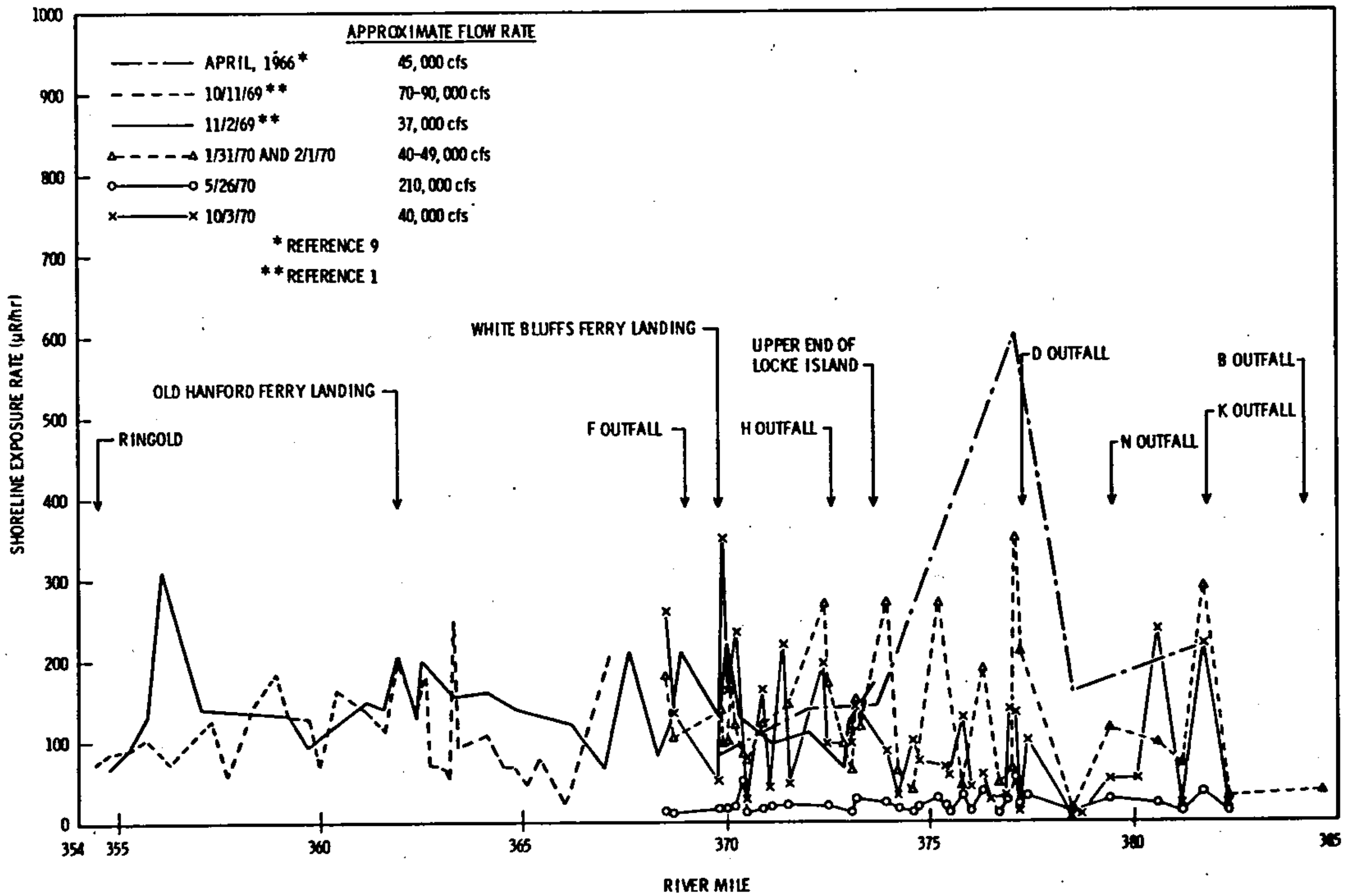

Figure 23. River Shoreline Exposure Rates Measured With A 40-Liter Chamber At 3' Above The Ground

Table III

Concentration Of ^{60}Co And $^{46}Sc+^{65}Zn$
In Mud And Foam Collected On 2/1/70

Shoreline Location	Columbia River Mile	Sample Type	Concentration (pCi/g) ^{60}Co	Concentration (pCi/g) $^{46}Sc+^{65}Zn$	Shoreline Measurements 40-Liter At 3 Ft. μR/hr	Shoreline Measurements GM At Surface c/m
13	377.4	Foam	< 90	860	-	1000-3000(20,000)*
17	377.0	Mud	< 20	200	64	1000-3000
31	373.9	Mud	-	350	270	2000-4000
33	373.1	Mud	40	380	150	2000
36	373.1	Foam	< 270	1400	-	1000-2000
48	370.9	Mud	-	90	170	800
49	370.5	Mud	30	670	75	500-600
52 a.**	370.1	Mud	< 10	120	170	1000(2500)*
b.		Mud	70	1100		
54	370.0	Mud	50	1000	97	800-1000
55	369.8	Mud	10	2500	68	400-2000

* *Hot spots shown in parentheses.*

** *At this location, one sample (a.) was taken of the general, typical shoreline. The other (b.) was taken in a small cove nearby.*

that the radiological hazard from ingesting this mud is insignificant, since ingestion is unlikely and since radionuclide concentrations in the mud are so low.

Riverbank Springs

The radionuclide content of groundwater emerging as riverbank springs was briefly investigated during the present study. Springs existed in at least one location along this portion of the river long before the Hanford plant was constructed.[11] Ground disposal of reactor effluents and other liquids in the 100 Areas has created additional riverbank springs, at least some of which contain measurable radioactivity of Hanford origin. The number, location, and radioactivity had not been examined closely in recent years, however, so two special surveys were made from 100-BC Area downstream to the Hanford Townsite in December 1970 and January 1971. The first survey, performed by boat on 12/16/70, was hampered by high wind downstream from 100-D. This portion of the shoreline was reexamined on 1/25/71, and portions around 100-H and along the Hanford Slough were examined on 1/26/71. Springs were found in five areas--near 181-BC, near 107-KW, near the downstream end of the 100-K trench, near the 100-N effluent crib, and at Hanford, approximately between river miles 362 and 364.

Total beta and tritium concentrations found in samples taken from the above areas are shown in Table IV. The tritium data indicate sources of Hanford origin at locations 3, 4, and 5, and suggest possible sources of Hanford origin at locations 1 and 2. (Tritium concentrations in upstream grab samples averaged about 1900 and 840 pCi/l in 1969 and 1970, respectively, with a maximum of 4000 pCi/l.) Since the tritium concentration in spring samples near Hanford (i.e., locations 6 through 10) is not noticeably different from river concentrations, those springs are believed not to contain radioactivity of Hanford origin.

Of the total beta concentrations shown in Table IV, only those found at locations 4 and 5 are believed to be positive indicators of radioactivity of Hanford origin. The one at location 4 was assumed to be positive only because of its location and its tritium concentration. Since locations 6 through 10 are fed by a common groundwater source and since measurements at such low concentrations are not very accurate, the apparently greater total beta concentrations at locations 9 and 10 are assumed not to be valid.

Radioactivity in riverbank springs is insignificant in relation to public use of the river, except for the 100-N springs, location 5. Major radionuclides at that location are: ^{3}H, ^{32}P, ^{51}Cr, ^{90}Sr, ^{99}Mo, ^{131}I, and ^{133}I.[12] In 1969 ^{90}Sr, ^{131}I, and ^{133}I accounted for about 2, 5, and 85 percent, respectively, of the "total beta" activity in the 100-N springs. (^{51}Cr, a gamma emitter, and

^3H, whose beta energy is extremely low, are assumed not to contribute to the "total beta" activity. Nor, by comparison to the other radionuclides, are they significant in terms of their potential dose contribution.) At the "total beta" concentration (2900 pCi/l) found in the single sample on 12/16/70, ^{90}Sr, ^{131}I, and ^{133}I concentrations are estimated at 0.2, 0.5, and 2.5 times their respective Concentration Guides for individuals in uncontrolled areas.

Table IV

Total Beta And Tritium Concentration In Riverbank Springs

Location	Columbia River Mile	Date	Concentration (pCi/l) Total Beta*	Tritium	Remarks
1	384.6	12/16/70	60	5,200	Upstream from 181-BC
2	384.6	12/16/70	<40	2,900	Upstream from 181-BC
3	382.0	12/16/70	70	15,000	Below 107-KW
4	380.9	11/30/70	260	12,000	Below K Trench
5	379.5	12/16/70	2,900	54,000	100-N Springs**
6	363.6	1/26/71	70	480	These are four of about twenty springs along the plant shore of the Hanford Slough
7	363.4	1/26/71	70	800	
8	363.3	1/26/71	60	960	
9	362.9	1/26/71	200	1,100	
10	361.9	1/25/71	<150	950	Hanford Ferry Landing
		1/26/71	60	830	

* *Total Beta is calculated as* ^{106}Ru-^{106}Rh.

** *See discussion, page 37.*

<u>Exposure Rates At The Surface Of The River</u>

During the monthly shoreline surveys, exposure rate measurements are made while traveling by boat from one shoreline location to the next. Although single measurements are of questionable accuracy, due to the difficulty of using 40-liter ionization chambers in a moving boat, several such measurements viewed together provide a fair estimate of the average exposure rate over a given stretch of the river. Such measurements have shown "river surface" exposure rate averages from about 25 to 50 μR/hr from 100-F to 100-K with KE operating. Exposure rates of about 10 mR/hr can be found directly above the KE effluent plume, but the plume quickly disperses, greatly reducing exposure rates in a very short distance. With no reactors operating, average exposure rates of about 15 to 25 μR/hr have been observed over this portion of the river, some of this undoubtedly being direct radiation from reactor and other facilities. Exposure rates between 100-F and Richland with no reactors operating have appeared to average about 10 to 15 μR/hr. River surface exposure rates are generally a factor of two or more below the adjacent shoreline exposure rates (Table II), which are higher than the average land surface exposure rates away from the river (Table VII), except at retired waste disposal sites.

Immersion Exposure Rates In The Columbia River

Exposure rates in the river were routinely determined from a cluster of pencil chambers contained within submerged plastic bottles until July 1970, at which time they were replaced by thermoluminescent dosimeters (TLD). As shown in Table V, the location of immersion exposure measurements has changed from time to time, the most recent change occurring in July 1970. These changes, both in detector type and location, make difficult the observation of long-term trends. The occasional loss of detectors during high river flow rates has also complicated the measurement and evaluation of immersion exposure rates. It is for this reason that data for May through July are excluded from the table. The change to TLD detectors, assumed to be considerably more accurate than the pencil chambers, has created an apparent decrease in immersion exposure rates (cf 1970 pencil chamber and TLD data at Vernita and Richland). This discrepancy probably results in part from the overresponse of the pencil chambers to low energy gammas or x-rays and to the low energy cutoff of the TLD at about 150 keV. The greatest cause of the discrepancy may well be abnormal discharge of the pencil chambers when subjected to mechanical vibration by the river's turbulence.[13] Whatever the cause, TLD's are believed to provide data more closely related to whole-body exposure.

Table VI shows average immersion exposure rates estimated for use in calculating dose to swimmers and water-skiers. These estimates are based on the 1970 TLD data for two reasons. First, as discussed above, TLD data should be more accurate than pencil chamber data. Second, reactor operations were more typical during the last half of 1970, when TLD's were being used, than early in the year when the reactors were shut down for an extended period.

Table V

Summary Of Routine Immersion Measurements
In The Columbia River - 1967 Through 1970

Averages Of Weekly Immersion Exposure Rates*
(μR/hr)

Location	Pencil Chambers 1967	1968	1969	1970	TLD's 1970
Vernita**	25	21	29	18(Jan-April)	5(Nov-Dec)
100-K Barge					330(Oct-Dec)
100-D Far Shore				50(Jan-March)	Discontinued
D Island					100(Aug-Dec)
100-F Plant Shore		260†	270	150(Jan-April)	Discontinued
100-F Barge					28(Oct-Dec)
Hanford	140	120††		63(Jan-April)	Discontinued
Ringold	96	75	88	46(Jan-April)	Discontinued
Richland	100	79	110	120(Jan-April)	18(Aug-Dec)

* *Data from May through July are excluded due to problems caused by high flow rates. Measurements were made with submerged pencil chambers through June, 1970. Thereafter, measurements were made with TLD.*

** *Surveys were made near Vernita Bridge (plant shore), except from July, 1968 to December, 1969 when made at Priest Rapids Dam gauge station.*

† *Data only from August through December.*

†† *Data only for January through April.*

Table VI

Immersion Exposure Rates Used In
Estimation Of Dose To Swimmers And Water-Skiers

Location		Estimated Exposure Rate (μR/hr)
Vernita to Coyote Rapids (entire river)		5*
Coyote Rapids to D Island	Far Shore	5*
	Remainder	65**
D Island to 100-F (entire river)		40
100-F to Richland (entire river)		20

* *Assumed to be the normal background immersion exposure rate.*

** *Although the immersion exposure rate in the effluent plume is several times this value (see 100-K Barge and D Island data in Table V), it is doubtful that the average exposure rate for a swimmer, water-skier, or fisherman would exceed this.*

External Radiation On Plant

External radiation on the Hanford plant comes from several sources. Radionuclides in the river contribute to the exposure of persons along the shoreline* and at other locations in view of the river. Effluent vapors from 107 Basins and possibly from disposal trenches contribute to exposure rates near operating reactors. Cribs and burial grounds, both active and retired, and abandoned and standby reactor facilities contribute to external radiation near the 100 Areas. Soil contaminated by effluent system leakage in the 100 Areas, large expanses of soil slightly contaminated through the years by air-borne radioactive material, and roads and railroads occasionally contaminated during transportation of radioactive material all contribute slightly to external radiation on plant from Vernita downstream. Numerous surveys have been conducted to determine the nature and extent of these sources.

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* *Shoreline exposure is discussed separately on page 37.*

In September and October, 1970, a strip of land one half to one mile wide along the plant shore from Vernita to Hanford, a distance of 22 miles (excluding the 100 Areas), was surveyed on foot. This survey, whose purpose was to locate unknown sources of radiation beyond and between the 100 Areas, was performed with GM survey instruments having thin-walled detectors held near the ground. Since a complete survey of so large an area was impractical, surveyors walked random zigzag patterns at their discretion in order to survey those areas intuitively felt (by the surveyors) most likely to contain radioactivity of Hanford origin. GM instrument readings away from the 100 Areas seldom reached values twice those obtained between Vernita and 100-BC, a region assumed to be free of measurable radioactivity of Hanford origin. However, somewhat higher exposure rates do exist just outside the present 100 Area fences, especially near the 100-K and 100-N trenches, as discussed under "Radioactivity In And Around The 100 Areas" beginning on page 26. Only three significant sources, discussed under "Radioactive Owl Pellets" on page 68, were found away from 100 Area disposal sites.

In June 1970 and January 1971, special road monitoring surveys of all major and minor roads and of many trails within about a mile of the river were performed from 100-F to Vernita. The road monitor utilizes a bioplastic scintillation detector attached to the front end of a truck and positioned about 2 feet above the road surface.[14] Due to its nonuniform energy response, the instrument does not accurately indicate exposure rate (μR/hr), and normally is used only for locating contamination on roadways. However, for this study the road monitor was used for a quantitative comparison of 100 Area exposure rates with normal background exposure rates. The road monitor was calibrated with ^{226}Ra, and the assumption was made that measured gamma energies would not be sufficiently different from those of ^{226}Ra to introduce significant errors into this comparison.

Most of the road surveys were performed in June 1970. The remainder, in the area from 100-BC to Vernita and the areas immediately surrounding 100-DDR and 100-BC, were performed in January 1971. Check source measurements and measurements made at the same location during the two surveys indicated that the road monitor response was about 20 percent higher for the same exposure rate in January 1971 than in June 1970. However, this difference is of little importance, since these surveys were intended merely to identify those areas having radiation levels measurably greater than the general background. As measured by the road monitor, the general background in the vicinity of the 100 Areas seems to range from about 6 to 10 μR/hr, essentially the same range as measured by TLD at offsite locations (Table VII). Measured exposure rates of 12 μR/hr and greater are believed definitely to result from sources of Hanford origin. Figures 3-17 show locations where such exposure rates were found. No attempt has been made to pinpoint the source or to define the extent of these unusual radiation levels, except in a few instances involving spotty contamination on the roadway itself. The real value gained from these surveys is the knowledge that, as measured along roads, exposure rates throughout most of the observed area are not measurably different from normal background.

Surveys are performed annually along all plant railroad tracks lying outside of exclusion area fences. The surveys are performed with the "road monitor" system, as described on page 56, mounted on a motorcar. The last survey, performed in May 1970, detected no contamination in the vicinity of the 100 Areas.

Control plots, areas measuring 10 feet square, are periodically surveyed with GM survey instruments for deposited radioactive material. In June 1970, a special survey was performed of 38 control plots in and near the 100 Areas. At only four of these control plots, located at the 100-K and 100-N reactor areas, were radiation levels noticeably different from background radiation levels. At three of these the measured exposure rate was about twice background, while at one location the measured exposure rate was about five times background.

Surveys of the types mentioned above are supplemented by semiannual aerial surveys conducted at an altitude of 500 feet using a 3 inch by 5 inch NaI scintillation detector.[14] One flight pattern begins at Vernita Bridge, upstream from the 100 Areas, and continues down the center of the river to McNary Dam. Due to its extreme sensitivity, this instrument "sees" the 100

Areas (even the abandoned ones), and sees contamination on the shoreline and islands, as well as that in the river itself. Evidence of this sensitivity was obtained in late 1970, at a time when neither KE nor N was operating, when the instrument's response increased significantly over an island between 100-D and 100-H Areas. A thorough ground survey made yet that day failed to detect anything unusual, the source of the aerial monitor's increase probably being attributable to accumulation of a slight amount of contamination on the large shallow land mass at the upper end of the island. Such aerial surveys tend to confirm the belief that no significant source of radioactivity lies outside the 100 Areas or their immediate vicinity.

Probably the most meaningful measurements of external radiation on plant were those obtained from thermoluminescent dosimeters (pencil chambers prior to July 1970) at several locations from Vernita (Midway prior to July 1970) to the 700 Area in Richland. Figure 24 shows the exposure rates measured over the period 1968-1970. No data were collected at Midway during 1969. Measurements at 100-B Area were discontinued in July 1970, while measurements at Hanford were discontinued during the period July 1969 through June 1970. The decrease in exposure rates beginning in July 1970 is assumed to be only an apparent decrease caused by the change at that time from pencil chambers to TLD. (See discussion under "Immersion Exposure Rates In The Columbia River" on page 53.) The TLD data obtained since July 1970 are believed to be more accurate than those obtained previously with pencil chambers. In order that these measurements will be more representative of the general exposure rates available to the public (rather than higher, localized exposure rates within the 100 Areas), the measurement points at 100-B, 100-K, 100-D, and 100-F are located near the original area perimeter fence entrances, several hundred yards from the nearest significant source of exposure. Average exposure rates measured by TLD both onsite and offsite during the last half of 1970 are shown in Table VII. Probably the most important observation to be made from these data is the slight difference between exposure rates measured at areas where little radioactivity of Hanford origin should exist and, at the other extreme, 100-K Area, an operating reactor site.

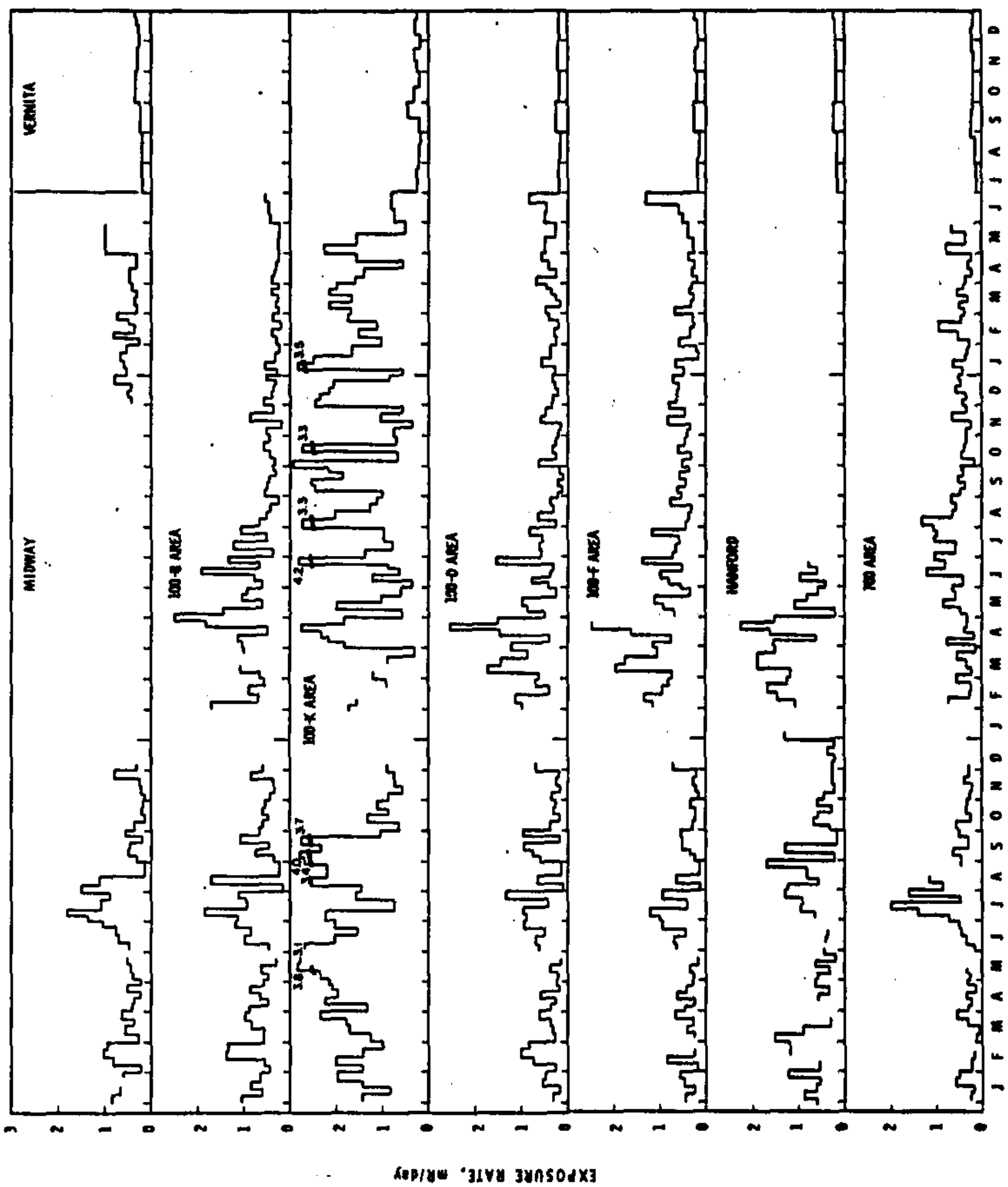

Figure 24. External Radiation On Plant

Table VII

Typical Land Surface Background Exposure Rates*

July To December, 1970

Location	Average Exposure Rate mR/day	μR/hr
Vernita**	0.22	9.2
100-K Area	0.27	11.
100-N Area	0.23	9.6
100-D Area	0.17	7.1
100-F Area	0.17	7.1
Hanford	0.16	6.7
Ringold	0.16	6.7
Byers Landing	0.17	7.1
700 Area	0.13	5.4
Pasco	0.18	7.5
Kennewick	0.15	6.3
McNary Dam	0.20	8.3
Wahluke Watermaster	0.18	7.5
Wahluke #2	0.20	8.3
Berg Ranch	0.18	7.5
Eltopia	0.20	8.3
Benton City	0.18	7.5
Walla Walla	0.16	6.7

* *Measured by TLD.*

** *There is some indication that KE effluent vapors have contributed to the measured exposure rate at this location.*

Radioactivity In Fish

Since fishing is expected to be one of the greatest recreational activities on the river, a limited study of ^{32}P and ^{65}Zn concentrations in whitefish was conducted from May through November 1970. The study was made on whitefish since, as pointed out by Wilson and Essig,[15] "Whitefish are the sports fish that usually contain the greatest concentrations of radioactive materials." The purpose of the study was to compare concentrations in fish taken at about the same time from three different locations--100-K to White Bluffs, White Bluffs to Ringold, and Ringold to Richland. As expected, there was no significant reduction in concentration with downstream distance from the reactors (Figure 25). Furthermore, a comparison with past data (Figures 26 and 27) shows, on a concentration basis, that fish taken near the reactors in 1970 constitute a smaller source of exposure than fish taken below Ringold previously.

Radioactivity In Gamebirds And Game

Waterfowl and other gamebirds taken on or near the river downstream from the reactors may acquire ^{32}P, ^{65}Zn, and other radionuclides from ingesting insects, algae, vegetation, and water containing these radionuclides. The concentration of radionuclides at the time gamebirds are eaten is dependent upon the bird species, the geographical location of the birds, their feeding habits, and the elapsed time between the bird's being killed and eaten.

Average concentrations of ^{32}P and ^{65}Zn in muscle (the edible portion) of major gamebird species collected during the 1968, 1969, and 1970 hunting seasons are shown in Table VIII. For all species except goose, the concentrations of both radionuclides are distinctly lower in 1970 than in earlier years. This probably reflects the shutdown of KW reactor on February 1, 1970, and also reflects the extended shutdowns of KE reactor during the year.

Gamebirds generally are not plentiful near the reactor areas. Most of the results included in the averages of Table VIII were from analysis of birds taken downstream from 100-F--more by necessity than intent. While such birds might contain less radioactivity than birds taken near 100-K and 100-N Areas, they would more nearly represent the typical gamebird that would be available to hunters if the river were opened. The average dose that could be received from immediate consumption of these gamebirds is shown in Table IX.

On several occasions in 1969 and early 1970, gamebirds containing considerably higher than average concentrations were collected on or near reactor liquid waste disposal trenches. The most significant of these was a duck collected from the 100-N Trench in March 1970. Immediate consumption of one-half pound of this duck by an adult would have resulted in a bone dose of 6 rem and a whole-body dose of 0.25 rem, compared with yearly guidelines of

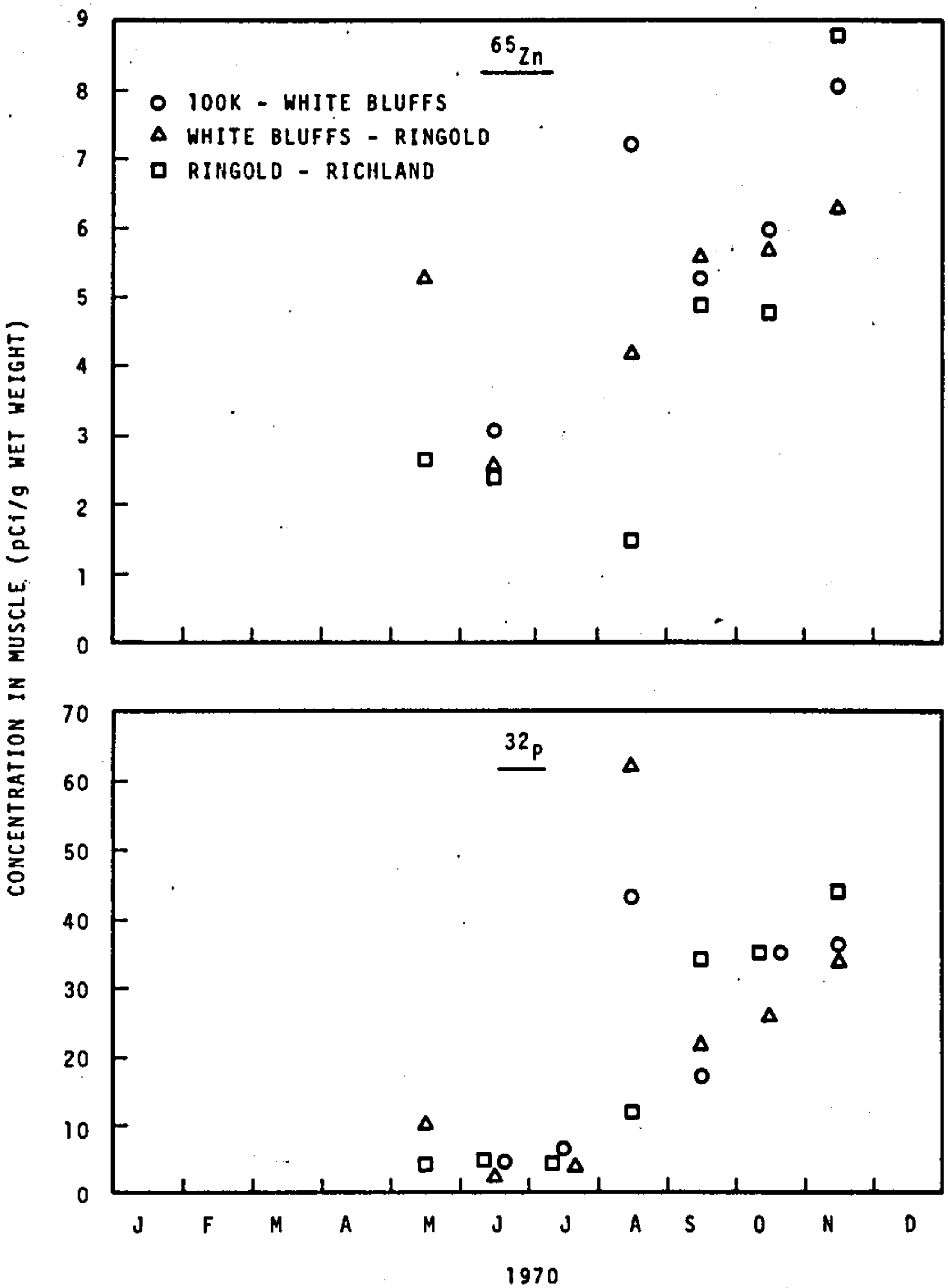

Figure 25. Radionuclides In Whitefish

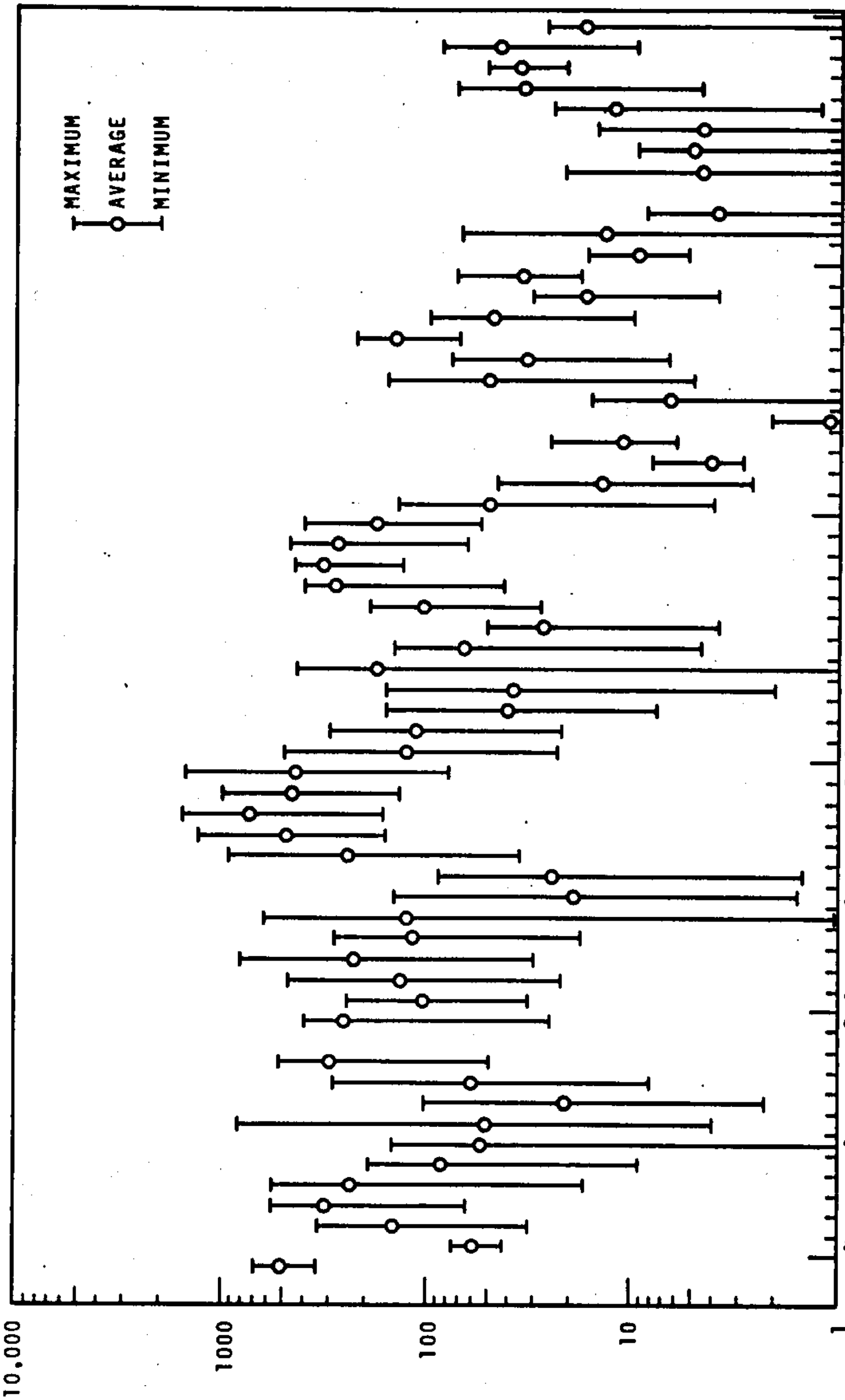

Figure 26. Monthly Average ^{32}P Concentrations In Flesh Of Whitefish Caught In The Columbia River Between Ringold and Richland (pCi/g, Wet Weight)

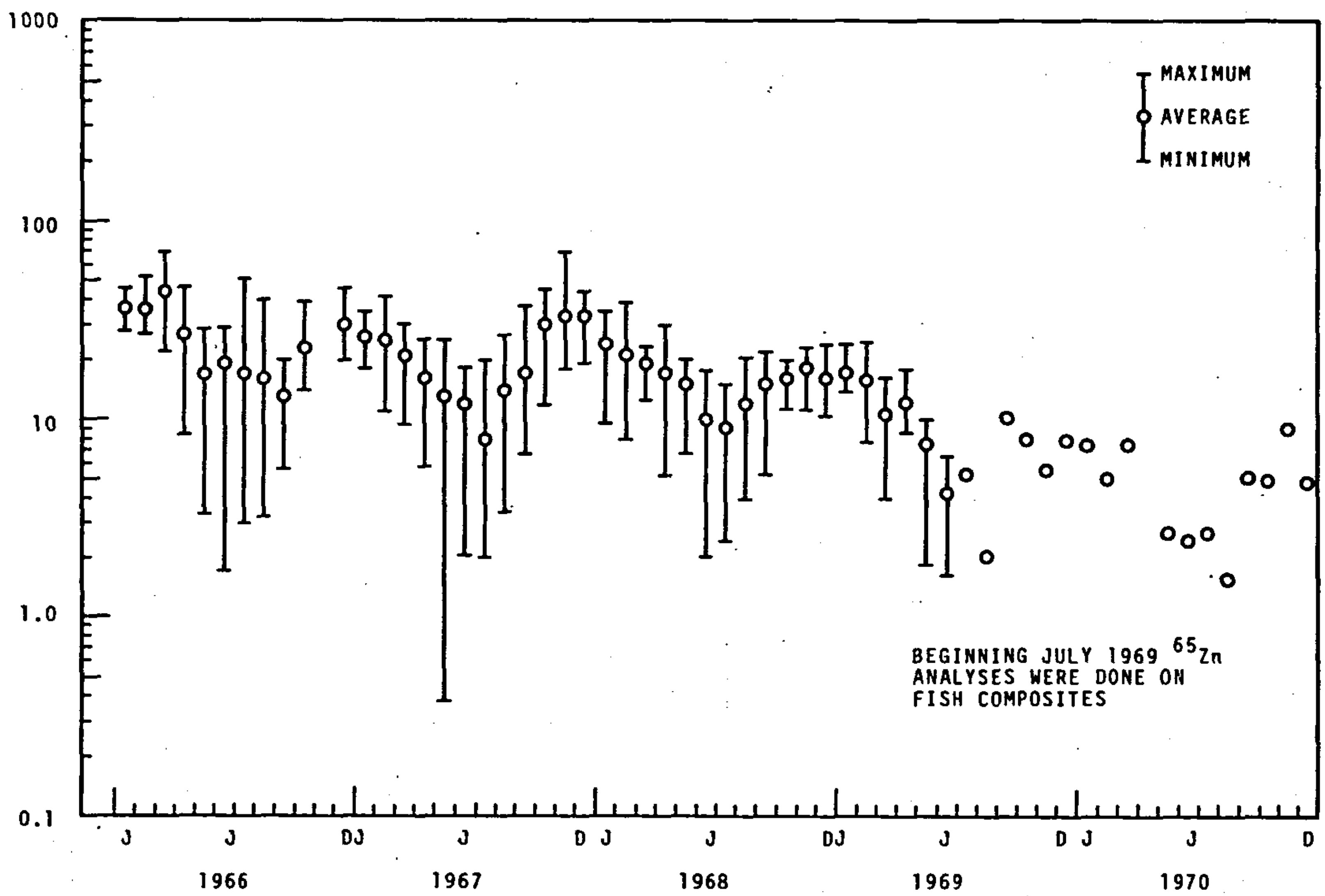

Figure 27. Monthly Average ^{65}Zn Concentrations In Flesh Of Whitefish Caught In The Columbia River Between Ringold and Richland (pCi/g, Wet Weight)

Table VIII

^{32}P And ^{65}Zn In Gamebirds

Species	Average Concentration In Muscle (pCi/g)					
	^{32}P			^{65}Zn		
	1968	1969	1970	1968	1969	1970
Duck	53. (59)*	72. (46)	9.6(79)	3.3(59)	5.1(46)	1.2(79)
Goose	1.4(19)	3.6(12)	14. (17)	1.5(19)	8.3(12)	5.3(17)
Quail	41. (35)	19. (18)	3.6(21)	3.5(35)	2.0(18)	1.0(21)
Pheasant	10. (21)	18. (18)	3.0(28)	4.9(21)	2.7(18)	2.3(28)

* *The number of each species sampled is shown in parentheses.*

Table IX

Dose From Ingesting One Half Pound Of "Average" Gamebirds Shown In Table VIII

Species	Dose (mrem) Received From					
	^{32}P*			^{65}Zn**		
	1968	1969	1970	1968	1969	1970
Duck	2.3	3.1	0.4	0.005	0.007	0.002
Goose	0.06	0.2	0.6	0.002	0.01	0.008
Quail	1.8	0.8	0.2	0.005	0.003	0.001
Pheasant	0.4	0.8	0.1	0.007	0.004	0.003

* *Bone dose if eaten immediately (i.e., before significant decay of ^{32}P)*

** *Whole-body dose.*

1.5 and 0.5 rem, respectively, established by the Federal Radiation Council. Radioactive decay during any delays between the bird's feeding and its being eaten would reduce the radionuclide concentration and, consequently, the dose below these values. The consumption of such a bird by any member of the public is considered to have been unlikely in view of the fact that very few birds (out of over 200,000 in the area) would be likely to spend sufficient time on the trenches near the reactor areas to accumulate such large amounts of radioactive material. In addition, such situations are corrected as they are discovered. The K and N Trenches were screened in the spring of 1970 to prevent further access by waterfowl.

Since ingestion of deer and small game has not been considered a source of internal exposure to the public, no routine sampling of these animals has been performed. Deer have been purposely sampled on only a few occasions, but many deer road-killed within the Hanford reservation have been analyzed through the years. In 1970, three deer were killed within about a mile of the Columbia River. The first, on March 26, 1970, was shot near the 100-N Trench as part of the environmental evaluations program. On April 7, 1970, another deer was shot north of Gable Mountain, again as a special sample for the environmental evaluations program. On December 3, 1970, a road-killed deer was obtained about one mile northwest of the Hanford Townsite. The major radionuclides observed in the muscle of one or more of these deer are listed in Table X. For comparison, the maximum concentration of four of these radionuclides found in beef cattle raised on irrigated pasture downstream from Ringold during 1970 are also shown in the table. (The other radionuclides found in deer were not found in these beef cattle.) Although the deer probably fed in the vicinity of the 100 and 200 Areas, the concentrations of radionuclides found in them did not differ significantly from concentrations measured in beef cattle raised on river-irrigated land downstream from the Hanford project.

Doses from the ingestion of 2 kg/yr of this deer meat are shown in Table XI. By comparison, Radiation Protection Guides of 1.5, 0.5, and 1.5 rem/yr have been established for individuals by the Federal Radiation Council for bone, whole body, and GI Tract, respectively.

Table X

Major Radionuclides In Deer Muscle

Location/Date When Killed	Average Concentration (pCi/g)						
	^{32}P	Sr*	^{65}Zn	^{137}Cs	^{60}Co	^{106}Ru	$^{144}Ce-Pr$
Near 100-N Trench/ 3-26-70	<15.	NA	9.6	0.25	1.0	<0.35**	<0.82
North of Gable Mountain/4-7-70	< 6.8	0.054	1.0	<0.05	<0.04	--	<0.53
One Mile Northwest of Hanford Town-site/12-3-70	--	0.15	0.8	0.09	--	--	--
Beef Downstream From Ringold	31.		4.6	0.04		0.1	

* *Total strontium, presumed to be mostly ^{90}Sr.*
** *Liver concentration. ^{106}Ru not found in muscle.*
NA *Not analyzed.*

Table XI

Dose From Ingesting Two Kilograms* Per Year Of Meat Containing Radionuclide Concentrations Listed In Table X

Location/Date When Killed	Dose (mrem) Received By		
	Bone**	Whole Body†	GI Tract (LLI)††
Near 100-N Trench/ 3-26-70	<6.	0.15	<0.6
North of Gable Mountain/4-7-70	<5.4	<0.21	<0.2
One Mile Northwest of Hanford Town-site/12-3-70	7.5	0.5	--

* *An annual "typical" intake of 2 kilograms, as used by the Bureau of Radiological Health,(16) was assumed for this table. Note, however, that the SUMMARY dose estimate in BNWL-B-71 Part I conservatively assumes an annual intake of 50 pounds, believed to be more representative of a "maximum individual's" intake.*
** *Calculated as $^{32}P+^{90}Sr$, except for 3-26-70 deer, for which Sr data are not available. Assumes no decay of ^{32}P.*
† *Calculated at $^{65}Zn+^{137}Cs+^{90}Sr$.*
†† *Calculated as ^{60}Co, ^{106}Ru, and $^{144}Ce-Pr$.*

Radioactive Owl Pellets

While performing a land survey between 100-K and 100-BC, a small spot of low-level contamination was found in the abandoned Hanford Irrigation Project pumping station (Figure 5). At first the contamination was believed associated with the numerous swallow nests in the building, since the use of contaminated mud by swallows for building nests has been observed many times in the 100 Areas. Later findings, however, suggest that the contamination originated from pellets regurgitated by a great horned owl seen that day and subsequently in the Hanford Irrigation Project building. The major radionuclides identified in this sample were ^{60}Co, ^{65}Zn, ^{95}Zr-Nb, ^{106}Ru-Rh, and ^{144}Ce-Pr.

Several days later, during the land survey from 100-D to 100-H, a great horned owl pellet measuring approximately 200 mrad/hr near the surface was found at the base of a tree in a grove upstream from 100-H (Figure 11). The following day, a pellet containing deer mouse bones measuring less than 1 mrad/hr near the surface was found near 100-F Area at the base of a tree in a grove known to be inhabited by a pair of great horned owls (Figure 17). Radionuclide concentrations measured in these samples are listed in Table XII.

Later in the year, after the deciduous trees had shed their leaves, an "owl pellet" survey was made of all areas within a mile of the river, from Hanford to Vernita. No additional radioactive pellets were found. There seems to be no way of identifying the source of these radionuclides, since efforts to trap mice near potential sources have been unsuccessful and since the identified radionuclides are characteristic of numerous burial grounds, trenches, and other disposal sites. Since the great horned owl may range several miles for food, since the great horned owl population at Hanford is small, and since the survey revealed no additional pellets, the significance of radioactive owl pellets seems minor from the standpoint of this "opening the river" study.

Contamination Of Boats And Other Equipment

The possibility that boats, water skis, fishing tackle, and other equipment placed in the river might become contaminated by dissolved or suspended

Table XII

Owl Pellet Concentrations (μCi/g)

	Above 100-H	Near 100-F
^{32}P	Not Significant	$1.2 \times 10^{-5} \pm 9.2 \times 10^{-6}$
^{54}Mn	10.2	
^{58}Co	Trace	
^{59}Fe	1.5±0.31	
^{60}Co	25.5	1.1×10^{-1}
^{90}Sr	0.64	2.6×10^{-2}
^{95}Zr-Nb	4.5	
^{106}Ru	1.8±1.7	
^{124}Sb	0.45±0.26	
^{137}Cs	0.17±0.11	
^{141}Ce	0.30±0.29	
^{144}Ce-Pr	6.0±2.5	
^{154}Eu	Trace	
^{155}Eu	Trace	
^{233}Pa	Trace	
^{239}Pu	0.0085	$<1.1 \times 10^{-5}$

radionuclides was considered. The answer to this question was obtained by measuring the contamination on AEC equipment frequently used in the project stretch of the river and on a barge moored (100-F) in the river.

Surveys of fishing equipment (line, lures, etc.) used in the 100-K to White Bluffs section of the river have shown no detectable contamination. Barely detectable but insignificant contamination (less than 150 c/m above background with a thin-walled GM detector) has been observed along the waterline of the environmental evaluations fishing boat immediately after use in the 100-K to White Bluffs section of the river. The contamination seemed to be directly related to the amount of foam, algae, and other debris in the water. Contamination measurements made through the hull of the barge moored in the river at 100-F suggested that contamination on the barge was no greater than on the fishing boat.

It must be concluded from these surveys that contamination of boats, water skis, fishing tackle, and other equipment used in the river is insignificant.

Radiological Aspects Of Dredging A Navigation Channel

Proposals for dredging a navigation channel in the Columbia River through the Hanford project have been made for several years. Detailed charts of the locations and depths of material to be removed have been drawn by the U. S. Corps of Engineers. Such a channel could be constructed for commercial navigation without opening the Hanford stretch of the river to the general public. However, evaluation of the potential radiological impact on the public of dredging operations and large piles of spoil containing low concentrations of radioactive material is a logical part of this present study.

Potential sources of radiation exposure to the public from dredging include:

1. External exposure from large masses of spoil.
2. Internal exposure from inhalation of airborne spoil.
3. Internal exposure from ingestion of milk, meat, and crops grown on spoil used as fill.
4. Internal exposure from ingestion of water derived from the Columbia River during dredging.

In addition, there could be some radiation exposure to the workers during the dredging operations, either directly from the spoil or indirectly from contaminated equipment. These exposures would not be significantly greater than those evaluated below for the general public. A few spot measurements made during dredging operations would confirm this study's estimates of radioactive material concentrations in the river-bottom material.

Concentrations Of Radionuclides In River-Bottom Materials

Behavior of radionuclides in Columbia River water and sediments has been the subject of several special studies.[10,17,18] Nelson[18] reported concentrations of several radionuclides in coarse sand and gravel sampled in the vicinity of Richland during a period (November 1964) when all nine production reactors were still in operation. A weighted average of the concentration measured with depth to 14 inches yielded the following: 2.6 pCi ^{46}Sc/g, 53 pCi ^{51}Cr/g, 3.7 pCi ^{54}Mn/g, 4.0 pCi ^{60}Co/g, and 45 pCi ^{65}Zn/g. The majority of the radionuclides were found in finely divided particles (diameter less than 74 μ) in the top 3 inches of material. Some of this upper layer is composed of biological material (living or dead) which has sorbed radionuclides from the water. Watson and Templeton[19] have reported in situ radiation doses measured with TLD's placed adjacent to biota growing on rocks on the bottom of the river. They reported that the doses measured in the vicinity of Richland were somewhat higher than those measured in the immediate vicinity of the reactor outfalls, perhaps because of slower moving water in the McNary Dam pool at Richland.

In any event it appears reasonable to assume that the average concentrations in river-bottom material in the vicinity of the reactors would be no higher than that given above for the Richland location. This is especially true since the material to be dredged includes larger rocks and boulders whose interiors are free of unnatural radioactivity.

The shutdown of several production reactors since November, 1964, has been responsible for a lowering of radionuclide concentrations in the river and hence in the sediments. The quantities of radionuclides present in the bottom material have decreased because of radioactive decay of ^{46}Sc, ^{51}Cr, and to some extent the other three nuclides of interest (^{54}Mn, ^{60}Co, and ^{65}Zn). The annual spring runoff scours material from the bottom, especially in the swifter-moving water, and moves it farther downstream, thus lowering the concentrations of both short- and long-lived nuclides in the vicinity of the reactors.[10]

With only N and KE reactors operating, these processes lower the average concentrations in the material to be dredged to values probably less than one third of those reported above. The concentrations of the nuclides at the time of dredging are then approximately 0.9 pCi ^{46}Sc/g, 18 pCi ^{51}Cr/g, 1.2 pCi ^{54}Mn/g, 1.3 pCi ^{60}Co/g, and 15 pCi ^{65}Zn/g. (If only the N reactor were operating, the concentrations would be still lower, depending upon the time since operation of KE.)

During the first year after dredging, these concentrations would decrease by radioactive decay so that the average concentration present over the first year would be:

$$\overline{C} = \frac{C(1-e^{-\lambda t})}{\lambda t}$$

Where $\overline{C}$ = average concentration over time t
C = concentration at time t = 0
λ = decay constant in units of years^{-1}
t = years

Applying the decay correction to the concentrations given previously for time of dredging, the values of ($\overline{C}$) become: 0.3 pCi ^{46}Sc/g, 2.0 pCi ^{51}Cr/g, 0.8 pCi ^{54}Mn/g, 1.2 pCi ^{60}Co/g, and 9.4 pCi ^{65}Zn/g. These latter values are the ones employed throughout the subsequent calculations of potential radiation dose from exposure to the spoil.

External Dose From The Spoil

The maximum possible exposure rate in the vicinity of a large mass of bottom material is conservatively estimated as one half the exposure rate at the center of an infinite volume of material. Since we are just interested in the external whole-body dose, only gamma radiation need to considered. The exposure rate can be calculated as follows for each radionuclide:

$$\overline{DR} = 1.065\times10^{-3}\ \overline{C}\ \overline{E}_\gamma$$

Where $\overline{DR}$ = annual average exposure rate in mR/hr
$\overline{C}$ = annual average concentration of the nuclides in the spoil in pCi/g
$\overline{E}_\gamma$ = average gamma energy in MeV/dis.

The exposure rate contribution of each of the five radionuclides must be calculated separately and added together. Annual dose is estimated by multiplying exposure rate by the annual exposure time in hours.

The average exposure rate during the first year of exposure near a large mass of bottom materials is calculated to be 0.010 mR/hr. At this exposure rate, the annual dose to an avid sportsman spending 100 hours on or near a spoil pile would be only 1 mrem.

If the spoil were to be used for fill dirt, either for farm land or home construction, the exposure rate at 3 feet above a uniformly contaminated plane surface would be about 0.005 mR/hr resulting in a total whole-body dose of 44 mrem during the first year.

Internal Dose From Inhalation Of Airborne Material

Persons living near the spoil pile or near land covered by spoil used as fill, could inhale airborne material containing low concentrations of radionuclides. Measurements of dust loading in the local atmosphere have been made at Richland by personnel of Hanford Environmental Health Foundation (HEHF) since October, 1969[20] and at several locations in the vicinity of Hanford since July, 1970 by personnel of the Environmental Evaluations group of BNW.[21] Both sets of measurements yield a long-term average dust load of approximately 10^{-4} g/m^3 of air.

The maximum inhalation of radionuclides can be estimated by assuming continuous exposure to airborne material contaminated to concentrations of the five radionuclides previously calculated. In a year's time, an adult breathing 20 m^3/day of air containing 10^{-4} g/m^3 of dust would inhale a total of only 0.73 grams of material. This corresponds to inhalation of the following quantities of radionuclides in that year: 0.2 pCi ^{46}Sc, 1.4 pCi ^{51}Cr, 0.6 pCi ^{54}Mn, 0.9 pCi ^{60}Co, and 6.8 pCi ^{65}Zn.

Radiation doses estimated for the principal radionuclide, ^{65}Zn, demonstrate the insignificance of inhaling such small quantities of this dust. Doses to the whole-body, bone, liver, GI-LLI (from soluble ^{65}Zn) and to the lung (from insoluble ^{65}Zn) would all be in the range of 10^{-5} to 10^{-3} mrem/yr. Addition of the other radionuclides would not increase these doses significantly.

Internal Dose From Ingestion Of Crops Raised On River-Bottom Material

If the material dredged from the Columbia River were used as land fill over a large area, it is possible that it could also be used as farm land. The potential radiation dose that could result from consumption of food crops, milk, and meat produced on such a farm was evaluated. Doses calculated for ^{65}Zn demonstrate the insignificance of this exposure pathway. An adult was assumed to consume 730 liters per year of milk, 80 kg per year of meat, and 260 kg per year of vegetables all produced on farms where the annual average ^{65}Zn concentration in soil was 9.4 pCi/g throughout the plow layer. The concentrations of ^{65}Zn at the time of human consumption were estimated to be 18 pCi/liter milk, 0.7 pCi/kg meat, and 9.6 pCi/kg of vegetables. No reduction was included for radioactive decay between harvest and consumption nor for dilution with products not produced on such fill.

The doses from ^{65}Zn to various organs resulting from ingestion of these foods produced during the first year after dredging were estimated to be 0.08 mrem to the whole body, 0.06 mrem to the bone, 0.2 mrem to the liver, and 0.2 mrem to the GI Tract. Doses to a four-year-old child were also evaluated assuming consumption of 365 liters per year of milk, 30 kg per year of meat, and 130 kg per year of vegetables. In addition, the values of the dose factors (mrem per pCi intake) for the child were reevaluated on the basis of the smaller values for his organ size and mass, and the shorter travel time of material through his GI Tract. The estimated doses received from consumption of the foods raised during the first year were 0.1, 0.08, 0.3, and 0.05 mrem to the whole body, bone, liver, and GI Tract, respectively. None of these doses would be increased to significant values by inclusion of the other four radionuclides present in the spoil.

Internal Dose From Ingestion Of Water Derived From The Columbia River During Dredging

During construction of cofferdams at Priest Rapids and Wanapum Dams, river turbidities of 100 to 200 ppm were observed intermittently downstream. Dredging operations, which will dislodge some river-bottom material, could result in similar concentrations over a two-year period, except for temporary work stoppages during high water or extremely cold weather. The impact on sanitary water drawn from the river was conservatively estimated by assuming that these suspended solids would reach the intake of the Richland and Pasco water plants. The concentration of suspended solids in finished water leaving these plants is not likely to exceed 2 ppm. Thus, the annual radionuclide intake by the average resident can be estimated as follows:

$$I(pCi/y) = 2\ (ppm) \times 10^{-3}\ (g/l/ppm) \times 680\ (l/y) \times \overline{C}\ (pCi/g)$$

Using the values of $\overline{C}$ given on page 72, the annual intake during the first year of dredging would be about: 0.4 pCi ^{46}Sc, 3 pCi ^{51}Cr, 1 pCi ^{54}Mn, 2 pCi ^{60}Co, and 13 pCi ^{65}Zn. The resulting internal (GI Tract) dose would be less than 0.001 mrem for the entire year.

Radiological Consequences Of Reactor Accidents

Persons on or along the Columbia River near the reactors would be subjected to potentially serious radiation exposure in the event of a reactor accident. This exposure potential has been examined, as described in this section.

The KE reactor has been shut down recently and its fuel has been discharged preparatory to placing the reactor in a standby condition. Therefore, potential exposure from postulated K reactor accidents has not been considered here.

Two postulated accidents for N reactor, the maximum credible accident (MCA) and the design basis accident (DBA), have been evaluated. Both of these accidents postulate the loss of coolant followed by melting of fuel and a release of fission products to the environs.

For people in boats on the river near N reactor, the potential modes of exposure considered were:

1. External exposure from being in or near the passing radioactive cloud.

2. Internal deposition from inhalation during passage of the radioactive cloud.

3. External exposure to direct radiation from released contamination moving downstream in the river.

4. Internal deposition from drinking contaminated river water.

Accident Description

The maximum credible accident[22] involves the loss of coolant to the reactor core and the failure of fuel containing 30% of the core fission product inventory. The fission product release and leak rate parameters are given in Tables XIII and XIV.

Extensive modifications of the reactor have been made since the reactor was built. Independent and redundant fuel oil supplies, fuel lines, emergency diesels and pumps, and emergency raw water lines have been added to the reactor. These and other changes should limit the severity of possible accidents to something less than the original MCA.[23,24] The design basis accident is now considered to be equivalent to a single tube melt. Blockage of coolant flow to several tubes would not be expected to cause melting of more than the highest power element or elements in a tube. On this basis, the melting of 3 elements in each of 6 tubes would be equivalent to melting all the elements in one tube. Flow blockage does not result in melting all the fuel elements in a tube because the combined cooling effects of the graphite cooling system and cooling from adjacent tubes keeps fuel in tubes in the fringes of the core below melting temperatures.[24]

The single tube equivalent melt accident is taken as the DBA. The parameters for the DBA are the same as for the MCA; however, much less material is released since the failed fuel contains only 0.1% of the fission product inventory.

Table XIII

Fission Product Release Parameters

Parameter	Noble Gases	Halogens	Volatile Solids	Others
Release Fraction From Failed Fuel	100%	50%	50%	1%
Plateout in Primary Piping	NONE	50%	70%	70%
Removal by Fog Spray	NONE	90%	90%	90%
Filter Removal	NONE	95%	99.95%	99.95%

NOTE: The percentage removed represents the fraction of the material in the atmosphere before the removal step was taken.

Table XIV

Leak Rate Parameters

Leakage From Confiner	-	-	-	200 cfm
Release From Stack	-	-	-	3800 cfm
Delay Time For Confiner Leakage	-	-	-	6 min
Delay Time For Stack Release	-	-	-	32.5 min

N Reactor Liquid Effluent System

N reactor has a recirculating, pressurized light water coolant system with a "feed and bleed" system to maintain coolant purity. The bleed water is discharged directly to a rock-filled crib located several hundred feet from the reactor. The discharged water contains activation products, and some fission products resulting from occasional fuel ruptures. When a fuel element rupture occurs, the water from that tube is valved to the crib along with the bleed water and some other streams, such as the graphite coolant system bleed, the fuel storage basin overflow, and some other minor streams.

In a major accident, one which calls for the emergency raw water system, the primary coolant is dumped to a covered quench tank. The quench tank contains about one half million gallons of cool water to condense the hot pressurized primary coolant. The emergency raw water coolant flowing through the reactor would soon fill the quench tank to its overflow level. The coolant water overflowing the quench tank would be routed to the crib at whatever flow rate is being used to cool the reactor. This water would be contaminated with both fission and activation products.

An overflow trench about one third mile long is necessary for crib overflow, since the capacity of the crib to absorb water is too low to absorb all the flow that would be required for a major accident. The contaminated water from the crib and overflow trench percolates into the ground and eventually is discharged to springs along the bank of the Columbia River.

The travel time from the crib to the riverbank springs has been analyzed for several nuclides for the N reactor groundwater system. Nuclide travel times have been determined for iodine, strontium, and cesium. Tests have shown that strontium and cesium have much larger travel times than iodine. Crews and Tillson[25] estimate the travel time for ^{131}I to be 9±1 days from the N crib to the Columbia River. This delay ensures that there would be no immediate hazard to the public from consuming or from being in or near contaminated river water.

Potential Exposures

There is no evacuation alarm system at N reactor capable of warning the public in case of an accident. Adequate warning systems installed to promptly warn individuals boating on the river or picnicking on the banks could minimize their exposure to radiation for the following reasons. If an accident occurs there would be a delay between the time of occurrence and the time that the plume of radionuclides escape from the confiner or from the stack. This time is at least 6 minutes for unfiltered leakage from penetrations in the building, such as steam vents, and it is more than 30 minutes until the start of release from the stack. Exposure of people at distances greater than 100 yards to gamma radiation from the plume of released fission products would begin with the release to the atmosphere. In the case of inhalation, travel of the radioactive cloud to reach an individual on the river would provide an additional time lag before exposure would occur.

The dose an individual might receive is dependent on a variety of factors, primarily on the time required for evacuation. Secondarily the dose depends on such things as atmospheric dispersion, fractionation of nuclides, and release rate from the confiner.

Wind direction is perhaps the most important factor in determining potential exposure of boaters on the river during an N reactor accident. Even if the wind is blowing in the general direction of the boater it is possible to minimize the exposure. Figure 28 shows the relationship between the wind speed and the minimum boat speed (relative to land) needed to get to B Area, H Area, and the river bend 4 1/2 miles downstream ahead of the radioactive cloud. For example, if the wind speed were 5 mph the boat would have to travel at an average speed of 5.8 mph (relative to land) to beat the cloud to H Area. The curves of Figure 28 are based on the assumption that the boat starts to move from a point adjacent to N Area at the start of the accident.

Dose calculations have been performed for the DBA and MCA for two cases:

1. A boat anchored 50 feet from shore at N Area, and
2. A boat passing through the cloud as it crosses the river 4 1/2 miles downstream from the reactor.

Parameters for the calculations are given in Table XV. Moderately stable atmospheric conditions with an invariant wind direction were used for both cases to maximize dose.

The results for the boat stationary in river, Case 1, are given in Table XVI. For the 10 m/sec wind speed very little dose is received for about

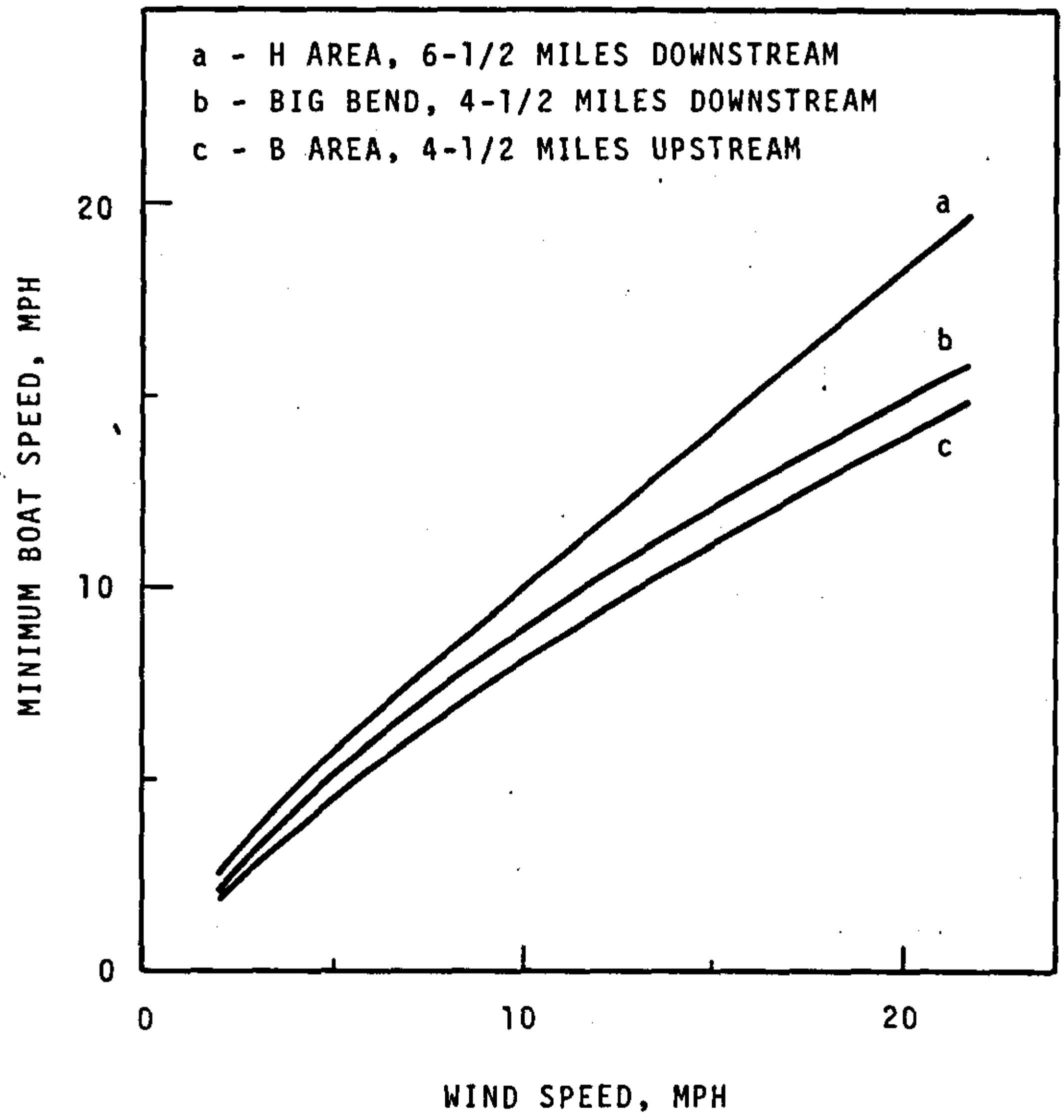

Figure 28. Minimum Boat Speed Necessary To Avoid Being Overtaken By Cloud

6.3 minutes (emission delay time + cloud travel time) and for the 1 m/sec wind speed little dose is received for about 9 minutes. However, as shown in the table, failure to evacuate promptly could result in large doses.

Table XV

Parameters For Dose Calculations

Parameters	Case 1	Case 2
Distance from release	550 feet	4 1/2 miles
Release height	Ground	Ground
Wind speed, m/sec	1 and 10	1 and 10
$\sigma_\theta \bar{u}$ (for Hanford Meteorological Model)	0.024	0.024
Wind direction	Toward River	Parallel to river
Boat speed (relative to land)	0	2 and 15 mph

Table XVI

Estimated Dose To Boaters Anchored On River Adjacent To N Reactor At Selected Time After A Major Accident

		Estimated Dose* During:			
		First 10 Minutes**		First 30 Minutes**	
Wind Speed	Organ of Interest	DBA†	MCA†	DBA†	MCA†
1 m/sec	Thyroid	5.6	1.7×10^3	83.	2.5×10^4
	Whole Body	7.8×10^{-3}	2.3	0.21	63.
10 m/sec	Thyroid	22.	6.4×10^3	320	9.6×10^4
	Whole Body	4.2×10^{-3}	1.3	0.11	33.

* *Dose in rem for thyroid, rad for whole body.*

** *No release occurs during first six minutes after shutdown.*

† *DBA - Design Basis Accident*
MCA - Maximum Credible Accident

The results of the second case are presented in Table XVII. The 2 mph boat speed corresponds to a drifting boat. The results indicate that no significant exposure would result in 4 1/2 miles downstream from a DBA. However, persons on a slow-moving boat may get a significant thyroid dose from an MCA at 4 1/2 miles.

Table XVII

Estimated Dose To Boaters Moving Away From N Reactor At Two Arbitrarily Selected Speeds After A Major Accident

Wind Speed	Organ of Interest	Estimated Dose* For Boat Traveling At: 2 mph** DBA†	2 mph** MCA†	15 mph** DBA†	15 mph** MCA†
1 m/sec	Thyroid	0.12	36.	2.1×10^{-2}	6.3
	Whole Body	1.4×10^{-2}	4.4	2.9×10^{-3}	0.86
10 m/sec	Thyroid	3.3×10^{-2}	9.5	5.5×10^{-3}	1.6
	Whole Body	1.6×10^{-3}	0.48	3.1×10^{-4}	9.2×10^{-2}

* *Dose in rem for thyroid, rad for whole body.*

** *mph - miles per hour.*

† *DBA - Design Basis Accident*
MCA - Maximum Credible Accident

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