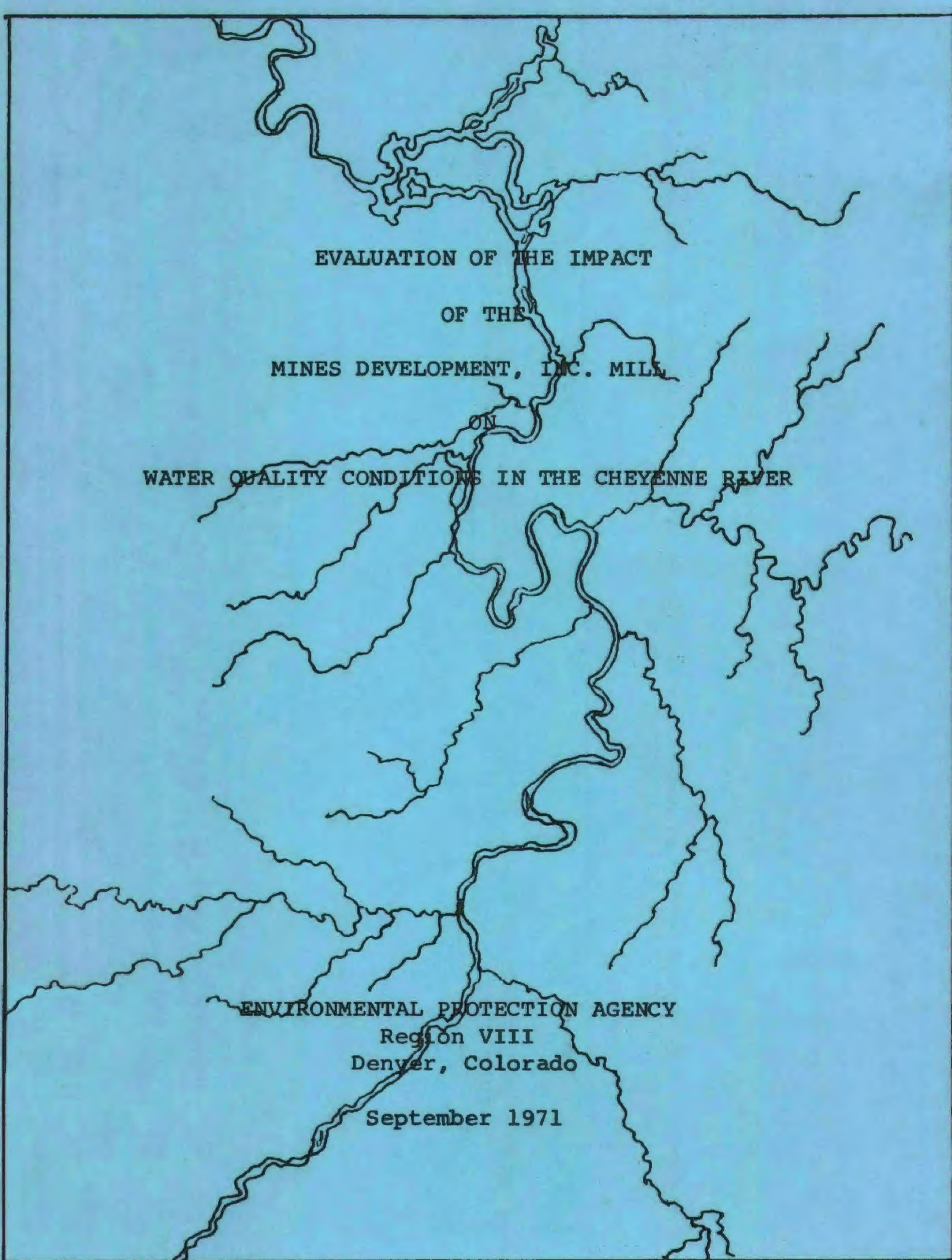

EVALUATION OF THE IMPACT

OF THE

MINES DEVELOPMENT, INC. MILL

ON

WATER QUALITY CONDITIONS IN THE CHEYENNE RIVER

ENVIRONMENTAL PROTECTION AGENCY
Region VIII
Denver, Colorado

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

I. INTRODUCTION

An intensive water quality study of the Cheyenne River and the tributary stream, Cottonwood Creek, in the environs of the Mines Development Mill located at Edgemont, South Dakota, was conducted by EPA personnel1/ during July 26-30, 1971. The objectives of the study were to determine and evaluate:

1. Water quality conditions in Cottonwood Creek and the Cheyenne River during a period of dry weather flow.
2. Chemical and radioactivity loadings (mass/day) on Cottonwood Creek and the Cheyenne River as the result of seepage from mill ponds.
3. Radioactivity levels in the water, biota and bottom sediment of Angostura Reservoir.

The July study was conducted at the request of the South Dakota State Department of Health. In this respect, the study represented a continuation of the support provided to the State in its long-term program to monitor and assess the environmental impact of mill operations. Mines Development personnel were

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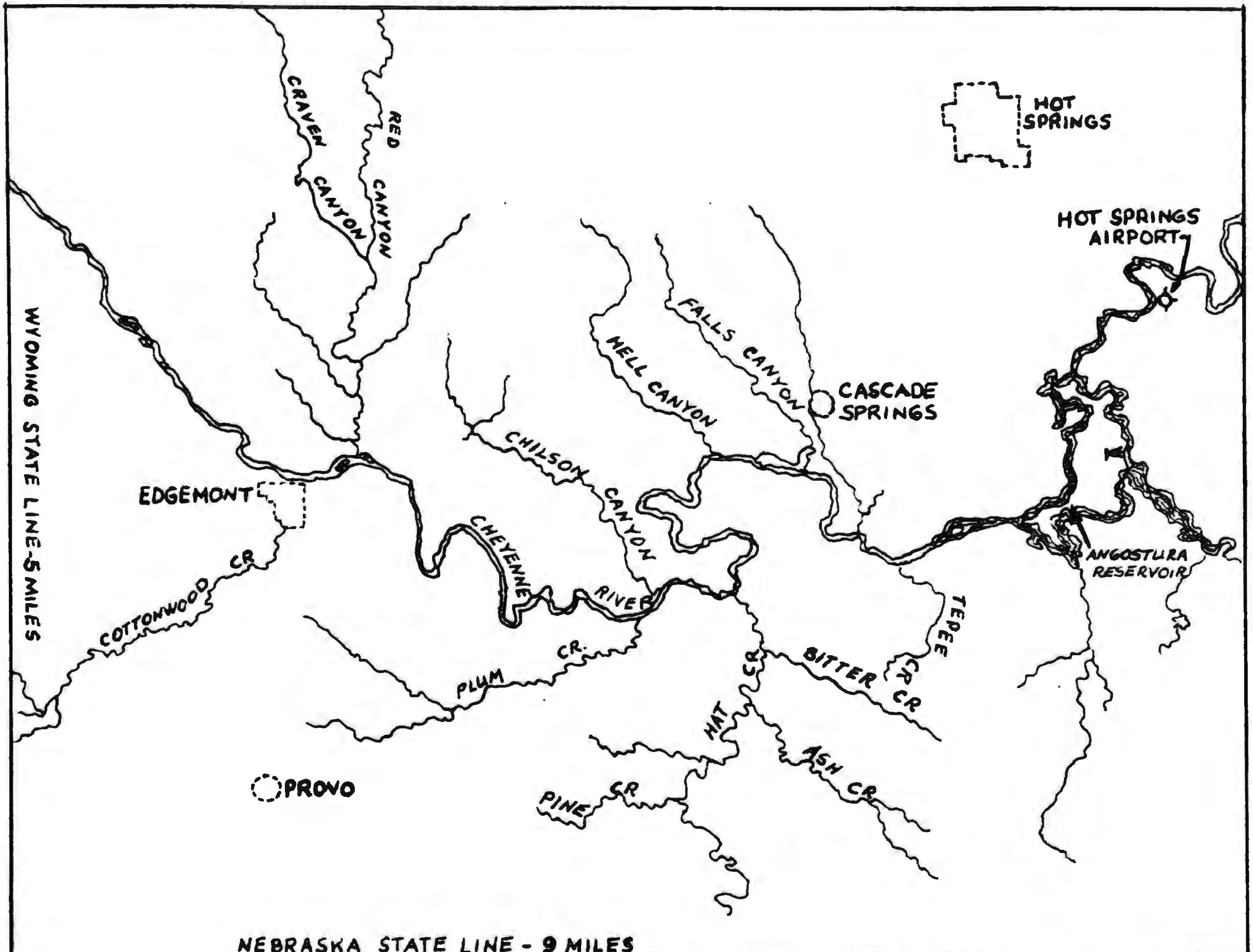
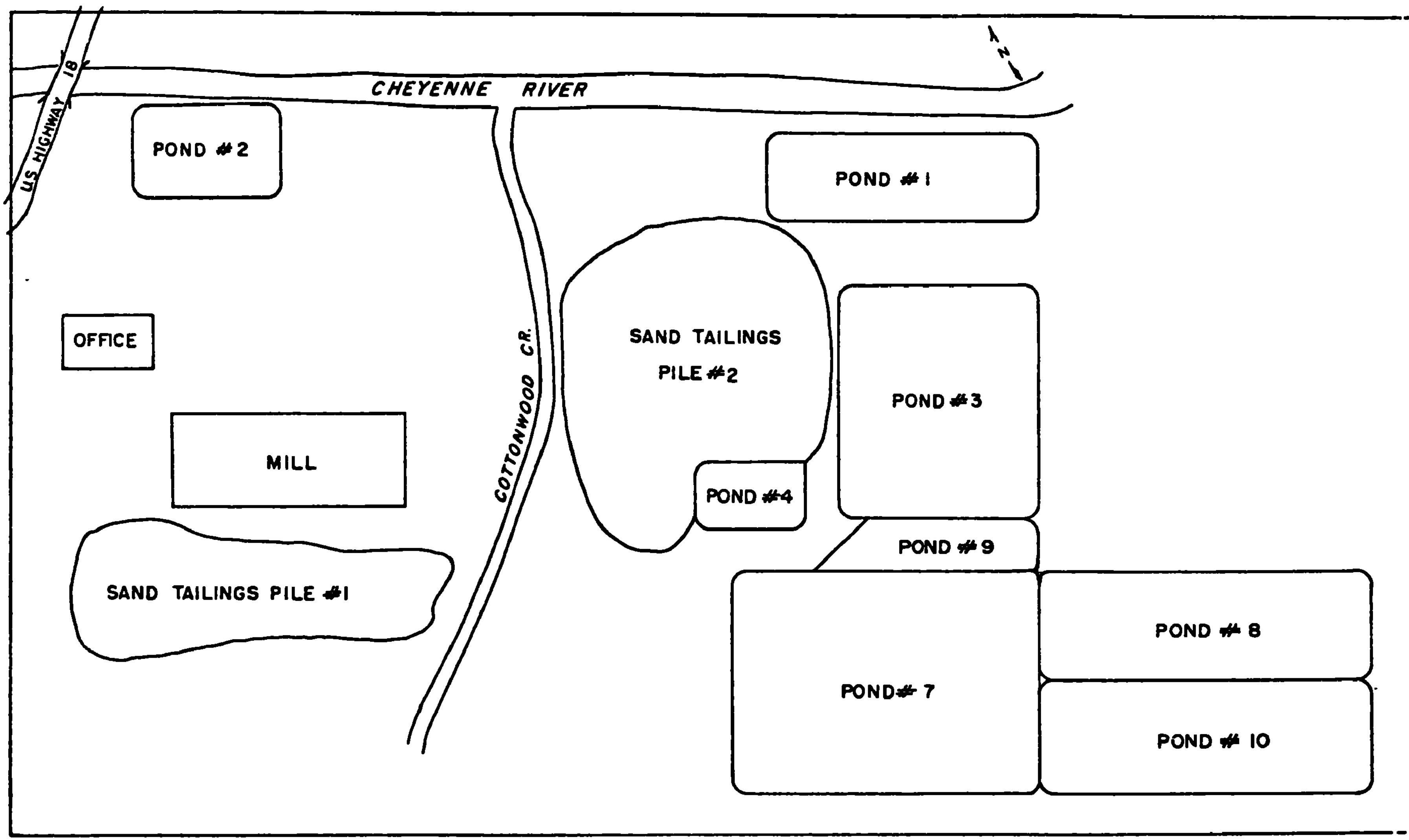
1/ Radiological Activities Section, Division of Technical Support, Office of Water Programs, Cincinnati, Ohio most cooperative in providing the field team with unlimited access across mill property and bench space in the mill laboratory.

The "Edgemont" mill is operated by Mines Development, Inc., a subsidiary of the Susquehanna Corporation. As shown in Figure I, the mill is located in the southwest corner of South Dakota on the south bank of the Cheyenne River. A tributary to the Cheyenne River, Cottonwood Creek, traverses the mill property and is flanked on both sides by inactive sand tailings piles (Figure 2). Angostura Reservoir, a recreational lake, is located about thirty-five miles downstream near the city of Hot Springs.

Mineral processing operations carried out at the mill involve the recovery of uranium, vanadium, and molybdenum (a contaminant in the uranium ore). Recovery and extraction operations for vanadium and uranium are housed in separate buildings. However, the two circuits are connected with the slime tailings effluent from the uranium circuit becoming the feed solution to the vanadium circuit after clarification in the mill ponds. Uranium ore is locally obtained from shaft and open-pit mines. A foreign source of ore is used as the dry feed to the vanadium circuit to supplement the soluble vanadium feed from the uranium circuit. During the July study, the average



LOCATION MAP
FIGURE 1



MINES DEVELOPMENT, INC.
URANIUM MILL
PROCESS PONDS AND TAILINGS PILES
FIGURE 2

ore feeds to the uranium and vanadium circuits were 400 and 15.5 tons/day, respectively. For uranium, this corresponded to operation at approximately sixty percent of plant capacity, 650 tons/day.

Pre-operational surveillance of the Cheyenne River was performed during February, 1956, by personnel of the South Dakota Department of Health and U. S. Public Health Service. Four stations were sampled: (1) upstream from the mill site at the State Highway 18 bridge, (2) approximately 1.5 miles downstream from Edgemont, (3) at Falls Canyon and (4) just upstream from the confluence with Tepee Creek. Unfortunately, since the mechanics of environmental surveillance were in the developmental stages at that time, radioactivity analysis was limited to gross procedures instead of the more definite analysis for specific radionuclides. Water samples contained 10 to 40 picocuries per liter (pCi/l) of dissolved alpha activity and 10 to 120 pCi/l of dissolved beta activity; suspended radioactivity was negligible. In retrospect, dissolved gross alpha and beta concentrations at the upper limits of the observed ranges now seem unusually high for natural background conditions. Bottom sediment samples showed an average content of 10 and 15 picocuries per gram (pCi/g) of dry solids of alpha and beta activity, respectively. All the biological samples (algae, insects, minnows and plankton) showed corresponding low concentrations of gross radioactivity. The initial post-operational monitoring effort (June 1957) did not show levels of dissolved radioactivity in either the Cheyenne River or Cottonwood Creek greater than background levels, despite a low flow drainage from the sand tailings pond to the creek containing 1400 and 1800 pCi/l of dissolved alpha and beta activity, respectively.

II. SUMMARY

Uranium and vanadium recovery operations carried out at the Edgemont mill generate liquid wastes and spent ore solids which are discharged to a system of ponds. These ponds retain the fine (slimes) and coarse (sand tailings) ore solids on the mill property. However, due to the permeability of the soil in which the ponds are excavated, liquid wastes are lost to the ground and eventually reach the Cheyenne River and Cottonwood Creek in the form of seepage. The impact of this seepage in the water environment is the following:

1. Unsightly discoloration of stream bank and channel areas by the accumulation and/or deposition of "iron-rich" solids.

   Although the areas so affected are rather extensive during low flow conditions, the only area which is readily visible from the State Highway 18 bridge is the seepage zone adjacent to Pond No. 2.

2. Increases chemical and radioactivity concentrations in Cottonwood Creek and, to a much lesser extent, the Cheyenne River.

   The 1964 study showed dissolved uranium and radium-

226 concentrations in Cottonwood Creek substantially in excess of background concentrations (30 and 100X greater, respectively). In subsequent studies, radium and uranium concentrations were lower; approximately one order of magnitude greater than background levels.

Consistent with the findings for Cottonwood Creek, the maximum radioactivity concentrations in the Cheyenne River were obtained in the 1964 study. At a location about 1.5 miles below the mill, dissolved radium-226 and uranium concentrations were 2.5 pCi/l and 130 μg/l, respectively. These values corresponded to a ten-fold increase above background. The results for other studies at this same sampling station and other downstream stations were substantially lower - values less than 1.0 pCi/l of radium-226 and 50 μg/l of uranium.

Flow data for the 1971 study indicated that Hat Creek has a decided impact on Cheyenne River water quality conditions, at least during low flow periods. During the 1971 study, Hat Creek was responsible for 80 percent of the Cheyenne River flow at the State Highway 71 bridge.

Increased radioactivity levels in the Cheyenne River downstream from the mill do not pose a health hazard from excessive exposure to radiation. Obviously, the non-use of the Cheyenne River for domestic water supply makes this conclusion a fact. However, a comparison of the observed concentrations of radium-226 and uranium with currently accepted standards (Table I) also shows that the radiological quality of the Cheyenne River is acceptable for drinking water purposes. Based on the radium-226 concentrations observed during low flow conditions, it seems possible that the annual average concentration of radium-226 does not exceed 1.0 pCi/l. If the Cheyenne River was used as a regular source of drinking water, the resultant intake would be only 5% of the transient rate of daily intake for the general population, as recommended by the Federal Radiation Council (upper limit of Range II). The fact that the maximum radium concentration observed in the Cheyenne River was less than the current Public Health Service guideline for radium-226 in drinking water also demonstrates the absence of a potential health hazard from this radionuclide. Similarly, the dissolved uranium concentrations in the river have not approached levels of public health significance. The maximum concentration

TABLE I RADIOACTIVITY STANDARDS

Radionuclide	Drinking Water Standard	Limiting Rate Of Daily Intake From All Sources (Annual Average)	Recommending Authority
Radium-226	3.0 pCi/l[(a)]	20 pCi/day	U.S. Public Health Service
		0 to 2 pCi/day-Range I[(b)] 2 to 20 pCi/day-Range II 20 to 200 pCi/day-Range III	Federal Radiation Council
Uranium	700 ug/l[(c)]	0.7 mg/day[(d)]	International Commission on Radiological Protection (ICRP)
	22 mg/l[(c)]	22 mg/day[(d)]	National Committee on Radiation Protection (NCRP)

(a) The limit may be exceeded if the radioactivity intake from all sources in addition to that from water does not exceed intake levels recommended by the Federal Radiation Council for control action (the upper limit of Range II).

(b) Action required:
Range I - Periodic confirmatory surveillance as necessary.
Range II - Quantitive surveillance and routine control.
Range III - Evaluation and application of conditional control measures as necessary.

(c) Calculated from the limiting rate of daily intake by assuming a daily intake from drinking water of 1 liter/day and no intake from other sources.

(d) Based on 1/30 of the maximum permissible concentration for natural uranium for continuous occupational exposure, the specific activity for uranium-238, an activity ratio (uranium-234/uranium-238) equal to unity, and a daily water intake of 2.2 liters/day from all sources.

of dissolved uranium observed in Cheyenne River was about 20% of the ICRP standard; negligible in comparison to the NCRP standard. (Note: To date, the more restrictive ICRP standard has not been formally adopted by the NCRP.)

The contaminated reach of Cottonwood Creek lies wholly within the mill property with access to the general public restricted. Therefore, the creek is not a direct source of radiation exposure to the general public.

Based on visual observations, sand tailings from the three storage areas (Pile No. 1, Pile No. 2, and Pond No. 2) are entering the water environment by wind and/or water errosion. Such off-site losses of these high-radioactivity solids is most undesirable and should be curtailed at an early date.

III. RECOMMENDATIONS

1. The bottom and sidewalls of the retention ponds should be sealed to eliminate seepage into Cottonwood Creek and the Cheyenne River.

2. A two phase program providing for the stabilization and ultimate disposal of sand tailings should be developed with a reasonable timetable for implementation. As a first phase, immediate action should be taken to stabilize the huge bulks of sand tailings stored in Pile No. 1, Pile No. 2, and Pond No. 2 against wind and/or water errosion. The most desirable alternative for the second phase of the program, ultimate disposal, seems to be storage in the excavated portions of the open-pit uranium mine operated by Mines Development, Inc.

3. Monitoring stations should be established on Cottonwood Creek (at the mouth) and the Cheyenne River (downstream from the mill) to determine the extremes in chemical and radioactivity concentrations as well as the annual average radioactivity concentrations. As a minimal effort, weekly grab samples should be collected with analyses performed on monthly composites. Monitoring should be continued

after recommendation (1), above, has been implemented to show the sustained integrity of the sealed ponds. During this stage, the frequency of sample collection could be reduced to monthly grabs.

4. The classification of Cottonwood Creek should be resolved in regard to applicable standards, i.e., effluent limits or receiving water standards. Upstream from the mill the creek is an intermittent stream whereas flow in the reach traversing mill property is maintained by seepage, possible spring flow, and drainage from an abandoned railroad well.

IV. WASTE MANAGEMENT PRACTICES

The waste management program conducted by Mines Development essentially provides for the on-site retention of liquid and solid wastes with no direct release to the water environment. Briefly, liquid wastes from the uranium and vanadium extraction circuits are discharged to a system of process ponds wherein volume reduction occurs by evaporation and seepage. Seepage losses are the result of pond excavation in a zone of permeable soil. In order to control the total volume of required ponding, water is recycled for use as process water. Sand tailings are stored in two unstabilized piles and two retention ponds. An areal schematic showing the locations of the ponds and the sand tailings piles is presented in Figure 2.

Operational functions of the various ponds are summarized in Table II. The flow scheme for the pond system is the following:

1. Slime tailings and sand tailings from the uranium circuit are discharged to Pond No. 7, a pond functioning as a retention and sedimentation basin.
2. Clarified vanadium-bearing liquor (blue liquor) is pumped to Pond No. 3.

TABLE II MILL PROCESS & RETENTION PONDS

	Pond Use	
Pond	Current	Past
No 1	Disposal of raffinate from the vanadium extraction circuit.	Retention of slime tailings from the uranium circuit.
No 2	Sand tailings storage.	Disposal of vanadium raffinate and retention of slime tailings.
No 3	Storage basin for vanadium-bearing liquor (blue liquor).	Retention of slime tailings.
No 4	Not in use.	"Polishing" sedimentation basin for vanadium-bearing liquor.
No 7	Retention and storage of slime tailings and sand tailings; sedimentation basin to produce clarified blue liquor.	Same as current use except for the storage of sand tailings.
No 8	Contingency.	
No 9	Not in use.	
No 10	Contingency.	

3. Clarified blue liquor is pumped from Pond No. 3 to the head-end of the vanadium extraction circuit.

4. Vanadium raffinate is discharged to Pond No. 1.

There is sufficient flexibility built into the pumping system to transfer liquid between any two ponds, including the two ponds which are in standby condition.

Until the weekend of August 27-28, 1966, Pond No. 2 was used for the storage and retention of slime tailings and vanadium raffinate. At that time, the discharge of repulped sand tailings was diverted from Pile No. 2 to this pond. This was an attempt to seal the bottom of Pond No. 2 with ore solids; thereby stopping the seepage into the Cheyenne River at the base of the bank. The resultant mass of sand tailings stored in this area rises above the original elevation of the pond surface. Based on visual observations, the tailings appear to be drifting toward Highway 18 and down the river bank with perhaps some level of entry into the Cheyenne River. This was anticipated when it was noted in the report on the 1966 study that "storage of sand tailings in Pond No. 2 does present this somewhat undesirable feature of placing the sand directly on the bank of the Cheyenne River."

Sand tailings Pile No. 1 is contiguous with Cottonwood Creek for a distance of several hundred feet (conservatively estimated). Therefore, there is undoubtedly some loss of solids to the creek as the result of errosion during a period of high runoff and wind transport. Although the bulk of sand tailings Pile No. 2 is located at much higher elevation than the channel of Cottonwood Creek, there appears to be sloughing of material from the pile onto the flood plain. In essence, sand tailings from the inactive piles are probably reaching the Cheyenne River with subsequent transport downstream into Angostura Reservoir.

V. PREVIOUS WATER QUALITY STUDIES

Short-term field studies to monitor water quality conditions in the Cheyenne River and Cottonwood Creek have been conducted on five occasions since the initial 1957 post-operational study: October 17-18, 1962; August 6-7, 1964; September 7-9, 1966; early December, 1967; August 15, 1968. These have been cooperative investigations between the South Dakota State Department of Health and the Environmental Protection Agency[a]. For all studies, the radiochemical analyses were performed in EPA laboratories. In the case of 1966 study, water and bottom sediment sampling was a cooperative undertaking. State personnel were solely responsible for sample collection in the other studies. A list of the stations at which water and bottom sediment samples have been collected in the course of these studies is given in Table III.

The results of the physical and chemical analyses of water samples are summarized in Tables IV and V. Similar data for the seepage samples collected during the 1966 study are pre-

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(a) Organizational predecessors of the Office of Water Programs, Environmental Protection Agency. That is, the U.S. Public Health Service (Division of Water Supply and Pollution Control), the Federal Water Pollution Control Administration and the Federal Water Quality Administration.

TABLE III CHEYENNE RIVER AND COTTONWOOD CREEK SAMPLING STATIONS

Station	Description
1	Cheyenne River just upstream from the Highway 18 bridge outside of Edgemont.
2	Cottonwood Creek at the pedestrian bridge; 200 feet above sand tailings Pile No. 1 and just south of the fence that forms the south boundry of mill property.
3	Cottonwood Creek several hundred feet upstream from its confluence with the Cheyenne River; downstream from sand tailings Pile No. 2.
4	Cheyenne River between the Cottonwood Creek confluence and Pond No. 1.
5	Cheyenne River about 1.5 miles downstream from the mill.
6	Cheyenne River at the Highway 71 bridge.
7	Cheyenne River in the headwaters of Angostura Reservoir; 0.5 miles downstream in Tepee Canyon.
8	Central portion of Angostura Reservoir.
9	Cheyenne River about 0.25 miles below Angostura Dam.

TABLE IV DISSOLVED RADIOACTIVITY IN CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES

	Dissolved Radioactivity					
Station	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Radium-226 (pCi/l)	Lead-210 (pCi/l)	Uranium (µg/l)	Thorium (µg/l)
1 - 1962	12	55	----	---	--	----
1964	--	--	0.26	---	17	----
1966	15	61	0.25	0.6	12	----
1967	--	--	0.10	0.9	13	N.D.
1968	--	--	0.10	---	7	N.D.
2 - 1962	9	--	----	---	--	----
1964	--	--	0.26	---	7	----
1966	17	163	0.10	0.7	18	----
1967	--	--	----	---	--	----
1968	--	--	0.11	---	18	N.D.
Cottonwood Creek at the seepage zone adjacent to Pond No. 7 (1968)	--	--	0.86	---	100-200[(a)]	----

(a) Analytical difficulty prevented reporting of a specific concentration.
N.D. - Not detectable, i.e. net counting rate less than two standard deviations counting rate

TABLE IV (Continued) DISSOLVED RADIOACTIVITY IN CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES

Station	Dissolved Radioactivity Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Radium-226 (pCi/l)	Lead-210 (pCi/l)	Uranium (μg/l)	Thorium (μg/l)
Cottonwood Creek at the seepage zone adjacent to sand tailings Pile No. 2 (1967)	--	--	0.60	N.D.	53	2.3
3 - 1962	48	180	----	---	--	----
1964	--	--	24	---	550	----
1966	1	53	1.6	1.2	49	----
1967	--	--	0.60	N.D.	64	5.7
1968	--	--	0.46	---	12	5.0
Cheyenne River adjacent to Pond No. 2 seepage zone						
1964	--	--	0.26	---	4	----
1966	14	--	0.50	4.7	18	----
1967	--	--	0.10	0.2	26	----
1968	--	--	0.27	---	15	----

TABLE IV (Continued) DISSOLVED RADIOACTIVITY IN CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES

Station	Dissolved Radioactivity					
	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Radium-226 (pCi/l)	Lead-210 (pCi/l)	Uranium (µg/l)	Thorium (µg/l)
4 - 1966	15	50	0.29	---	--	----
1967	--	--	----	---	--	----
1968	--	--	0.44	---	10	N.D.
5 - 1962	11	56	----	---	--	----
1964	--	--	2.5	---	130	----
1966	9	127	0.50	0.2	26	----
6 - 1962	20	--	----	---	--	----
1964	--	--	0.44	---	8	----
1966	5	101	0.30	N.D.	13	----
1967	--	--	0.40	N.D.	19	8.5
7 - 1962	3	37	----	---	--	----
1966	5	51	0.26	0.1	9	----
8 - 1966	5	23	0.14	---	--	----
9 - 1966	3	29	0.28	0.1	13	----

TABLE V **CHEMICAL AND PHYSICAL CHARACTERISTICS OF CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES**

Station	Dissolved Solids (mg/l)	Susp. Solids (mg/l)	Total Iron (mg/l)	Sulfates (mg/l)	Nitrates (mg/l)	pH	Vanadium (μg/l)
1 - 1962	3552	--	--	----	----	--	---
1964	----	--	36	2140	0	7.8 - 8.0	---
1966	3098	28	--	----	----	--	---
1967	----	--	--	----	----	--	<100
1968	----	--	--	----	----	--	<20
2 - 1962	4160	--	--	----	----	--	---
1964	----	--	20	2350	0	7.0	---
1966	4112	39	--	----	----	7.3	---
1967	----	--	--	----	----	--	---
1968	----	--	--	----	----	--	<20
Cottonwood Creek at the seepage zone adjacent to Pond No. 7 (1968)	----	--	--	----	----	--	<20

TABLE V (Contined) CHEMICAL AND PHYSICAL CHARACTERISTICS OF CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES

Station	Dissolved Solids (mg/l)	Susp. Solids (mg/l)	Total Iron (mg/l)	Sulfates (mg/l)	Nitrates (mg/l)	pH	Vanadium (µg/l)
Cottonwood Creek at the seepage zone adjacent to sand tailings Pile No. 2 (1967)	----	--	--	----	----	--	<100
3 - 1962	5328	--	--	----	----	--	---
1964	----	--	67	2400	0.29	6.4	---
1966	6286	268	--	----	----	6.3	---
1967	----	--	--	----	----	--	<100
1968	----	--	--	----	----	--	<20
Cheyenne River adjacent to Pond No. 2 seepage zone							
1964	----	--	196	3240	0.36	6.0	---
1966	19500	178	--	----	----	6.5	---
1967	----	--	--	----	----	--	<100
1968	----	--	--	----	----	--	<20

TABLE V (Continued) CHEMICAL AND PHYSICAL CHARACTERISTICS OF CHEYENNE RIVER AND COTTONWOOD CREEK WATER SAMPLES

Station	Dissolved Solids (mg/l)	Susp. Solids (mg/l)	Total Iron (mg/l)	Sulfates (mg/l)	Nitrates (mg/l)	pH	Vanadium (μg/l)
4 - 1966	3556	21	--	----	----	--	---
1967	----	--	--	----	----	--	---
1968	----	--	--	----	----	--	<20
5 - 1962	3624	--	--	----	----	--	---
1964	----	--	42	3667	1.52	7.4	---
1966	3538	6	--	----	----	--	---
6 - 1962	3084	--	--	----	----	--	---
1964	----	--	47	1593	0.10	7.8	---
1966	2664	5	--	----	----	--	---
1967	----	--	--	----	----	--	<100
7 - 1962	824	--	--	----	----	--	---
1966	1558	37	--	----	----	--	---
8 - 1966	1656	2	--	----	----	--	---
9 - 1966	1668	3	--	----	----	--	---

sented in Table VI. Although data for the 1962, 1964, and 1966 studies were the subject of a previous report, these data are included herein to maintain continuity and to present the complete historical record, particularly for comparative purposes.

As shown in Table IV seepage into Cottonwood Creek results in significant degradation of water quality. The specific reductions in chemical, physical and radiological quality were the following:

1. Significant increases in the concentration of dissolved gross alpha and beta radioactivity, radium-226, uranium, and lead-210. The maximum concentrations of radium-226 and uranium were observed in 1964. These values, 550 μg/l of uranium and 24 pCi/l of radium-226 were approximately 30 and 100 times the respective background levels.
2. Increases in the dissolved solids and total iron (dissolved) concentrations.
3. pH decrease.
4. Discoloration to the extent that the creek has been described as "running red" on occasion. This was considered to be attributable to a chemical reaction between the natural water and the iron-bearing seepage.

TABLE VI PHYSICAL AND RADIOLOGICAL CHARACTERISTICS OF SEEPAGE SAMPLES

Description	Dissolved Radioactivity					Dissolved Solids (mg/l)	pH
	Gross Alpha (pCi/l)	Gross Beta (pCi/l)	Radium-226 (pCi/l)	Lead-210 (pCi/l)	Uranium (μg/l)		
Seepage from bank of Cottonwood Creek adjacent to Sand Tailings Pile No. 2	148	187	32	0.8	175	8212	6.3 to 6.7
Seepage from bank of Cheyenne River upstream from Pond No. 1	35	342	1.4	0.4	89	21,800	5.7

Presumably, iron-bearing precipitate was formed which gave the stream a red to reddish-brown appearance when suspended and transported in the liquid phase.

Although the flow in Cottonwood Creek is intermittent in nature upstream from the mill, seepage or a combination of seepage and spring flow apparently maintain flow in the creek throughout the reach on mill property. Intermittent flow appears to be the reason for the finding of maximum concentrations during the 1964 study. There was no observable flow upstream from the seepage zone in 1964 - the only study period for which such a condition was noted. Correspondingly, the differences in concentration increases indicated by the five studies are considered to be more a function of specific flow conditions and the dilution provided rather than differences in seepage flow or quality.

Several factors indicated the process and retention ponds were a major source of the seepage entering Cottonwood Creek: the extension of the zone of active seepage to bank height(s) substantially above the water surface, accumulation of reddish-brown deposits in the seepage zone considered to be indicative of high iron content in the seepage, and the physical and radiological characteristics of the seepage samples. The high radium-226 and uranium concentrations (Table VI) low pH, and implied high iron content of the seepage samples were consistent with the physical and chemical composition of the vanadium raffinate and vanadium-bearing liquors held in the ponds. These ponded liquors were characterized by low pH values (2.0 to 2.5), dissolved radium-226 concentrations in the range of 60 to 300 pCi/l, and dissolved iron concentrations in excess of 500 mg/l.

Another possible source of seepage in 1966 was drainage from sand tailings Pile No. 2 since the pumping of repulped tailings (50% slurry) was terminated only two weeks before the study. Moreover, mill personnel believed that as far as bulk flow into the creek was concerned, an underground spring rather than pond seepage or tailings pile drainage was the causative agent. If an underground spring is responsible for sustained flow in the creek, the water quality conditions in the creek indicate that the spring flow is contaminated by pond seepage.

The adverse effect of seepage from Pond No. 2 into the Cheyenne River was the unsightly discoloration of the stream bed at the base of the bank and for some distance downstream. Although the 1966 water samples from this location showed increased radioactivity levels (Table IV), the results were judged to be representative of partially diluted seepage percolating up through the stream bed; not stream quality. These samples were collected from a channel of flowing water adjacent to the dike, but separated from the main channel by a sand bar. As such, the indicated change in radiological water quality represented only a minute fraction of the Cheyenne River flow at this site.

Seepage into the Cheyenne River at a point just upstream from Pond No. 1 contained concentrations of dissolved radium and uranium in excess of surface water background levels (Table VI). However, the concentrations were much lower than those found in the seepage flowing into Cottonwood Creek - an order of magnitude less for radium-226. The seepage had no effect on Cheyenne River water quality because the observed flow was only trickle.

Downstream from the confluence with Cottonwood Creek, the Cheyenne River showed recovery to nominal or background levels in the vicinity of Station 5 or 6. Consistent with the findings for Cottonwood Creek, the maximum results for dissolved radium-226 and uranium concentrations in the Cheyenne River were observed in the 1964 study - 2.5 pCi/l of radium-226 and 130 µg/l of uranium. This is in contrast to the results of the other studies which have shown radium-226 and uranium concentrations in the river to be only slightly in excess of background levels. For example, with exception of the 2.5 pCi/l result, the maximum radium-226 concentration was 0.5 pCi/l at Station 5 during the 1966 study.

Chemical and radioactivity results for bottom sediment samples are presented in Table VII. Although the vanadium results indicated somewhat higher levels in the seepage zone of Cottonwood Creek, the finding was not considered definitive in terms of providing positive identification of vanadium liquors as a major source of seepage. This was due to the limited number of samples analyzed and the relative insensitivity of the analytical procedure. Similarly, the iron data did not provide a quantitive-type illustration of the bank and channel discoloration. This was, in part, attributable to the method of sample collection. Sediment samples were collected in a manner such that they were representative of the average condition at each location and were not limited to the collection of obviously discolored material (unless the discoloration was distributed across the channel width).

Radium-226 and uranium concentrations in the bottom sediments showed the same contamination pattern as that exhibited by the corresponding results for water samples. That is, the

TABLE VII RADIOACTIVITY CHEMICAL CONTENTS OF BOTTOM SEDIMENTS FROM THE CHEYENNE RIVER AND COTTONWOOD CREEK

Station	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Radium-226 (pCi/g)	Uranium (μg/g)	Vanadium (μg/g)	Iron (μg/g)
1 - 1962	7	37	---	---	---	----
1964	--	--	1.4	2.4	---	----
1966	5	18	1.2	---	---	----
1967	--	--	---	---	---	----
1968	--	--	1.2	0.6	<50	4720
2 - 1962	70	195	---	---	---	----
1964	--	--	4.4	5.6	---	----
1966	7	41	2.0	---	<50	>2500
1967	--	--	---	---	---	----
1968	--	--	2.3	2.2	60	8180
Cottonwood Creek at the seepage zone adjacent to Pond No. 7 (1968)	--	--	7.9	2.7	<50	9530

TABLE VII (Continued) RADIOACTIVITY CHEMICAL CONTENTS OF BOTTOM SEDIMENT FROM THE CHEYENNE RIVER AND COTTONWOOD CREEK

Station	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Radium-226 (pCi/g)	Uranium (µg/g)	Vanadium (µg/g)	Iron (µg/g)
Cottonwood Creek at the seepage zone adjacent to sand tailings Pile No. 2						
1966	55	61	12	---	---	----
1967	--	--	15	9.5	310	>2500
3 - 1962	124	195	--	---	---	----
1964	--	--	74	62	---	----
1966	55	61	12	---	---	----
1967	--	--	45	6.5	190	>2500
1968	--	--	31	8.5	90	6350
Cheyenne River at base of Pond No. 2 dike						
1964	--	--	1.1	9.3	---	----
1966	4	24	1.0	---	<50	1550
1967	--	--	1.8	1.9	<50	>2500
1968	--	--	1.1	0.6	<50	1890

TABLE VII (Continued) RADIOACTIVITY CHEMICAL CONTENTS OF BOTTOM SEDIMENTS FROM THE CHEYENNE RIVER AND COTTONWOOD CREEK

Station	Gross Alpha (pCi/g)	Gross Beta (pCi/g)	Radium-226 (pCi/g)	Uranium (µg/g)	Vanadium (µg/g)	Iron (µg/g)
4 - 1966	11	33	2.9	---	<50	1875
1967	--	--	3.7	2.2	<50	1970
1968	--	--	2.7	1.6	60	3010
5 - 1962	14	64	---	---	--	----
1964	--	--	3.9	11	--	----
1966	15	25	2.7	---	--	----
1968	--	--	2.1	1.5	< 50	3150
6 - 1962	13	91	---	---	--	----
1964	--	--	0.9	1.4	--	----
1966	7	24	1.7	---	< 50	1075
1967	--	--	0.9	0.9	< 50	825
7 - 1962	11	47	---	---	--	----
1966	8	31	1.7	---	--	----
8 - 1966	6	32	1.5	---	--	----
9 - 1966	4	17	1.3	---	--	----

highest level of contamination occurred in Cottonwood Creek with concentrations ranging from 12 to 74 pCi/gram for radium-226 and 7 to 85 μg/gram for uranium (Table VII -Station 3). These values are in comparison to background concentrations on the order of 1.0 to 2.0 pCi of radium-226 and 1.0 to 2.0 μg of uranium. In the Cheyenne River, the sediment concentrations decreased to background levels in the reach between Stations 5 and 6. Radium-226 and uranium concentrations at the pedestrian bridge across Cottonwood Creek (Station 2) were slightly greater than background levels. A possible explanation is periodic contamination of this location by windblown sand tailings from Pile No. 1 (located several hundred feet downstream).

Radium-226 results for fish collected from Angostura Reservoir during the September, 1966, study are shown in Table VIII. Based on a comparison with similar results for fish collected at locations upstream from uranium mills in the Colorado River Basin, the Angostura fish were at typical background levels. This was consistent with the background level of dissolved radium-226 in Angostura Reservoir.

TABLE VIII RADIUM-226 CONCENTRATIONS IN ANGOSTURA RESERVOIR FISH SEPTEMBER, 1966

Species[a]	Radium-226 in Flesh: Live Weight of Composite Sample (gram)	Radium-226 in Flesh: pCi/gram Ash Weight	Radium-226 in Flesh: pCi/kilogram Wet Weight	Radium-226 in Bone: pCi/gram Ash Weight
Black Crappie (3)	105	0.06	0.75	0.08
Bluegill (6)	151	0.04	0.52	0.07
Ringed Perch (48)	727	0.47[b]	5.3[b]	0.10

(a) Number in parentheses refers to the number of fish in the composite sample
(b) Probably high as the result of the fusion of the sample with the porcelain dish during dry ashing.

VI 1971 FIELD STUDY

The July 1971 field study was conducted by personnel of the Environmental Protection Agency (Radiological Activities Section, Office of Water Programs) in cooperation with the South Dakota State Department of Health. Sampling extended over the five day period of July 26-30.

STUDY PROCEDURES

Sampling stations on the Cheyenne River and three tributaries, Cottonwood Creek, Hat Creek, and Cascade Springs, are listed in Table IX. Water samples were collected daily at the Cheyenne River and Cottonwood Creek stations (excluding Stations 9 and 10) whereas single grab samples were collected from Hat Creek and Cascade Springs. Bottom sediment samples were collected once at each station during the study period.

Staff gages (rated with a pygmy current meter) were used to meter the flow in Cottonwood Creek at each of the three sampling stations. The permanent gaging stations of the U. S. Geological Survey were used to obtain the flows in the Cheyenne River above the Edgemont mill and downstream at the State Highway 71 bridge. Flow in Hat Creek was also obtained from a U.S.G.S. gaging station.

TABLE IX COTTONWOOD CREEK AND CHEYENNE RIVER SAMPLING STATIONS - 1971

Station	Description
1	Cheyenne River just upstream from the State Highway 18 bridge outside of Edgemont; at the railroad bridge.
2	Cottonwood Creek upstream from mill property at the county road bridge; off State Highway 52.
3	Cottonwood Creek at the road culvert; downstream from sand tailings Pile No. 2.
4	Cottonwood Creek at confluence with the Cheyenne River.
5	Cheyenne River about 1.5 miles downstream from the mill.
6	Cheyenne River about 6 miles downstream from the mill; at Gull Hill Park.
7	Cheyenne River at ford on County Road 11.
8	Cheyenne River at State Highway 71 bridge.
9	Cheyenne River in the headwaters of Angostura Reservoir.
10	Cheyenne River below Angostura Dam.
11	Hat Creek.
12	Cascade Springs.

In addition to the collection of samples at the main stations on Cottonwood Creek and the Cheyenne River, bottom sediment samples were also collected in the following areas:

(a) Cottonwood Creek:

Six locations between the pipeline suspension bridge immediately upstream from sand tailings Pile No. 2 and the pedestrian footbridge. Sampling locations were selected to assess the variations in radioactivity concentrations throughout this previously unsampled reach.

(b) Cheyenne River:

Along the edge of the river channel extending from the downstream edge of Pond No. 1 for a distance of approximately one mile downstream (seven samples). This area was characterized by reddish-brown discoloration.

Thirteen soil samples were collected from the bank and dry stream bed adjacent to Pond No. 2.

Seepage samples were collected at four locations by excavating small collection basins in the bank proper:

(1) Cottonwood Creek just upstream from the pipeline suspension bridge (at the bank-stream bed interface).

(2) Cottonwood Creek several hundred yards upstream from the pipeline suspension bridge (approximately six feet above the water level in the creek).

(3) Cheyenne River just upstream from Pond No. 1 (approximately two feet above the stream water level).

(4) Cheyenne River about 1 1/2 miles downstream from the mill (just above the stream water level).

The collection basins were allowed to flush overnight and the samples collected the following morning with a polyethlene beaker or glass pipette. At the base of the Cheyenne River bank adjacent to Pond No. 2, seepage was collected from a natural depression in the dry steam bed.

Water and bottom sediment samples were collected from Angostura Reservoir at thirteen locations, providing complete coverage of the impoundment. At each station, the water column was sampled at the surface and near the bottom. Fish samples for radiological analysis were obtained from the fish sampling study conducted earlier in the year by the Division of Field Investigations - Denver, Environmental Protection Agency.

To assess the chemical and radiological characteristics of ground water in the mill environs, grab samples of well water were collected from the Edgemont reservoir well, Edgemont park well, Edgemont airport well, Mines Development process water well, an abandoned railroad well (next to Pond No. 2), and the Cheyenne River campground well (across the river from the mill).

SAMPLE PROCESSING PROCEDURES

Surface water samples and seepage samples were filtered on the day of collection. Well water samples were not filtered. All pH measurements were performed in the field or in the mill laboratory (within a few hours of collection) with a Yellow Springs portable meter.

Chemical and radiochemical analyses will be performed on the daily water samples collected at the Cottonwood Creek and Cheyenne River stations as well as 5-day composite samples. In the case of seepage in the vicinity of Pond No. 1, analyses will be performed on a composite sample prepared from the samples collected on two consecutive days.

Due to the large number of samples requiring analysis, the time required for a radium-226 determination, and the complexities of preparing sediment samples for radiochemical analysis, the quantitive data to be reported herein are largely limited to pH, dissolved uranium, and total alpha radium (dissolved) for water samples. A complete compilation of the radioactivity results will be the subject of a supplemental report.

Spectrographic metals analysis of the seepage samples was performed by the EPA Analytical Quality Control Laboratory, Cincinnati, Ohio.

RESULTS

Flows in Cottonwood Creek during the study period averaged 0.1 cfs at the upstream stations, 0.4 cfs at the road culvert, and 0.5 cfs at the mouth. The small increase between the culvert and the mouth might represent the drainage into the creek from the abandoned railroad well. However, the small difference is within the limits of metering error. Flow in the Cheyenne River was about 5 cfs at the upstream railroad bridge and approximately 132 cfs at the State Highway 71 bridge. The increase was largely attributable to Hat Creek (100 cfs) and Cascade Springs. All other tributaries were dry.

The limited results on water quality conditions in Cottonwood Creek and the Cheyenne River are presented in Table X. These data show the same pattern of water quality degradation as observed in past studies. That is, due to seepage, the dissolved uranium concentration in Cottonwood Creek approached a level in excess of 10X the natural level. In contrast, there

TABLE X DISSOLVED RADIOACTIVITY IN THE CHEYENNE RIVER, COTTONWOOD CREEK, HAT CREEK, AND CASCADE SPRINGS

	Dissolved Radioactivity[a]			
Station	Total Alpha Radium (pCi/l)	Uranium (μg/l)	Thorium (μg/l)	pH
1	0.11	16	4	8.0 - 8.2
2	0.67	26	3	7.0 - 7.1
3	0.75	147	2	6.4 - 6.8
4	0.09	177	1	6.7 - 7.1
5	0.17	28	7	7.8 - 8.0
6	0.32	14	5	8.1 - 8.4
7	0.11	19	3	7.9 - 8.2
8	0.10	14	3	7.9 - 8.2
9	0.14	10	3	-----
10	0.11	12	-	-----
11	0.08	24	2	7.7
12	0.08	5	-	6.8

(a) With the exception of single grab samples for Stations 11 and 12, the values refer to 5-day composite samples.

was a negligible concentration increase in the Cheyenne River downstream from the mill. This finding is consistent with the flow data which showed the dilution capacity afforded by the Cheyenne River was on the order of 50 times.

The total alpha radium analysis is commonly used as a quick guide to the probable radium-226 concentration. However, the analysis is not particularly sensitive and should not be depended upon completely to demonstrate small differences. For example, the results for the total alpha concentrations in the Cottonwood Creek samples indicated essentially no increase in the dissolved radium-226 concentration in the reach receiving seepage, a finding which was not consistent with the uranium results. However, radium-226 determinations on the composite samples for Stations 2 and 3 showed dissolved concentrations of 0.26 and 3.1 pCi/l, respectively. This was in complete accord with the uranium results.

By visually inspecting the reach of Cottonwood Creek extending from the pipeline bridge to the pedestrian bridge, the occurence of seepage from mill ponds was observed to extend at least as far upstream as a point opposite the north edge of Pond No. 7. In this area, the high bank was observed to be moist (and "dripping") to heights of over six feet above the water surface. Further, pooled sections of the creek were observed to have the same yellowish-green color as the seepage samples. Quantitative support for the conclusion that the mill ponds were a significant source of seepage was the high concentrations of molybdenum (5 to 25 mg/l) in the seepage samples. Molybdenum is a mill byproduct and dissolved concentrations in the ponds ranged from 20 to 75 mg/l[a]. The seepage samples also showed traces of iron and manganese (<2 mg/l) and, in one case, chromium, nickel and lead concentrations in the range of 5 to 25 mg/l.

Areas of reddish-brown (reddish-orange) channel discoloration were observed in Cottonwood Creek as far upstream as the pedestrian bridge and on both sides of the channel. This suggested the possibility that natural sources (springs, etc.) were partly responsible for the channel discoloration effect. However, the magnitude of discoloration within the mill proper indicates that seepage intensifies the problem and the overall situation is undoubtedly much worse than it would be in the absence of seepage from the ponds.

Based on the discoloration of the dry stream channel adjacent to Pond No. 2, seepage from the pond has not been com-

(a) Analysis of samples collected from the ponds.

pletely stopped despite the fact that the pond is an inactive repository for uranium sand tailings. The pond was not completely dry but contained a small pool of water in the end nearest the mill. Presumably, drainage from the abandoned railroad well is entering the pond.

The impact of seepage in the area of Pond No. 1 was substantially greater than that observed in 1966. During the 1966 study, the seepage caused only a small localized effect. However, in this most recent study, the impact of the seepage as measured by channel discoloration was observed for a distance of over one mile downstream. It was not determined whether this was the result of differences in Cheyenne River flow or increased seepage flow.

Dissolved uranium concentrations in the Angostura Reservoir samples were at natural background levels. The overall concentration range was 6 to 13 ug/1 with no significant differences between the surface and "bottom" samples.

ADDENDUM I

TO

"EVALUATION OF THE IMPACT OF THE MINES DEVELOPMENT, INC. MILL ON WATER QUALITY CONDITIONS IN THE CHEYENNE RIVER"

DISSOLVED MERCURY IN CHEYENNE RIVER, COTTONWOOD CREEK, AND SEEPAGE SAMPLES- 1971

Station	Dissolved Hg (ug/l)
1. Cheyenne River just upstream from the State Highway 18 bridge outside of Edgemont.	2.1
2. Cottonwood Creek upstream from mill property at the county road bridge; off State Highway 52.	3.5
3. Cottonwood Creek at the road culvert; downstream from sand tailings Pile No. 2.	4.2
4. Cottonwood Creek at confluence with the Cheyenne River.	1.8
5. Cheyenne River about 1.5 miles downstream from the mill.	0.6
6. Cheyenne River about 6 miles downstream from the mill; at Gull Hill Park.	3.0
7. Cheyenne River at ford on County Road II.	3.2
8. Cheyenne River at State Highway 71 bridge.	0.8
9. Cheyenne River in the headwaters of Angostura Reservoir.	1.8
Seepage into Cottonwood Creek just upstream from the pipeline suspension bridge.	1.0
Seepage into Cottonwood Creek several hundred yards upstream from the pipeline suspension bridge.	2.3

Station	Dissolved Hg (ug/l)
Seepage into the Cheyenne River just upstream from Pond No. 1.	2.2

NOTE: Analyses performed on field-filtered samples by the Division of Field Investigations - Cincinnati, Environmental Protection Agency. With the exception of the seepage samples, the dissolved mercury values refer to 5-day composite samples.

ADDENDUM II

TO

"EVALUATION OF THE IMPACT OF THE
MINES DEVELOPMENT, INC. MILL
ON
WATER QUALITY CONDITIONS IN THE CHEYENNE RIVER"

1. Page 1: In the fourth line, change the superscript 1/ to a/. Similarly, change the footnote designation from 1/ to a/.

2. Page 6: Insert the superscript 1 after the last word on this page.

3. Page 7, Item 2: "Increases" should be changed to "Increased".

4. Page 10, Table I: Insert superscripts 2,3,4, & 5 after U. S. Public Health Service, Federal Radiation Council, International Commission on Radiological Protection (ICRP), and the National Committee on Radiation Protection (NCRP), respectively.

5. Page 11: The following paragraph is to be added after the second paragraph:

   Despite the fact that the increased radioactivity concentrations in Cottonwood Creek and the Cheyenne River do not pose a public health hazard, steps should be taken to eliminate or substantially reduce the radioactivity of the seepage entering Cottonwood Creek and the Cheyenne River. This is consistent with a policy of minimizing the release of radioactive materials to man's environment insofar as is practicable. That is, the waste management program should be the best available provided the specific practices are technologically feasible and economically reasonable. Moreover, elimination of the aesthetically displeasing discoloration of bank and channel areas requires curtailment of the seepage from the retention ponds (or substantial reduction thereof).

   In the fourth line of the third paragraph, insert the superscript a/ after "... high-radioactivity solids..". This change is accompanied by the following footnote at the bottom of the page:

a/ A Sample of drained sands from Pile No. 2 collected during the 1966 study contained 230 pCi of radium-226 per gram dry weight.

6. Page 26: In the second sentence, insert the superscript 6 after "report".

7. A section listing references, Section VII, should be added as the last page of the report and noted in the Table of Contents.

VII. REFERENCES

1. Tsivoglou, E. C., Kalda, D. C., and Dearwater, J. R., "The Resin-In-Pulp Uranium Extraction Process. Mines Development Company, Edgemont, South Dakota", Technical Report W62-17, U. S. Public Health Service, R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio (1962)

2. U. S. Public Health Service, "Drinking Water Standards-1962", Publication No. 956.

3. Federal Radiation Council, "Background Material for the Development of Radiation Protection Standards", Staff Report No. 2 (September, 1961).

4. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection, as Amended 1959 and Revised 1962", ICRP Publication No. 6, Pergamon Press, New York, New York (1964).

5. National Committee on Radiation Protection,"Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure", Handbook 69 (including Addendum I), U. S. Department of Commerce, National Bureau of Standards (August 1963).

6. Federal Water Pollution Control Administration, "Evaluation of the Radioactivity Levels in the Vicinity of the Mines Development, Inc. Uranium Mill at Edgemont, South Dakota, 1966", Technical Advisory and Investigations Branch, Physical and Engineering Sciences Section, Cincinnati, Ohio (May 1967).