SECTION 6.0

GROUNDWATER QUALITY RESTORATION, SURFACE RECLAMATION AND PLANT DECOMMISSIONING

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6.1 AQUIFER RESTORATION PROGRAM

Prior to discussing restoration methodologies and results of the R & D restoration, discussion of the ore body genesis and the chemical and physical interactions between the ore body and the lixiviant is provided.

6.1.1 Ore Body Genesis

The Crow Butte uranium deposit is a roll front deposit in a fluvial sandstone. The deposit is very similar to those in the Wyoming basins such as Gas Hills, Shirley Basin and the Powder River Basin. The origin of the uranium in the deposit could be from within the host rock itself either from the feldspar or volcanic ash content of the Basal Chadron Sandstone. (The source of the uranium could also be the volcanic ash of the Middle Chadron Formation which directly overlies the Basal Chadron Sandstone). Regardless of the origin of the uranium, the uranium has been precipitated in several long sinuous roll fronts. The individual roll fronts are developed within subunits of the Basal Chadron Sandstone. The Basal Chadron Sandstone is divided into local subunits by thin clay beds that confined the uranium bearing waters to several distinct hydrologic subunits of the sandstone. These clay beds are laterally continuous for hundreds of feet but control the deposition of the uranium over greater distances as other clay beds exert vertical control when the locally controlling beds pinch out. Precipitation of the uranium resulted when the oxidizing water containing the uranium entered reducing conditions. These reducing conditions probably resulted from H_2S and to a lesser degree organic material and pyrite.

Solution mining of the deposit is accomplished by reversing the natural processes that deposited the uranium. Oxidizing solution would be injected into the mineralized portion of the Basal Chadron Sandstone to oxidize the reduced uranium and to complex it with bicarbonates. The uranium bearing solution is then drawn through the mineralized portion of the sandstone between the clay beds toward a recovery well by pumping. The presence of reducing agents will increase oxidant requirements over that necessary to only oxidize the uranium.

Since the deposition of the uranium was controlled between clay beds within the Basal Chadron Sandstone, the mining solutions will be largely confined to this portion of the sandstone by selectively screening these intervals. This will limit the contamination and thus the required restoration of unmineralized portions of the sandstone.

6.1.2 Chemical and Physical Interactions of Lixiviant with Ore Body

The following discussion is based on a range of lixiviant conditions from 0.5 to 3.0 grams per liter total carbonate and a pH of from 6.5 to 9.0. This represents the most likely range of operating conditions for the Crow Butte Commercial Plant.

6.1.3 Ion Exchange

The main ion exchange reaction will be the exchange of sodium from the lixiviant onto exchangeable sites on ore minerals with the release into solution of calcium, magnesium and potassium. This reaction can be shown as follows:

$$Ca_{clay} + 2\ Na^{+}_{soln} = 2\ Na_{clay} + Ca^{++}_{soln}$$

Similar reactions can be written for magnesium and potassium. Due to higher solubility of their sulfate and carbonate compounds and their low concentrations in Basal Chadron groundwater and the ore, magnesium and potassium in solution should have no impact. The limited solubility of calcium carbonate, and to a lesser degree, calcium sulfate, may lead to the potential for calcium precipitation.

Laboratory tests have indicated that the maximum calcium ion exchange capacity of the ore in a sodium lixiviant with 3 g/l total carbonate strength is 1.21 milliequivalents of calcium per 100 grams of ore. This equates to roughly 1/2 pound of calcium or about 1.2 pounds of calcium carbonate per ton of ore which could potentially be precipitated. Not all of this calcium, however, will be realized since the laboratory testing is

run in such a way as to indicate the maximum amount of calcium which can be exchanged. Somewhat less than this will be released and only a portion of that precipitated. There are no ways to directly control the buildup of calcium in the lixiviant circuit. In practice, one controls the lixiviant carbonate concentration and the lixiviant pH. The formation characteristics dictate an equilibrium calcium concentration in the lixiviant system and ion exchange and/or precipitation will occur until this equilibrium is satisfied. The overproduction bleed represents a departure from this equilibrium and as such has some effect on the amount of calcium exchanged. If the bleed is kept generally small, on the order of a few percent, the effect of the bleed on the ion exchange will be small.

6.1.4 Precipitation

In the presence of carbonate ions and bicarbonate ions in the lixiviant system, calcium ions will precipitate provided the limit of saturation has been reached. Calcium precipitation is a function of total carbonate, pH, and temperature. For example, at 15°C, a pH of 8.5, and 3 grams/liter total carbonate in a lixiviant solution the solubility of calcium will be approximately 1 to 5 ppm. Under the same conditions at pH 7.5, the equilibrium solubility will be in the range of 15 to 30 ppm, while at the same conditions in a pH 6.5 lixiviant the equilibrium solubility will be from 200 to 500 ppm. At 15°C, a pH of 7.5 and 1 gram/liter carbonate in lixiviant, the equilibrium solubility of calcium will be approximately 40 to 100 ppm. Some uncertainty is seen in these numbers due to the effect of ionic strength and supersaturation considerations. However, these figures do illustrate the effect of carbonate concentration and pH on the equilibrium solubility of calcium.

The amount of calcium produced depends on the ion exchange which is taking place, white the precipitation of calcium is a function of the lixiviant chemistry, and the degree of supersaturation which is observed in the system. As a first approximation, the proportion of calcium precipitation

occurring above ground and underground will occur in the ratio of the residence times. In other words, if the residence time is much longer underground than it is above ground, as is the case in most every in-situ leach operation, then more of the calcium will precipitate underground than above ground. The calcium precipitation is a function of turbulence in the solution, changes in CO_2 partial pressure or pH, and the presence of surface area. The most likely places for calcium to precipitate are underground where the ore provides abundant surface area for precipitation, at or near the injection or production wellbore where changes in pressure, turbulence and CO_2 partial pressure are all observed, and on the surface in the filters, in pipes, and in tanks. If all the calcium were to precipitate underground (based on 1.2 lb $CaCO_3$ per ton of ore) the precipitate would occupy about 0.15% of the void space in that ton of ore.

Calcium may be removed from the system in the following ways: filters will be routinely backwashed to the ponds and periodically will be acid cleaned if necessary to remove precipitated calcium carbonate from the filter housing or the filter media; the solution bleed taken to compensate for over production will also serve to eliminate some calcium from the system. Should precipitation in pipes and tanks become excessive, the precipitate will be pumped to the waste ponds. Should precipitation of calcium carbonate at or near the well bore of the wellfield wells become a problem, these wells will be air lifted, surged, water jetted, or acidified as necessary to remove the precipitated calcium. Any water recovered from these wells containing dissolved calcium carbonate or particulate calcium carbonate will be collected and placed into the evaporation ponds. A liquid seal will be maintained on any calcium carbonate in the ponds. Upon decommissioning, calcium carbonate from the plant equipment and pond residues will be disposed of in either a licensed tailings pond, if available, a regional compact disposal site, if available, or a commercial disposal site.

The other possible precipitating species which has been identified is iron which would probably precipitate as either the hydroxide or the carbonate and could cause some fouling. Such fouling is usually evidenced by a

reduction in the ion exchange capacity of the resin in the extraction circuit. Should this fouling become a serious problem, the resin can be washed and the wash solution disposed of in the evaporation ponds. Due to the small amount of iron present in the Basal Chadron Sandstone, however, ion precipitation is not anticipated to be a problem.

6.1.5 Hydrolysis

Hydrolysis reactions, those which involve ore minerals and hydrogen or hydroxide ions, are not expected to play an important role in the ore/lixiviant interaction. In the pH range of 6.5 to 9.0, the concentration of hydrogen and hydroxide ions is so small that these types of reactions do not occur to any great degree. The only potential impact would be a small increase in the dissolved silica content of the lixiviant system, a possible small increase in the cations associated with the silicious minerals. The hydrolysis reactions are not expected to have a significant effect on operations.

6.1.6 Oxidation

The oxidant consumers in the Basal Chadron Sandstone are hydrogen sulfide in the groundwater, uranium, vanadium, iron pyrite, and other trace and heavy metals. The impacts of these oxidant consumers on the operation of the pilot plant will be to generally increase the oxidant consumption over that which would be required for uranium alone. The second effect will be the release of iron and sulfate into solution from oxidation of pyrite. A third effect will be to increase the levels of some trace metals such as arsenic, vanadium and selenium in solution. As mentioned previously, the iron solubilized will most likely be precipitated as the hydroxide or carbonate, depending on its oxidation state. Any vanadium which is oxidized along with the uranium will be solubilized by the lixiviant, recovered with the uranium and could potentially contaminate the precipitated yellowcake product. The Crow Butte Pilot Plant used hydrogen peroxide precipitation of uranium in an effort to reduce the amount of vanadium precipitated in the product. Oxidation will also solubilize arsenic and selenium. The restoration program will return these substances

to acceptable levels. A final potential oxidation reaction is the partial oxidation of sulfur species resulting in compounds such as polythionates which can foul the ion exchange resins. In in-situ operations using chemistries similar to the proposed at Crow Butte, these sulfur species are completely oxidized to sulfate and Crow Butte is not expected to be different.

6.1.7 Organics

Organic materials are generally not present in the Crow Butte ore body at levels greater than 0.1 to 0.2%. Where present their effect will be to increase the oxidant consumption and make uranium leaching a bit more difficult. On longer flow paths, organic material could potentially reprecipitate uranium, should all of the oxidant be consumed and conditions become reducing. Another potential impact of organics could be the coloring and fouling of leach solutions should the organics be mobilized. FEN plans to operate at pH's in the range of 6.5 to 9.0, which should be low enough to avoid mobilization of organics and coloring of the leach solutions.

6.2 Restoration Goals

The FEN restoration program is designed to return the water quality of the affected zone to the quality level specified by the NDEC which is a quality of use consistent with the "uses for which the resource was suitable" prior to the activity.

Restoration criteria will be established by the NDEC prior to the initiation of mining activity in an area.

FEN proposes that the restoration criteria be established on a mine unit average basis. An average mine unit will be approximately 22.5 acres and FEN proposes that one well per acre be designated as a representative well for purposes of establishing restoration criteria. The representative wells (23 in an average mine unit) will be sampled three times at two week intervals and analyzed for the list shown in Table 5.7-6 (Section 5). The

average of all analyses will be determined and the standard deviation. Outliers will be evaluated utilizing the "Recommended Criteria for Single Samples", taken from the 1977 Annual Book of ASTM Standards. This method involves comparing a test-statistic (TS) to a critical value (CV). If the value of the calculated TS is greater than the CV for a specific number of observations at a specified alpha level, the outlier is rejected. Thus the test statistic:

$$TS = \frac{x_n - x}{s}$$

Where:

x = arithmetic average of all n values
x_n = doubtful value
s = estimate of the population standard deviation based on the sample data.

FEN utilized an alpha level of 0.05, one-sided test in calculation of CV. The actual CV varies depending on n or a total number of obsevations in the data set. Values of CV for various n values are tabulated in the reference cited above.

Restoration criteria for a mine unit will be established as the average plus two standard deviations for any parameter that exceeds the applicable drinking water standard. If a drinking water standard exists for a parameter, and baseline is below that standard, the drinking water standard will be used to establish the restoration criteria. If there is no drinking water standard for an element, for example vanadium, the restoration criteria will be based on best practicable technology. The restoration criteria for the major cations (Ca, Mg, K) should allow for the concentation of these cations to vary by as much as one order of magnitude as long as the TDS restoration value is met. The total carbonate restoration criteria should allow for the total carbonate to be less than 50% of the TDS.

At the conclusion of restoration and during stabilization, the representative wells will be sampled and if the average meets the restoration criteria, the mine unit will be considered restored.

6.3 R & D Groundwater Quality Restoration

FEN operated a R & D facility at Crow Butte from July 1986 to present. Two wellfields (WF-1 and WF-2) were operated during the R & D phase. Leaching activities were terminated in WF #2 in January of 1987 and restoration was initiated on February 9, 1987. Restoration was conducted following the Restoration Plan submitted to the USNRC on October 9, 1986.

The goal of the Restoration Plan was to return all groundwater affected by the R & D mining to restoration values as defined by Nebraska Department of Environmental Control (NDEC) based on baseline groundwater sampling. FEN accomplished aquifer restoration by utilizing a series of stages carefully designed in a specified sequence. The stages utilized in the program were:

1. Halo Recovery Stage
2. Permeate Injection/Reductant Stage
3. Aquifer Recirculation

Prior to the initiation of restoration, samples were taken from wells PT-21, PT-22, PT-23, PT-24 and PT-25 to establish the post mining water quality. The data from these samples are found in Table 6.3-1 through 6.3-5.

6.3.1 Halo Recovery Stage

The first step in the restoration process was to draw contaminated water in toward the wellfield until the majority of the plume of contamination was drawn inside the perimeter injection wells. The solution was recalled by operating the recovery well in the wellfield with no injection. This stage was continued until it was clear that the major portion of the contamination had been recalled from the area surrounding the wellfield. Samples from the injection wells and comparative volume calculations were used to help make that determination. This stage required 15 days, and a total of 707,800 gallons of water was removed.

TABLE 6.3-1

WELL #PT-21

PARAMETER	RESTORATION VALUE	POST-MINING (2-9-87)	RESTORATION SAMPLE (6-15-87)	RESTORATION SAMPLE (8-26-87)
As	.05	0.023	0.009	.004
B	1.112	1.16	1.00	.95
Ba	1	1.16	<0.10	<0.1
Ca	160	47	19	9.3
Cd	.01	<0.001	0.001	<0.001
Cl	250	292	234	168
Cr	.05	<0.005	0.007	<0.005
Cu	1	0.06	0.02	<0.01
F	2.4	0.90	0.62	.6
Fe	1	<0.005	<0.005	<0.03
Hg	.002	<0.0002	<0.0002	<0.0002
K	112	19	12.8	9.0
Mg	40	11.3	4.4	2.4
Mn	.2	0.024	0.011	.005
Mo	1	0.09	0.01	<0.01
Na	500	676	479	321
NH_4 as N	.5	0.24	0.46	.23
Ni	.2	<0.01	<0.01	<0.01
NO_2 as N	1	0.066	0.028	.018
NO_3 as N	10	0.39	0.09	.02
Pb	.05	<0.005	0.011	<0.005
pH	6.5-8.5 s.u.	7.84	7.89	7.91
Ra-226	1611 pCi/l	2198	1020	359.3
Se	.01	0.020	<0.001	<0.001
SO_4	600	508	408	282
TDS	1186	2130	1518	948
TOT. CARB.	<593	895	454	278
U	5.0	40.1	14.8	3.793
V	.01	1.08	0.13	.03
Zn	5	0.03	<0.01	<0.01

*All units are mg/l unless otherwise noted.

TABLE 6.3-2

WELL #PT-22

PARAMETER	RESTORATION VALUE	POST-MINING (2-9-87)	RESTORATION SAMPLE (6-16-87)	RESTORATION SAMPLE (8-26-87)
As	.05	0.022	0.005	<0.001
B	1.184	1.14	1.02	.95
Ba	1	<0.1	<0.10	<0.10
Ca	151	46	19.5	9.2
Cd	.01	<0.001	<0.001	<0.001
Cl	250	323	231	167
Cr	.05	<0.005	<0.005	<0.005
Cu	1	0.02	<0.01	<0.01
F	2.4	0.9	.6	.64
Fe	1	0.03	<0.03	<0.03
Hg	.002	<0.0002	<0.0002	<0.0002
K	116	24	12.9	9.2
Mg	38	9.7	4.2	2.2
Mn	.2	0.024	.012	.006
Mo	1	0.09	.01	<0.01
Na	500	768	479	332
NH_4 as N	.5	0.14	.32	.24
Ni	.2	<0.01	<0.01	<0.01
NO_2 as N	1	0.43	.021	.033
NO_3 as N	10	0.79	.05	.07
Pb	.05	<0.005	<0.005	.005
pH	6.5-8.5 s.u.	7.69	7.94	7.98
Ra-226	1281 pCi/l	2365	1028	97
Se	.01	0.02	0.001	<0.001
SO_4	600	497	414	288
TDS	1157	2270	1508	982
TOT. CARB.	<579	1039	465	274
U	5.0	7.428	1.59	.258
V	.01	0.82	.02	<0.01
Zn	5	0.11	<0.01	<0.01

*All units are mg/l unless otherwise noted.

TABLE 6.3-3

WELL #PT-23

PARAMETER	RESTORATION VALUE	POST-MINING (2-9-87)	RESTORATION SAMPLE (6-16-87)	RESTORATION SAMPLE (8-26-87)
As	.05	0.029	0.003	<0.001
B	1.101	1.15	.99	.96
Ba	1	<0.1	<0.1	<0.1
Ca	152	45	18.8	9.1
Cd	.01	<0.001	<0.001	<0.001
Cl	250	291	234	164
Cr	.05	<0.005	<0.005	<0.005
Cu	1	0.01	<0.01	<0.01
F	2.4	0.9	.6	.6
Fe	1	0.05	<0.03	<0.03
Hg	.002	<0.0002	<0.0002	<0.0002
K	105	11	13.3	9.0
Mg	39	11	4.4	2.2
Mn	.2	0.024	.012	.006
Mo	1	0.10	<0.01	<0.01
Na	500	735	482	322
NH_4 as N	.5	0.17	.52	.25
Ni	.2	<0.01	<0.01	<0.01
NO_2 as N	1	0.046	.027	.009
NO_3 as N	10	0.51	.08	.02
Pb	.05	<0.005	<0.005	.013
pH	6.5-8.5 s.u.	7.73	7.87	7.93
Ra-226	52 pCi/l	2741	975	96.5
Se	.01	0.018	<0.001	<0.001
SO_4	600	508	408	288
TDS	1147	2106	1508	946
TOT. CARB.	<574	898	455.8	274
U	5.0	6.256	.143	.0558
V	.01	0.84	0.01	<0.01
Zn	5	0.03	<0.01	.01

*All units are mg/l unless otherwise noted.

TABLE 6.3-4

WELL #PT-24

PARAMETER	RESTORATION VALUE	POST-MINING (2-9-87)	RESTORATION SAMPLE (6-17-87)	RESTORATION SAMPLE (8-26-87)
As	.05	0.025	0.006	.001
B	1.081	1.15	.98	.95
Ba	1	<0.10	<0.1	<0.1
Ca	125	48	18.8	9.0
Cd	.01	<0.001	<0.001	<0.001
Cl	305	289	233	169
Cr	.05	<0.005	<0.005	<0.005
Cu	1	0.01	<0.01	<0.01
F	2.4	0.90	.62	.6
Fe	1	<0.03	<0.03	<0.03
Hg	.002	<0.0002	<0.0002	<0.0002
K	129	12	12.9	9.0
Mg	38	9.8	4.1	2.2
Mn	.2	0.021	.011	.005
Mo	1	0.10	.02	<0.01
Na	500	700	476	327
NH_4 as N	.5	0.10	.42	.27
Ni	.2	<0.01	<0.01	<0.01
NO_2 as N	1	0.018	.021	.008
NO_3 as N	10	0.59	.08	<0.01
Pb	.05	<0.005	<0.005	.011
pH	6.5-8.5 s.u.	7.64	7.98	7.84
Ra-226	1436 pCi/l	2605	928	96.4
Se	.01	0.019	<0.001	<0.001
SO_4	600	508	408	282
TDS	1277	2092	1498	942
TOT. CARB.	<639	901	460	278
U	5.0	7.904	3.689	.0708
V	.01	0.86	.02	<0.01
Zn	5	0.04	.01	<0.01

*All units are mg/l unless otherwise noted.

TABLE 6.3-5

WELL #PT-25

PARAMETER	RESTORATION VALUE	POST-MINING (2-9-87)	RESTORATION SAMPLE (6-17-87)	RESTORATION SAMPLE (8-26-87)
As	.05	0.032	0.02	<0.001
B	1.229	1.13	1	.95
Ba	1	<0.10	<0.1	<0.1
Ca	128	44	18.5	9.0
Cd	.01	<0.001	<0.001	<0.001
Cl	250	301	231	163
Cr	.05	<0.005	<0.005	<0.005
Cu	1	0.01	<0.01	<0.01
F	2.4	0.90	.6	.6
Fe	1	<0.03	<0.03	<0.03
Hg	.002	<0.0002	<0.0002	<0.0002
K	124	21	13	9.0
Mg	30	9.7	4.2	2.2
Mn	.2	0.021	.012	.005
Mo	1	.09	<0.01	<0.01
Na	500	735	484	322
NH_4 as N	.5	0.12	0.52	.26
Ni	.2	0.01	<0.01	<0.01
NO_2 as N	1	0.011	.024	.013
NO_3 as N	10	0.94	.07	.02
Pb	.05	<0.005	<0.005	.007
pH	6.5-8.7 s.u.	7.78	7.92	7.92
Ra-226	387 pCi/l	2330	944	85.4
Se	.01	0.018	<0.001	<0.001
SO_4	600	507	408	294
TDS	1168	2130	1500	960
TOT. CARB.	<584	925	468	274
U	5.0	6.47	.712	.0418
V	.01	0.82	0.02	<0.01
Zn	5	.08	<0.01	.01

*All units are mg/l unless otherwise noted.

All water removed during this stage was pumped from the center well in WF-2, which was PT-21. During this stage, it became apparent that the uranium concentration was higher in wells PT-22 and PT-24 and that it would be beneficial to pump from these wells. A pump was installed in PT-22 and PT-24 and the solution was pumped into the PT-21 casing and then pumped into the plant for processing. Table 6.3-6 shows the uranium, sulfate, sodium and pH values obtained on samples from the individual wells during the halo recovery stage. As can be seen from the data, the concentration of the sodium and sulfate showed a general decreasing trend while the uranium concentration was variable. The variation in the uranium concentration was most likely due to the transfer of solutions from PT-22 and PT-24 into PT-21 for transfer to the plant.

The water recovered during the halo recovery was processed by a reverse osmosis (R.O.) unit in order to minimize waste volumes in the evaporation ponds. The clean water (permeate) produced by the R.O. was sent to the east pond and the brine was sent to the west pond. The clean water was further treated by R.O. to reduce contaminant levels to standards specified by the NDEC for land application of water. The clean water was then land applied.

6.3.2 Permeate Injection/Reductant Phase

After Halo Recovery had been completed, the Permeate Injection/Reductant stage was initiated. In the Permeate Injection/Reductant stage, the water recovered from the wellfield was processed in a water treatment system using a reverse osmosis unit and the permeate (clean water) was injected into the wellfield.

Reductant was added to the permeate injection stream a number of times during this phase. Table 6.3-7 shows a chronology of the activities that occurred during this phase. The Table also shows a water balance during this phase.

TABLE 6.3-6

HALO RECOVERY ANALYSIS DATA WF-2

	2-9-87	2-12-87	2-15-87	2-17-87	2-25-87	2-28-87	3-4-87
PT-21							
U_3O_8	43	60	52	49	83	21	75
Na		647			600		552
SO_4		453			446		411
pH		7.5			7.5		7.5
PT-22							
U_3O_8	5	76	115	127	149	128	119
Na		724			680		597
SO_4		516			470		426
pH		7.5			7.3		7.3
PT-23							
U_3O_8	8	5	7	6	6	7	4
Na		641			680		707
SO_4		453			458		455
pH		7.8			7.6		7.5
PT-24							
U_3O_8	9	41	38	37	45	46	41
Na		453			426		430
SO_4		373			364		358
pH		7.8			7.6		7.6
PT-25							
U_3O_8	7	8	3	2	4	5	4
Na		624			495		497
SO_4		433			385		376
pH		7.6			7.9		7.7

*All units are mg/l except pH which is in Standard Units (S.U.)

NOTE: Recovery was stopped from 2-17-87 to 2-25-87 to obtain approval from NDEC to allow recovery from PT-22 and PT-24

TABLE 6.3-7

PERMEATE/REDUCTANT INJECTION CHRONOLOGY

DATE START	DATE END	DESCRIPTION	GALLONS PRODUCED	GALLONS INJECTED
2-9-87	3-3-87	HALO RECOVERY	707,800	0
3-4-87	3-10-87	PERMEATE INJECTION, RECIRCULATION	263,933	266,815
3-11-87	3-25-87	RECIRCULATION	710,970	710,784
3-26-87	4-7-87	REDUCTANT INJECTION, 400# Na_2S	543,310	541,957
4-8-87	4-12-87	RECIRCULATION	222,467	214,805
4-13-87	4-20-87	REDUCTANT INJECTION, 350# Na_2S	408,034	405,054
4-21-87	4-29-87	RECIRCULATION	360,290	361,364
4-30-87	5-6-87	REDUCTANT INJECTION, 400# Na_2S	368,448	368,277
5-7-87	5-17-87	RECIRCULATION	442,520	444,200
5-18-87	5-25-87	SHUT-IN TO MONITOR RESPONSE	0	0
5-26-87	5-28-87	RECIRCULATION	137,267	136,482
5-29-87	5-31-87	PERMEATE INJECTION, TDS REDUCTION	154,208	147,328
6-1-87	6-9-87	REDUCTANT INJECTION, 200# Na_2S	429,924	428,314
6-10-87	6-21-87	SHUT-IN, SAMPLED ALL WELLS	12,417	10,775
6-22-87	6-23-87	RECIRCULATION	105,586	105,462
6-24-87	X	REDUCTANT INJ. PT-21, 60# Na_2S	0	11,268
6-25-87	7-8-87	SHUT-IN	0	0
7-9-87	7-12-87	RECIRCULATION WITH RADIUM SEL COMP	147,234	144,040
7-15-87	X	PT-22 PUMP AND SAMPLE	1,458	1,261
7-16-87	7-20-87	PT-25 RECIRCULATION WITH R.S.C.	115,836	116,789
7-21-87	7-30-87	PT-25 PERMEATE INJ, 130# Na_2S	387,784	347,786
7-31-87	8-2-87	PT-21 RECIRCULATION W/O PROCESSING	107,288	99,033
8-03-87	8-07-87	PERMEATE INJ, REDUCT INJ, 60# Na_2S	178,839	160,865
8-08-87	8-13-87	RECIRCULATION WITH RADIUM SEL COMP PLUS 20# Na_2S	233,054	235,640
8-14-87	8-15-87	PERMEATE INJ, REDUCT INJ, 30# Na_2S	82,816	83,882
8-16-87	8-19-87	RECIRCULATE WITH R.S.C.	147,288	147,105
8-20-87	8-22-87	PERMEATE INJ, REDUCT INJ, 30# Na_2S	130,800	125,128
8-23-87	8-26-87	RECIRCULATE WITH R.S.C + 20# Na_2S	114,353	112,926
8-26-87		SPLIT SAMPLES WITH NDEC/EPA, SHUT-IN WELLS	0	0
		TOTAL	**6,513,722**	**5,727,340**
		OVER PRODUCTION	**786,382**	

An evaluation of Table 6.3-7 shows that the wellfield was recirculated a number of times during this phase. Recirculation was conducted to allow the reductant (Na_2S) to contact as much of the host rock as possible and to make the aquifer more reducing.

6.3.2.1 Wellfield Configuration

During Halo Recovery, the primary pattern used consisted of pumping from the center well in the WF-2 five spot (PT-21). Figure 6.3-1 shows the general layout. FEN modified the pumping pattern periodically to reduce specific contaminants in Wells PT-22 and PT-24. Pumps were placed in these wells and the solutions transferred to PT-21 for transfer to the plant.

During the Permeate Injection/Reductant Phase, the pattern used was normally similar to the mining pattern which used the center well (PT-21) for recovery and the perimeter wells (PT-22, PT-23, PT-24, PT-25) for injection. This pattern was modified periodically to allow the injection of reductant into specific wells in an effort to reduce uranium.

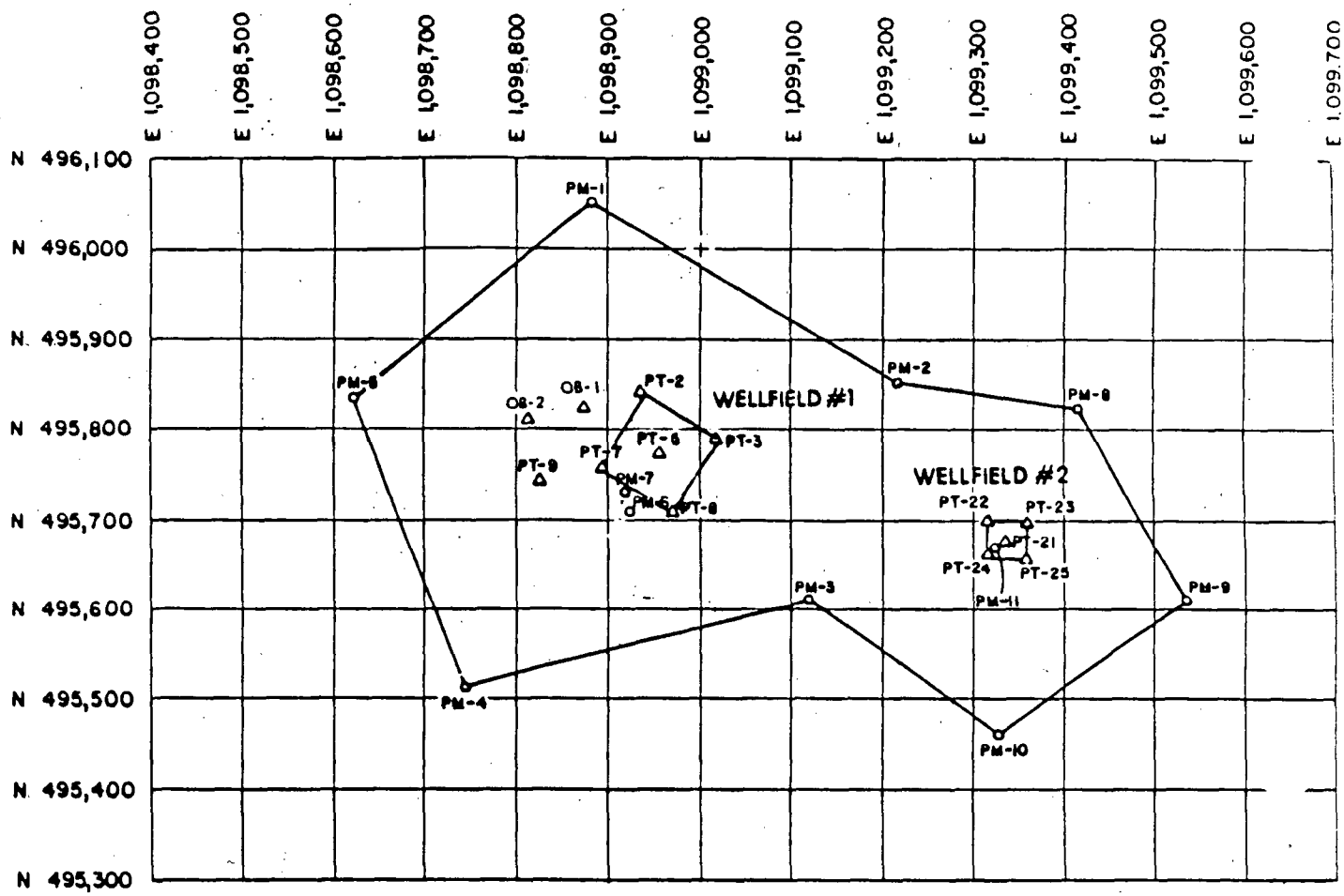
6.3.2.2 Plant Operations

The water recovery during the Halo Recovery phase or restoration was treated using Reverse Osmosis (R.O.) until the water was suitable for land application as authorized by the NDEC and USNRC. The R.O. system used for treatment of the Halo Recovery water was similar to the system used for the Permeate Injection Phase.

A Process Schematic of the R.O. System is shown in Figure 6.3-2 and a description of the system follows:

(a) Uranium Removal

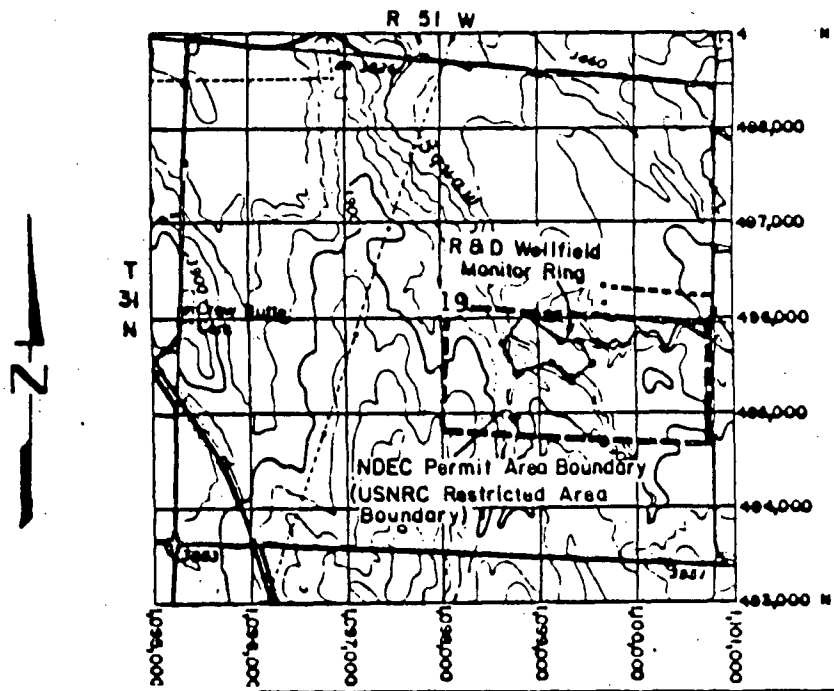
The recovered solution was filtered and then passed through the IX Column to remove uranium.



Legend

△ Pilot Test Wells

○ Pilot Monitor Wells



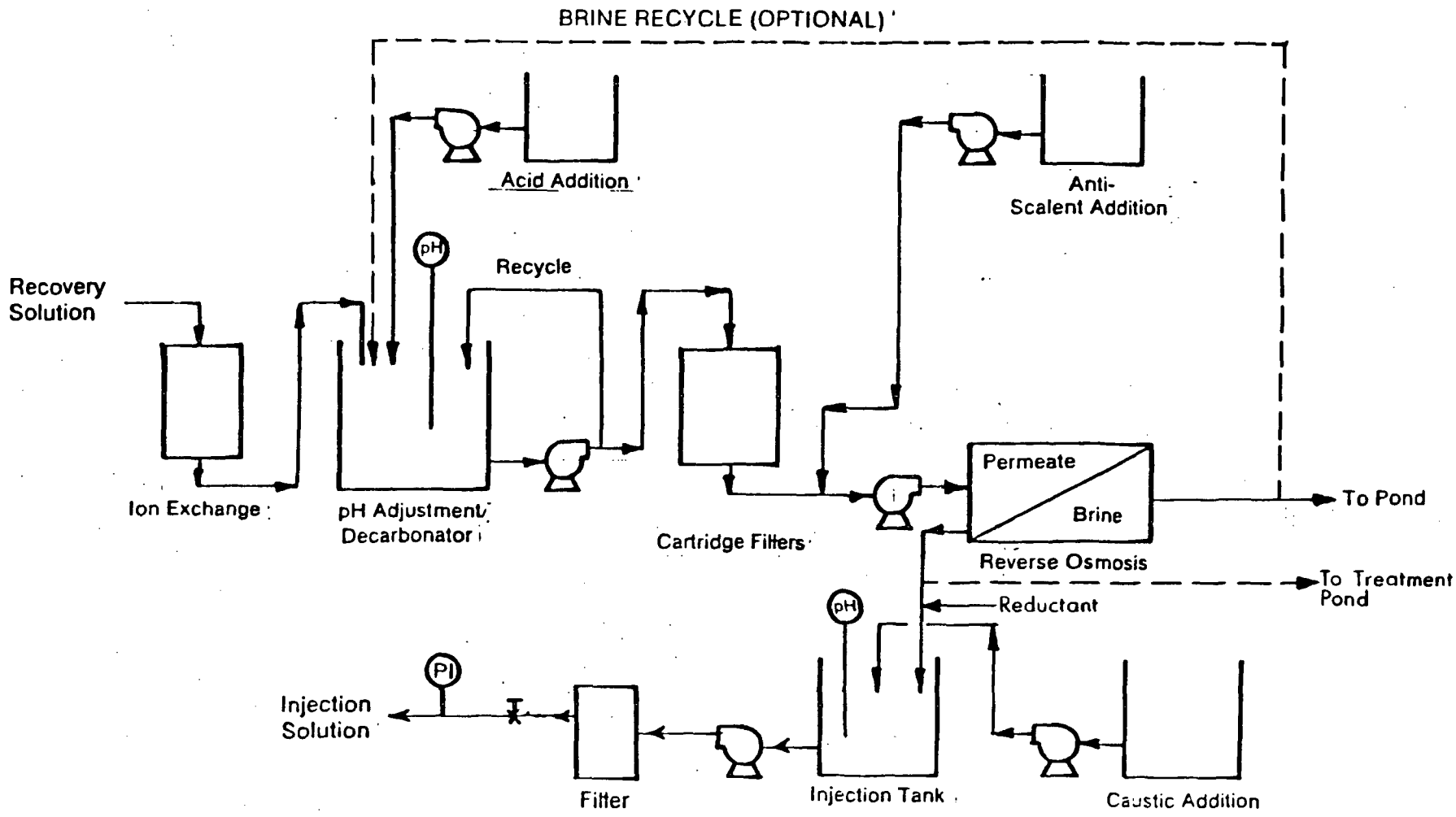
Scale 1" = 200'

50 25 0 50 Meters

200 100 0 200 Feet

6.0(18), 07/29/87

REV DATE	FERRET OF NEBRASKA, INC.	
	CROW BUTTE PROJECT Dawes County, Nebraska	
	R & D WELLFIELD WATER QUALITY WELLS	
	PREPARED BY: F. E. N.	
	DWN. BY: JC / DATE: 8/87	FIGURE 5.1-1



PERMEATE INJECTION/REDUCTANT

PROCESS SCHEMATIC

FIGURE 6.1-2

(b) pH Adjustment

After uranium removal, the pH was adjusted with acid to a pH of 3.5 to 7.0. This pH range is the desired range for the R.O. membranes that were used.

(c) Filtration

After pH adjust, the solution was filtered to remove all suspended solids prior to R.O. treatment.

(d) Anti-Scalent Addition

An anti-scalent was added to suppress the precipitation of sparingly soluble compounds in the R.O. and thus prevent fouling of the membranes.

(e) Reverse Osmosis Treatment

After adequate pretreatment, the recovered solution was introduced into the R.O. where the soluble species were concentrated in a brine stream that was 10 to 20% of the feed volume. About 80 to 90% of the feed volume was in the clean water stream (permeate) which was sent to a pH adjustment system prior to injection in the wellfield.

(f) Permeate pH Adjustment

The permeate pH was adjusted to the desired pH by the addition of caustic or reductant prior to injection into the wellfield.

6.3.2.3 Results-Permeate Injection/Reductant Phase

Samples were taken daily from PT-21 and analyzed for U_3O_8, V, $CO_{3(T)}$, pH, Ca, Na, Cl, SO_4 and conductivity. An aliquot of each daily sample was taken and a monthly composite sample prepared and analyzed. The results of the monthly samples from PT-21 (the recovery well during mining) are shown in Table 6.3-8. As can be seen from Table 6.3-8, all Restoration values except vanadium have been met on the August 1987 samples. The Restoration values, the post mining water quality analyses and the results of the post Restoration samples are found on Tables 6.3-1 through 6.3-5. A review of the data show that the Restoration values have generally been achieved.

FEN is now at Phase II of Restoration as defined in the NDEC Permit. During Phase II, the representative well (PT-21), and any monitor well which was placed on excursion status (none) during mining must be sampled monthly for the Restoration parameters found in Part IV of the NDEC/UIC permit. Phase II will be completed when the representative well (as defined earlier) samples have reached the Restoration values found in Part IV of the NDEC/UIC permit. The values for PT-21 are found in Table 6.3-8. Prior to stabilization, samples were taken from Wells PT-21, PT-22, PT-23, PT-24 and PT-25 and analyzed for the Restoration Values. These samples were taken on August 26, 1987 and results are shown in Table 6.3-1 through 6.3-5 and Table 6.3-8.

Phase III will be initiated at the completion of Phase II. Phase III is the stabilization stage and during Phase III, samples shall be taken for a period of six months from representative wells (as defined earlier) and analyzed for the Restoration Parameters as specified on the Restoration Table. This data will be submitted to the USNRC and the NDEC when available.

6.3.2.4 Discussion of Restoration Results

A review of the restoration results found in Tables 6.3-1 through 6.3-5 and Table 6.3-8 indicate that all restoration values were met on all wells with the following exceptions:

TABLE 6.3-8

WELL #PT-21

PARAMETER	RESTORATION VALUE	JAN 1987	FEB 1987	MAR 1987	APR 1987	MAY 1987	JUNE 1987	JULY 1987	AUG 1987
As	.05	.016	.015	.008	.013	.002	.01	.006	.004
B	1.112	1.22	1.12	1.02	1.02	.96	.96	.96	.95
Ba	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	160	59	33.4	25.7	29.4	25.3	14.4	17.8	9.3
Cd	.01	.002	<0.001	<0.001	.004	<0.01	<0.001	<0.001	<0.001
Cl	250	347	226	277	284	318	234	209	168
Cr	.05	<0.005	<0.005	<0.005	<0.005	<0.05	<0.005	<0.005	<0.005
Cu	1	.09	.07	.02	.04	.03	.04	.06	<0.01
F	2.4		.9	.56			.62		0.6
Fe	1	.11	.09	.04	.06	.04	.04	.05	<0.03
Hg	.002	.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0[illegible]
K	112	18	19.9	14.5	17.7	13.1	12.2	11.6	[illegible]
Mg	40	13.8	9.6	6.2	6.8	6.3	4.9	4.53	2.4
Mn	.2	.003	.055	.012	.012	.012	.01	.013	0.005
Mo	1	1	.08	.05	.02	.03	.07	<0.01	<0.01
Na	500	852	650	479	562	532	486	428	321
NH_4 as N	.5		.24	.29			.46		
Ni	.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.
NO_2 as N	1		.066	.101			.028		.018
NO_3 as N	10		.39	.19			.09		.02
Pb	.05	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
pH	6.5-8.5s.u.	7.61	7.44	8.15	7.66	8.02	7.89	8.13	7.91
Ra-226	1611 pCi/l	3127	1654	860	1040	1156	723	666	359
Se	.01	.027	.015	.009	.002	<0.001	.002	<0.001	<0.001
SO_4	600	477	411	388	436	371	408	345	282
TDS	1186		2130	1436	1600	1800	1518	900	948
TOT. CARB.	<593	1183	702	577	582	558	447	493	278
U	5.0	66.3	43.9	22.8	21.3	21.0	8.434	8.889	3.
V	.01	1.84	1.2	.68	.36	.16	.13	.05	[illegible]
Zn	5	.35	<0.01	<0.01	<0.01	.02	.19	.13	<0.01

*All units are mg/l unless otherwise noted.

Note: 8-26-87 sample split with EPA

o **Radium-226 on Well Number PT-23.**

The baseline radium-226 concentration in Well PT-23 was 52 pCi/l. The average radium-226 baseline for PT-21 through PT-25 was 953 pCi/l with a standard deviation of 690 pCi/l. The range obtained on the radium-226 baseline data (52 pCi/l to 1611 pCi/l) indicates that the aquifer is not homogeneous with respect to radium-226 concentration. The baseline radium-226 concentration in a sample from a well appears to be a function of the amount of radium-226 in the host rock in the vicinity of the well bore. During mining, the radium-226 in the groundwater increases and tends to become more homogeneous. Since radium-226 is removed from water by precipitation as the sulfate and by ion exchange with the clays it would also be expected that the radium in the host rock will also become more homogeneous.

During restoration the radium-226 concentration in the groundwater is lowered by treatment above ground. The treated water is injected into the aquifer and the radium-226 concentration in the water will equilibrate at a level dependent on the radium-226 concentration in the host rock. The mining process does not significantly change the amount of radium-226 in the host rock but it does change the distribution of radium-226 in the host rock. With this distribution change, the radium-226 concentration in the various wells will approach the average concentration that existed prior to mining, but the concentration in any single well may be above baseline. This is the situation that exists with Well PT-23. Although the radium-226 concentration in this well exceeds baseline for this well, radium-226 concentration after restoration does not exceed the baseline average for wells PT-21 through PT-25. The radium-226 level in PT-23 is 96.5 pCi/l (as of 8-26-87) which is far below the average baseline value of 953 $\pm$ 690 pCi/l for Wells PT-21 through PT-25.

The average radium-226 concentration after restoration (as of 8-26-87) in wells PT-21 through PT-25 is 147 $\pm$ 119 pCi/l which is also well below the average baseline concentration of 953 $\pm$ 690 pCi/l for the same wells. During the stabilization period, the present average radium-226 levels in wells PT-21 through PT-25 may increase to an equilibrium level approaching

the average baseline concentration for the same wells. Based on the above evaluation, FEN believes that the restoration criteria for radium-226 and most other elements should be based on the average concentration in the field and not on the concentration found in a single well.

o The vanadium concentration in the restoration samples exceeds the restoration value of 0.01 mg/l in Well PT-21.

The restoration value for vanadium for Well PT-21 is 0.01 mg/l and the measured value on the 8-26-87 sample is 0.03 mg/l. All other wells sampled showed vanadium levels of less than 0.01 mg/l.

As can be seen from the data, the measured values are very close to the restoration value. The restoration value for vanadium was set at baseline (0.01 mg/l) because there are no criteria for vanadium in any EPA drinking water standards. FEN has lowered the vanadium concentration to a level approaching the restoration values using the best available technology. The vanadium concentration in the restored water does not exceed any standards and has no environmental impact. Thus, the vanadium levels achieved by FEN should be considered acceptable for restoration.

o **Water Balance**

Table 6.3-7 shows the volume of water produced, injected and overproduced during the restoration program. As can be seen from the data in Table 6.3-7, the majority of the overproduction occurs during the Halo Recovery Phase. The 707,800 gallons produced in this Phase are equivalent to approximately 2.36 pore volumes. The pore volume estimate for Wellfield #2 is based on the results of computer modeling using the Bureau of Mines model ISL-50. This model defined a maximum pore volume as approximately 300,000 gallons.

Further review of Table 6.3-7 indicates that very little water was overproduced during the permeate injection/reductant stage of restoration.

Approximately 1,276,000 gallons of water were treated by reverse osmosis during the permeate injection/reductant stage and approximately 90% of this volume was reinjected and 10% was sent to the evaporation ponds as brine.

The remainder of the water produced and injected, as shown in Table 6.3-7 was recirculated in an effort to lower the uranium and radium concentrations below the restoration values. Reductant was periodically added during recirculation in an effort to suppress the solubility of uranium and the solutions were periodically passed through a radium selective complexer to remove radium. Approximately 4,456,000 gallons of water (14.9 pore volumes) were recirculated during the restoration program. During recirculation, there is no overproduction.

The recirculation volume used for the R & D restoration program is larger than that expected for the commercial restoration. As was noted earlier, the primary purpose of the recirculation was to reduce the uranium levels and the secondary purpose was to reduce the radium levels. The uranium levels during restoration at the commercial facility will be lower than the levels encountered during R & D restoration. R & D restoration was initiated with a significant amount of uranium remaining in the cell and in the areas immediately adjacent to the cell. This causes the uranium to be mobilized during the restoration program. During restoration at a commercial facility, the uranium is mined more completely and mobilization is minimized during restoration and thus less reductant will be required to reduce uranium concentration to the restoration value.

The radium levels observed during the R & D restoration program were discussed earlier. FEN will propose that restoration values for radium at the commercial facility be determined from the average concentration in a wellfield and this will also reduce the recirculation requirement and may lower the water consumption requirement also.

In summary, the water balance during the R & D program follows:

	Gallons Produced	Over Production
Halo Recovery	707,800	707,800
Permeate Injection/Reductant	1,198,177	78,582
Recirculation	4,607,745	0
	6,513,722	786,382

The total number of pore volumes produced was approximately 19 and approximately 16.4 pore volumes were reinjected with approximately 2.6 pore volumes of overproduced water. FEN has demonstrated, the use of best available technology during the R & D restoration program and has demonstrated achievement of virtually all restoration values with minimal consumptive use of water.

6.4 Hole Plugging and Abandonment

All monitor, injection and production wells will be plugged and abandoned prior to final closure of the site and after NRC and NDEC have accepted groundwater restoration.

The plugging method to be used is as follows: Approved abandonment mud (a mud-polymer mix) will be mixed in a cement unit and pumped down a hose, which is lowered to the bottom of the well casing using a reel. When the hose is removed, the casing is topped off and a cement plug placed on top. A hole is then dug around the well, and, at a minimum, the top 3 feet of casing removed. The hole is backfilled and the surface revegetated.

6.5 Shut-Ins or Well Failures

Reasons for shutting in and abandoning a well fall into basically two categories; first, well damage or second, inability to restore well performance. Fracturing of a well casing and casing damage due to maintenance operations are two possible examples of situations requiring well replacement. The second category of failures might be typified by a

well which, due to formation damage or other reasons, will not respond to treatment allowing adequate injections or production. In the event of either of these occurrences, FEN's well abandonment procedures will be used to assure proper plugging.

Should a well failure be detected, the well will be integrity tested to try and determine the nature of the failure. If repair is feasible, the well will be repaired and integrity tested again. If the well passes the integrity testing it will be put back in service and monitored closely. Should the well fail integrity testing or be beyond repair, it will be plugged and abandoned in accordance with Section 6.4.

6.6 Reclamation of Disturbed Lands

At the end of restoration, disturbed lands will be returned to their premining use. A total of approximately 750 acres will have been affected by mining activities. The plant area, ponds site and access roads will experience the greatest amount of disturbance.

Reclamation will consist of several operations. Within the wellfield, disturbance will be minimal. Soil may be compacted in areas from the drilling and maintenance traffic. Closure of the wells will also require some surface disturbance immediately surrounding each well. The non-vegetated or disturbed areas including roads will be plowed or disced to aerate the soil. A grass seed mixture and fertilizer will then be spread. Assistance will be obtained from the U.S. Soil Conservation Service to determine the proper seed mix and rate of application.

Preparation of the plant and pond areas will follow standard land reclamation practices. Excess soil from the built-up plant base and pond embankments will be returned to the ponds as fill. Land surface contours will be similar to original contours. Finally, topsoil will be replaced on all plant and pond disturbed areas. Reseeding and fertilizing will follow U.S. Soil Conservation Service recommendations.

A period of one to two years will be required to firmly establish grass populations. During this time, fences will be maintained to keep livestock out of the area and away from new vegetation. After that time, the land may be returned to its premining use, grazing.

6.7 Plant Decommissioning

Prior to release from the site for unrestricted use, all equipment, buildings and other items will be checked for radioactive surface contamination. Records will be kept of equipment and corresponding surface contamination levels for all items released. If contamination exceeds the limits given in USNRC-Attachment A, further attempts should be made to reduce levels. All items not in compliance with these levels will be disposed of at a site approved for by-product materials, such as an active mill tailings disposal site.

An alternative may be to sell the equipment and building to a source material license holder. If so, then equipment and building parts will be cleaned of easily removable contamination prior to shipping. Those final levels may be higher than for unrestricted release but will comply with D.O.T. shipping restrictions.

Dismantling of the facility and pond closure will take place after groundwater restoration has been confirmed by NRC and NDEC. Reusable equipment will be segregated from worn-out or scrap items, both types cleaned, and distributed appropriately as determined by residual surface contamination levels. Cleaned refuse may be disposed of in sanitary landfills.

Pond closure will be as follows: First, any remaining liquids will be transferred to vessels of suitable construction and shipped to an approved disposal site. Bottom sludge can then be loaded into a tank truck or placed in drums for disposal. The pond liners are then cleaned to the degree possible. If after cleaning they meet the limitations for surface contamination, the liners will be cut into smaller pieces, placed in the pond bottoms and covered with soil to final contours. If contamination limits

are exceeded, the liners will be placed on trucks and hauled to an approved disposal site. Cement from storage pads and the building floor will be decontaminated if necessary, broken up and placed in the pond bottom. Road bed materials and the parking surface area will also go into the pond. Underdrain piping will remain in place or be shipped as appropriate.

Other radioactive solid waste produced by the mining activities will be shipped to an approved by-product disposal site.

6.8 Postreclamation and Decommissioning Radiological Surveys

After the equipment, building and piping have been removed from the wellfield area, a gamma survey will be conducted over the same wellfield grid as was surveyed preoperationally. Results will be compared with those detected initially. Soil samples will then be obtained from locations indicated as "hot spots" and areas of significant recorded lixiviant spills. These surface samples will be analyzed for natural uranium and radium-226 content. Based upon the results, contaminated soil will be removed and shipped to a disposal site if necessary.

The plant area will be comprised of compacted earth, some surface covering material, a cement foundation and the building. Once the building and cement pads have been removed, a walk around gamma survey will be made of the compacted area. Any contaminated areas will be sampled and removed for proper disposal. The compacted area will then be dozed for recontouring, excess soil placed in the pond pits and the topsoil replaced. A final gamma survey will be performed and the results compared with the preoperational survey.

6.9 Financial Assessment

Following is an estimate of costs to be incurred by FEN or an independent contractor during Restoration, Decommissioning and Reclamation of the Crow Butte Site:

RESTORATION, RECLAMATION AND DECOMMISSIONING
COST ESTIMATE

The following cost estimate is based on the cost per year to restore one mine unit and reclaim one mine unit. The FEN mine plan calls for sequential restoration and reclamation and FEN will have approximately 2 to 3 mine units in restoration, mining or reclamation at any time.

Groundwater Restoration per Mine Unit

Average Mine Unit Size = 22.5 acres
Average Affected Thickness = 10.0 feet
Average Porosity = 0.29
Average Pore Volume (PV) = 65 acre-feet

Restoration Process

. Remove three PV for Halo Recovery and transfer to existing ponds.	
Pumping cost @ 40,000 KW-hr/PV	$ 9,500.00
. Treat two PV with R.O. and reinject permeate @ $2.00/1000 gal;	
R.O. cost plus pumping cost	$ 61,000.00
. Recirculate three PV with reductant	
Pumping cost plus chemical cost @ 1 lbs. reductant/1000 gal.	$ 41,000.00
. Treat two PV with R.O. @ $2.00/1000 gal	
R.O. cost plus pumping cost	$ 61,000.00
Subtotal	**$172,500.00**

Sampling and Monitoring

. Phase I (as per NDEC Permit); Assume 20 representative wells per mine unit:	
20 wells x 6 parameters x 6 months @ $6.00/parameter	$ 4,320.00
. Phase II: 20 wells x 32 parameters x 2 months @ $6.00/parameter	$ 7,680.00
. Phase III: 20 wells x 32 parameters x 6 months @ $6.00/parameter	$ 23,040.00
Subtotal	**$ 35,040.00**

Labor

. Two operators per shift + 4 support personnel for 12 personnel total @ $26,400/year	$316,800.00
Total Restoration per Mine Unit	**$524,340.00**

Note: The above Restoration estimate is based on the following assumptions:

(1) 400 gpm R.O. equipment and all plant equipment will be existing,

(2) The $2.00/1000 gal. operating cost for the R.O. includes electrical, chemical and maintenance,

(3) Solar evaporation ponds will be available.

Reclamation Cost per Mine Unit

. Well plugging and abandonment:	
216 mining wells and 20 monitor wells per mine unit @ $100/well	$ 24,600.00
. Surface reclamation: 22.5 acres @ $1,200/acre	$ 27,000.00
. Roads and other affected areas: 3 acres @ $1,200/acre	$ 3,600.00
TOTAL	**$ 55,200.00**

Site and Plant Decommissioning

. Building and Equipment Decontamination and removal	$225,000.00
. Dryer removal and Disposal	$ 40,000.00
. Solar Evaporation Ponds:	
- 30 acres @ $1,200/acre Reclamation	$ 36,000.00
- Removal and disposal of liners and contaminated solids.	$125,000.00
. Plane site, road, parking area, pipeline reclamation	
- 40 acres @ $1,200/acre	$ 48,000.00
TOTAL	**$374,000.00**

	Cost Estimate Per Mine Unit
TOTALS	
Restoration	**$524,340.00**
Reclamation	**$ 55,200.00**
	$579,540.00

FEN proposes that the surety bond in effect at any time should be determined by the number of mine units that are in operation (operation is defined as mining, restoration or reclamation) at that time. The surety bond will be reviewed annually, and the bond will be adjusted based on the status of operations. The above evaluation indicates that the surety bond for site decommissioning of $374,000 will be in effect over the life of the project, and that a surety bond of $579,540 will be in effect for each mine unit in operation.

At any one time, FEN expects to have three mine units in various stages of operation, restoration or reclamation. On this basis, FEN would anticipate restoration/reclamation cost per mine unit plus the site decommissoning estimate. Using the above cost estimates, the bond would be three times $579,540 plus $374,000 or $2,112,620. The surety bond would be raised accordingly in the event that FEN has more than three mine units in mining, restoration or reclamation.

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