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OAK RIDGE NATIONAL LABORATORY
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SUBJECT: GENERAL DESCRIPTION OF OAK RIDGE SITE AND SURROUNDING AREAS - HAZARDS EVALUATION, VOL. 2

TO: F. L. Culler

FROM: E. G. Struxness

ABSTRACT

Purposeful or accidental releases of radioactive material to the immediate environs of ORNL and surrounding areas have been examined. Evaluation of the consequences of releases requires rather detailed knowledge of the atmosphere, the hydrosphere, and the lithosphere. By various means the vulnerability of the area to concentrated radioactive fallout or to radioactive liquids released onto or into the terrain and water courses must be determined. Factual data are provided, and an attempt has been made to relate these to the control of radioactive contamination.

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1.0 CLINCH-TENNESSEE RIVER BASINS

1.1 Description

The Clinch River and its tributaries (Fig. 1) flow generally in a southwesterly direction and drain an area of 4413 sq mi in Tennessee and the extreme southwestern corner of Virginia. The Powell River, a principal tributary, roughly parallels the Clinch, joining the latter a short distance above Norris Dam. The Emory River, its second largest tributary, flows in a southeasterly direction and joins the Clinch River at Mile 4.4. The Clinch and Powell Rivers originate in the ridges of western Virginia near the Kentucky and West Virginia state boundary. From there to the Oak Ridge site the drainage area of 3343 sq mi has an elongated, fingerlike shape, the length being some 190 mi and average width about 18 mi.

The northwestern boundary of the basin is formed for the most part by the crests of the Cumberland Mountains, which range from about 2500 to more than 4000 ft above sea level. The southeastern boundary for the most part follows Clinch Mountain and Black Oak Ridge.

The terrain in the basin is characterized by a series of long ridges running more or less parallel to the Cumberland and Clinch Mountains. The tributaries of the Clinch River flow parallel to it for long distances before joining the river. Slopes along the principal ridges are frequently steep, but almost all the land at the lower elevations is rolling. Much of the basin, particularly on the steeper slopes, is covered by second-growth forests.

Other smaller tributaries between Norris Dam and the Oak Ridge Reservation are Coal, Hinds, Bullrun, and Beaver Creeks.

1.2 Rainfall

The average annual rainfall above the Oak Ridge Reservation is 47.2 in., based on data at 23 stations where records have been kept for 20 years or more. At five of these stations in the Clinch River Basin, where there are continuous precipitation records for 40 years or more, the average annual rainfall is 47.9 in. By way of comparison, the mean annual rainfall for the Tennessee Valley above Chattanooga for a 67-year period amounts to 50.8 in. At stations above Norris the average annual rainfall ranges from 41.6 in. in the extreme northeast to 54.2 in. in the southwest. Below Norris Dam average amounts range from 44.9 to 59.6 in./year. However, in East Tennessee daily rainfalls vary widely over small areas.

1.3 Stream Flow

Based on records available for several stations (Table 1), the average annual runoff computed for 1921-1932, considered typical of long-term conditions, amounts to 5270 cfs just above the outfall of White Oak Creek. This is equal to 21.4 in./year on the drainage area, or about 45% of the average rainfall. Table 2 gives maximum, mean, and minimum daily flows for the Clinch, Emory, and Tennessee Rivers, 1945-1951.

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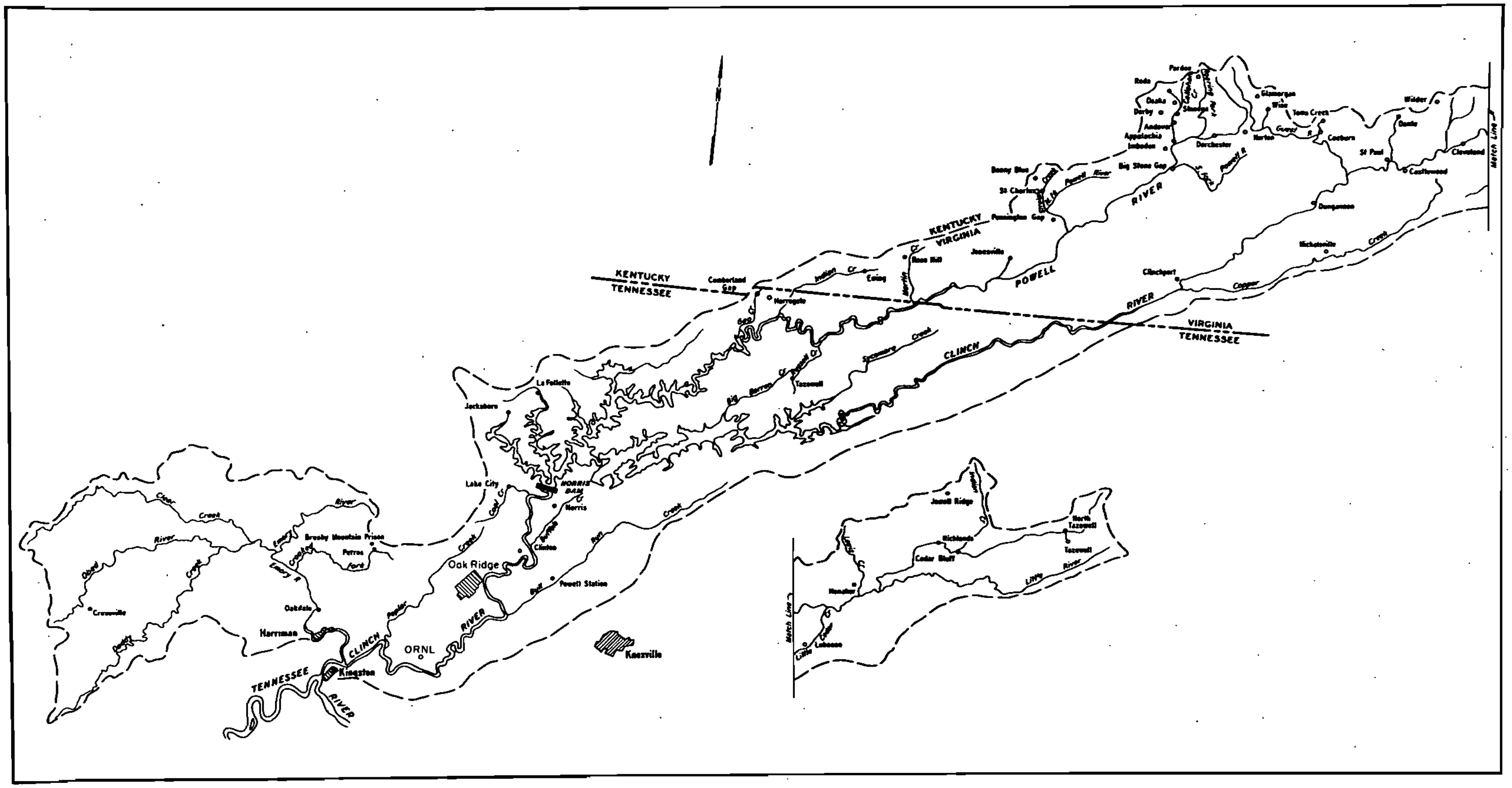

Clinch River and its Tributaries

Fig. 1.

The flow in Watts Bar Reservoir downstream from White Oak Creek during the period May-September is profoundly modified by differences in water temperature of the Clinch River and Watts Bar Reservoir. When Clinch River water is significantly cooler, stratified flow conditions due to density differences may exist, the cooler water flowing on the bottom beneath the warmer. This phenomenon markedly affects the travel time of water through the reservoir and complicates the analysis of flow. In addition, during the period of stratified flow some Clinch River water may flow up the Emory River as far as the Harriman water plant intake.

Table 1. Location of Stream Flow Stations near ORNL

Location	Drainage Area, sq mi	Period of Record
Norris Dam	2913	1936-1957
Lake City*	2921	1927-1943
Clinton	3056	1903-1927
Edgemoor	3089	1937-1943
Scarboro	3300	1941-1957
Wheat	3385	1936-1941

*Known as Coal Creek prior to 1951.

Table 2. Flows in Clinch, Emory, and Tennessee Rivers, 1945-1951

	Flow, cfs														
	Clinch River						Emory River			Tennessee River					
	Miles 20.8 and 13.2			Mile 4.4[a]			Mile 12.8			Mile 529.9			Mile 465.3		
	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.
Jan.	22,900	8,960	1,620	70,700	14,400	2,120	50,000	4,450	178	181,000	47,700	15,800	218,000	63,900	23,200
Feb.	27,700	10,100	1,230	89,800	15,800	2,250	69,000	4,550	468	204,000	50,800	17,900	195,000	67,900	19,700
Mar.	12,700	5,850	690	26,700	9,450	1,830	15,400	2,910	507	100,000	32,400	13,300	148,000	44,200	19,500
Apr.	8,540	3,400	306	13,300	5,620	752	6,660	1,800	249	43,700	23,800	5,200	82,000	27,700	13,200
May	8,080	2,750	298	19,700	4,700	520	13,100	1,610	58	38,300	20,000	3,000	95,900	28,800	17,900
June	7,420	2,820	224	9,280	3,320	262	5,300	396	14	32,100	18,900	8,200	32,800	25,500	18,900
July	7,630	2,930	259	12,800	3,400	281	9,230	360	21	87,500	19,600	6,500	106,000	26,400	15,400
Aug.	8,390	4,520	374	8,760	4,800	378	3,060	177	4	37,600	21,400	9,900	43,300	28,100	17,800
Sept.	8,450	4,620	341	13,000	4,940	462	5,500	224	2	39,900	22,200	6,900	54,400	30,100	17,100
Oct.	9,200	5,130	150[b]	14,200	5,300	150[a]	5,040	93	1	67,100	23,500	9,800	72,800	29,700	16,300
Nov.	12,700	4,430	453	40,500	5,830	556	27,800	1,100	2	128,000	25,400	10,300	167,000	34,000	13,600
Dec.	27,000	8,360	569	60,300	11,700	593	33,300	2,720	24	112,000	41,000	11,800	139,000	53,600	21,100
Oct.-Apr.[c]		6,600			9,730			2,520			34,900			45,900	
May-Sept.[d]		3,530			4,230			553			20,400			27,800	

[a]Flows shown for Clinch River Mile 4.4 include Emory River flows.

[b]On Aug. 28, 1943, TVA agreed to maintain a flow of at least 150 cfs in the Clinch River for the benefit of Oak Ridge.

[c]Nonstratified flow period.

[d]Stratified flow period.

1.4 Water Use

The most important uses of water in the Clinch-Tennessee Rivers are for power, navigation, community water supplies, irrigation, and fishing and other forms of recreation. The water uses of greatest interest from the viewpoint of this report are community water supplies and irrigation along the Clinch and Tennessee Rivers downstream from ORNL.

Contamination of community drinking-water supplies is the most serious potential hazard that may result from discharges of radioactive materials to the Clinch River system. The seriousness of the hazard depends on the population potentially exposed as well as on the intensity and duration of contamination in the water-supply systems.

The estimated total population of communities downstream from ORNL and served by surface-water sources on or adjacent to the Clinch and Tennessee Rivers is about 200,000 (Table 3). More than 80% of this population is in the municipality and suburbs of Chattanooga, 125 miles downstream from ORNL, which must use the Tennessee River water to supply their large requirements for domestic and industrial uses. In addition to potential health hazards, the possibility must be considered that radioactive contamination in the water supply might make it unsuitable for use in certain industrial processes.

The pumping and use of water from the Watts Bar and Chicamauga Reservoirs for irrigation of agricultural crops is increasing very rapidly. One estimate in 1955 indicated that there were then more than 1000 such irrigation installations in Tennessee, that they had increased in number more than 10-fold in a 7-year period, and that raw river waters were used for supplementary spray irrigation on various cultivated crops and pastures for cattle. Radioactive contamination in water used for irrigation of human or animal food crops is a potential hazard of human exposure through food or milk.

1.5 Population

The 1950 census data (Table 4) indicate a population density within a radius of 25 miles of Oak Ridge of 147 persons per square mile in urban areas. There has been no significant shift in population since 1950. The rural population density of the surrounding counties varies from 22 to 178 persons per square mile (Table 5).

Table 3. Community Water Systems in Tennessee Downstream from ORNL Supplied by Intakes on Clinch and Tennessee Rivers or Tributaries That May Be Affected by Main Stream Conditions

Community	Estimated Population*	Intake Source		Remarks
		Stream	Approx. Location	
ORGDP - K-25 Area	5,000	Clinch R.	CRMi. 14	Industrial plant water system
Harriman	6,000	Emory R.	ERMi. 12	Mouth of Emory R., CRMi. 4.5
Kingston Steam Plant (TVA)	<500	Clinch R.	CRMi. 3	
Kingston	2,000	Tenn. R.	TRMi. 570	River used for supplementary supply
Watts Bar Dam (Resort Village and TVA Steam Plant)	1,000	Tenn. R.	TRMi. 530	
Dayton	3,000	Richland Cr.	RCMi. 3	Opposite TRMi. 505
Cleveland	15,000	Hiwassee R.	HRMi. 15	Mouth of Hiwassee R. is at TRMi. 500
Soddy	2,000	Tenn. R.	TRMi. 488	
Chattanooga	155,000	Tenn. R.	TRMi. 465	Metropolitan area served by City Water Company
South Pittsburg	3,000	Tenn. R.	TRMi. 435	
Total	192,000			

*Based on published 1957 estimates.

Table 4. Populations (1950) of Towns within a Radius of 25 Miles of Oak Ridge

City or Town*	Distance from ORNL Site, miles	Direction	Population
Oak Ridge	7	NNE	30,236
Lenoir City	10	SSE	5,159
Harriman	12	W	6,389
South Harriman	12	W	2,761
Clinton	15	NE	3,712
Knoxville	19-26	E	124,183
Rockwood	20	W by S	4,272
Fountain City	23	ENE	11,500
Sweetwater	22	SSW	4,119

*Included are towns within a 30-mile radius that had a population of 2000 or more according to the 1950 census, as reported in the 1952 edition of the Rand-McNally Commercial Atlas and Marketing Guide, 83rd ed., 1952.

Table 5. Populations of Counties Surrounding Oak Ridge

County	Total Area, sq mi	Rural Population Density,* persons/sq mi
Anderson (immediately adjacent)	338	62**
Blount	584	67
Campbell	447	48
Cumberland	679	22
Knox (immediately adjacent)	517	178
Loudon (immediately adjacent)	240	54
McMinn	435	39
Meigs	213	29
Monroe	665	26
Morgan	539	22
Rhea	335	33
Roane (immediately adjacent)	379	50**
Scott	549	26
Union	212	38

*Includes all county population except communities with population of 500 or more.

**Does not include Oak Ridge.

2.0 WHITE OAK CREEK DRAINAGE BASIN

2.1 Topography and Geology

The area under consideration (Fig. 2) is within the Oak Ridge Reservation in Roane and Anderson Counties, Tennessee. White Oak Creek is a tributary of the Clinch River, entering that river from the north bank just above Jones Island at about Mile 20.8 of the Clinch. The watershed of the creek, which extends in a generally northeast direction from its mouth, has an area of 6 sq mi and is roughly diamond-shaped. It lies primarily in Roane County with a small portion of the upper watershed in Anderson County.

The topography is typical of the Valley and River Province, being characterized by northeast-trending ridges and valleys. The ridges and valleys are a result of the geologic structure and stratigraphy. The rocks in the area dip 20 to 30 degrees in approximately a southeasterly direction. The more resistant rocks hold up the ridges, and the less resistant ones have been eroded to form the valleys. The same formations are repeated by the intervention of a major thrust fault. Elevations in the area range from about 750 ft where White Oak Creek enters Clinch River to 1356 ft at Melton Hill, giving a maximum relief of about 600 ft.

Four principal rock units are present in the area: the Rome sandstone of Cambrian age; the Conasauga shale, also of Cambrian age; the Chicamauga limestone of Ordovician age; and the Knox dolomite of Cambro-Ordovician age. The Rome formation, which forms Haw Ridge, consists of even-bedded, very-fine-grained sandstone and much shale of red, green and other colors. In the Oak Ridge area the formation is more than 1000 ft thick. The Conasauga shale underlies all of Melton Valley. Although the residual material that covers the formation is quite uniform in appearance, the formation may be subdivided into four distinct types of rocks on the basis of core drilling. At the base is a zone about 300 ft thick of dark red silty shale with numerous thin beds of light green sandstone. Overlying this is about 450 ft of dark gray calcareous shale with numerous thin beds of light gray crystalline limestone. Above this is a transitional zone of interbedded shale and limestone. The top zone of the Conasauga, which forms the northwest slope of Copper Ridge, is predominantly limestone. In Bear Creek Valley this zone is about 300 ft thick.

The surface of Melton Valley is covered by an average of 2 or 3 ft of residual clay, and the underlying rock is badly weathered and decomposed to a depth of 15 to 20 ft. From 20 ft down to 60 or 70 ft the rock, while relatively sound and unweathered, contains abundant small fractures and joints which become smaller and less common with increasing depth.

The Knox group of formations, about 2600 ft thick, lies above the Conasauga. It consists largely of light-to-dark-gray cherty dolomitic limestone. It is a ridge-former and underlies Copper Ridge immediately southeast of Bethel Valley and Chestnut Ridge immediately northwest of Bethel Valley. The Knox is nearly everywhere covered by a cherty residual white-to-red clay soil that ranges from 30 to more than 100 ft in thickness.

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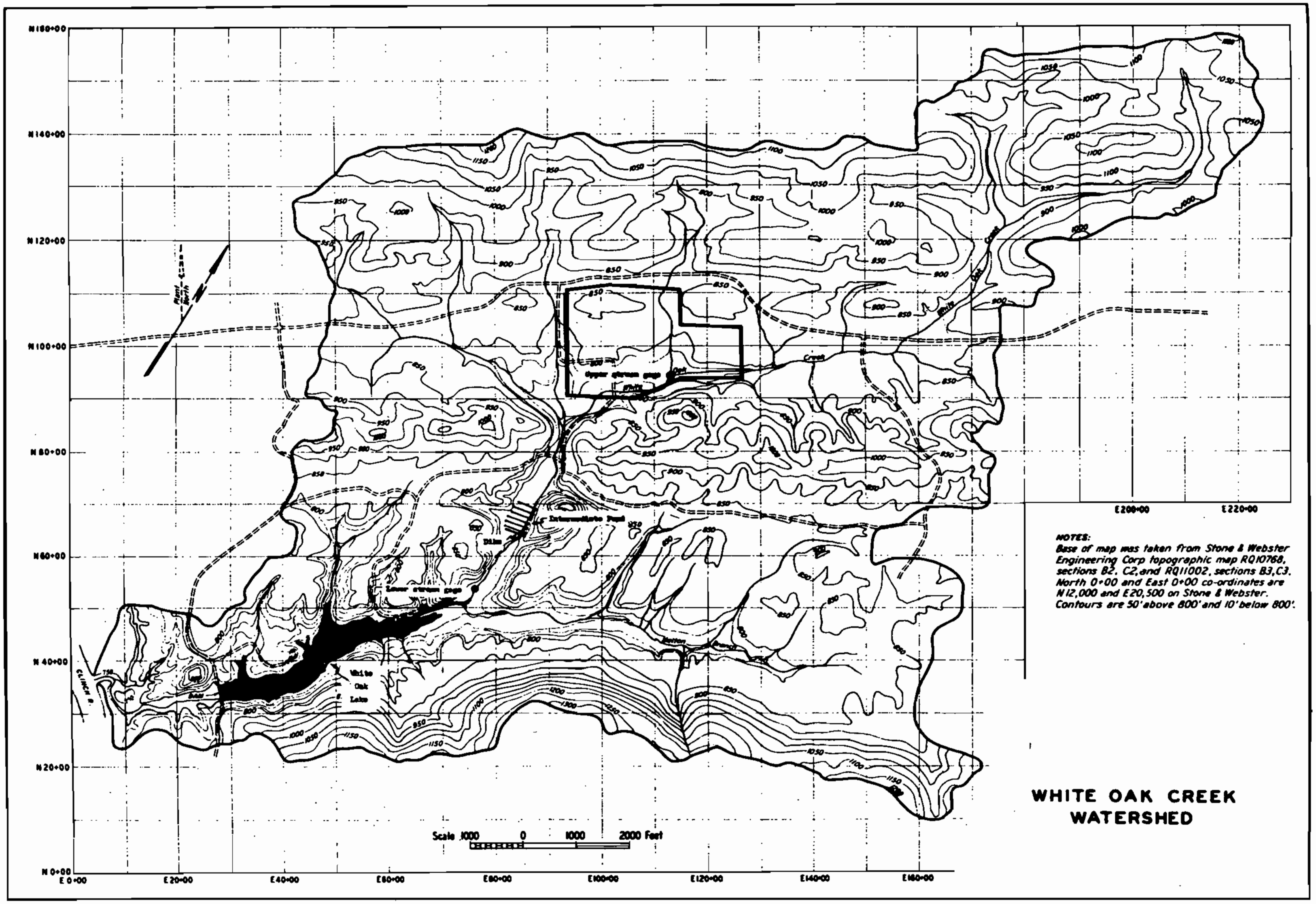


Fig. 2.

The Chickamauga limestone, which stratigraphically overlies the Knox, underlies Bethel Valley in which the X-10 Plant is located. This unit, which is about 1000 ft thick in the area, consists of thin-bedded limestone and shale. Bedrock is overlain by a thin blanket of residual clay soil rarely more than 10 ft thick.

2.2 Meteorology

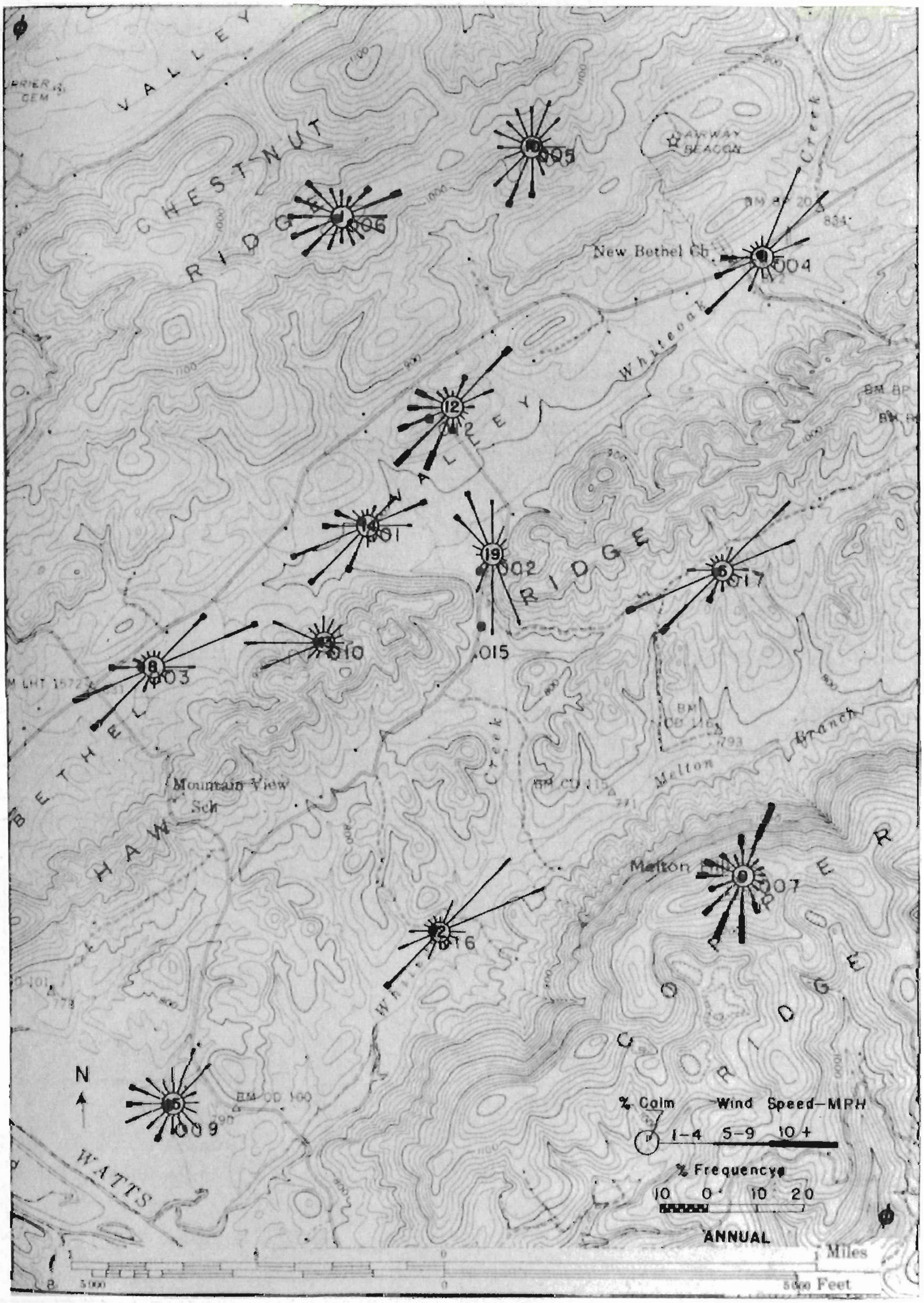
Wind Flow. The meteorology and climatology of the Oak Ridge area has been summarized in detail by the U. S. Weather Bureau Office at Oak Ridge.* The information reported here is taken from that report and supplemented by more recent data.

The valleys in the Oak Ridge area are oriented northeast-southwest, and considerable channeling of the winds in the valleys may be expected. The annual wind rose map for the ORNL area is shown in Fig. 3. The arms on these wind rose diagrams point in the direction from which the wind comes. The prevailing wind directions are up-valley from southwest and west-southwest about 40% of the time, with a secondary maximum of down-valley winds from northeast and east-northeast about 30% of the time. Although the percentage of calms increases at night under stable conditions, the predominant wind distribution is essentially the same day and night. The directional frequency is given in Table 6.

Table 6. Annual Frequency (1951) of Wind Direction

Wind Direction	Frequency of Area Winds at 70 ft, % of time		
	Stable	Unstable	All Observations
Calm	8	1	5
NNE	4	3	4
NE	21	15	19
ENE	15	13	14
E	2	3	3
ESE	2	2	2
SE	1	1	1
SSE	1	0	1
S	1	2	2
SSW	5	7	6
SW	13	20	16
WSW	18	21	20
W	4	6	5
WNW	1	2	1
NW	1	1	1
NNW	1	1	1
N	2	1	1

* U. S. Weather Bureau, "A Meteorological Survey of the Oak Ridge Area," ORO-99, November 1953.



Annual wind rose map, Bethel Valley-Melton Valley area.

Fig. 3.

The prevailing wind regimes reflect the orientation of the broad valley between the Cumberland Plateau and the Smoky Mountains, as well as the orientation of the local ridges and valleys. The gradient wind in this latitude is usually southwest or westerly, so that the daytime winds tend to reflect a mixing down of the gradient winds. The night winds represent drainage of cold air down the local slopes and the broader Tennessee Valley. The combination of these two effects, as well as the daily changes in the pressure patterns over this area, give the elongated shape of the typical wind rose at a channeled valley station.

Considerable variation may be expected in both direction and wind speed within small distances in Melton Valley because of local irregularities in the ground contours, as well as the presence of the broad river valley which intercepts land valleys and ridges. Thus during stable conditions or a period of low wind velocity during the day, a down-river flow of air may be expected at night.

It may be concluded that, at night or under stable conditions, the winds tend to be generally northeast and east-northeast and rather light in the valley, regardless of the gradient wind, except that strong winds aloft will control the velocity and direction of the valley winds, reversing them or producing calms when opposing the local drainage. During the day the surface winds tend to follow the winds aloft, with increasing reliability as the upper wind speed increases. Only when there are strong winds aloft or winds parallel to the valleys would it be of value to attempt to extrapolate air movements for any number of miles by using valley winds. In the well-developed stable situation, however, a very light air movement will follow the valley as far downstream as the valley retains its structure, even though the prevailing winds a few hundred feet above the ground are in an entirely different direction. In general, air transport from a valley location will be governed by the local valley wind regime and the degree of coupling with the upper winds.

2.3 Hydrology

Ground Water. Information on the occurrence of ground water in the sandstone and shale of the Rome formation is sparse, since few wells have been drilled in the formation. However, the Rome is well expressed in many road cuts through the water gaps in Haw Ridge, and observations of its physical properties indicate that the formation is probably quite impermeable and that the rate of ground-water movement through it is relatively low.

The Conasauga shale formation in Melton Valley is almost devoid of permeability below a depth of about 100 ft. Exploratory drilling in Bear Creek Valley, which is also underlain by the Conasauga group, indicated that limestones in the upper part of the Conasauga contain cavities several feet wide and extending at least 100 ft below the surface.

In general, the ability of the Conasauga to transmit water or other fluids increases with increasing lime content. Hence the lower two members which underlie the northwest side of Melton Valley transmit water less readily than the more limey upper members which underlie the valley to the southeast. Observations of water levels in wells in Melton Valley indicate that the water table may be as much as 60 ft below land surface on upland areas. At points of lower elevation, along Melton Branch and White Oak Creek, the water table is at or just beneath the ground surface.

The Chickamauga formation is practically devoid of solution cavities, as determined by core drilling in the ORNL area. Movement of ground water appears to be almost exclusively along joints and bedding planes. Depth to the water table is greatest along the higher northwest side of Bethel Valley and least on the southeast side, an area of ground-water discharge.

Ground water in the Knox formation occurs in and moves through solution cavities, some of which are cavernous. There are many sinkholes in the areas of outcrop, and sizeable springs issue from the bases of the ridges. Because of the high permeability of the cavernous bedrock, which permits free and rapid movement of ground water, the depth of water may exceed 100 ft along ridge tops. Frequently the position of the water table coincides approximately with the interface between rock and residual clay overburden.

Stream Flow. The U. S. Geological Survey has operated gaging stations to obtain continuous records of stream flow at sections on White Oak Creek and Melton Branch. Below is summarized the information from four stations; the natural flow at all four is affected by operation at Oak Ridge.

White Oak Creek at White Oak Lake Dam

Drainage area: 6.0 sq mi
Records available: July 1953 - September 1955
Average discharge: 2 years, 11.2 cfs
Extremes: Maximum discharge, 669 cfs Dec. 29, 1954
Minimum daily discharge, no flow July 17-20, 1953; December 1, May 18-19, 1954; Sept. 3-6, 1955

White Oak Creek Below ORNL

Location: 0.1 mile upstream from mouth of Melton Branch
Drainage area: 3.6 sq mi
Records available: June 1950 - July 1953; July 1955 to date
Average discharge: 6 years, 9.37 cfs
Extremes: Maximum discharge, 642 cfs, Aug. 30, 1950
Minimum daily discharge, 1.9 cfs, Oct. 2, 1950

Melton Branch, upstream from White Oak Lake

Location: 0.1 mile upstream from White Oak Creek
Drainage area: 1.5 sq mi
Records available: August 1955 to date
Average discharge: 4 years, 2.228 cfs
Extremes: Maximum discharge, 121 cfs, Jan. 21, 1959
Minimum daily discharge, no flow on many days during August, September, October, November 1955

White Oak Creek at ORNL

Location: 1.2 miles upstream from Melton Branch, 1000 ft above effluent from settling basins
Drainage area: 2.1 sq mi
Records available: June 1950 - July 1955
Extremes: Maximum discharge, 616 cfs, Aug. 2, 1950
Minimum daily discharge, 0.7 cfs Nov. 2, 1950; Aug. 2, 8, 12, 13, 21, 26, 28, 30, 31, Sept. 8, 9, Oct. 14, 1951; July 25, 26, 1953

2.4 Ecology

The White Oak Creek drainage basin is in an area that is primarily forest. The vegatative cover may be described according to three topographic situations: the ridge tops, the slopes, and the valley lowlands. The ridge tops support relatively old forests (former wood lots) which are predominantly deciduous, with oaks and hickories dominating. The sloping sides of the ridges support a variety of deciduous, coniferous, and mixed stands, which occur in a complex patchwork of wood lots and old pastures extending into the valleys. The gentler slopes of the valleys contain old fields in various stages of plant succession.* Some of the old fields were cultivated or in pasture in 1942, but tree rings and air photos of 1935 and 1925 show that others had been abandoned for one to several decades previous to that date. Thus the old fields contain several rapidly changing stages and types of vegetative cover: from fields abandoned in 1942 which support such herbaceous vegetation as weeds, coarse grasses, briars, bushes, and saplings to older fields that have been invaded by tree species. Prominent natural invaders in many of these former fields are three species of conifers: shortleaf pine, scrub pine, and red cedar.** Some of the pine stands near the liquid waste pits were planted by the Civilian Conservation Corps and are about 25 years old. Since 1948 additional plantations of shortleaf pine and loblolly pine have been established in many of the open areas of the Reservation, but it is mainly pre-1953 stands in Bear Creek and East Fork Valleys that have closed canopies. More recent plantations are common in the Bethel Valley portion of the White Oak Creek drainage area. Because differences in vegatation and in surface humus conditions (controlled by vegetation) affect the interception of aerial contamination and its removal by surface waters, a systematic study of present conditions and trends is now underway.

This variety of vegetation supports an abundant population of birds, mammals, and insects that have access to the zones of contamination and could transport radioactive materials. The most numerous birds in the Melton Valley area, which includes the lower portion of the White Oak Creek, are those associated with forested areas, such as the vireos and wrens, while such familiar birds as the

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* L. A. Krumholz, "A Summary of the Findings of the Ecological Survey of White Oak Creek, Roane County, Tennessee, 1950-53," ORO-132, 1954.

** D. A. Crossley, Jr., and K. K. Bohnsack, "Long-Term Study in the Oak Ridge Area: III. The Oribatid Mite Fauna in Pine Litter," Ecology, in press.

mockingbird, robin, and starling are virtually absent because of the paucity of open areas. In Bethel Valley and near the plant sites the latter birds occur more frequently.* Migratory waterfowl formerly appeared on White Oak Lake** and still appear on the Laboratory settling basin and the pool above White Oak Dam.

Common mammals in the wooded areas are the opossum, the raccoon (near streams), the gray fox, and the eastern gray squirrel. Whitetail deer have become established in the remote wooded areas of the Reservation and, while they are uncommon as yet, they may enter the White Oak Creek drainage basin. In the old fields, which support herbaceous and brushy vegetation, the eastern cottontail and the woodchuck are numerous. Along the streams the muskrat, rice rat, and, rarely, the mink occur. The striped skunk and the red fox occur in both old field and wooded habitats. The smaller mammals (species of rats, mice, and shrews) occur throughout the drainage basin; they are certainly more numerous than the larger forms mentioned above and probably comprise a larger biomass.***

The White Oak Creek system itself contains two types of habitats for aquatic organisms: the fast-flowing water of the creeks and the relatively static portions of impounded water, such as the settling basin and the standing pool above White Oak Dam. The quieter waters are suitable for algal blooms, aquatic insects, and planktonic organisms in general, while the flowing waters contain less plankton. Spectacular plankton blooms of *Volvox* and *Euglena* were reported in White Oak Lake,+ and in the settling basin plankton blooms have required control measures.++ In the creek itself *Tubifex* and chironomid larvae are abundant in the mud, and other insects and some crustaceans, including crayfish, are present. Fish and other aquatic vertebrates can enter White Oak Creek from the Clinch River; carp are seen frequently in the portion of the creek that flows through White Oak Lake bed. The control gate now under construction in the dam will prevent fish from entering that part of the drainage basin above the dam.

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*J. C. Howell, "Long Range Ecological Study in the Oak Ridge Area: I. Observations on the Summer Birds in Melton Valley," ORNL CF-58-6-14, 1958.

**L. A. Krumholz, *loc. cit.*

***J. C. Howell and P. B. Dunaway, "Long-Term Ecological Study in the Oak Ridge Area: II. Observations on the Mammals with Special Reference to Melton Valley," ORNL CF-59-10-126, October 1959.

+L. A. Krumholz, *loc. cit.*

++K. Z. Morgan and F. Western, "Contamination of Water Discharge from Clinton Laboratories," MON-H-259, 1947.

3.0 OAK RIDGE NATIONAL LABORATORY SITE (X-10 AREA)

In 1948-49 an investigation was made of the geology and hydrology of the X-10 Area. The following description is based principally on information in the report* of this investigation.

3.1 Topography and Geology

Oak Ridge National Laboratory is located in Bethel Valley. The area is about 1/2 mile long and 1/2 mile wide and comprises about 160 acres. Elevations range from 780 to 900 ft above mean sea level. The Laboratory is bounded on the northwest by Chestnut Ridge, with elevations up to 1200 ft, and on the southeast by Haw Ridge, with elevations up to 1000 ft.

The entire area is underlain by rocks of the Chickamauga group of Ordovician age. In this area the thickness of the group is 1735 ft. The rocks are mainly limestone; however, variations in types of rock permit separation into eight distinguishable and mappable subdivisions (Fig. 4). The composite section of the Chickamauga group, in descending order of units, is summarized as follows:

Unit	Description of Rock	Thickness, ft	
H	Siltstone, calcareous, gray, olive, maroon; with shaly partings and thin limestone lenses	85	
	Limestone of varied types; gray, olive-gray buff, drab; mostly thin-bedded; with argillaceous partings; weathers to shaly appearance; with fossiliferous zones	180	
	Limestone, argillaceous (calcareous siltstone), gray, olive-gray, "pinkish" maroon; even-bedded, with shale partings	35	
			300
G	Limestone of various types, dark gray to brownish gray; mostly nodular with abundant black irregular clay partings; dense to medium grained; mostly thin-bedded, partly massive; with shale partings; weathers to a lighter colored shaly or "nodular" appearance; with some fossiliferous horizons; mostly covered in lowlands		300
F	Siltstone, calcareous, alternating with shale; olive-gray to maroon; even-bedded; laminated; weathers to a red shaly appearance; produces a slight rise in topography; a very distinctive unit		25

*P. B. Stockdale, "Geologic Conditions at the Oak Ridge National Laboratory X-10 Area Relevant to the Disposal of Radioactive Waste," ORO-58, Aug. 1, 1951.

Unit	Description of Rock	Thickness, ft	
E	Limestone, mostly gray to drab, partly pinkish maroon, mottled; brittle, thin-bedded to massive; with shaly partings	60	
	Limestone, similar to "G" above, mostly covered in lowlands	220	
	Calcareous shale and argillaceous limestone, gray to buff; in alternating thin even beds; yielding small roundish slabs upon weathering, with yellow-buff color	45	
	Limestone of various types, gray; most argillaceous and nodular; in thin irregular beds with shale partings; abundant fossils	55	
			380
D	Limestone and chert; limestone is gray to olive-gray, in part nodular, shaly, and thin-bedded, in part massive; with abundant chert in thin, even bands, breaking into angular fragments upon weathering; produces a chain of low hills		160
C	Shale, calcareous, olive-gray to light maroon; fissile; evenly laminated	10	
	Limestone of various types, gray; fine-to-coarse grained, partly crystalline, partly nodular; mostly massive; with occasional patches of chert; partly fossiliferous; "quarry beds"	105	
			115
B	Siltstone, in even beds up to 2 ft thick, laminated, alternating with calcareous shale; olive-gray, buff, maroon; some limestone, nonresistant; more shale at base		215
A	Limestone of various types, dark gray to buff; with shale partings; with gray to black chert in nodules and lenses	80	
	Chert, thin-bedded, with shaly partings	15	
	Siltstone, calcareous, olive-gray to maroon; weathers to shaly appearance	30	

Unit	Description of Rock	Thickness, ft	
	Siltstone and chert, in alternating beds; siltstone is calcareous, gray, olive, maroon; weathers to shaly appearance; with abundant granular chert in even beds up to 6 in. thick, breaking into angular blocks upon weathering	90	
	Limestone; mostly covered	25	
			240
	Total thickness		1735

The direction of dip of all the rocks in the X-10 Area is southeast, and the angle of dip is between 30 and 40 degrees. The average direction of strike is north 58 degrees east.

The Chicamauga group is covered by a mantle of clayey soil derived from the decomposition of the underlying consolidated bedrock. The unconsolidated material ranges in thickness from about 1 to 25 ft, averaging perhaps 10 ft.

3.2 Hydrology

The area is drained by White Oak Creek and its tributaries. Just south of the Laboratory, White Oak Creek flows out of Bethel Valley through a gap in Haw Ridge. Information on the discharge of White Oak Creek is given in the section on White Oak Creek Drainage Basin above.

Ground water in the rock beneath the Laboratory is derived from precipitation that falls on the area and its immediate surroundings. The water in the ground is constantly moving from points of recharge to points of discharge at lower elevations. The geologic map (Fig. 4) shows that ground water occurs under water-table rather than artesian conditions. Thus groundwater discharge contributes to the base flow of the surface streams in the area and ultimately augments the flow of Clinch River.

The limestones and shales of the Chickamauga group are quite impermeable and are incapable of transmitting large amounts of water. The openings in the rock are confined to narrow seams developed along bedding planes or joints. These decrease with depth, and below a depth of about 100 ft the rock is generally devoid of openings. It is probable that most of the ground water in the area moves through the unconsolidated soil rather than the rock.

The depth to water in the area ranges from 25 to 30 ft below land surface at points of high elevations to at or near land surface along the surface streams. Figure 4 shows the configuration of the water table on June 20, 1950.

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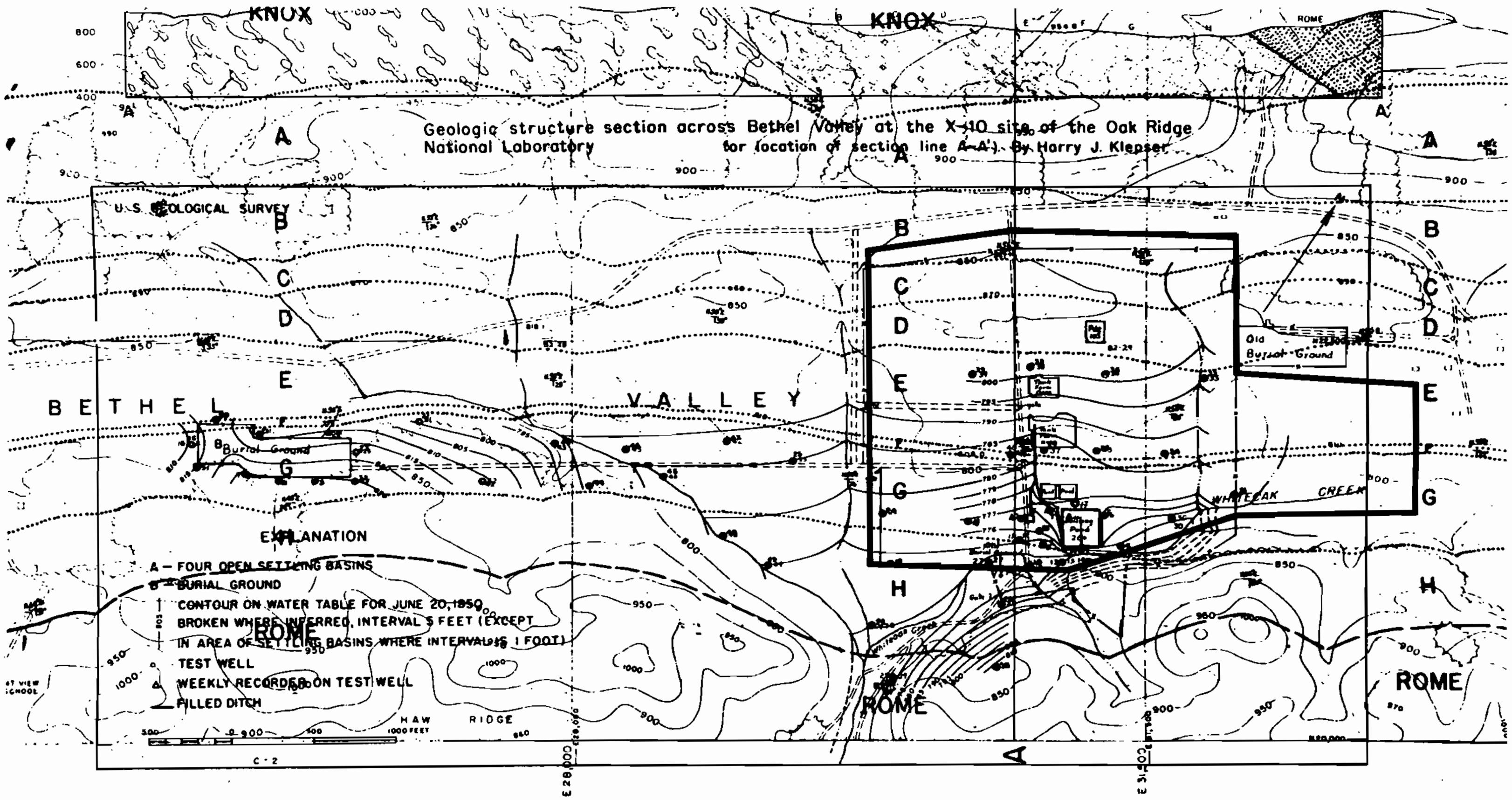

Geological and Water Table Map of ORNL Area (by George D. DeBuchananne).

Fig. 4.

4.0 SIGNIFICANCE OF ENVIRONMENTAL FACTORS

Whereas localized accidents may pose serious threats to a few individuals, even moderate contamination of the whole Laboratory or its environment could jeopardize the continued use of the expensive facilities that have been placed here; it could undermine the public's confidence in the future of the nuclear industry, perhaps out of proportion to the seriousness of the accident itself. The preceding sections described the environment that might become contaminated by ORNL operations and accidents and some of the environmental factors that would affect the movement of radioactive materials. Below, these factors are related to releases of radioactivity that have occurred or that might occur under circumstances considered in other reports of this series.

4.1 Physical and Chemical Factors

a. Factors Affecting Aerial Contamination

Wind Direction and Velocity. Meteorological computations for estimating the environmental build-up of radioactivity have recently been simplified by Culkowski* and compared with data on foliage contamination at a series of stations radiating in several directions from ORNL.** For dogwood leaves, which proved to be convenient natural collectors for fallout, gamma spectrometry showed detectable I^{131} 8 miles northeast of ORNL (5 μμc/g) and 4 miles to the southwest (7 μμc/g), northwest (5 μμc/g), and southeast (1 μμc/g); concentrations at 1 mile were 189, 59, 28, and 2 μμc/g, respectively. These distributions correspond in a general way with the earlier generalization that southwesterly and northeasterly winds are most important on an average annual basis. Closer study of winds during the month preceding sample collection (September 1959) suggests that the effects of southwest winds may be over-represented and south-southeast winds under-represented in this contamination pattern, that is, that stack effluents have been contaminated at irregular times when the wind did not happen to represent average conditions for the weeks involved. For estimating consequences of individual major incidents, long-term wind averages are approximate only for relative probabilistic estimates of the chance that a certain area might be contaminated above some specified level. Calculations for individual meteorological situations are needed to make an estimate of the pattern of contamination as a function of location for individual accidents.***

Particle Size. One discrepancy in the quantitative comparison of predictions based on turbulence theory vs direct observations on the ground is the relatively great contamination occurring very close to the source. These locations near the stack should not be reached by the narrow plume of radioactive effluent moving away from the stack, but may nevertheless be reached by radioactive particles because of settling of particles by gravity, especially during

*W. M. Culkowski, "Estimate of Accumulated Exposures and Environmental Buildup of Radioactivity," Sixth AEC Air Cleaning Conference, Idaho Falls, Idaho, July 7-9, 1959.

**J. S. Olson, ORNL, personal communication, April, 1960.

***U. S. Weather Bureau, "Meteorology and Atomic Energy;" see also "Meteorology of the Oak Ridge Area," ORO-99.

periods of calm or of precipitation. Even contaminants like iodine, which are initially gaseous, are known to become quickly adsorbed on coarser particles. Perhaps this kind of phenomenon helps to explain concentrations up to 583 μμc/g foliage 0.15 mile northeast of the central off-gas stack in the study of Olson mentioned above, compared with 194 μμc/g only 0.08 mile southwest. Ruthenium-106 showed maximum activity at the same station (113 μμc/g), even though significant contributions from the Laboratory appear to reach out a mile or two to the northeast and southwest (12 to 17 μμc/g, compared with values to be expected from weapons fallout of 2 to 9 μμc/g at more distant stations). The ruthenium contamination of November 1959 further emphasized the short distances of transport and irregular distribution on the ground which might be expected in the case of isotopes adsorbed on particles that fall rapidly after leaving the stack. Fortunately, contamination of this type poses even less threat than radioiodine to populated areas outside the X-10 Area, but it concentrates the difficulties of sanitation in areas where the investment in facilities is greatest and can lead to concentrations of run-off in a single watershed, the White Oak Creek basin.

Other fission products show even less indication of significant stack contribution to fallout over most of the White Oak Creek drainage area, but local concentrations in the Laboratory proper may again be due to adsorption on particles. Maximum concentration for Cs^{137} (22 μμc/g) occurred 0.15 mile northeast of the Graphite Reactor, while that of Zr^{95}-Nb^{95} (68 μμc/g) occurred 0.08 mile southwest. Cerium-144-praseodymium-144 exceeded 200 μμc/g at both these stations but decreased to less than one-tenth this value at stations more than 1 mile distant.

<u>Surface Conditions</u>. Whereas stack effluents are injected into the air stream, other kinds of radioactive dispersal by wind, such as blowing of dust, can be controlled to a considerable degree by providing adequate vegetation cover. It has been Laboratory policy for several years to provide such cover on areas bared by construction.

b. Factors Affecting Soil and Water Contamination

<u>Surface Conditions</u>. Except for the initial distribution and concentration of radioactive materials, the problems raised by solid or liquid contaminants are much the same as for fallout. On the one hand radioactive material will be leached by rainfall from the solids, and on the other, much of the radioactive material in any released contaminated liquid will be adsorbed by the soil. The environmental factors in hazards evaluation can therefore be reduced, as a first approximation, to a prediction of the consequences of releasing a mixture of liquids and solids into the environment.

Abundant laboratory and field experience shows that all the more hazardous fission products, with the possible exception of ruthenium, can be very firmly adsorbed by the right kind of minerals in the soil. Where adequate contact between any contaminated liquid and soil or rock can be provided, the liquid is very largely decontaminated by ion exchange. Adsorption does not provide a permanent bond, however, and some materials, for example, strontium, are apparently subject to slow removal by leaching, while others, for example, cesium, are much more firmly held.

It is therefore desirable to decrease as far as possible any direct runoff over the land surface, for such water, having a minimum contact with the soil, would have the greatest opportunity of carrying contaminants in solution. It is also desirable to decrease soil erosion and flooding of the small streams in the area, for it is in flood that they are principally active in scouring their channels and carrying the sediment out into the Clinch River.

The dominantly clay soils of the Oak Ridge area are generally of low permeability so that, particularly in winter, surface runoff is rapid. Discussions with the Forest Service suggest that considerable improvements in the natural conditions will occur as forest cover and humus mature and that improvements can be hastened by the application of well-understood methods of land management and engineering.

Substrate and Soil Materials. The Conasauga shale formation, in which the intermediate-level waste pits are excavated, is an extensive formation which is quite heterogeneous in structure and relatively low in permeability.* The depth and extensiveness of the formation provide a large capacity for decontamination of the intermediate-level waste stream, and the slow rate of percolation improves the efficiency of decontamination of the waste stream by ion exchange and radioactive decay. On the debit side, the heterogeneity of the formation makes difficult the prediction of exact patterns and rates of the movement of water and, hence, the fission products contained therein. It has been noted, however, that most of the seepage is along bedding planes parallel to the strike.

There is very little probability of ground-water contamination in areas removed from the ORNL site, and there are no developed ground-water resources in the area. The lack of ground-water resources is due to the fact that formations present are, for the most part, too impermeable to hold or transmit economically valuable quantities of water. This means that surface runoff is rapid.

The above discussion indicates three serious shortcomings in the natural environment of ORNL: (1) the high rainfall results in marked leaching of adsorbed activity, (2) the surface runoff leads to erosion and sediment transport, and (3) the heterogeneity of ground-water movement patterns makes monitoring procedures difficult.

In the solid burial facility leaching of activity from the area is decreased by impermeable covers on the burial trenches, which reduces the amount of water percolating through the wastes.

Conasauga shale, the soil of White Oak Lake bed, and the Clinch River sediments show moderate-to-high specificities for nearly all fission products, thus providing a safety factor in the case of an accidental release of radioactive cations. In addition, these formations and sediments provide effective decontamination of liquid waste effluents before discharge to the Clinch River, and the fresh sediments encountered in the river after discharge continue to remove fission products from solution. This is an important factor for downstream water users; the mechanical filtering of sediments from

*P. B. Stockdale, "Geologic Conditions at the Oak Ridge National Laboratory (X-10) Area Relevant to the Disposal of Radioactive Waste," ORO-58, 1951.

the water in a water-treatment plant could be expected to further remove substantial percentages of activity from the water. On the other hand, the decontamination processes result in contaminated sediments and soils, which may be subsequently leached over long periods of time or may move due to erosional processes into surface drainageways and be transported as sediment in the rivers. The contaminated sediments, whether they remain in situ or move into the river, may lead to local accumulation of fission products by living organisms.

Waste Properties. Normally the waste effluents have a high pH, which is beneficial in increasing the effectiveness of decontamination by soil, especially for strontium. However, there is a distinct possibility that continued operation of the intermediate-level waste pits might result in a loss of structural rigidity of the side walls of the pits. The subsequent leaching of sediments and the lowering of the pH may result in release and rapid movement of the strontium retained during the initial operations.

4.2 Biological Factors

Uptake by Organisms. Studies of the ecology of the drained basin of White Oak Lake bed* have shown great differences among plants and animal species living in that area in their uptake of radioactive isotopes from the contaminated soils. Native plants had concentrations of Sr^{90} ranging from 2×10^{-4} to 2×10^{-3} μc/g; concentrations of Cs^{137} ranged from 1×10^{-5} to 6×10^{-4} μc/g. Only one vegetation type removed more than 1% (on a unit area basis) of the soil burden of radionuclides.

Movement and accumulation of Sr^{90} and Cs^{137} in the food chains from plants to insects to birds has been related to the species physiology of the plants and the particular food habits, physiology, and behavior of the insects and birds. Winter resident bird populations from the North, for example, accumulated more radiocesium than radiostrontium by eating fallen seeds coated with lake bed soil having a high content of fixed Cs^{137}. Summer resident birds, which move south of Tennessee in the winter, accumulated more radiostrontium than radiocesium as a result of feeding on insects or seeds that were relatively higher in strontium content.** Although the quantities accumulated were small, the differences observed between populations of some species emphasized the danger of making evaluations based on limited biological data.

Studies of trees in a few acres surrounding the waste-pit area showed that Ru^{106} was accumulated from the ground water by the trees, translocated to their leaves (up to 1600 μμc/g), and deposited on the ground surface in fallen leaf litter.*** The presence of Co^{60} and Cs^{137} in vegetation at places

*S. I. Auerbach et al., "H. P. Ann. Prog. Rept. 1957, ORNL-2384; 1958, ORNL-2590; 1959, ORNL-2806.

**W. K. Willard (Summer student from U. of Ga.)., "Avian Uptake of Fission Products," Science, in press.

***S. I. Auerbach et al., op. cit. 1958, 1959.

where isotopes were not detectable in ground water monitoring wells has been interpreted to indicate aerial contamination by dust or aerosols blown from the vicinity of the nearby pits. Autoradiograms showing particulate radioactivity on both plant material and gummed paper trays suggest that this mechanism is involved but do not exclude the possibility that the extensive roots of plants will begin to take up these isotopes before they are detectable in wells. Concentrations of Zr^{95}-Nb^{95} found on these samples were comparable with those found* at locations several miles from ORNL and which can presumably be attributed to weapons fallout. On the other hand, Cs^{134} and traces of Zn^{65}, which have recently been detected in walnuts and in the outer hulls surrounding the walnuts, presumably reached the plants from the waste pits.** The fact that all the above-mentioned isotopes except Zr^{95}-Nb^{95} were found not only in hulls but also in the nuts, which had been protected from direct aerial contamination by the hulls, indicates definite physiological intake, at least from aerial parts of the plant and possibly from roots as well. There is no evidence that the concentrations involved are damaging the plants near the waste pits or that nuts or other contaminated plant materials are entering food chains leading to man. However, there are already releases exceeding usual fallout levels, and such releases could increase as a result of accidents or perhaps from redistribution of fission products already released to the pits.

Another example of localized plant uptake within the Laboratory proper was a silver poplar tree near the Cobalt building of the Radioisotopes Area which absorbed Co^{60}, Cs^{137}, and Sr^{90} from soils where these isotopes either had been spilled or had leaked underground.** Attention was called to this case as a result of pickup (on the muddy shoes of workers) of individual leaves which were radioactive enough to set off alarms.

Dispersal of Contaminated Organic Material. One study of a sycamore tree in Bethel Valley indicated that approximately 75% of the leaves fell within only 10 meters of the trunk, and well over 90% within 30 meters, under grassy field conditions in which leaves probably settled down after their initial flight from the tree. Lawn or bare dirt surfaces or trees of much greater height or greater exposure to wind could, however, lead to dispersal over distances several times greater, at least for a few leaves.

Insects that emerge from the contaminated waters or feed on the contaminated plants undoubtedly contribute to the spread of radioactive materials within the drainage area and possibly migrate outside the drainage area.*** Considerable dilution with distance would be involved, however, since the insects would not be expected to congregate off the drainage area.

Birds and mammals may be responsible for less total uptake of radioactivity than the insects because of their small numbers, but they provide larger individual accumulations of radioactive material inherently capable of moving further. Waterfowl may be discouraged from inhabiting waste pits by the chemical nature of the liquid but are seen to settle on the Laboratory settling basin and could be shot elsewhere and taken directly as human food. Nets or covers minimize these possibilities of contamination.

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*S. I. Auerbach, op. cit., 1959

**J. S. Olson, ORNL, personal communication, 1960.

***D. A. Crossley and H. F. Howden, ORNL, "Pioneer Insect Invaders of White Oak Lake Bed," in manuscript.

Recent assays of radioactivity in animals near the waste pits emphasize the great variability in the contamination of organisms of different habits. A cotton rat and corn snake exceeded 30,000 cpm (total body) of gamma activity (counting efficiency less than 10%), while golden mice from the same area had only about 2000 cpm. Increased sampling and analyses are being carried on and related to animal habits in order to provide better estimates of possible dispersal of isotopes by animals.

A general conclusion is that there are many means of local dispersal of contaminated organisms or organic material within the White Oak Creek drainage basin, but dispersal over great distances would be exceptional and would involve only a small fraction of the total biological contamination. Dispersal would be accompanied by dilution of the contaminated organisms in the environment, but an occasional large contaminated animal could move a great distance.

Cyclic Movements of Isotopes. Even after contaminated organic material reaches the ground, there will be differences in rates of decay and release of the isotopes to soil minerals. In the case of cesium, fixation would probably occur, and only a small percentage of the isotope might be returned to plants for repeated cycles of movement through biological materials. Strontium and perhaps other elements seem more likely to be involved in the cycling of biologically available contamination in the ecosystem. Basic studies of the circulation of elements in the ORNL environment will improve the basis for evaluating hazards of radioactive isotopes that reach the natural environment.

5.0 SUITABILITY OF WHITE OAK CREEK DRAINAGE BASIN FOR WASTE DISPOSAL

For some years after the start of operations at the Laboratory small amounts of low-level radioactive waste were run into White Oak Creek just south of the main Laboratory area and from there into White Oak Lake. A large but uncertain proportion of the radioactive material was adsorbed onto the clay and silt in suspension in the stream, and much of this solid material settled out and came to rest in the bed of White Oak Lake. An unknown proportion of the contaminated mud and some radioactive materials that had remained in solution were carried on through the lake into the Clinch River and, with time, down the Clinch into the Tennessee River. Samples of mud from the river bed for some miles downstream showed activity. At least two processes are involved in the movement downstream of the radioactive materials: transport of contaminated clay and silt in suspension in the river water and flow of water that not only has some radioactive materials in solution but also leaches activity out of the mud and silt and carries this away in solution.

The Process Waste Water Treatment Plant was put into operation late in 1957 to partly decontaminate the dilute waste water which previously had gone directly into White Oak Creek and White Oak Lake. The results of this new plant were immediately apparent in decreasing the amount of activity going into White Oak Creek. The beneficial effect of the plant, which removes an average of 88% of the activity in the water treated, should show up in a few years in decreased radioactivity in the river. Further, the operation of the treatment plant is itself being improved, and contemplated additions and alterations can increase both its capacity and the overall decontamination factor.

The contamination of the stream and river system can now be used in a study to determine the safe limits of the environment for the discharge of radioactive materials.*

About 10 years ago the Laboratory began to discharge medium-level liquid waste into pits dug into the weathered Conasauga shale. The first pit was thought of as a tank, dug into an impermeable formation, where value could be measured by its volumetric capacity and safety by the inability of the contents to leak out. The first pit did leak, although very slowly, and analysis of the liquid in seeps which formed below the pit showed that the only radionuclide coming through was ruthenium and this only in greatly decreased concentration. The rest of the fission products were adsorbed by the soil and weathered rock. Subsequently three more waste pits were constructed on the crest of a low ridge and designed to operate primarily as ion-exchange columns whose capacity could be measured by their seepage rate and safety by the decontamination of the effluent by ion exchange in the soil.

While the pits represent a far more satisfactory use of the environment than direct discharge to surface streams, they suffer from certain fundamental defects. Most of the seepage is along bedding planes, that is, out from the pits parallel to the strike, and very largely in the partly decomposed rock above the original water table. Perhaps more serious are the maintenance and monitoring operations required after a pit is taken out of service. The pit could be filled with a combination of limestone, rock phosphate, and shale and finished with tamped clay and asphalt cap. This would lower the water table and limit the infiltration of precipitation, which would largely protect the adsorbed activity underground from being slowly leached. The effectiveness of such a procedure, however, is uncertain and will have to be determined by later, probably long-term monitoring. It is this type of uncertainty which makes it impossible to set a long-term, safe limit to the use of the pits.

5.1 New Waste Pit

A new waste pit is now under construction and will shortly be put into operation. It is oriented at right angles to the strike to give a maximum seepage rate and is located along the crest of a relatively high, wide ridge so that the seepage distance underground will be as great as possible. The pit has been made narrow and filled with coarse, broken limestone and mounded with dirt over the top. There are several advantages to this design. The earth cover will eliminate the radiation field in the pit area, which greatly curtails working time in the vicinity of the operating pits, and will eliminate air-borne contamination. The earth cover will also eliminate both direct inflow from rainfall and evaporation, which, as the former is larger, represents a net gain. The longer underground seepage distance represents an important increase in the basic safety of the operation. Fundamental research on mineral structure has shown that where a strontium-contaminated waste containing phosphate is run over limestone, an apatite-like mineral is formed which incorporates the strontium into the crystal lattice, a far more permanent type of fixation

*ORNL Health Physics Division, "Plan for Clinch River Study," attachment to letter from J. A. Swartout to H. M. Roth, Nov. 23, 1959.

than adsorption.* This generalization is not true for such aquifers as cavernous limestone like the Knox dolomite. However, ORNL has only one nuclear installation on this formation, viz., the Tower Shielding Facility.

If low- or medium-activity waste is discharged into pits dug in Conasauga shale along the crests of low ridges, the liquid can be forced underground slowly, although the permeability of the shale is so low that the sites for the pits have to be chosen with care. The location of pits is also restricted by the requirement that they must be well above the water table, and the water table in general tends to be high because the shale is poorly permeable.

Generally, it would be regarded as favorable that there are no developed ground-water resources in the White Oak Creek Drainage Basin which might be contaminated. As far as it goes, this viewpoint is undeniably correct, but it is too narrow and short-sighted. There are no ground-water resources because the local formations are, for the most part, too impermeable to hold or transmit economically valuable quantities of water. This means that surface runoff is rapid, and that it is difficult to get any contaminated water or liquid waste into the ground where one may take advantage of both the relatively slow movement of ground water as compared to surface streams and also of the great absorptive capacity of the soil. In general, the radioactive contaminants are not associated with the water but with the clay and silt carried by the water. Such transport is possible only by surface streams, and the possibility of contaminating ground-water supplies over any distance is relatively remote.

5.2 Ultimate Waste Disposal

Expansion of the nuclear fuel processing facilities at ORNL will require the construction of large, artificially cooled, high-activity waste storage tanks. Of the four formations in the area, the Conasauga shale is the best suited for all the more potentially hazardous operations; it is easily excavated but is still strong enough to provide excellent foundations; it is sufficiently permeable that some slow seepage into and through its upper weathered portion is possible; and it adsorbs and firmly holds relatively large quantities of fission products. Three ultimate disposal methods considered economical and safe for the Oak Ridge area are disposal of high-activity solid wastes in deep, mined-out cavities in rock and of low- or intermediate-activity liquid wastes on soil columns or by hydraulic fracturing.

High-Activity Solid Wastes. Like tank storage, the conversion of liquid waste to solids is primarily an engineering problem, and the prime safety consideration is the possibility of completely containing the operation. The choice of terrain is secondary, but must be considered because the nature of the storage vault, and in particular whether it will remain dry, will set the specifications for the solid. Dry cavities, mined out underground above the water table by driving a tunnel back into a hillside, and provided with a vertical shaft up to the hilltop for convective cooling, would place no other requirements on the solid waste than that it should not produce gases

*There is some thought of treating the waste run into the new pit with phosphate to take advantage of this reaction and trap a large proportion of the strontium on the broken limestone fill.

or vapors and that it should be able to stand temperatures high enough that it could be cooled in storage by convection. It need not be unleachable; the storage chamber would keep it dry, and the calcined waste solids would be contained in a sealed corrosion-resistant container.

The best formation in the immediate Oak Ridge area for mined-out chambers of this sort is probably the Knox dolomite. This formation is sufficiently permeable, due to solution cavities, that under the Knox ridges the water table is low. These same solution cavities, however, because they are irregularly distributed and difficult to predict, would make the layout of dry workings above the water table a little uncertain, and storage chambers in the Knox probably would not be satisfactory without considerable grouting. However, between 50 and 100 miles from Oak Ridge there are several abandoned mines in chemical-grade limestone which were worked by driving back horizontally into the hillside, and these workings are strong and dry. These mines, or others developed for the purpose, could provide safe storage for solid wastes.

Vertical shafts are expensive to construct and, even in tight rock like the Conasauga shale, tend to leak, as do the bottom workings. Unlike mined cavities above the water table which drain by gravity, these excavations would have to be kept dry by pumping if water did seep in. More importantly, heat dissipation would be difficult whether the waste was stored as a solid or a liquid, for it is difficult to get air to circulate down into a mine without fans, and the rock itself is a poor conductor of heat.

Low- or Intermediate-Activity Liquid Wastes on Soil Columns. Possible further improvements of the seepage-pit system would be small columns filled with several soil minerals having high specificities for strontium and cesium, which could be operated in series and the head-end unit abandoned in place when its adsorptive capacity was completely exhausted. The use of man-made soil columns would offer several advantages, such as improved waste-soil contact, positive location of adsorbed activity, and protection from leaching. Such a waste handling system would represent an outgrowth of and a departure from the present waste pits.

Low- or Intermediate-activity Liquid Wastes by Hydraulic Fracturing. Hydraulic fracturing through a horizontally slotted casing out into horizontal beds of shale at a depth of not over 1000 or 2000 ft tends to produce horizontal fractures. If so, waste-clay-cement mixtures could be forced out into a series of thin sheets one after another from a single well, working from the bottom to the top. One such sheet, with a volume of 26,000 gal, was formed at Oak Ridge by injection under pressure into the Conasauga shale at a depth of about 300 ft. The solid mixture formed by the cement on setting would not be unleachable, but, trapped in depth in a virtually impermeable shale, little water should move past it. Any radioactive materials that were leached out would be fixed by adsorption before they had moved far. Mixtures of high specific activity could be used, for heat dissipation from the thin sheets would be no problem. Cement-mud mixtures can probably be developed to set up with almost any waste; the method may be particularly suitable for handling decladding wastes and the like, which are difficult to treat in any other way because of their bulk chemical composition. The volume of even a single thin fracture is somewhat surprising if it is extensive enough; it is routine for the petroleum industry to put over a hundred thousand gallons of crude and over a quarter of a million pounds of sand into a single fracture in only a very few hours; a single good well should then be able to take some millions of gallons of mixture. The method could have very real application. The crucial problem at Oak Ridge, as elsewhere, is the predictability of the fracture pattern that one would get in the local shales, in this case the Conasauga.

5.3 Conclusions

The problems of ultimate waste disposal at Oak Ridge are reduced to the following requirements:

1. Convert all high-activity liquid wastes to packaged solids and store in underground facilities designed and located for the purpose.

2. Convert intermediate-activity liquid wastes to packaged solids (by calcination or ion exchange in man-made soil columns) and store underground or drive them into the Conasauga shale below zones of circulating water, e.g., by fracturing.

3. Decontaminate large-volume low-activity waste water with improved techniques for higher decontamination factors (10^2 or 10^3) and discharge to the creek and river for additional purification and dilution, or drive them into the Conasauga shale above the water table to take advantage of the high sorptive capacity.

6.0 SUITABILITY OF WHITE OAK CREEK DRAINAGE BASIN AS A SITE FOR A REACTOR FUEL PROCESSING PLANT

In evaluating the suitability of White Oak Creek drainage basin as a site for a chemical processing plant, it is necessary to consider the manner in which water moves through the basin, on the surface, and underground. In regions of abundant rainfall, such as East Tennessee, water is perhaps the most important vehicle that transports radioactive contaminants.

The principal source of ground water in the basin is precipitation that falls within its boundaries. Precipitation that reaches the water table moves through the subsurface and is discharged as springs and seeps at points of lower elevation along the streams. Due to the relative impermeability of the rocks that underlie Bethel and Melton Valleys and the configuration of the land surface, the distance of underground movement from points of recharge to points of discharge in these valleys is generally less than 1000 ft. The ground water so discharged supports the low flow of White Oak Creek and its tributaries, which, in turn, augment the flow of the Clinch River. Ground water is not taken from the basin for consumption and hence contaminated ground water is important only as a potential source of contamination of surface streams.

Oak Ridge National Laboratory is on White Oak Creek about 2.5 miles upstream from its confluence with the Clinch River. From the considerations above, water reaching the water table beneath Bethel and Melton Valleys is discharged at the surface after traveling 1000 ft or less underground. From there the water flows in White Oak Creek or its tributaries a maximum distance of 2.5 miles before reaching the Clinch.

The most important mechanism in fixing or decreasing the mobility of activity released in the White Oak Creek drainage basin is the sorptive properties of the soil and rock on or through which the water flows. Silt suspended in the surface streams also retards and modifies the downstream movement of contaminants.

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