EVALUATION OF THE SHEAR, PEPPERLING GOOD, AND PEPPERLING FAIR ROCK SAMPLES FOR THE LAKEVIEW, OREGON, UMTRA SITE

Submitted to:

U.S. Nuclear Regulatory Commission
Office of NMSS
Washington, DC 20555

Prepared by:

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July 1996

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INTRODUCTION

Typically, reclaimed uranium mill tailings impoundments are covered with a riprap layer to provide protection from weathering and natural erosive processes. U.S. Nuclear Regulatory Commission (NRC) regulations, in 10CFR40 Appendix A, specify that the tailings remain stable for periods of 200 to 1,000 years.

Current stabilization methods for waste disposal recommend that the waste material be placed below the ground surface. Below ground disposal may not be feasible if ground water resources are at risk or if geologic conditions, such as near surface bedrock, prevent cost-effective burial. When below ground burial is not possible, an earthen cap or cover is placed over the waste material. The aboveground impoundments can have embankment and cover slopes ranging from five to 30 percent. The regulations require a "self-sustaining" vegetative or rock cover to minimize erosion. A schematic of a typical aboveground waste impoundment protected with a riprap layer is presented in Figure 1.

One important facet of riprap covers is that they provide long-term stability with a minimum of active maintenance. The riprap cover must be effective for the long-term. While Jahns (1982) reports that numerous types of rocks are relatively resistant to weathering, most engineers and designers realize that the procedures used to quantify rock performance for long periods are limited. Unfortunately, not all rock types exhibit the quality nor durability necessary to sustain the 200 to 1,000-year period.

Rock quality is routinely determined based upon a suite of tests: Specific Gravity, Absorption, Sodium Sulfate Soundness, Los Angeles Abrasion, Tensile, and Schmidt Impact Hammer. The NRC developed a scoring procedure, based upon the rock test results, for rating rock quality acceptability of proposed rock types and rock sources for the erosion cover of uranium tailings impoundments (NRC 1990). It has been assumed that rock samples that attain a passing score will meet long-term durability requirements.

The reclaimed uranium tailings impoundment at Lakeview, Oregon, was covered with a riprap and riprap soil matrix for long-term erosion protection. After approximately five years, monitors observed degradation of the individual rocks comprising the riprap layer and questioned the durability of the protective layer. An evaluation team from

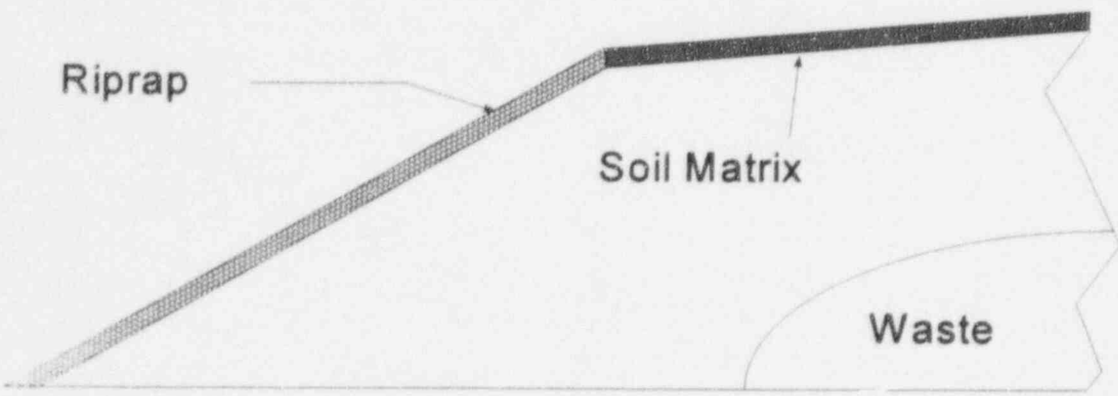

Figure 1 Schematic of Typical Waste Impoundment

Colorado State University was contracted to obtain rock samples from the Lakeview pile for the purpose of assessing the rock quantity, rock quality, and rock durability of the riprap layer. Based upon the assessment, the long-term stability of the rock layer can be determined.

The study site is located near Lakeview, Oregon, as indicated in Figure 2. The 20-acre site was constructed in the late 1980s utilizing a riprap and rock matrix cover for embankment stabilization. The rock was quarried from two local sources, mixed on site and placed on the embankment.

The uranium mill tailings were buried below ground level near the upstream portion of the drainage basin. A rock-soil matrix was placed on top of the reclaimed embankment (erosion protection layer) at a slope of approximately 3 percent. The top slope transitions to a riprap-covered side slope of 20 percent. A riprap lined diversion channel traversed the toe of the slope directing drainage from the toe to an outlet channel and away from the reclaimed pile. Rock placed on the top and on the side slopes of the embankment is well drained and, therefore, considered to be infrequently saturated. However, the toe diversion channel receives and retains drainage and, therefore, is considered to be an area of frequent saturation.

SAMPLING METHODOLOGY

In August 1995, the Colorado State University evaluation team visited the Lakeview, Oregon, site to observe the riprap layer, assess the adequacy (quantity) of the rock layer, and obtain representative samples from the riprap layer for laboratory testing.

In order to determine the rock composition of the riprap, two sample sites were selected along the embankment face using the random walk method. At each site, a two foot by two foot by one foot volume of rock was excavated from the riprap layer. The rock from each sample location was removed and sorted by a geologist. The rocks were determined to be olivine basalt. However, one sample was determined to be derived from the Shear Quarry while the remaining two samples were derived from the Pepperling Quarry. There appeared to be two distinct rock qualities from the Pepperling site and were identified as Pepperling Good and Pepperling Fair. Once the rock was sorted, each

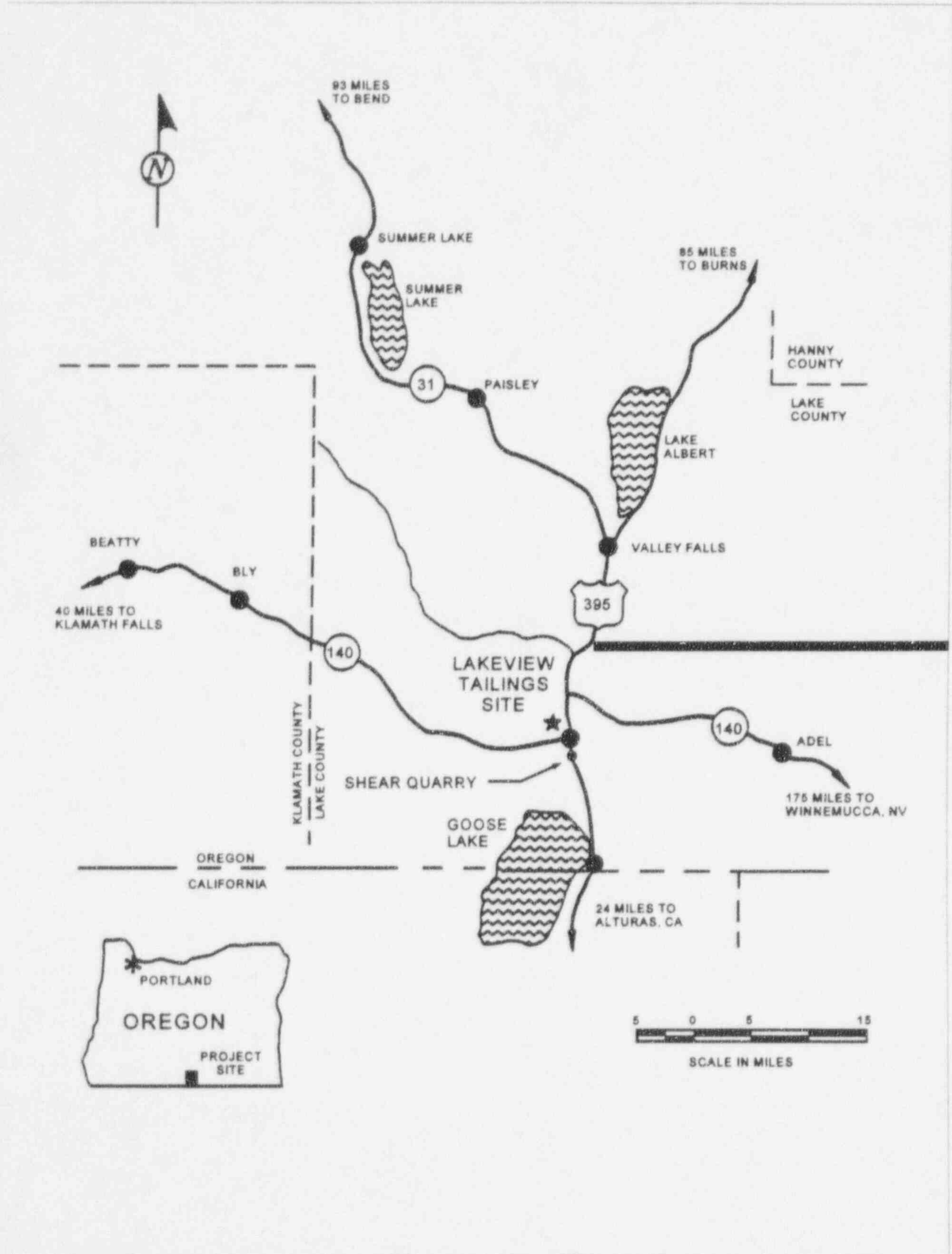

Figure 2 Location of Lakeview Tailings Site

sample was weighed using a portable dial scale accurate to ± 0.125 pounds. The scale was graduated in 0.25 pound increments with a capacity of 60 pounds.

At the first sample location, it was assumed that the fines, material too small to classify, comprised 15 percent of the total material excavated from the rock layer. At the second sample location, the fines were separated and weighed. The material removed from the sample locations on the embankment face was replaced and the surface smoothed.

Approximately 100 pounds of each of the three rock types (Shear, Pepperling Good, and Pepperling Fair) were required to conduct the desired laboratory tests. Each sample was segmented into 50 to 60 pound portions and placed into canvas bags for transport. The samples were packaged and shipped to Fort Collins, Colorado, for laboratory analysis.

CLIMATOLOGIC INFORMATION

Climatological information was collected from the Oregon State Climatological Service for the Lakeview airport extending from 1991 to 1995. The information collected included air temperature, dew point temperature, wind speed, wind direction, and barometric pressure. These data were recorded approximately seven times per day throughout the evaluation period. An analysis of the temperature data indicated the number of freeze/thaw cycles that can be expected annually. Table 1 presents the number of freeze/thaw cycles for each year of record.

Table 1 Freeze/Thaw Cycles in Lakeview

Year	Freeze/Thaw Cycles
1991/1992	77
1992/1993	80
1993/1994	115
1994/1995	93
AVERAGE	92

TESTING

A Fort Collins, Colorado, geotechnical laboratory (Terracon Consultants Western, Inc.) was contracted to perform a suite of rock quality tests on the samples collected at the Lakeview site. A complete copy of their report is included in Appendix A. Table 2 summarizes the tests conducted and the corresponding standards. The first six tests presented in Table 2 were suggested by the NRC to provide a quantitative assessment of riprap quality (NRC 1990). The freeze/thaw tests were conducted to examine the riprap's long-term durability when exposed to natural weathering processes.

Table 2 Summary of Geotechnical Tests

TEST	Reference Test Standard
Specific Gravity	ASTM C127
Absorption	ASTM C127
Sodium Sulfate Soundness (5 cycles)	ASTM C88
Sodium Sulfate Soundness (10 cycles)	ASTM C88
Los Angeles Abrasion	ASTM C131
Petrographic Examination	ASTM C295
Freeze/Thaw	AASHTO T103

Due to the need to quantify the effects of natural weathering on protective riprap, specimens from each sample were subjected to 100 continuous freeze/thaw cycles. The suite of tests outlined in Table 2 was conducted on all three rock samples collected (Shear, Pepperling Good, and Pepperling Fair) except the ten-cycle Sodium Sulfate Soundness test. Only specimens from the Shear and Pepperling Fair samples were subjected to the ten-cycle Sodium Sulfate Soundness test. Appendix A contains a complete description of the tests and modifications to the corresponding standards.

RESULTS

The composition of each of the three sample types, as placed on the embankment face, was determined by comparing the weights of each rock type identified at a sample

site. Tables 3 and 4 present the rock composition from the two sample sites. Samples one and two had total weights of 362.65 pounds and 306.0 pounds, respectively. As observed in Table 4, the fine material of sample two comprised approximately 16 percent of the total material extracted. The average composition of the Shear, Pepperling Good, and Pepperling Fair aggregate, as placed on the embankment, was 32.2 percent, 39.8 percent, and 12.5 percent, respectively.

Table 3 Results from Sample Site One

Sample Number	Shear (lb)	Pepperling Good (lb)	Pepperling Fair (lb)
1	27.0	29.25	29.25
2	32.0	29.75	26.0
3	25.0	30.0	4.0
4	27.0	33.25	
5	11.5	4.25	
TOTAL	122.5	126.5	59.25
% of Total	33.78	34.88	16.34

Table 4 Results from Sample Site Two

Sample Number	Shear (lb)	Pepperling Good (lb)	Pepperling Fair (lb)	Fines (lb)
1	29.0	31.0	26.5	27.5
2	28.0	32.0		21.5
3	36.5	30.5		
4		33.0		
5		10.5		
TOTAL	93.5	137.0	26.5	49.0
% of Total	30.56	44.77	8.66	16.01

The suite of durability tests outlined in Table 2 was conducted on specimens from each sample type at Terracon Consultants Western, Inc. in Fort Collins, Colorado. A summary of the test results is presented in Table 5. A complete description of the test results is presented in Appendix A.

Table 5 Summary of Durability Test Results

	TEST				
Sample Name	Specific Gravity	Absorption (%)	Sodium Sulfate (% Loss)		L.A. Abrasion (% Loss)
			5 Cycles	10 Cycles	
Shear	2.90	0.10	0	0.1	14.9
Pepperling Good	2.89	0.10	0	N/A	13.4
Pepperling Fair	2.83	0.20	0.1	0.5	15

It is noted that the results reported for the five cycle Sodium Sulfate Soundness tests are the percent losses on the largest size fraction that is comparable with the material placed at the Lakeview site. Specimens of the size placed at the Lakeview site were subjected to ten cycles of the Sodium Sulfate Soundness test. A detailed breakdown of the percent losses for each size fraction is presented in Appendix A.

A petrographic analysis was conducted by Richard C. Mielenz, P.E., Inc. (Appendix A). Ten representative specimens of each rock type (Shear, Pepperling Good, and Pepperling Fair) were selected and used for the petrographic analysis. The specimens analyzed were representative of the size placed on the Lakeview impoundment. Each sample was visually examined using a stereoscopic microscope. Sections showing the composition and internal structure of each rock were obtained by sawing across the major axis of each specimen. Due to the uniform lithology of each of the specimens, one microscopical thin section was obtained from each sample and examined as a grain mount under a petrographic microscope.

The Shear sample consisted of fragments of an olivine basalt that resembled olivine diabase in internal structure and texture. Each of the Shear specimens had one to six

surfaces that were exposed to weathering as placed on the impoundment. Six of the ten specimens were observed to be transected by natural partings or fractures in the rock. Hydrothermal activity occurring in the late stages of the volcanic formation and subsequent weathering has resulted in minor alterations to the basalt in the Shear specimens. It was reported that, from the standpoint of resistance to disintegration by weathering, the Shear specimen would be suitable for use as protection for the periods specified.

The Pepperling Good specimens were found to consist of fragments of olivine basalt more fine grained than that of the Shear specimens. Eight of the ten specimens were observed to have one or two natural joints transecting the specimen. Each of the Pepperling Good specimens had one to six surfaces that would be exposed to weathering at the original source. While the specimens exhibited minor alteration to the basalt as a result of hydrothermal activity during formation, only minimal effects as a result of weathering due to exposure were observed. It was reported that, from the standpoint of resistance to disintegration by weathering, the Pepperling Good specimen would be suitable for use as protection for the periods specified.

The Pepperling Fair specimens consisted of olivine basalt, which was similar to that observed in the Pepperling Good sample. All ten of the specimens contained natural joints and displayed one to six surfaces that were exposed to natural weathering at the source. The specimens exhibited appreciable alteration to the basalt as a result of deuteric activity during the latter part of the volcanic formation followed by weathering at the original source. Nine of the specimens displayed veinlets that contained varying amounts of clay and clay-like minerals. Due to the alteration in the basalt, the specimens would be expected to exhibit splitting as a consequence of freezing, and freezing and thawing, when and if subjected to subfreezing temperatures while saturated by water. The Pepperling Fair specimen was therefore considered marginally suitable for the designated use. A complete description of the petrographic analysis for each of the samples can be found in Appendix A.

In order to help quantify the effects of natural weathering, specimens from each of the three Lakeview samples were exposed to 100 freeze/thaw cycles. The testing

procedure was defined to alternate five dry cycles and five wet cycles. Dry cycles were defined by oven drying each sample specimen and then proceeding with the freeze/thaw cycles. At the end of every fifth cycle, the specimens were again oven dried and weighed. Wet cycles zero through forty were subjected to complete immersion during freezing. The samples were placed in a container and the specimens were covered with water. The samples were continuously immersed in water during the five cycles. At the end of the fifth cycle, the specimens were oven dried and the weights recorded. Beginning with wet cycle 45, the samples were submerged in water for approximately 12 hours, allowed to drain, each specimen wrapped in a wet towel and placed in the freezer. This procedure was repeated for each of the five cycles. At the end of the fifth cycle, the specimens were oven dried and the weights recorded. The specimens were photographically documented after each of the five cycles.

Figure 3 presents a graphical representation of the losses in percent of initial weight throughout 100 freeze/thaw cycles. It is observed from Figure 3 that the Shear, Pepperling Good, and Pepperling Fair specimens lost 0.84, 0.40 and 0.97 percent of their initial weight, respectively, after 100 freeze/thaw cycles.

The climatological data, presented in Table 1, indicate that the average number of annual freeze/thaw cycles for the Lakeview area is 92. Therefore, it is estimated that approximately 92,000 freeze/thaw cycles could be expected during one thousand years. Figure 4 presents a graphical extrapolation of time versus the number of freeze/thaw cycles expected during a thousand-year period. Estimations of the expected loss in initial weight (reported in percent of initial sample weight) of the placed riprap at various time intervals were determined. Table 6 displays an extrapolation of the freeze/thaw losses observed in Figure 3 incrementally over a hundred-year period. Figure 5 presents a graphical representation of the expected losses in percent of original sample weight over time. Trends exhibited in the losses due to freeze/thaw cycles indicate that the Shear, Pepperling Good, and Pepperling Fair rock would exhibit 100 percent losses in approximately 130, 272, and 112 years, respectively.

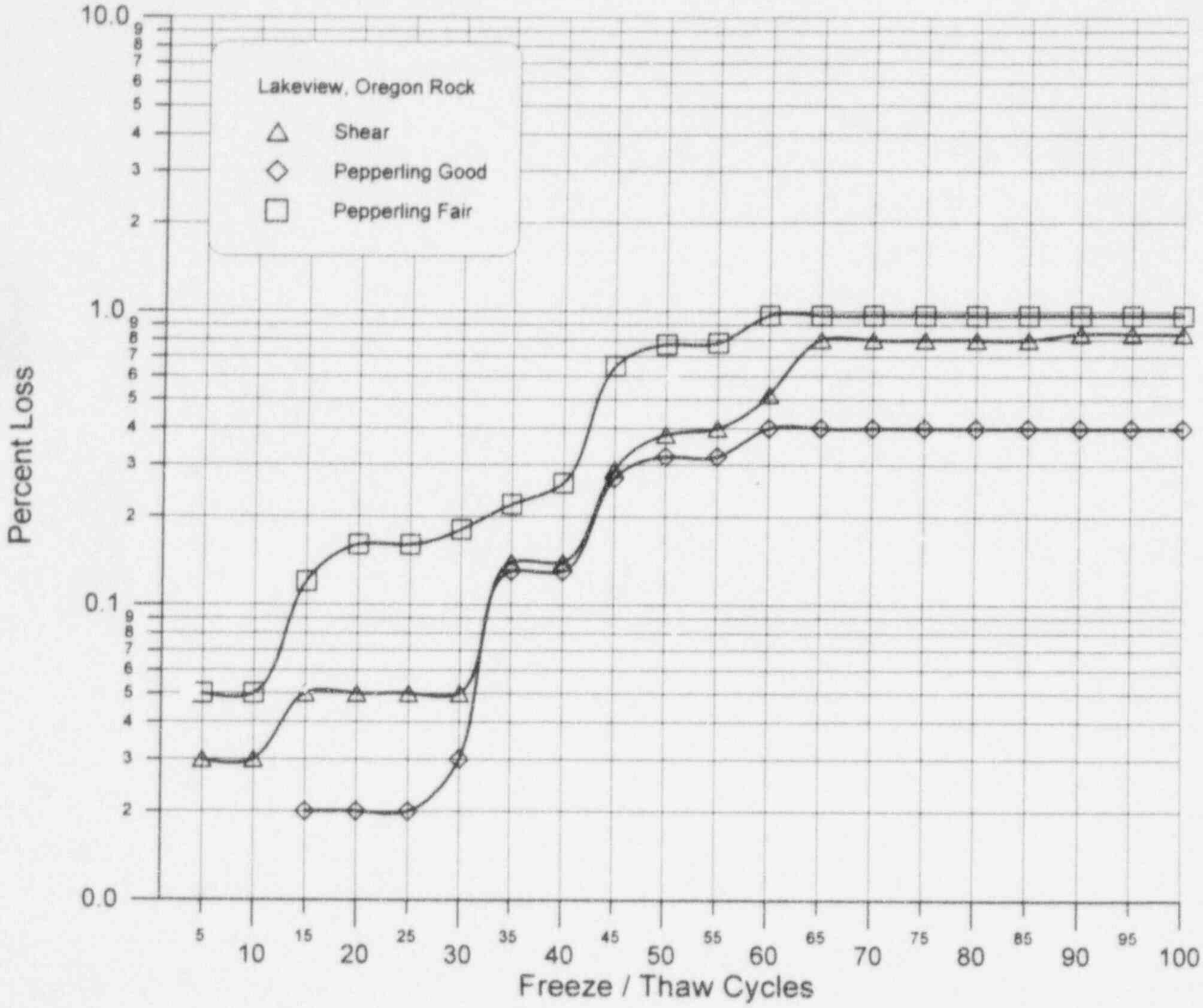

Figure 3 Graphical Representation of Freeze/Thaw Losses

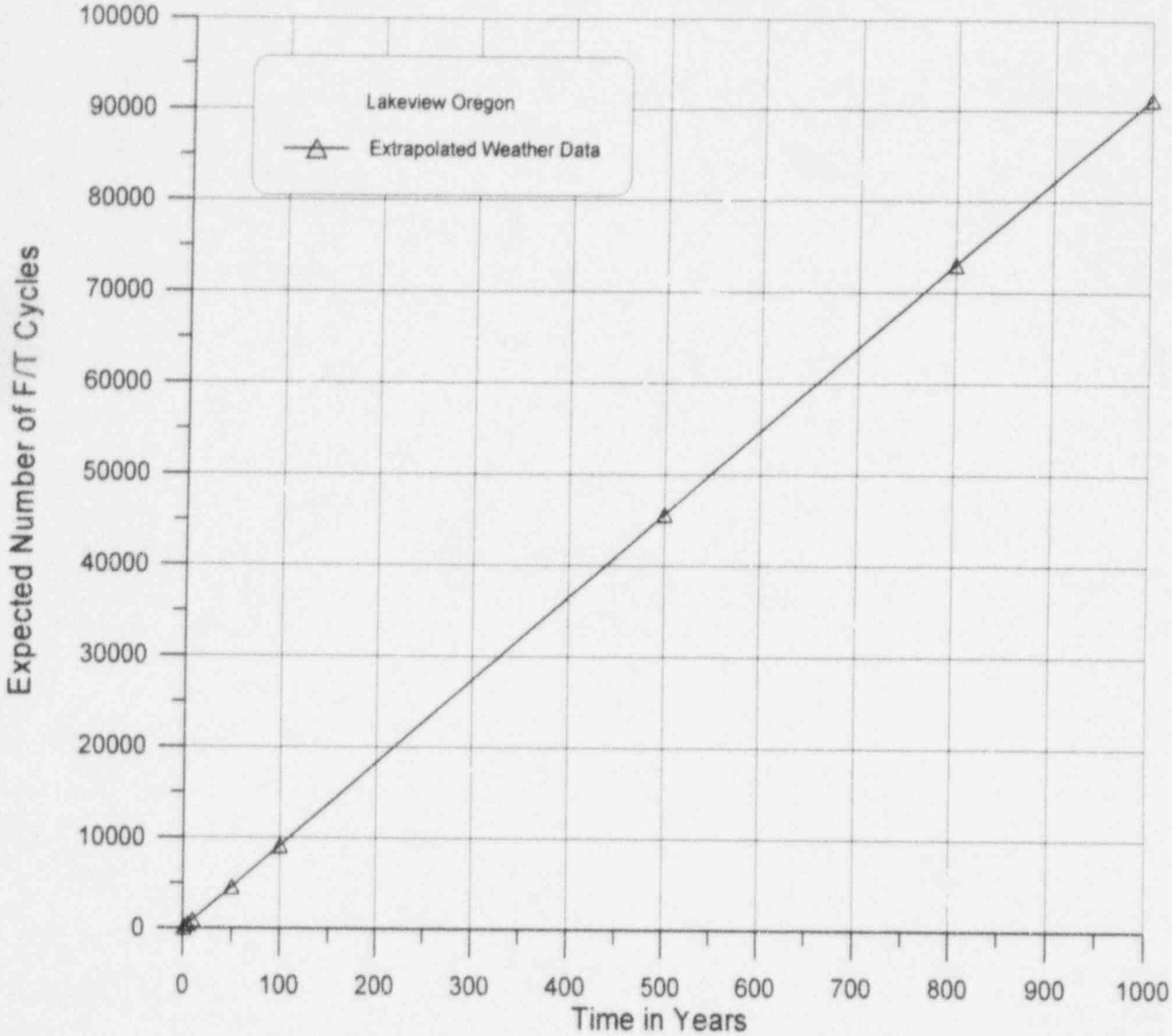

Figure 4 Extrapolation of Lakeview, Oregon, Freeze/Thaw Weather Data

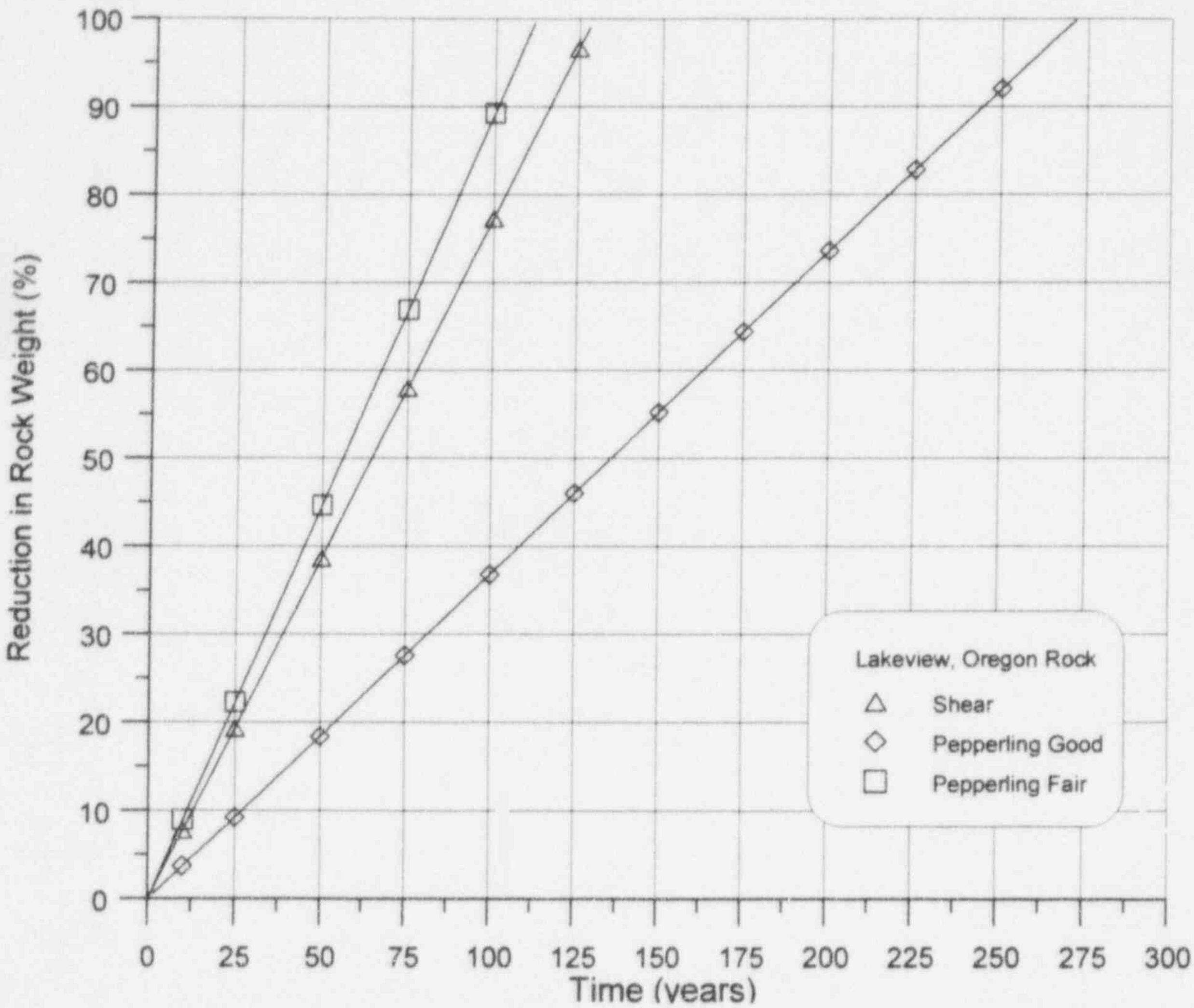

Figure 5 Losses Expected in Lakeview, Oregon, Rock Over Time

Table 6 Extrapolation of Freeze/Thaw Losses

Number of Years	Expected Number of Freeze/Thaw Cycles	Percent Loss (%)		
		Shear	Pepperling Good	Pepperling Fair
10	920	7.73	3.68	8.92
25	2300	19.32	9.20	22.31
50	4600	38.64	18.40	44.62
75	6900	57.96	27.60	66.93
100	9200	77.28	36.80	89.24

An additional concern, however, is the reduction in size of the placed riprap. While the rock may not disintegrate for several hundred years, it may become ineffective due to a reduction in size (i.e., reduction in D_{50}). Johnson et al. (1993) developed over sizing criteria for riprap. The over sizing criteria are dependent on the location where the rock is to be placed. Areas that are frequently saturated are generally more vulnerable to weathering than occasionally saturated areas. For rock over sizing purposes, the following criteria were presented:

A. Critical Areas. These areas included, as a minimum, frequently saturated areas, channels, toes, aprons, etc.

<u>NRC Rating</u>	<u>Over sizing Criteria</u>
80-100	No over sizing needed
65-80	Oversize using factor of (80-Rating)
Less than 65	Reject

B. Non-Critical Areas. These areas include occasionally saturated areas, top slopes, side slopes, and well-drained areas.

<u>NRC Rating</u>	<u>Over sizing Criteria</u>
80-100	No over sizing needed
50-80	Over size using factor of (80-Rating)
Less than 50	Reject

As observed from the over sizing criteria, rock placed in a critical area can be over sized a maximum of 15 percent, whereas rock placed in a non-critical area can be oversized as much as 30 percent.

An analysis was performed to determine the change in the rock diameter as a function of time. It was assumed that the riprap was ellipsoid in shape and had a placed D_{50} of 3.5 inches, Figure 6 presents a schematic of the assumed shape of the placed riprap and the defining variables. The volume of an ellipsoid may be calculated as:

$$\text{Volume} = \frac{4}{3}\pi a b c \quad (1)$$

Where

a = distance from axis origin to interception of X axis

b = distance from axis origin to interception of Z axis

c = distance from axis origin to interception of Y axis

It was also assumed that the distances *a* and *b*, as indicated in Figure 6, were equal and distance *c* was twice that of *a* and *b*. Substituting the assumptions into Equation 1 yields:

$$\text{Volume} = \frac{10}{3}\pi a^3 \quad (2)$$

The D_{50} of the placed riprap was then defined as:

$$D_{50} = 2a \quad (3)$$

The initial weight of the riprap was determined as:

$$\text{Weight} = \text{Specific Gravity} * \text{Unit Weight of Water} * \text{Volume of Sample} \quad (4)$$

Assuming a specific gravity of 2.65, losses were calculated at incremental time steps, as reported in Table 6. The loss in weight at the end of each time step was subtracted from the initial sample weight and the corresponding D_{50} calculated. Figure 7 presents a

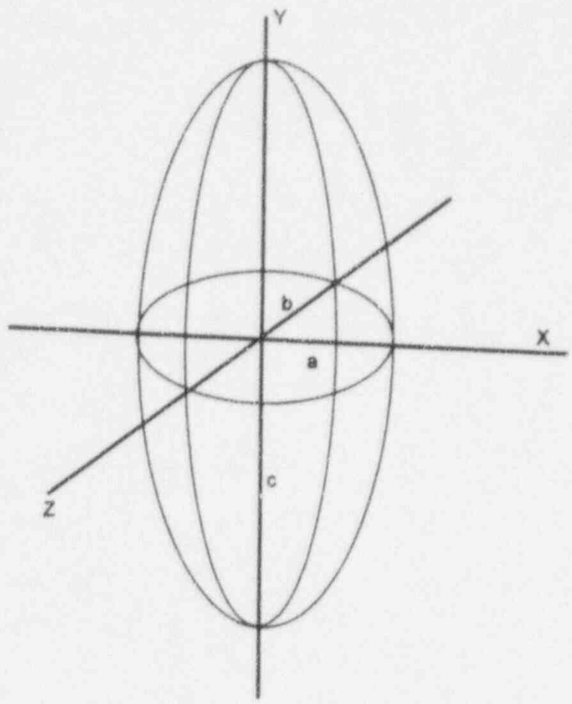

Figure 6 Schematic of Assumed Riprap Shape

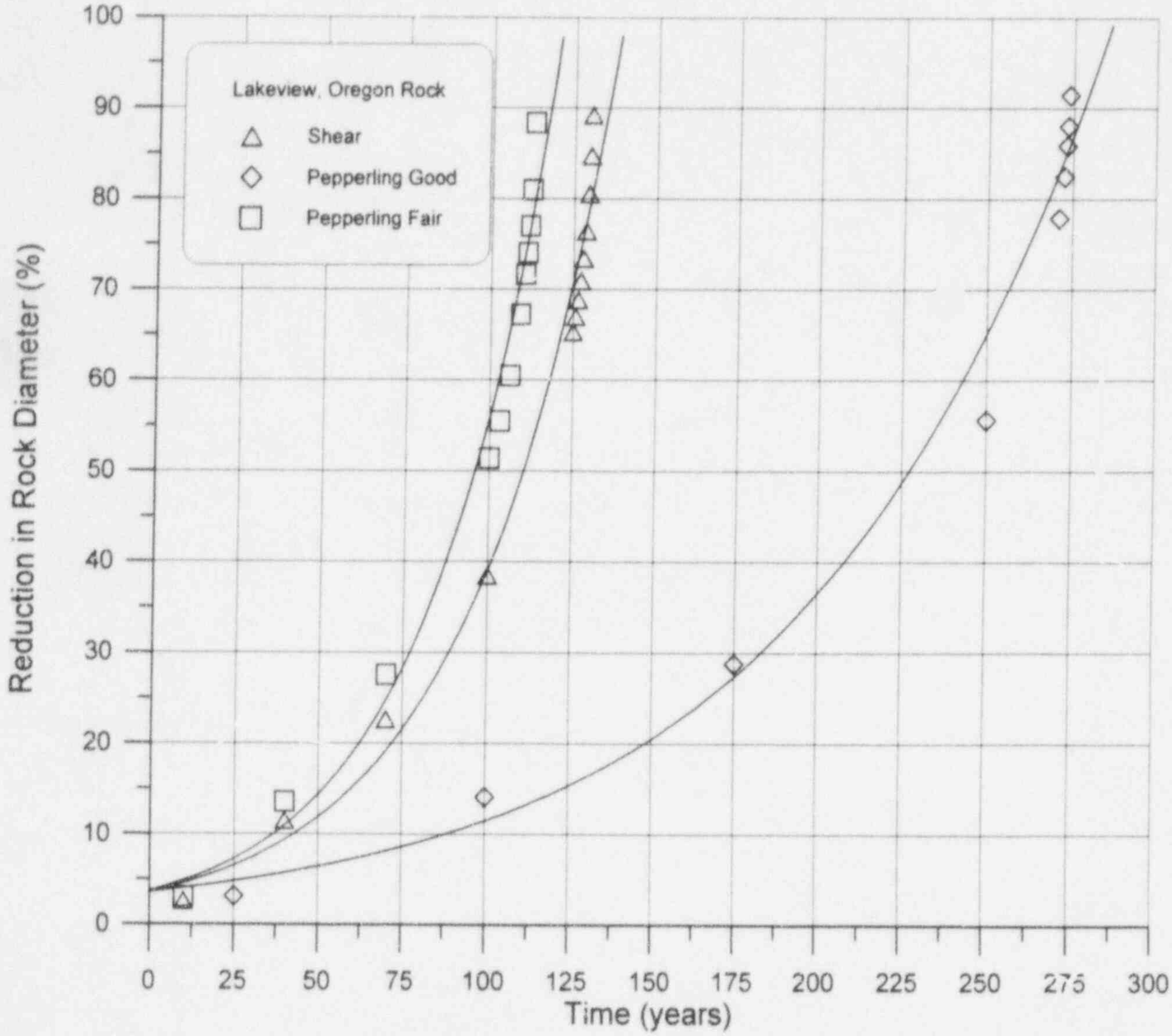

Figure 7 Reduction in Lakeview, Oregon, Rock Diameter Versus Time

graphical representation of the expected D_{50} of the placed riprap over time reported in percent of initial diameter.

The rock sample was derived from the pile side slope that is considered a non-critical area. Therefore, rock may be oversized by up to 30 percent, per the rock sizing criteria. It is observed from Figure 7 that the Shear and Pepperling Fair, which together comprise approximately 45 percent of the placed riprap, may be reduced (in diameter) 30 percent after approximately 80 and 90 years of exposure to natural weathering, respectively. Equations describing the reduction in rock size over time for the Shear, Pepperling Good, and Pepperling Fair samples extracted from the Lakeview, Oregon, pile, respectively, are expressed as follows:

$$RD = 3.61 * e^{0.024 \cdot T} \qquad (5)$$

$$RD = 3.60 * e^{0.012 \cdot T} \qquad (6)$$

$$RD = 3.69 * e^{0.027 \cdot T} \qquad (7)$$

where

RD = Reduction in rock diameter (%)

T = Time of exposure (years)

Each of the exponential fits resulted in a coefficient of determination (R^2) value of 0.98. Equations 1, 2, and 3 were applied to the as placed sieve results, included in Appendix A, of the Shear, Pepperling Good, and Pepperling Fair samples, respectively, with a hundred-year time of exposure. A comparison of the sieve results of the placed riprap verses the sizes projected after 100 years of exposure is presented in Figure 8. After 100 years of exposure, approximately 60 percent of the placed riprap would have a D_{50} less than 3.0 inches as observed in Figure 8.

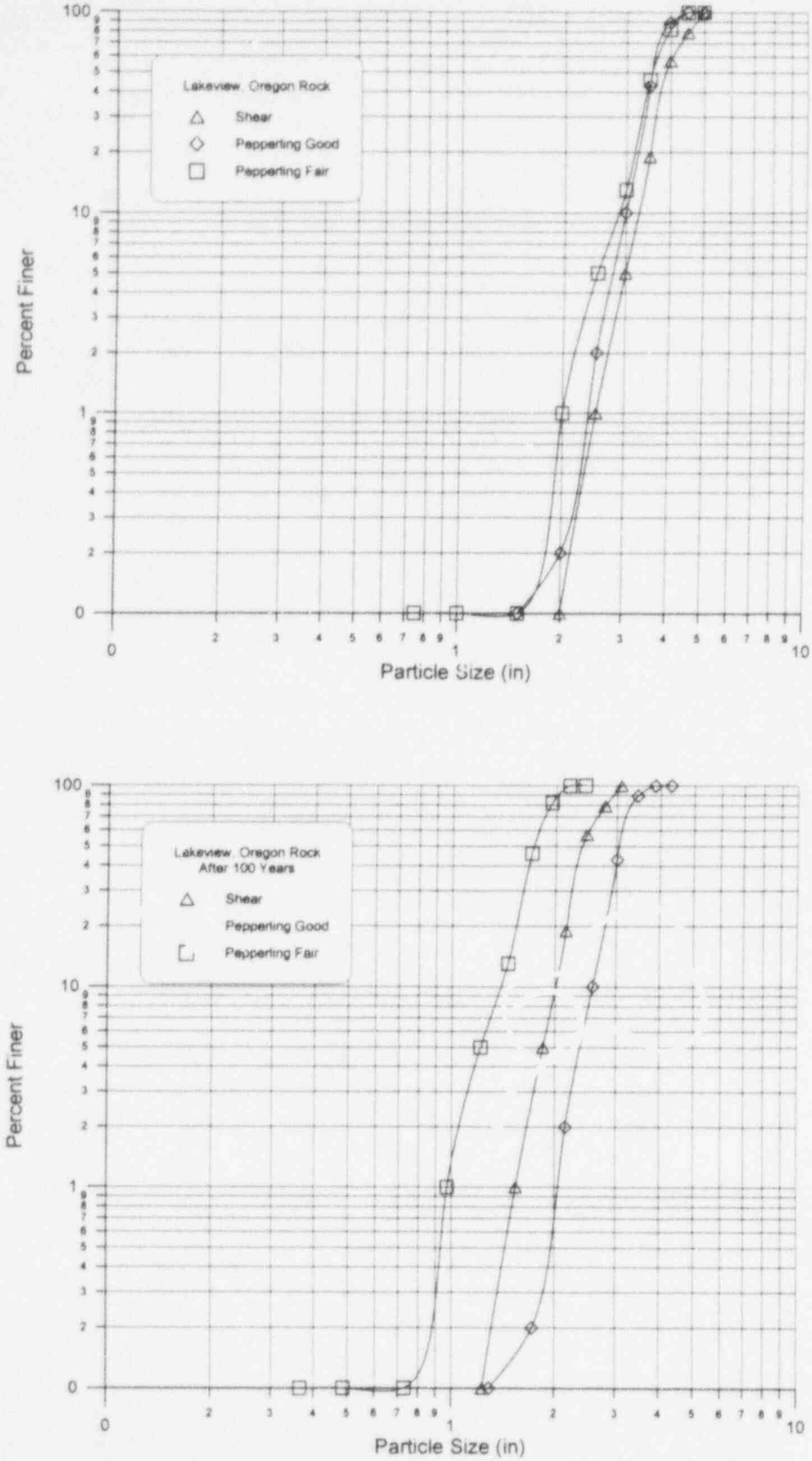

Figure 8 Comparison of Sieve Results

An attempt was made to correlate the percent losses determined from repeated Sodium Sulfate Soundness tests with those determined from repeated freeze/thaw tests. The Shear and Pepperling Fair samples were used in the analysis since each was subjected to ten cycles of the Sodium Sulfate Soundness test. Figure 9 presents a graphical representation of the losses determined after each of the ten cycles. For each of the two samples, the number of freeze/thaw cycles was compared to the number of Sodium Sulfate cycles that produced an identical loss in weight (measured in percent) of the specimen. Tables 7 and 8 display the results of the comparison for the Pepperling Fair and Shear samples, respectively.

Table 7 Comparison of Sodium Sulfate and Freeze/Thaw Data for Pepperling Fair Sample

Sodium Sulfate Cycle	Freeze/Thaw Cycle	Percent Loss (%)
1	15	0.12
2	30	0.17
3	32	0.19
6	40	0.27
10	43	0.49

Table 8 Comparison of Sodium Sulfate and Freeze/Thaw Data for Shear Sample

Sodium Sulfate Cycle	Freeze/Thaw Cycle	Percent Loss (%)
2	3	0.01
4	10	0.03
7	30	0.05
10	32	0.07

The data were then plotted and a power curve regression conducted. Figure 9 presents the graphical interpretation of the data. It is observed that the R^2 for the fitted curves are 0.85 and 0.97 for the Pepperling Fair and Shear data, respectively.

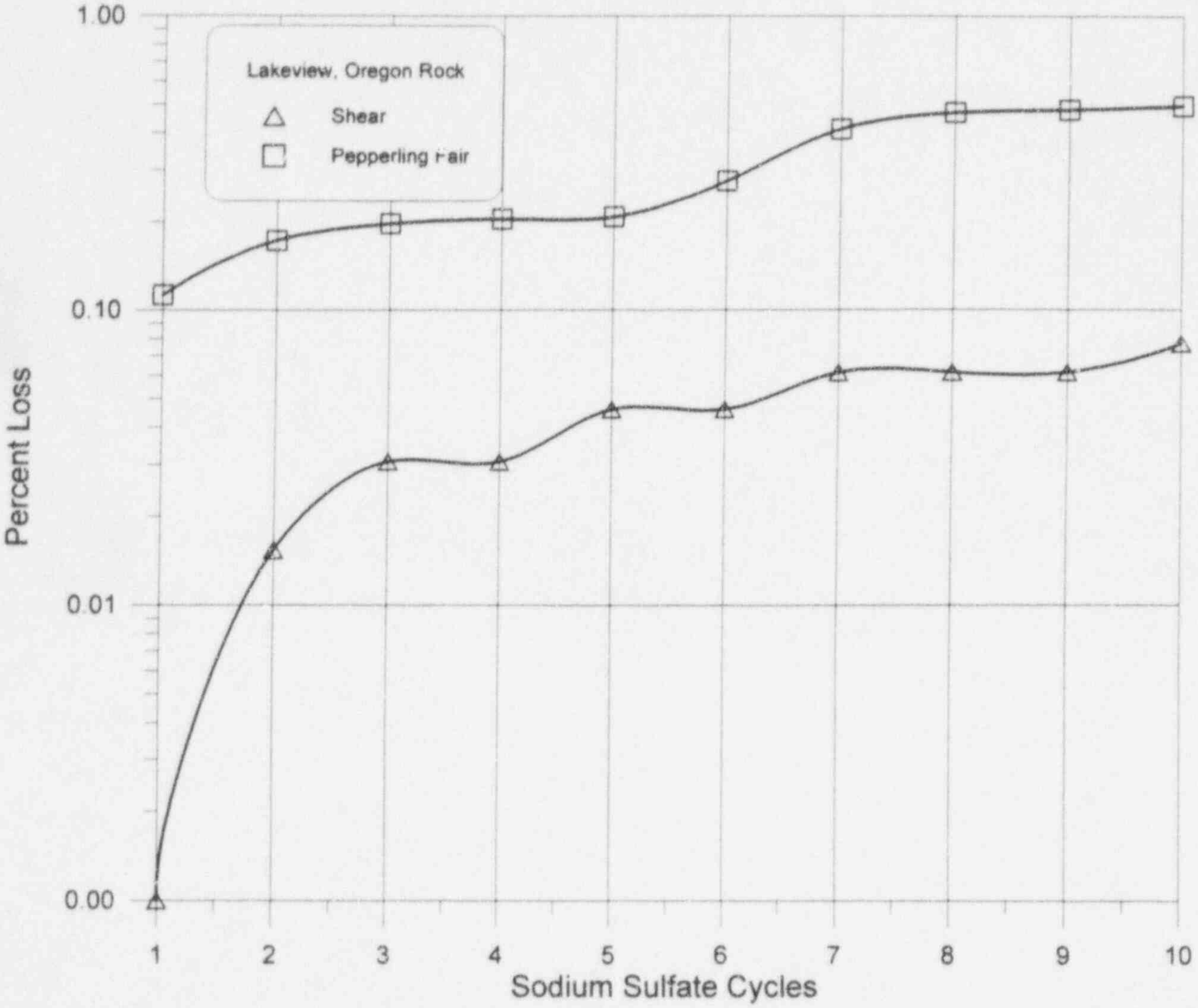

Figure 9 Results of Repeated Sodium Sulfate Soundness Tests

Samples of the Shear and Pepperling Fair rock derived from the Lakeview, Oregon, pile were subjected to one hundred freeze/thaw cycles and ten sequential Sodium Sulfate Soundness tests. Test cycles yielding equivalent losses from freeze/thaw and Sodium Sulfate Soundness was plotted as presented in Figure 10. It is observed that the two basalt samples yield different loss rates for five or fewer Sodium Sulfate Soundness cycles and 25 or fewer freeze/thaw cycles. However, as the number of Sodium Sulfate Soundness test cycles approaches ten and the number of freeze/thaw test cycles approaches 100, the two samples yield similar losses. Although each rock type will test differently, it is apparent that a single Sodium Sulfate Soundness test may not be indicative of the rock durability. These results suggest that as many as ten to 20 sequential Sodium Sulfate Soundness tests may be warranted to better predict long-term durability of a proposed rock sample.

FINDINGS

- It does not appear that the riprap layer comprised of olivine basalt derived from the Shear and Pepperling quarries and used at the Lakeview tailings site will be effective for a 200-year performance period.
- The initial rock quality tests and petrographic analysis indicated that the olivine samples derived from the Pepperling and Shear quarries and used at the Lakeview, Oregon, tailings site were acceptable for the long-term. However, after five years of service, individual rocks are degrading.
- The standard rock quality tests (i.e., Specific Gravity, LA Abrasion, etc.) and petrographic analyses are good indicators of rock quality and potential suitability for erosion protection applications. Rock quality tests may not necessarily be good indicators of rock durability, at the Lakeview, Oregon, site because of the potential for chemical alteration to occur.
- Rock durability should be examined to quantify the risk of long-term degradation.
- Hydrothermally crystallized basalts with smectite clay mineral and/or fractures may not be acceptable for long-term erosion control applications.

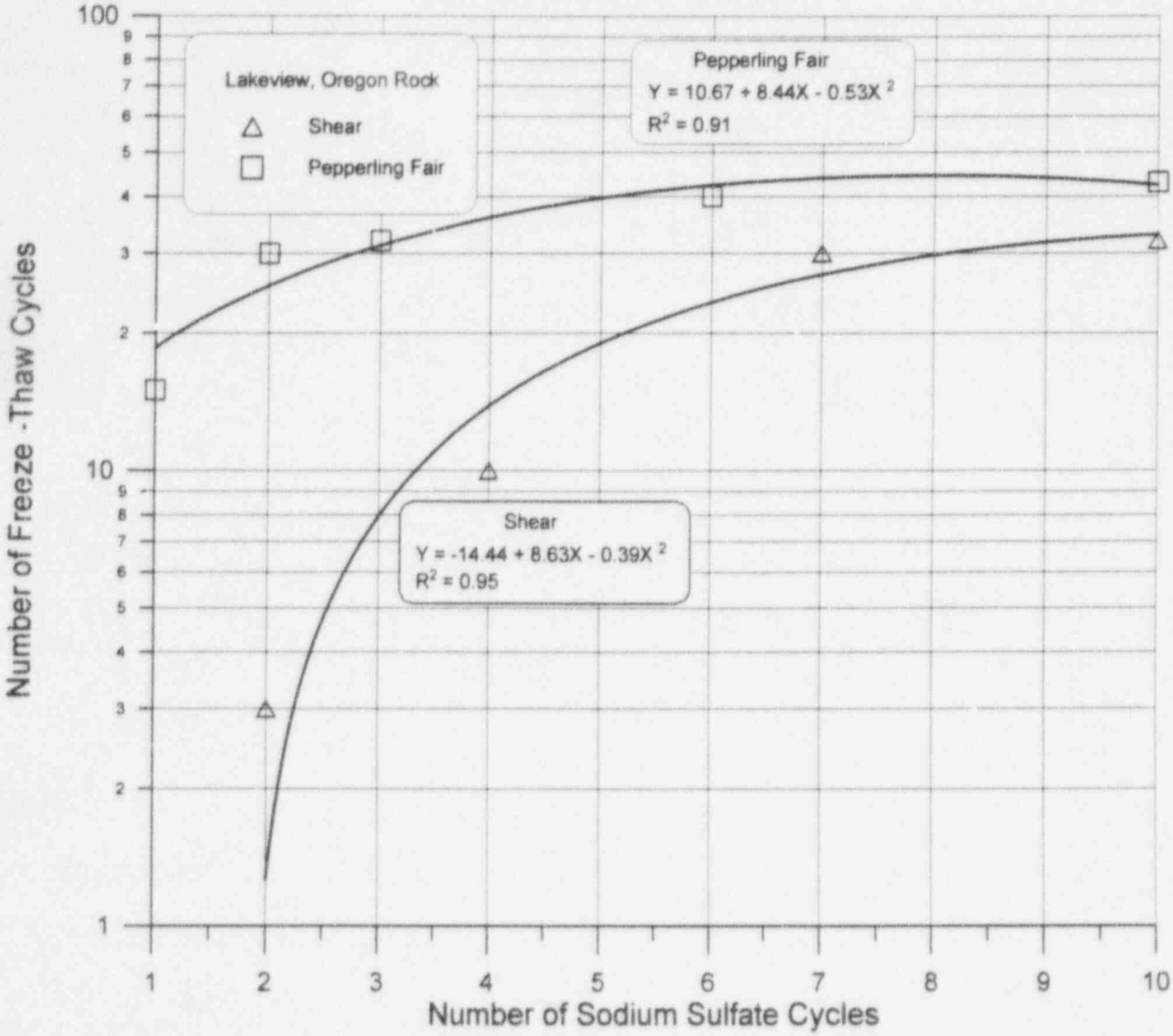

Figure 10 Comparison of Freeze/Thaw and Sodium Sulfate Data

- Based upon the premise that the Lakeview rock was oversized by as much as 30 percent, the rock diameter reduction analysis indicates that the Pepperling fair and Shear rock samples may become ineffective (no longer meet rock size criteria) in less than 80 years and 90 years, respectively. It is projected that Pepperling good rock may become ineffective in approximately 180 years.
- A procedure should be developed for assessing rock durability. The procedure should include site specific climatological fluctuations (i.e., freeze/thaw cycles). Repeated Sodium Sulfate Soundness tests (10 or more cycles) and freeze/thaw tests (100 or more cycles) may be needed to more fully evaluate the long-term durability of the samples.
- Freeze/thaw testing degraded the individual rock samples by:
  - General degradation by detachment of individual particles on the rock surface
  - Fracturing along fissures and joints resulting in the loss of components of the sample.
- A long-term surveillance program of the riprap is highly recommended for the Lakeview tailings site. Particular attention should be focussed in the channel and apron areas (frequently saturated zones).

SUPPLEMENTAL INFORMATION

An inquiry was made to determine if the rock used at the Lakeview disposal site had also been used by the Oregon Department of Transportation (ODOT). ODOT reported that aggregate derived from the Pepperling quarry had been used in paving applications in the Lakeview, Oregon, area. Representatives from ODOT indicated that sections of pavement utilizing the Pepperling aggregate are showing signs of deterioration. The deteriorating sections have been in place less than three years. There is currently a concern that the aggregate derived from the Pepperling quarry has contributed to the accelerated deterioration of the pavement.

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APPENDIX A

LABORATORY TESTING OF AGGREGATE
FOR U.S. NUCLEAR REGULATORY COMMISSION
URANIUM TAILINGS FACILITY, OREGON
PROJECT NO. 20954037

Terracon
CONSULTANTS WESTERN, INC.
EMPIRE DIVISION
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(970) 484-0359 Fax (970) 484-0454

Larry G. O'Dell, P.E.
Neil R. Sherrod, C.P.G.

May 3, 1996

Dr. Steven R. Abt
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

Re: Laboratory Testing of Aggregate
For U.S. Nuclear Regulatory Commission
Uranium Tailings Facility, Oregon
Project No. 20954037
Amended: Page 10 and Attachment

On November 13, 1995, your personnel delivered to our laboratory three (3) aggregate samples designated as Shear, Pepperling Good and Pepperling Moderate (fair). Each sample was delivered in two (2) canvas bags. The aggregate was reported to be from the above referenced project. Our personnel combined the two (2) bags of each designation into one (1) composite sample and performed a sieve analysis of the as received material. The aggregate was then separated into size fractions for testing and/or manual crushing for the designated test procedure(s).

At your request, we performed the following tests in general accordance with the procedure(s) shown below, or modified per your instructions.

TEST DESCRIPTION	TEST PROCEDURE	COMMENTS/DEVIATION
Sieve Analysis of Fine and Coarse Aggregate	ASTM C136 & C117	
Specific Gravity and Absorption of Coarse Aggregate	ASTM C127	4" Size Fraction was selected by client
Soundness of Aggregates by Use of Sodium Sulfate	ASTM C88	2" to 4" Aggregate crushed to size Shear 4" size was not crushed
Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine	ASTM C131	Aggregate crushed to size fraction for grading A
Soundness of Aggregate by Freezing and Thawing	AASHTO T103	Wet-dry alternating freeze cycles selected by client
Petrographic Examination of Aggregate for concrete	ASTM C295	

If you have any questions in regards to this report, please contact us at your earliest convenience. This report will be updated upon completion of the tests that are in progress. (Freeze-thaw).

Respectfully submitted,
TERRACON CONSULTANTS WESTERN, INC.

Mike L. Walker, CET
Manager of Construction Services

Reviewed By:

William J. Attwooll, P.E.
Assistant Office Manager

Attachments: Grain-size Distribution Curves
Petrographic Analysis

MLW/WJA/cjh

The test results completed to date are summarized as follows:

SIEVE ANALYSIS

Sieve Size	Shear	Pepperling Good	Pepperling Moderate
5"	100		
4-1/2"	79	100	100
4"	57	89	82
3-1/2"	19	43	46
3"	5	10	13
2-1/2"	1	2	5
2"	0	---	1
1-1/2"		0	---
1"			---
3/4"			0
Total Weight of Sample, lbs.	112.4	117.0	115.6

Also refer to Grain Size Distribution Curve (Figure 1-3); attached.

SIZE DISTRIBUTION (No. of Particles)

4-1/2"	4		
4"	5	3	5
3-1/2"	12	17	10
3"	6	16	17
2-1/2"	3	5	7
2"	1	2	5
1-1/2"		1	1
1"			3
3/4"			4
Total No. Particles	31	44	52

SPECIFIC GRAVITY AND ABSORPTION (4")	SHEAR	PEPPERLING (GOOD)	PEPPERLING (MODERATE)
Bulk Specific Gravity (dry)	2.89	2.88	2.82
Bulk Specific Gravity (SSD)	2.90	2.88	2.82
Apparent Specific Gravity	2.90	2.89	2.83
Absorption, %	0.1	0.1	0.2

LOS ANGELES ABRASION

Percent Loss	14.9	13.4	15.0
Grading	A	A	A

TEST SIZE FRACTION AFTER CRUSHING FOR LOS ANGELES ABRASION TEST

SIEVE SIZE		WEIGHT OF INDICATED SIZE AND GRAMS			
PASSING	RETAINED ON	SHEAR	PEPPERLING (GOOD)	PEPPERLING (MODERATE)	ASTM C131 GRADING A
1-1/2"	1"	1256.6	1245.0	1255.4	1250 ± 25
1"	3/4"	1249.0	1255.4	1252.7	1250 ± 25
3/4"	1/2"	1246.1	1252.6	1245.8	1250 ± 10
1/2"	3/8"	1253.6	1249.5	1247.5	1250 ± 10
TOTAL		5005.3	5002.5	5001.4	5000 ± 10

CRUSHED TEST SIZE FRACTION PRIOR TO SULFATE SOUNDNESS TESTING

PERCENT PASSING	SHEAR	PEPPERLING	PEPPERLING (MODERATE)
2"	100	100	100
1-1/2"	83	78	83
1"	67	29	33
3/4"	9	15	18
1/2"	4	5	8
3/8"	2	3	5
No. 4	0	0	0

SHEAR SAMPLE
SOUNDNESS TEST OF COARSE AGGREGATE
(5 Cycles-Sodium Sulfate)

Sieve Size	Grading of Crushed Sample, %	Weight of Test Fractions Before Testing,g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
2-1/2" to 1-1/2"	17	4974.6	0.2	0.0
1-1/2" to 3/4"	74	1527.7	0.5	0.4
3/4" to 3/8"	7	1005.5	1.0	0.1
3/8" to No. 4	2	-	1.0 (A)	0.0
TOTALS	100	7507.8		1

QUALITATIVE EXAMINATION OF COARSE SIZES
Particles Exhibiting Distress

Sieve Size	Splitting		Crumbling		Crackling		Flaking		Total No. of Particles Before testing
	No.	%	No.	%	No.	%	No.	%	
2-1/2" to 1-1/2"	-	-	-	-	-	-	-	-	23
1-1/2" to 3/4"	1	2	-	-	-	.	-	-	44

(A) The percentage loss (1.0%) of the next larger size is used as the percentage loss for the size, since this size contains less than 5.0% of the test sample after crushing.

PEPPERLING - GOOD
SOUNDNESS TEST OF COARSE AGGREGATE
(5 Cycles-Sodium Sulfate)

Sieve Size	Grading of Crushed Sample, %	Weight of Test Fractions Before Testing,g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
2-1/2" to 1-1/2"	22	5046.3	0.1	0.0
1-1/2" to 3/4"	62	1521.4	0.2	0.1
3/4" to 3/8"	13	1004.8	0.5	0.1
3/8" to No. 4	3	-	0.5 (A)	0.0
TOTALS	100	7572.5		0

<u>QUALITATIVE EXAMINATION OF COARSE SIZES</u>
Particles Exhibiting Distress

Sieve Size	Splitting No.	Splitting %	Crumbling No.	Crumbling %	Crackling No.	Crackling %	Flaking No.	Flaking %	Total No. of Particles Before testing
2-1/2" to 1-1/2"	-	-	-	-	-	-	-	-	27
1-1/2" to 3/4"	-	-	-	-	-	-	-	-	44

(A) The percentage loss (0.5%) of the next larger size is used as the percentage loss for the size, since this sample contains less than 5.0% of the test sample after crushing.

PEPPERLING - MODERATE
SOUNDNESS TEST OF COARSE AGGREGATE
(5 Cycles-Sodium Sulfate)

Sieve Size	Grading of Crushed Sample, %	Weight of Test Fractions Before Testing,g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
2-1/2" to 1-1/2"	18	4873.2	0.5	0.1
1-1/2" to 3/4"	64	1513.2	2.0	1.3
3/4" to 3/8"	13	1005.0	1.8	0.2
3/8" to No. 4	5	300.3	1.8	0.1
TOTALS	100	7691.7		2

QUALITATIVE EXAMINATION OF COARSE SIZES
Particles Exhibiting Distress

Sieve Size	Splitting		Crumbling		Crackling		Flaking		Total No. of Particles Before testing
	No.	%	No.	%	No.	%	No.	%	
2-1/2" to 1-1/2"	2	7	-	-	-	-	-	-	27
1-1/2" to 3/4"	-	-	-	-	-	-	-	-	41

(A) The percentage loss (0.5%) of the next larger size is used as the percentage loss for the size, since this sample contains less than 5.0% of the test sample after crushing.

SHEAR SAMPLE
SOUNDNESS TEST OF COARSE AGGREGATE
(10 Cycles-Sodium Sulfate)

Sieve Size	Grading of Crushed Sample, %	Weight of Test Fractions Before Testing, g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
4-1/2" to 4"	100	6512	0.1	0.1
TOTALS	100			

QUALITATIVE EXAMINATION OF COARSE SIZES Particles Exhibiting Distress									
Sieve Size	Splitting No.	%	Crumbling No.	%	Crackling No.	%	Flaking No.	%	Total No. of Particles Before testing
4-1/2" to 4"	-	-	-	-	-	-	-	-	3

SAMPLE WEIGHT AFTER EACH CYCLE

CYCLE NO. 1	INITIAL. GM
1	6512
2	6511
3	6510
4	6510
5	6509
6	6509
7	6508
8	6508
9	6508
10	6507

PEPPERLING (MODERATE)
SOUNDNESS TEST OF COARSE AGGREGATE
(10 Cycles-Sodium Sulfate)

Sieve Size	Grading of Crushed Sample, %	Weight of Test Fractions Before Testing, g	Percentage Passing Designated Sieve After Test
2-1/2" to 2"	100	2840.4	0.5
TOTALS	100	2840.4	-

QUALITATIVE EXAMINATION OF COARSE SIZES Particles Exhibiting Distress									
Sieve Size	Splitting No.	Splitting %	Crumbling No.	Crumbling %	Crackling No.	Crackling %	Flaking No.	Flaking %	Total No. of Particles Before testing
2-1/2" to 2"	1	1	-	-	-	-	-	-	11

SAMPLE WEIGHT AFTER EACH CYCLE

CYCLE NO. 1	INITIAL, GM
1	2837.2
2	2835.5
3	2834.8
4	2834.6
5	2834.5
6	2832.6
7	2828.7
8	2827.1
9	2826.8
10	2826.4

SOUNDNESS BY FREEZING AND THAWING
(5-Cycles Wet, 5-Cycles Dry, Alternate Every 5 Cycles)

CYCLES		SHEAR		PEPPERLING GOOD		PEPPERLING MODERATE	
No.	Condition	Dry Wt.,G	Loss %	Dry Wt.,G	Loss %	Dry Wt.,G	Loss %
0	Initial (Wet)	6573	0.00	6009	0.00	7731	0.00
5	Wet	6571	0.03	6009	0.00	7727	0.05
10	Dry	6571	0.03	6009	0.00	7727	0.05
15	Wet	6570	0.05	6008	0.02	7722	0.12
20	Dry	6570	0.05	6008	0.02	7719	0.16
25	Wet	6570	0.05	6008	0.02	7719	0.16
30	Dry	6570	0.05	6007	0.03	7717	0.18
35	Wet	6564	0.14	6001	0.13	7714	0.22
40	Dry	6564	0.14	6001	0.13	7711	0.26
45	Wet	6554	0.29	5993	0.27	7681	0.65
50	Dry	6548	0.38	5990	.32	7672	0.77
55	Wet	6547	0.40	5990	0.32	7671	0.78
60	Dry	6539	0.52	5985	0.40	7657	0.97
65	Wet	6521	0.80	5985	0.40	7657	0.97
70	Dry	6521	0.80	5985	0.40	7657	0.97
75	Wet	6521	0.80	5985	0.40	7651	0.97
80	Dry	6521	0.80	5985	0.40	7657	0.97
85	Wet	6521	0.80	5985	0.40	7657	0.97
90	Dry	6518	0.84	5985	0.40	7657	0.97
95	Wet	6518	0.84	5985	0.40	7657	0.97
100	Dry	6518	0.84	5985	0.40	7657	0.97

* Note: Wet cycles 0-40 were subjected to complete immersion during freezing. Wet cycles starting at No. 41 were submerged in water for approximately 24 hours, allowed to drain, wrapped in a wet cloth and then placed in the freezer.

COLORADO STATE UNIVERSITY

URANIUM MINE TAILINGS FACILITY
LAKEVIEW, OREGON

AGGREGATE TESTING
PROJECT NO. 20954037

PHOTOGRAPH APPENDIX

AGGREGATE DESCRIPTION
SHEAR
PEPPERLING GOOD
PEPPERLING FAIR (MODERATE)

By: TERRACON CONSULTANTS WESTERN, INC.

Reviewed By: Mike Walker

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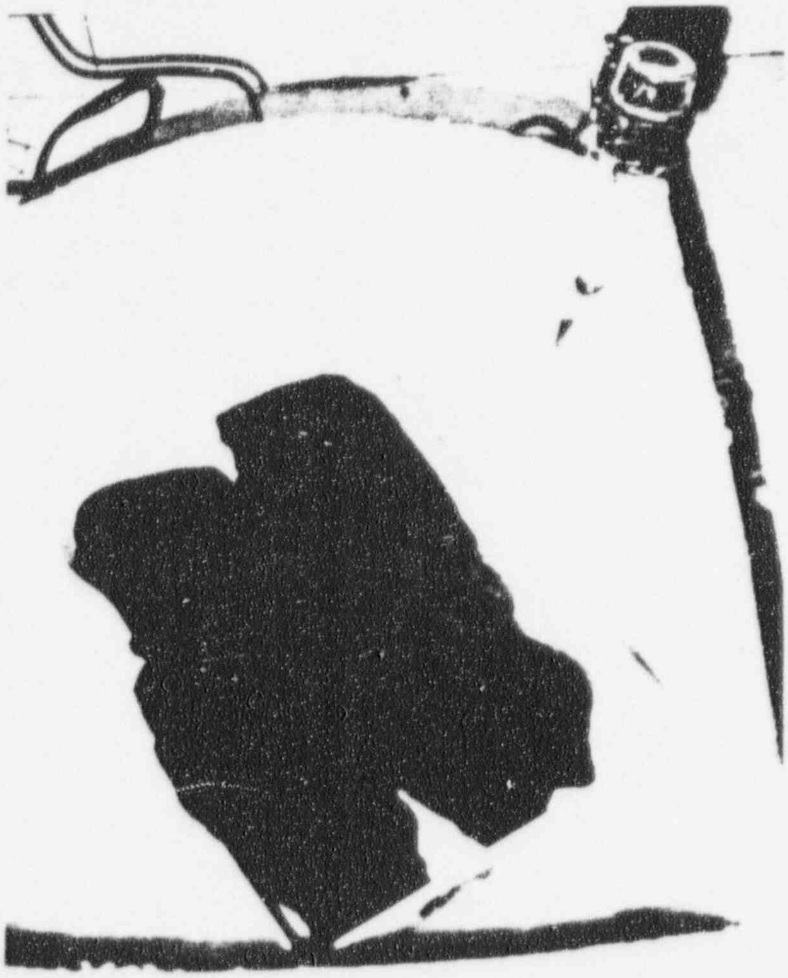
SHEAR AGGREGATE

Aggregate Size Distribution Prior To Testing

SHEAR AGGREGATE

SHEAR AGGREGATE

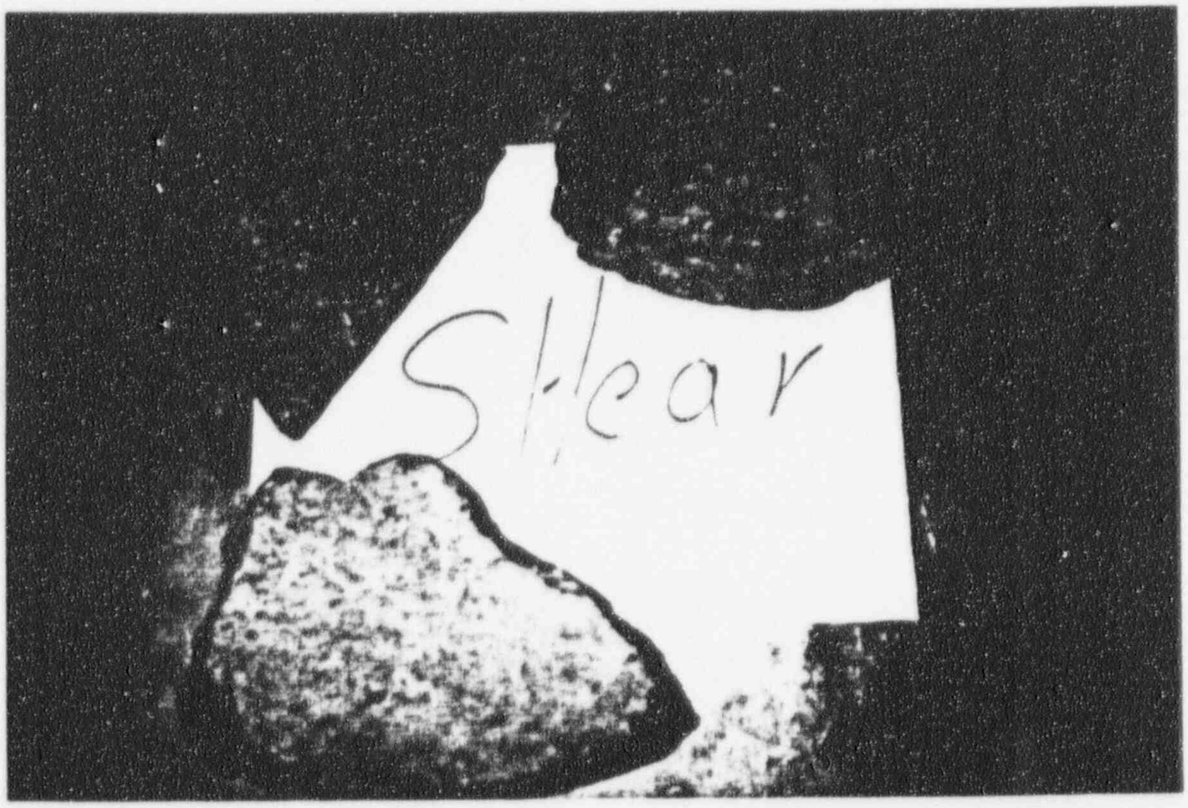


4" Aggregate During Sodium Sulfate
Soundness 10 Cycle Test

CSU Engineering Research Center
Uranium Mine Tailings Aggregate
Project No. 20954037

SHEAR AGGREGATE
FREEZE - THAW

ycle 5



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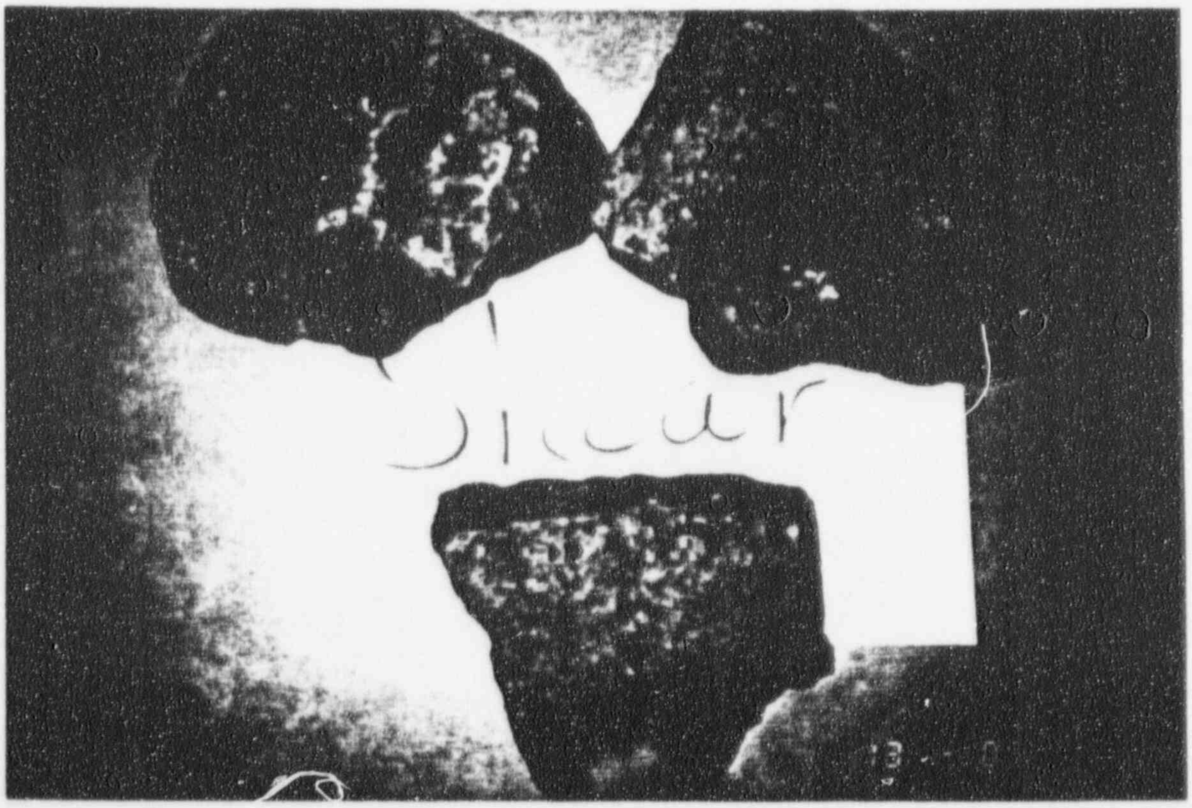
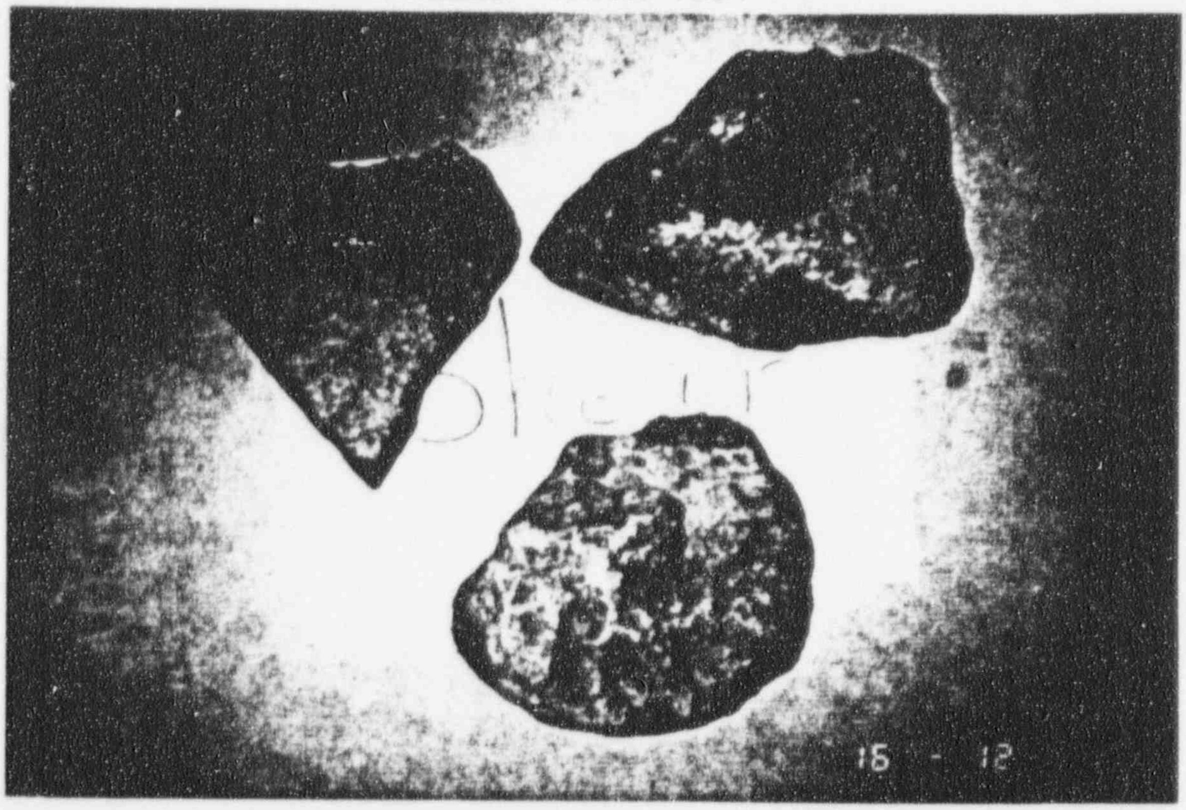


SHEAR AGGREGATE

FREEZE - THAW TEST

ycle 15



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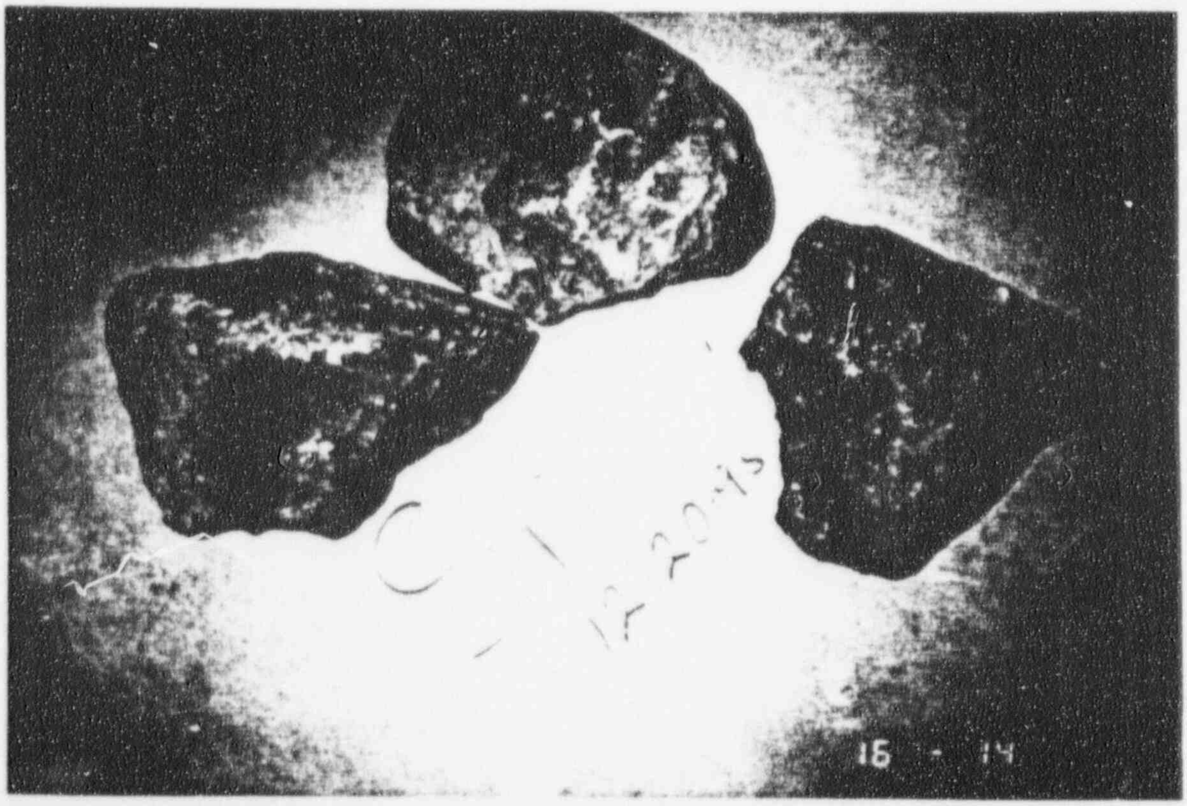
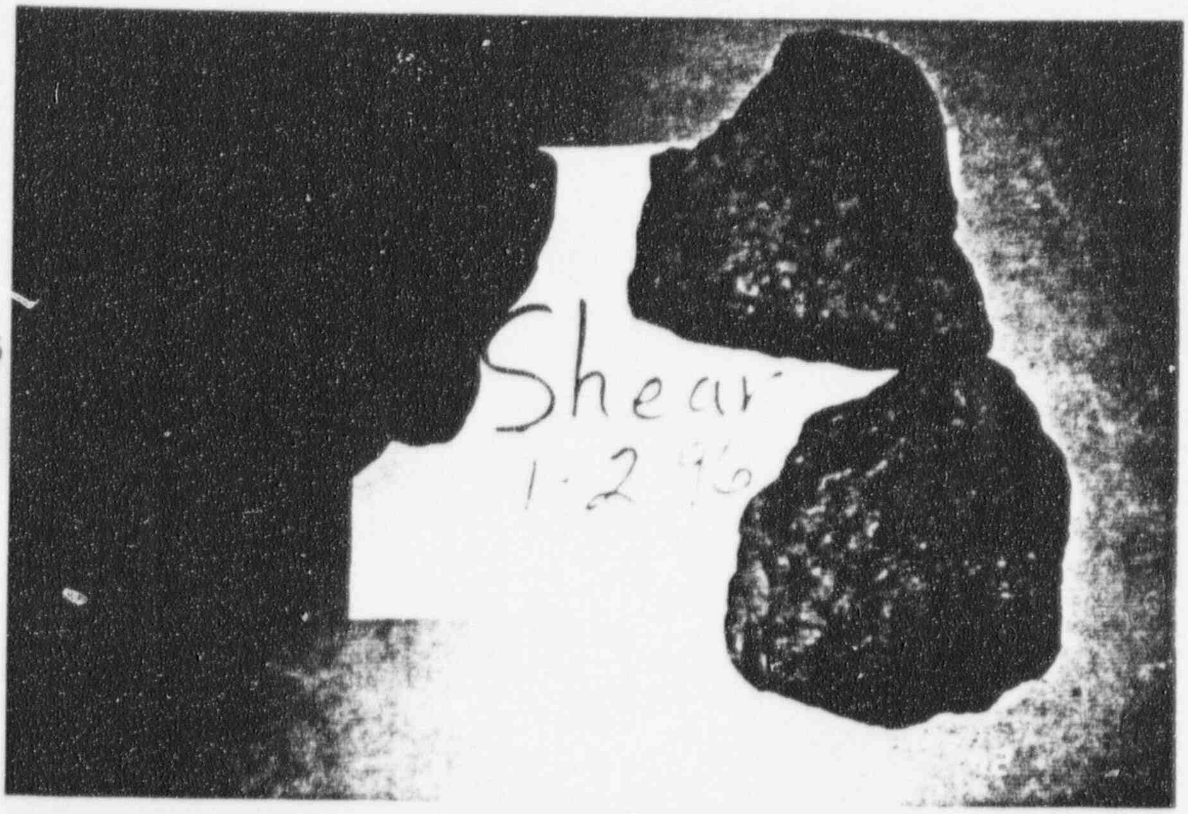


SHEAR AGGREGATE
FREEZE - THAW TEST

Cycle 25



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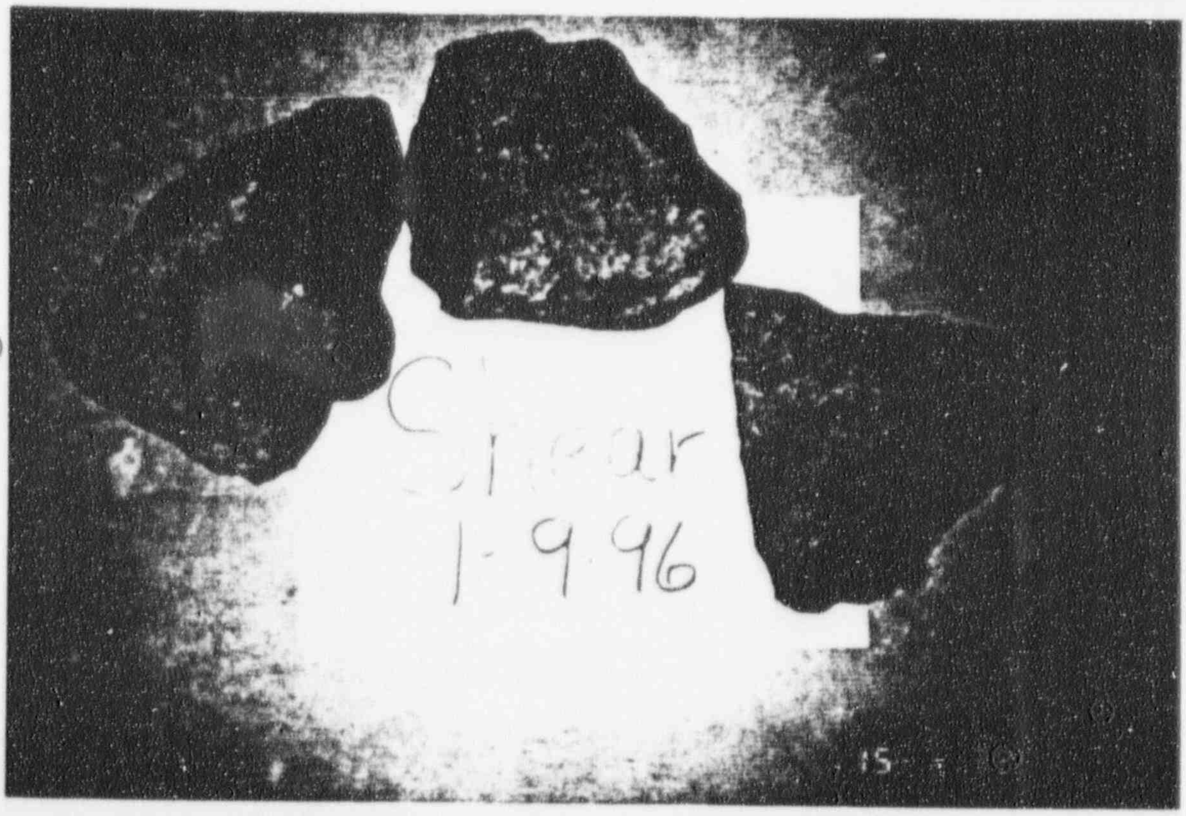
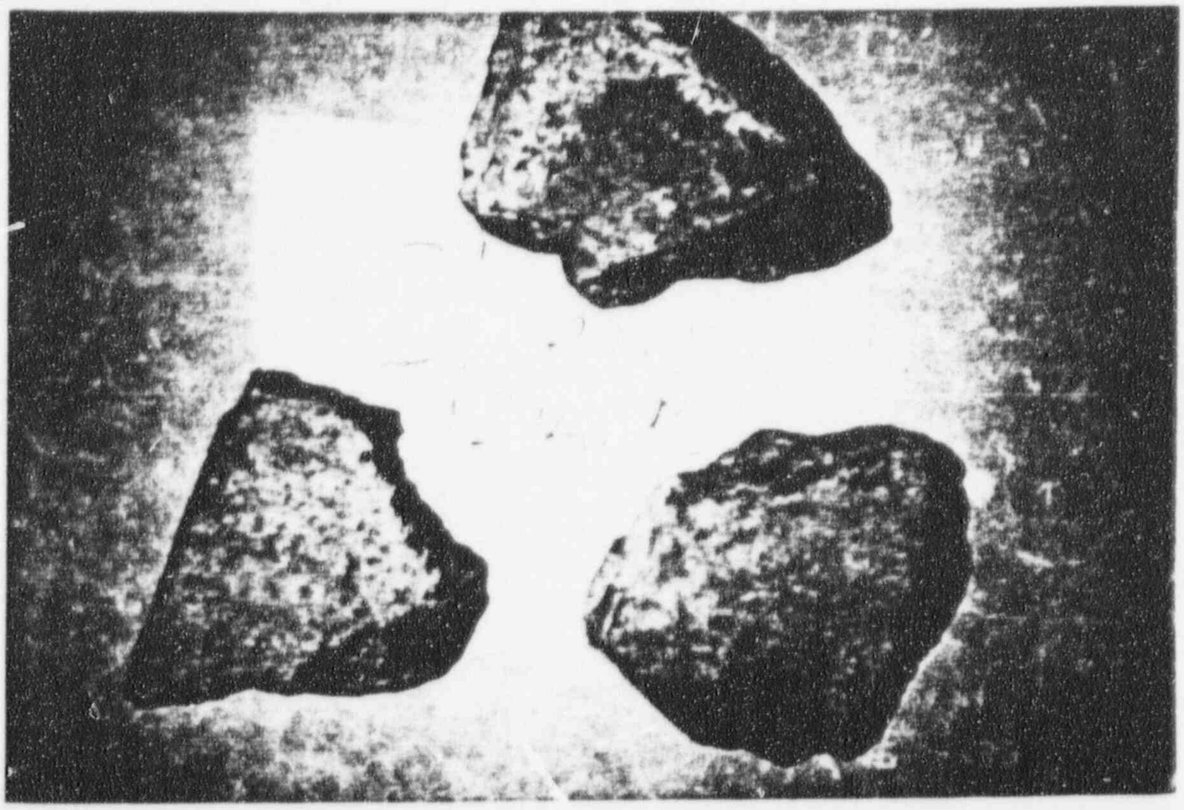


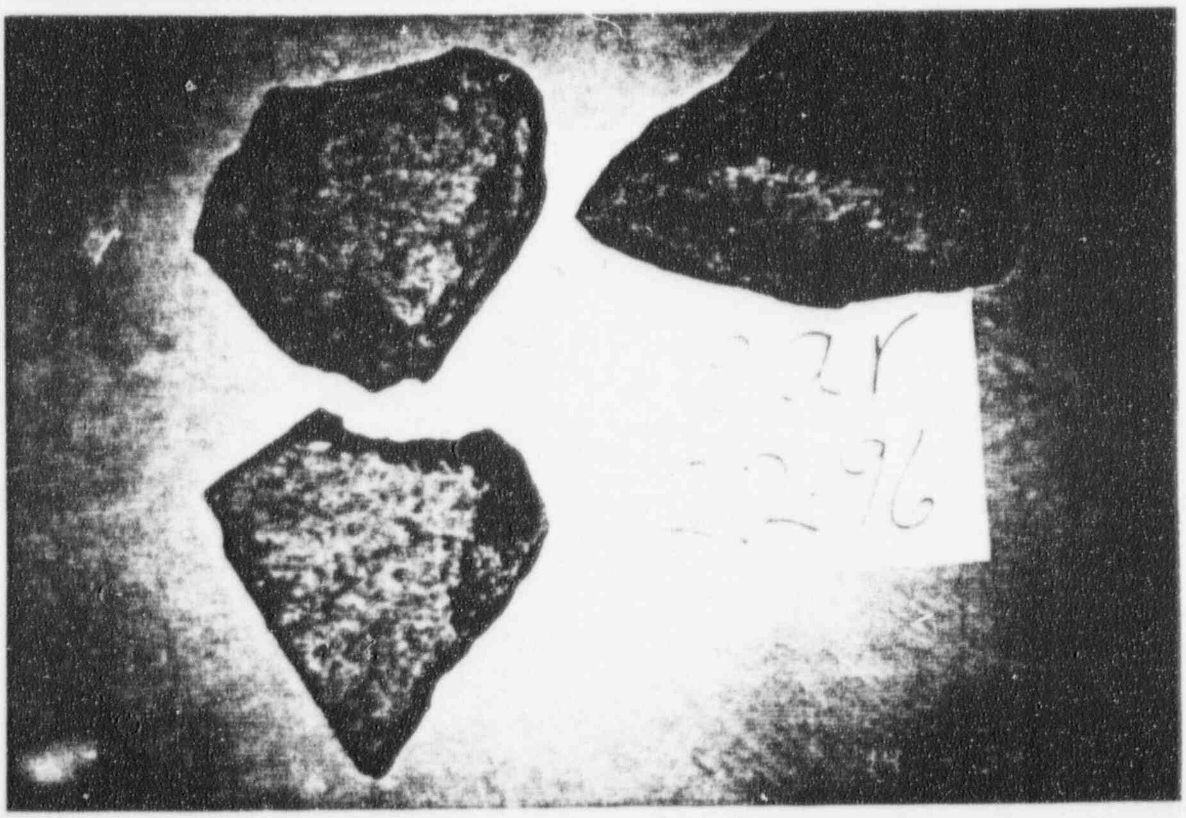
SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 35



Cycle 40

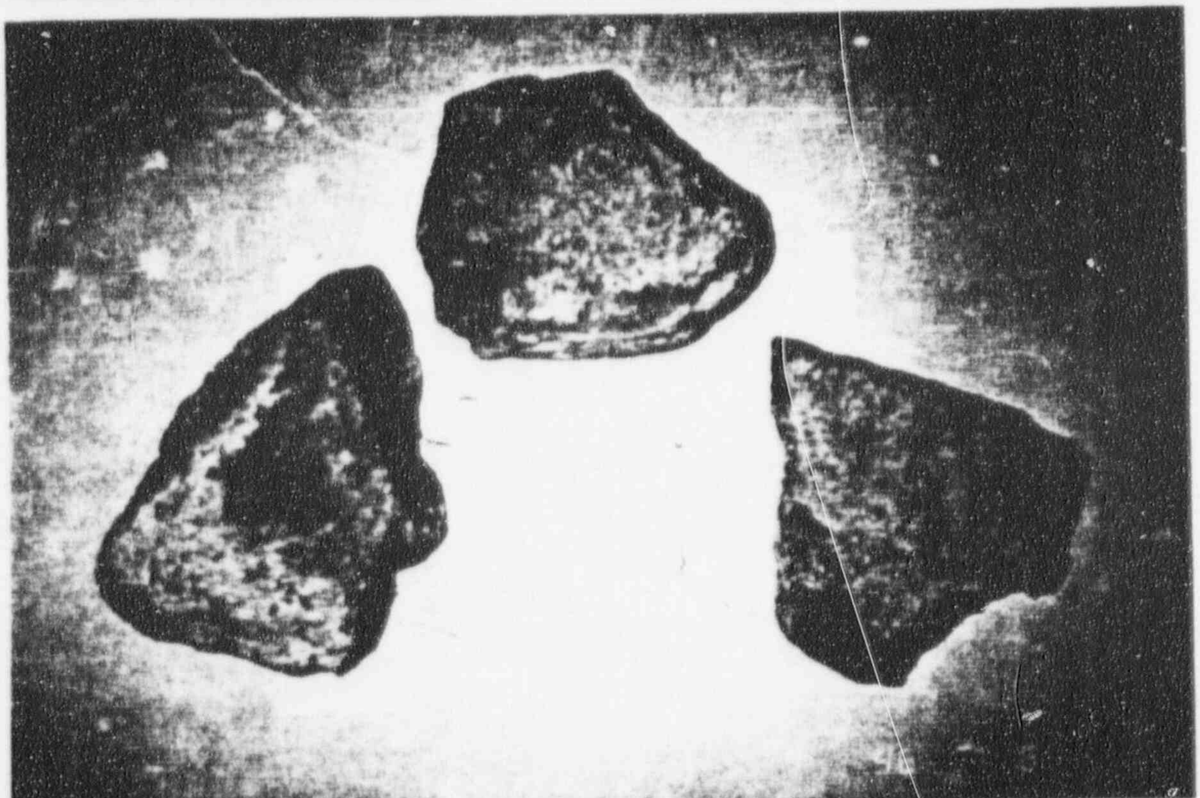


SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 45

Cycle 50

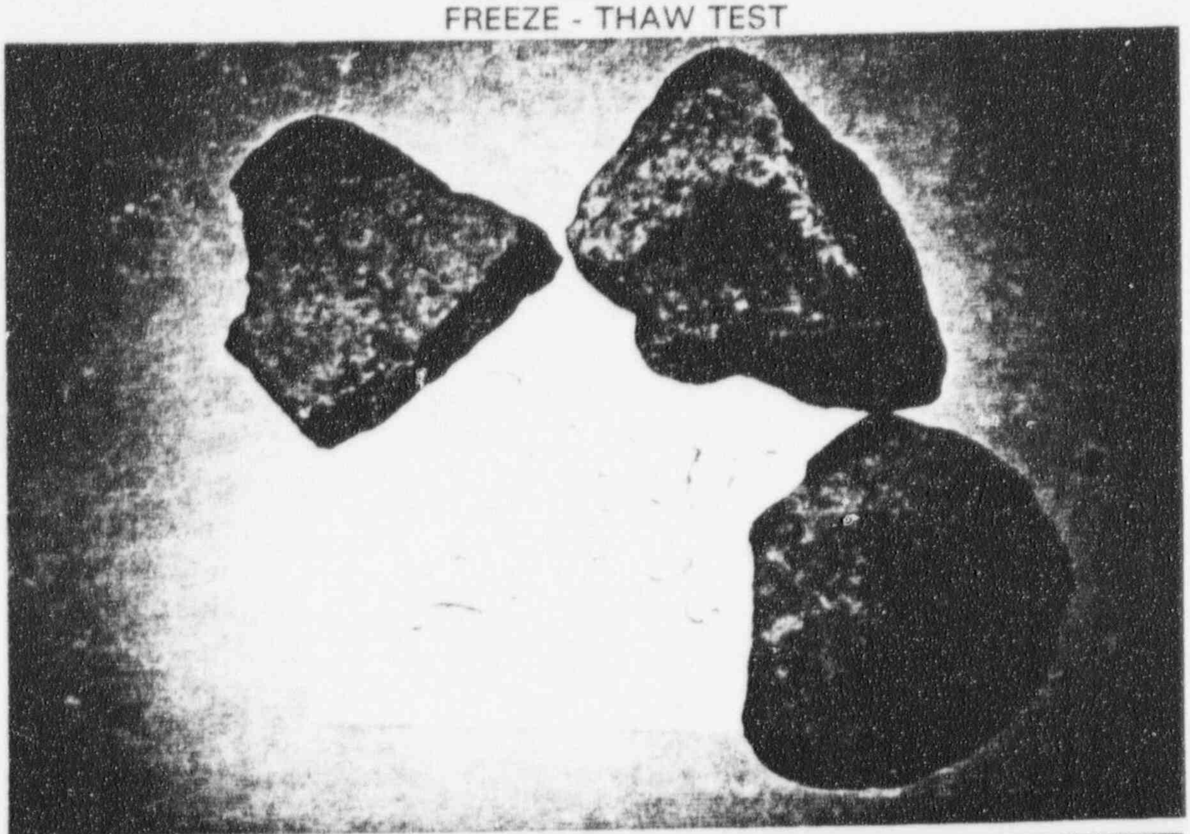


CSU Engineering Research Center
Uranium Mine Tailings Aggregate
Project No. 20954037

SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 55



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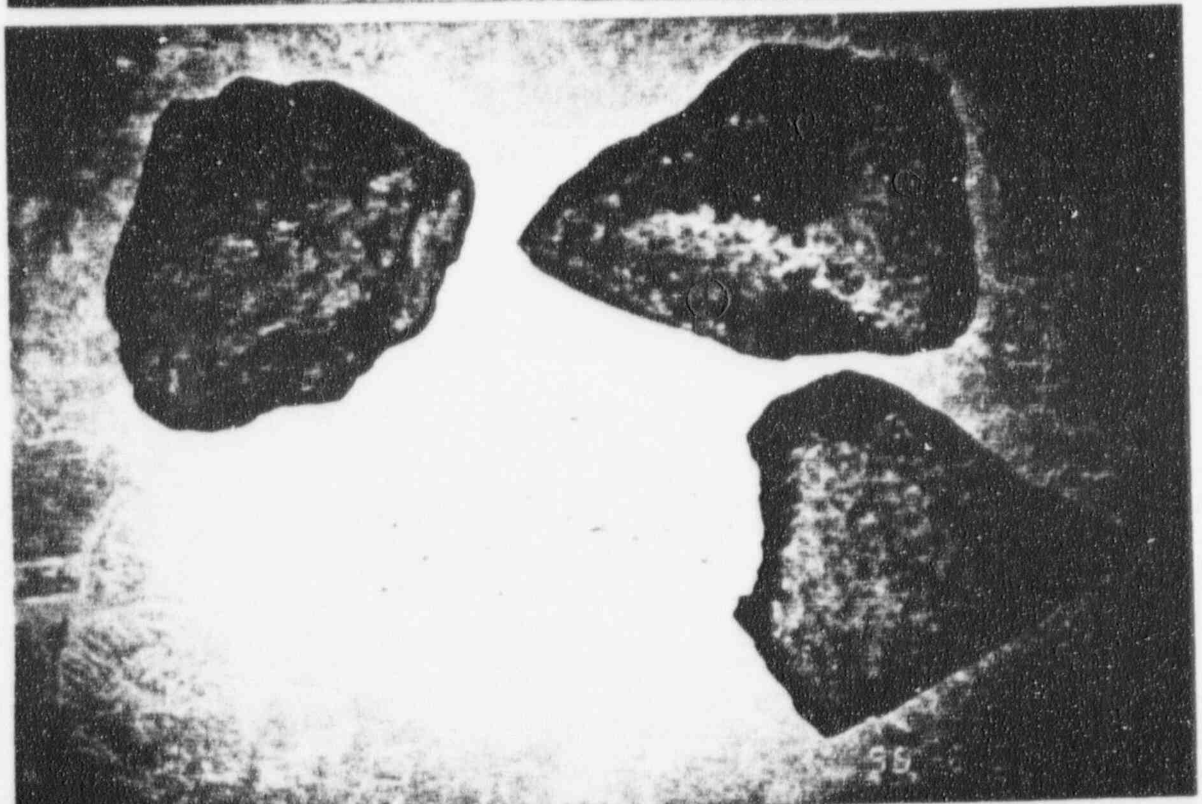
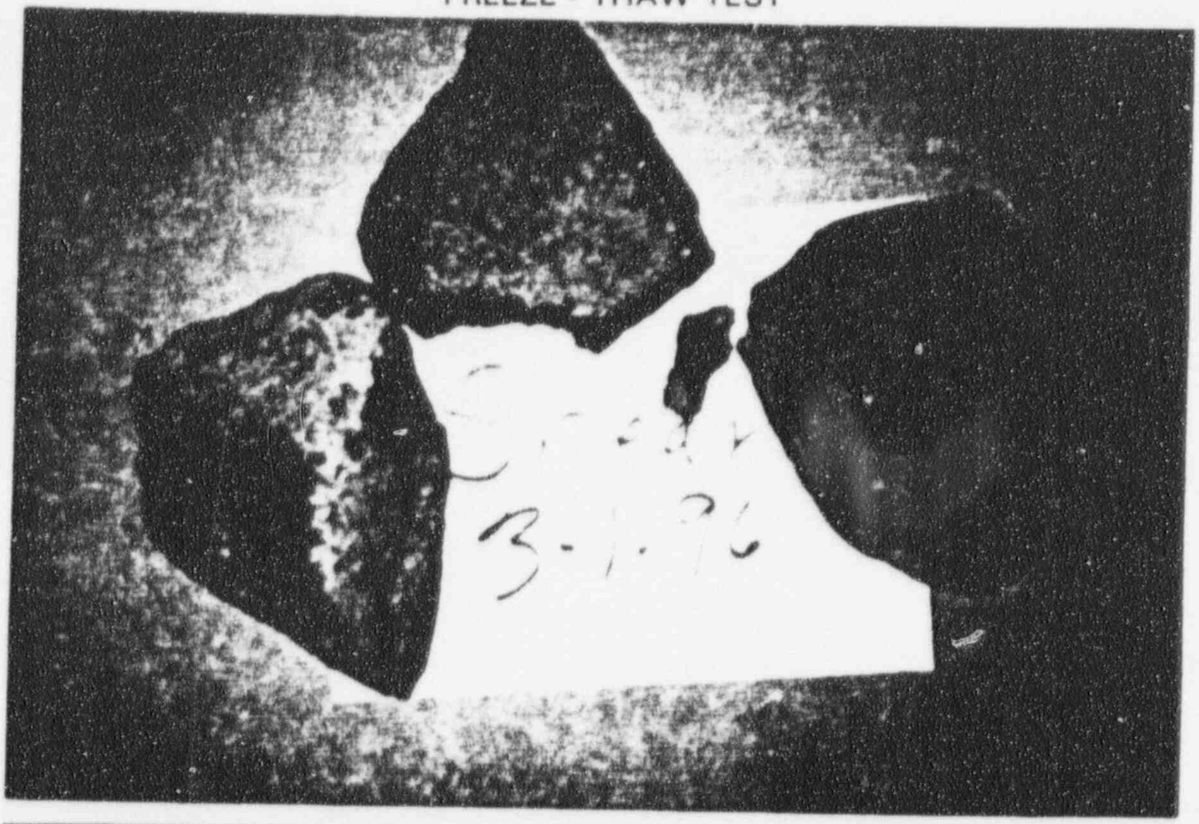


SHEAR AGGREGATE
FREEZE - THAW TEST

Cycle 65



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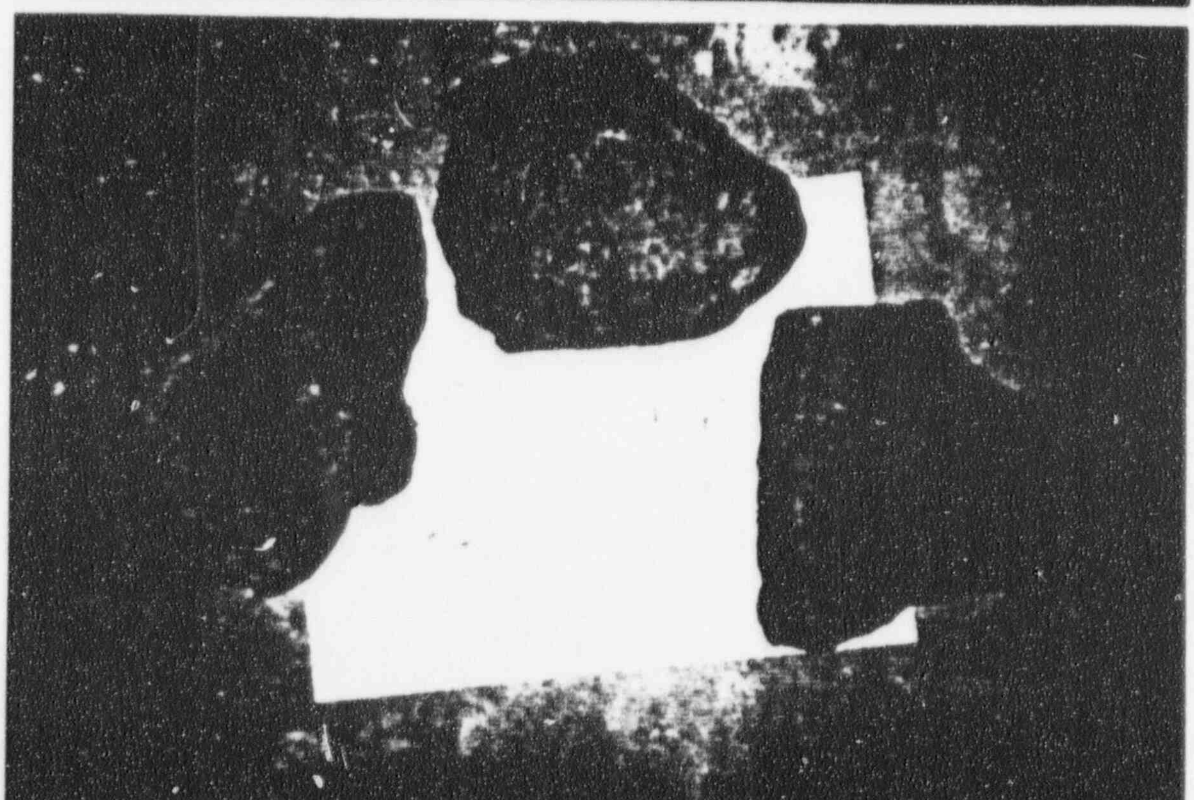
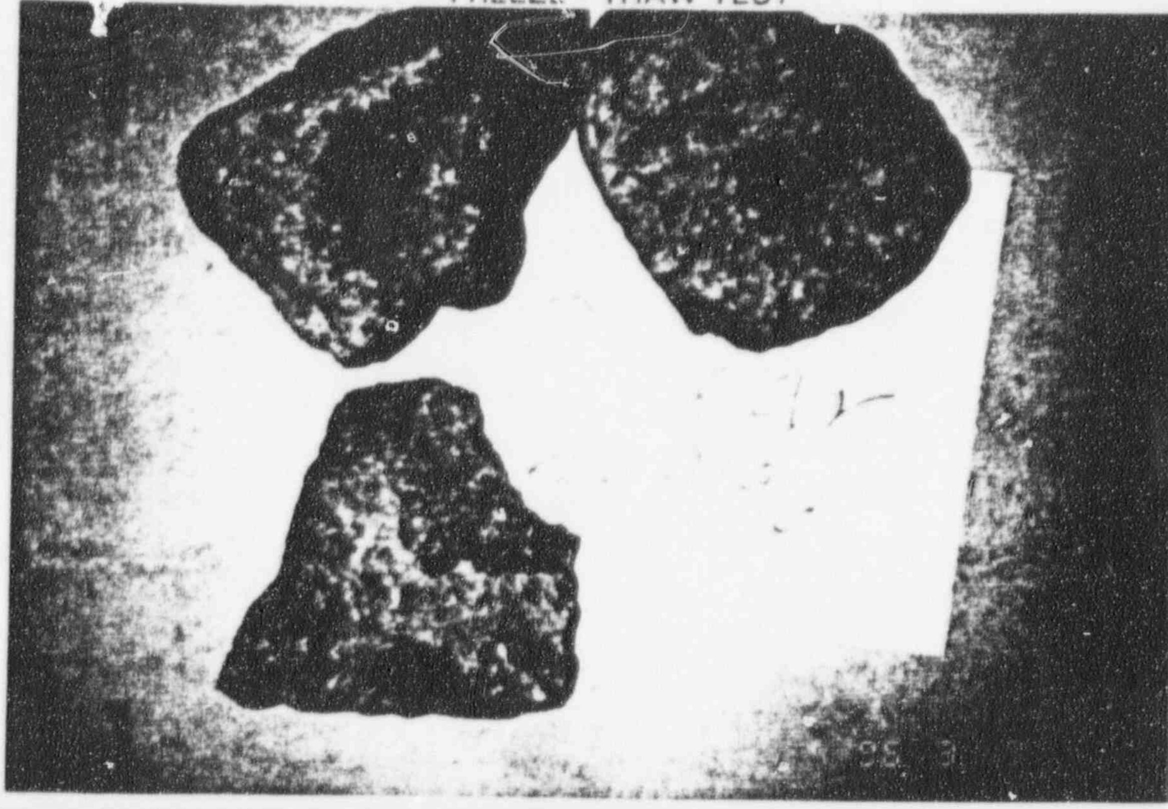


SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 75



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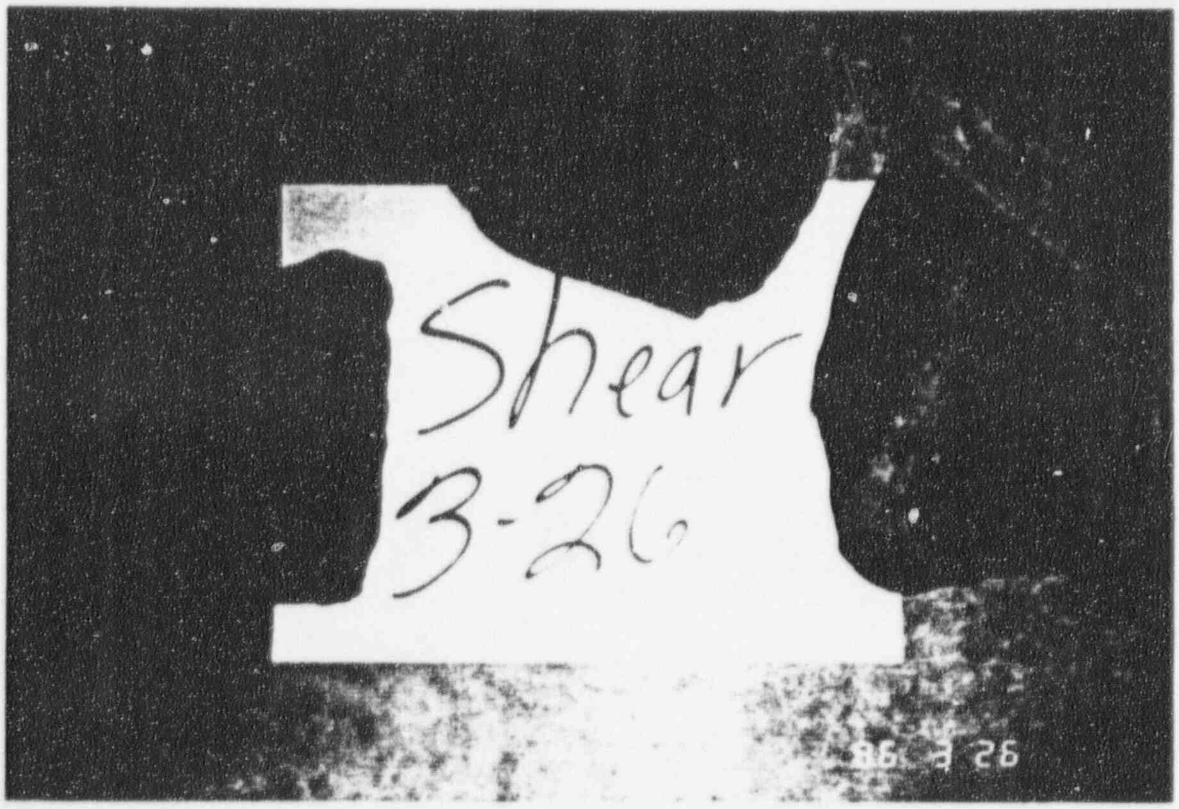
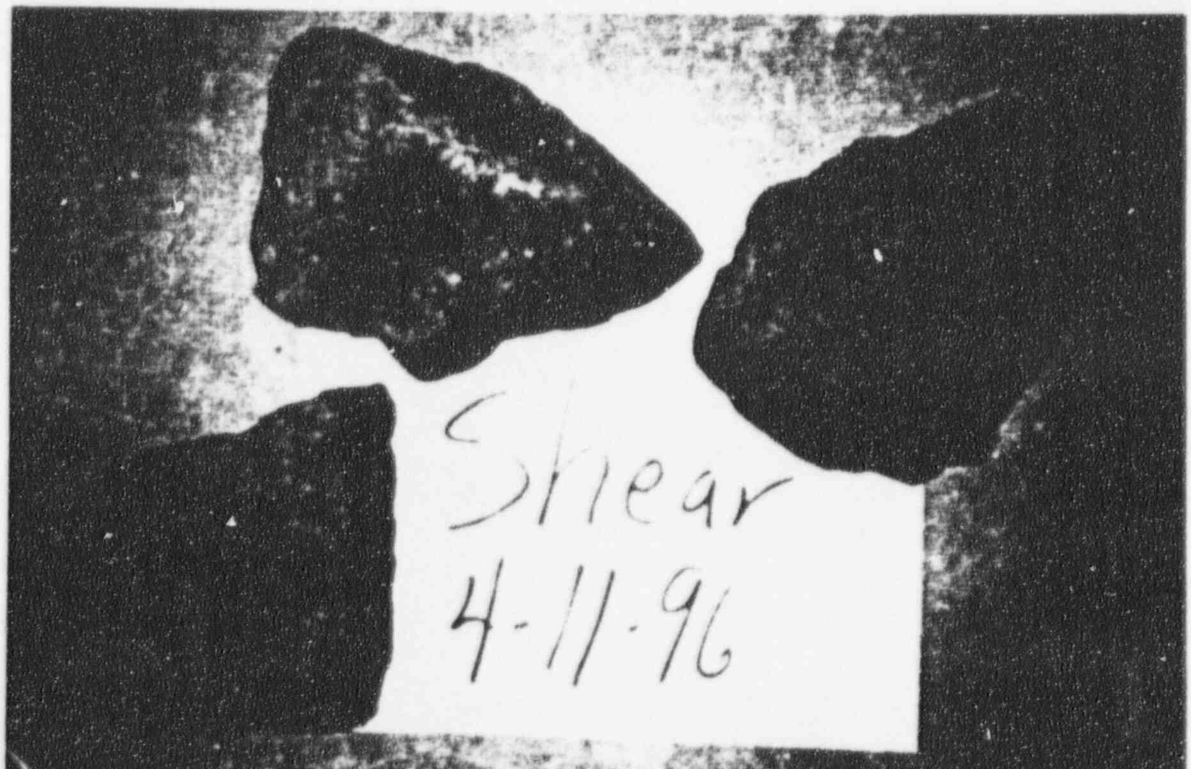


SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 85

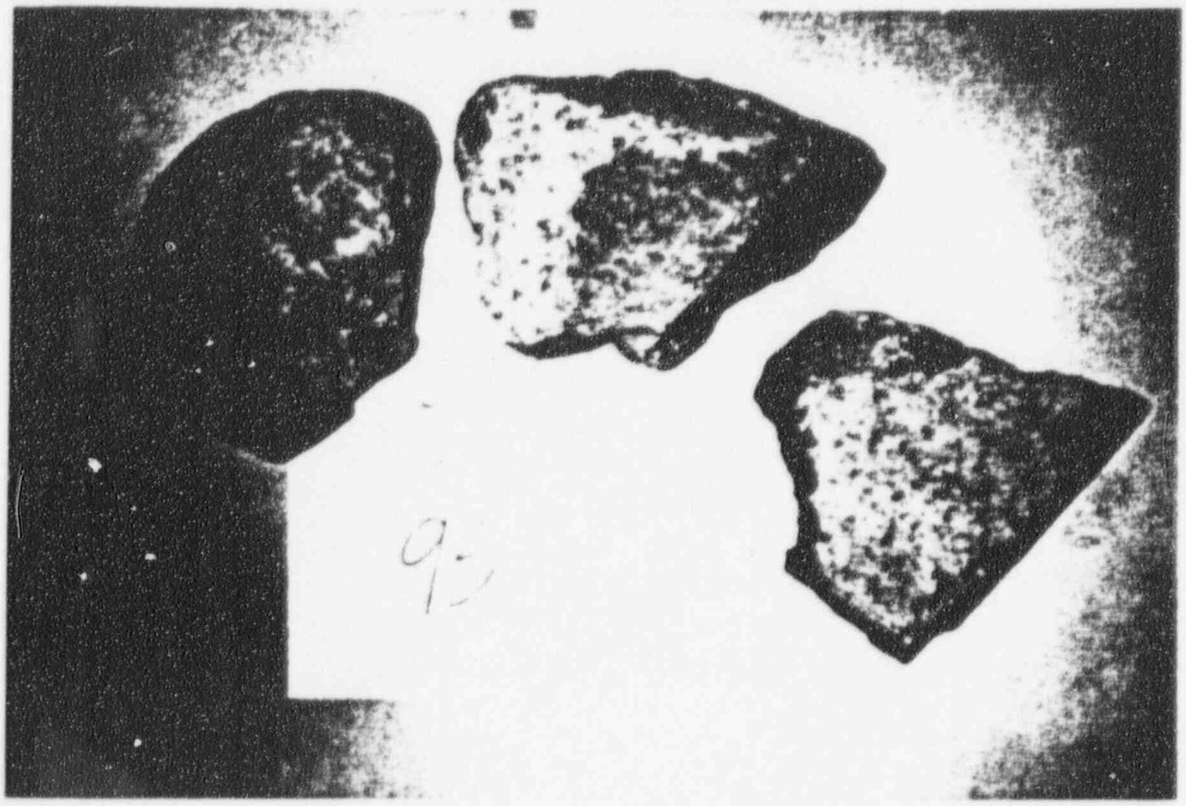
Cycle 90



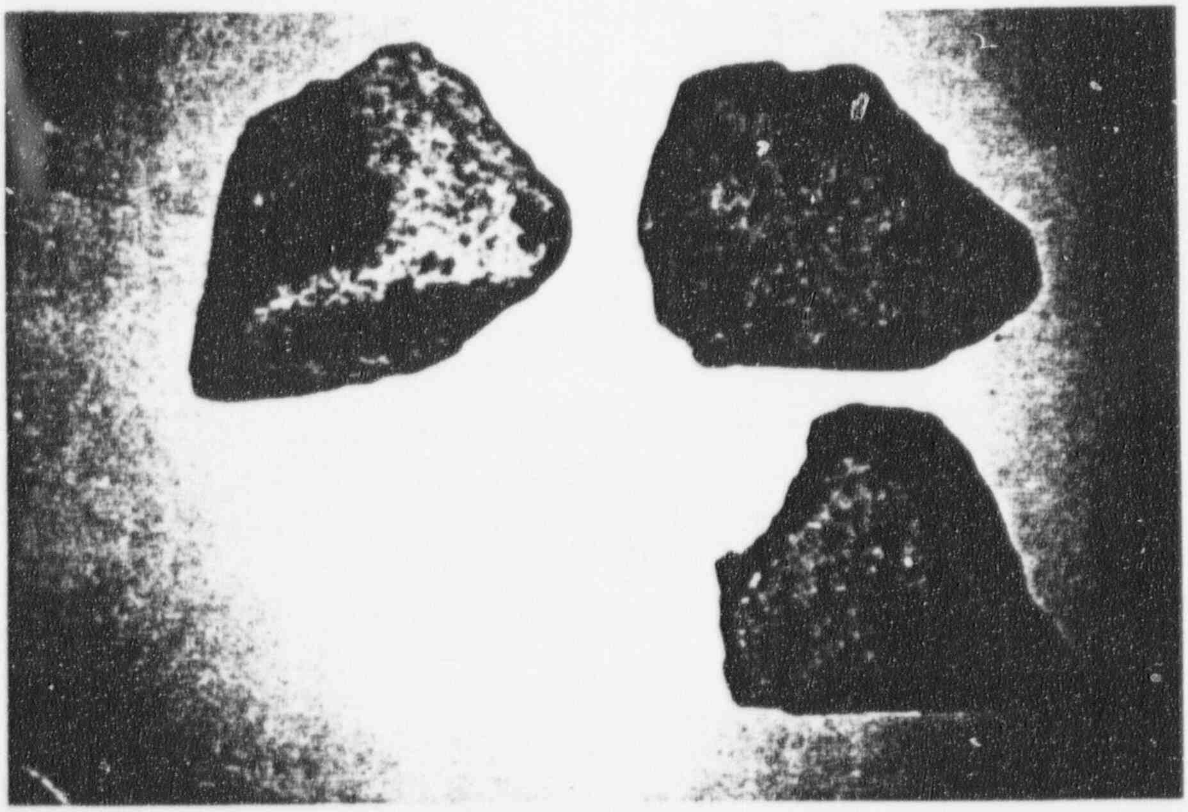
SHEAR AGGREGATE

FREEZE - THAW TEST

Cycle 95



Cycle 100



CSU Engineering Research Center
Uranium Mine Tailings Aggregate
Project No. 20954037

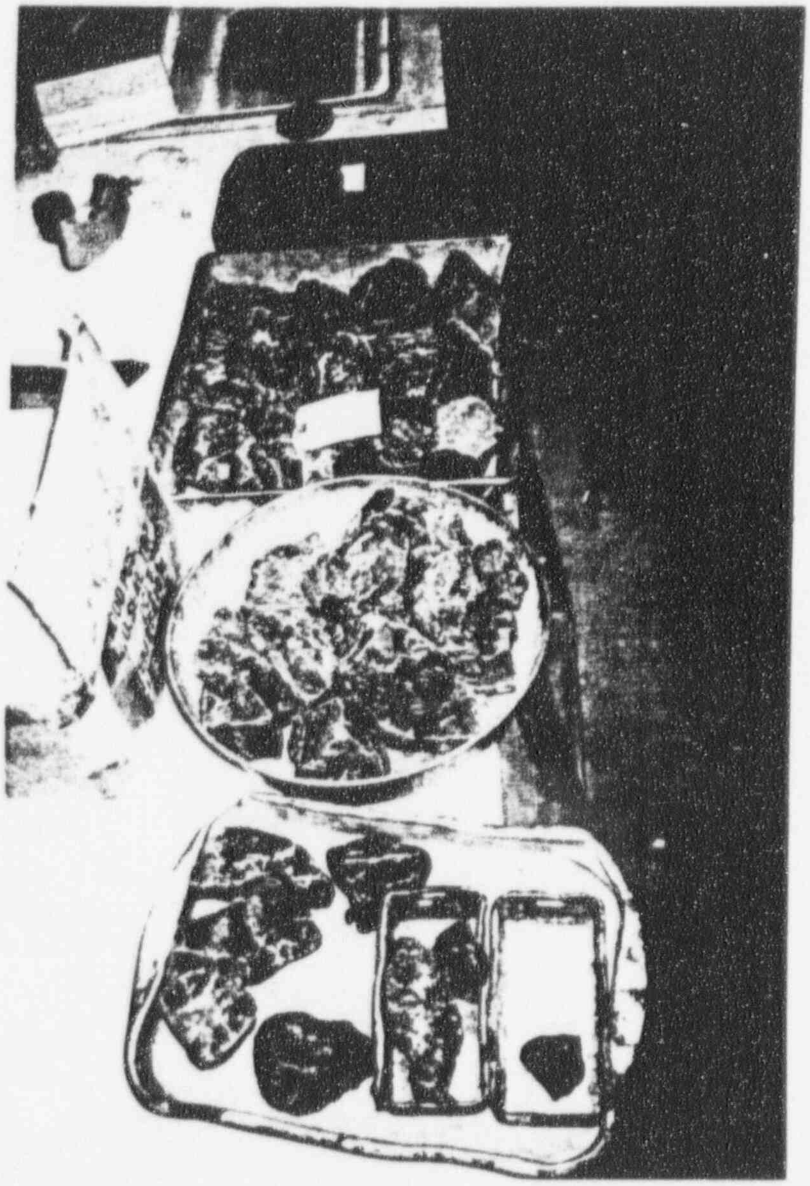
NOTES OF OBSERVATION

SHEAR:

OF THREE (3) PIECES, ONE (1) SHOWED NUMEROUS CRACKS AND ONE PIECE WEIGHING 27 GRAMS SEPARATED

PEPPERLING GOOD

PEPPERLING GOOD



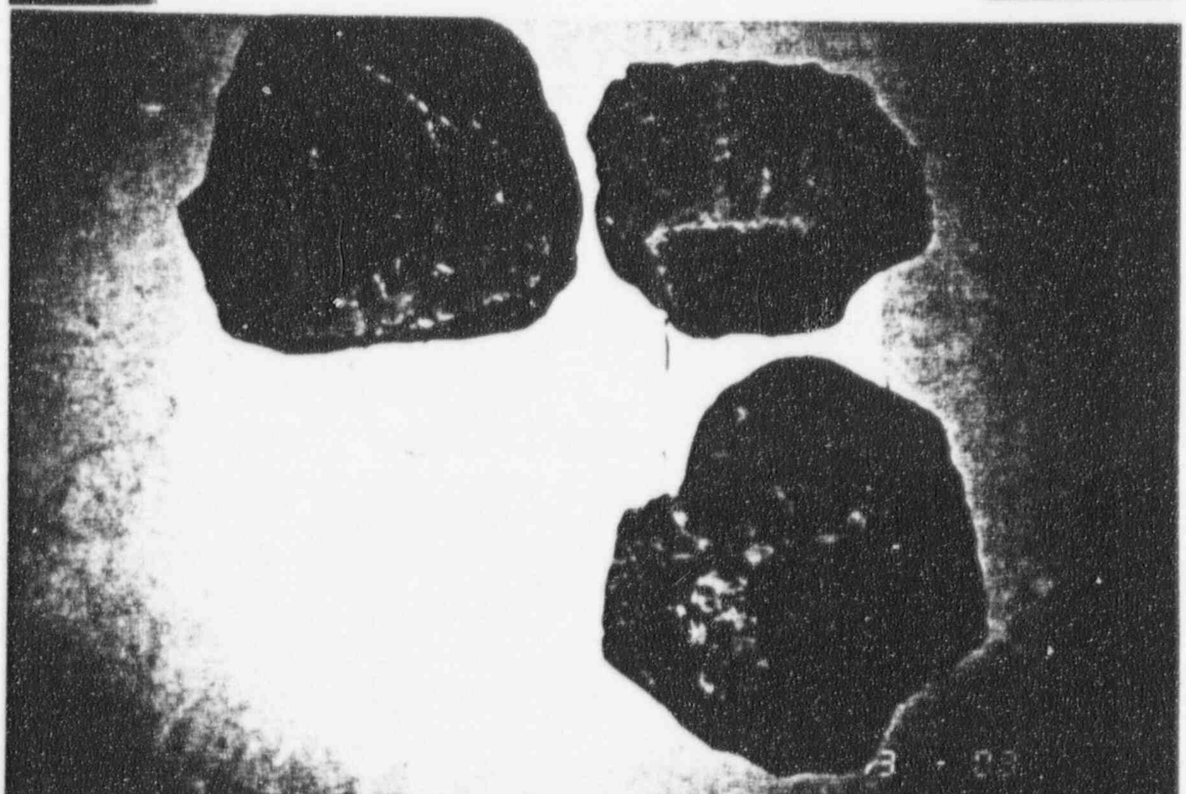
Aggregate Size Distribution Prior To Testing

PEPPERLING GOOD

FREEZE - THAW TEST

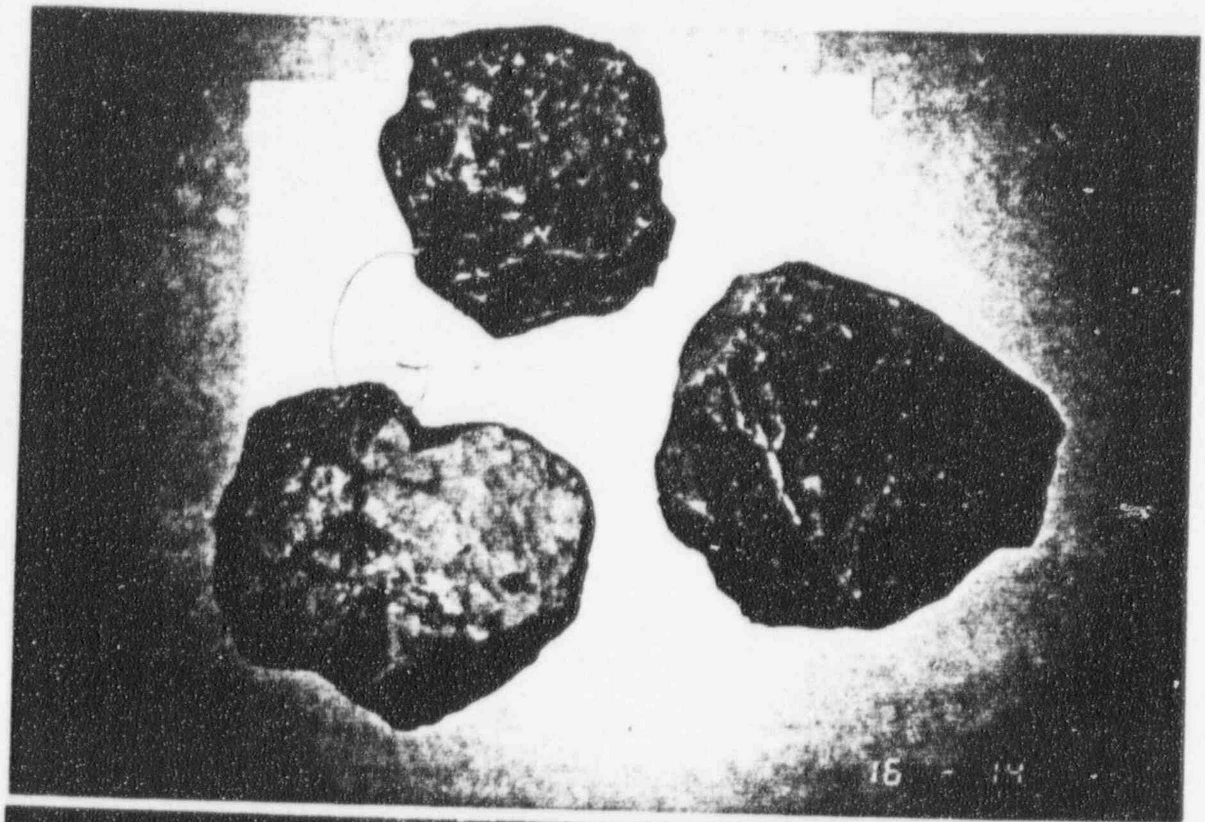
ycle 5

ᴗycle 10



PEPPERLING GOOD
FREEZE - THAW TEST

:ycle 15



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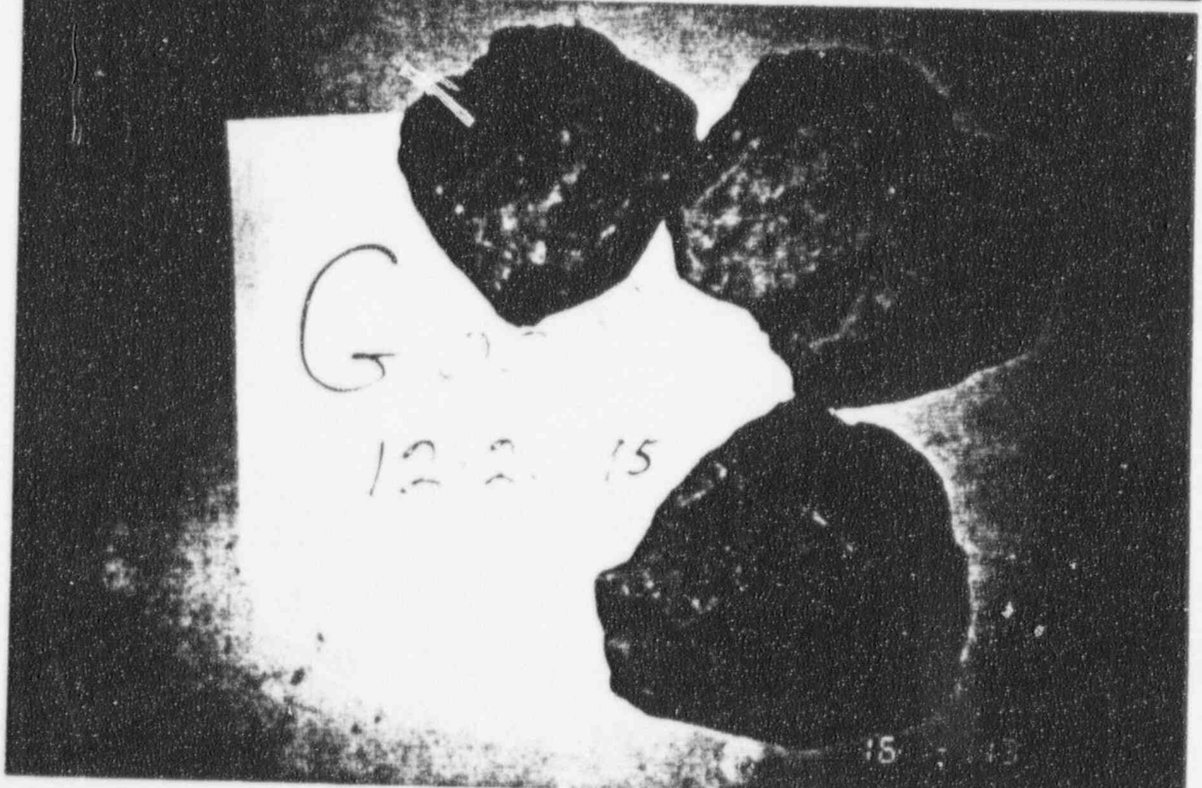
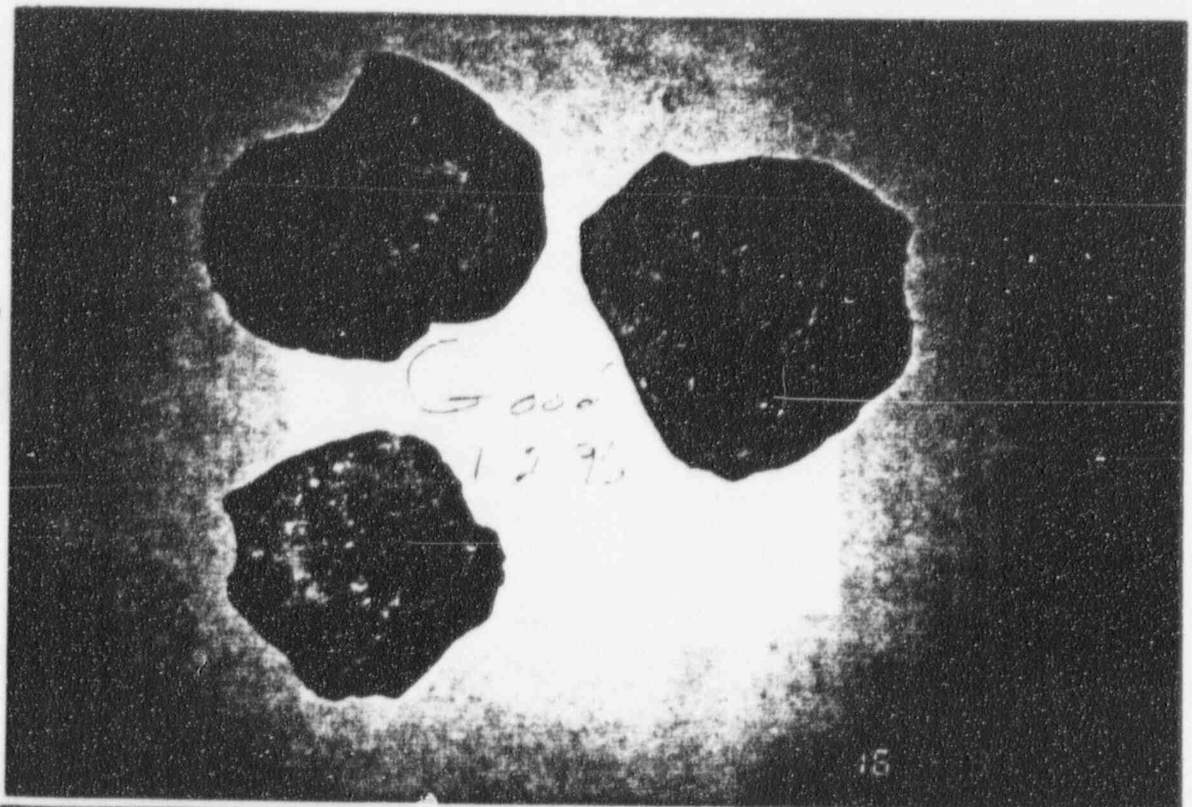


PEPPERLING GOOD
FREEZE - THAW TEST

ycle 25



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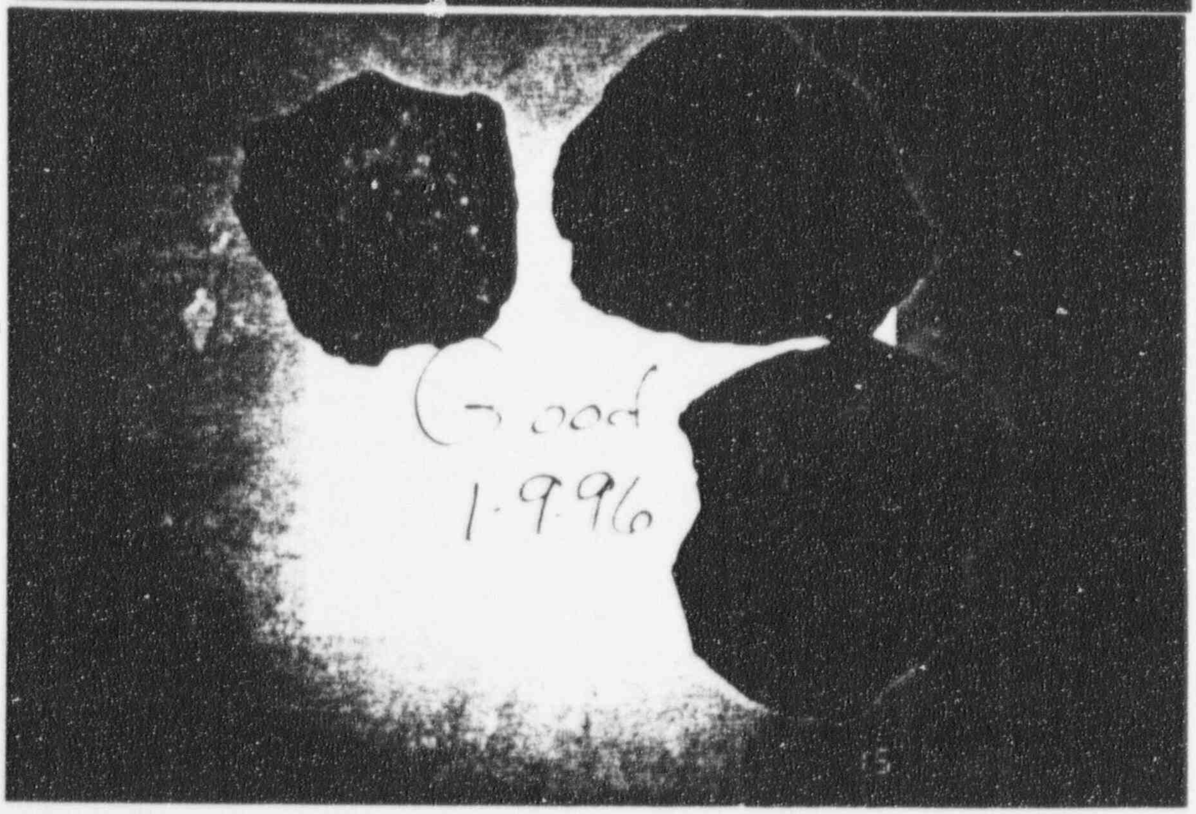
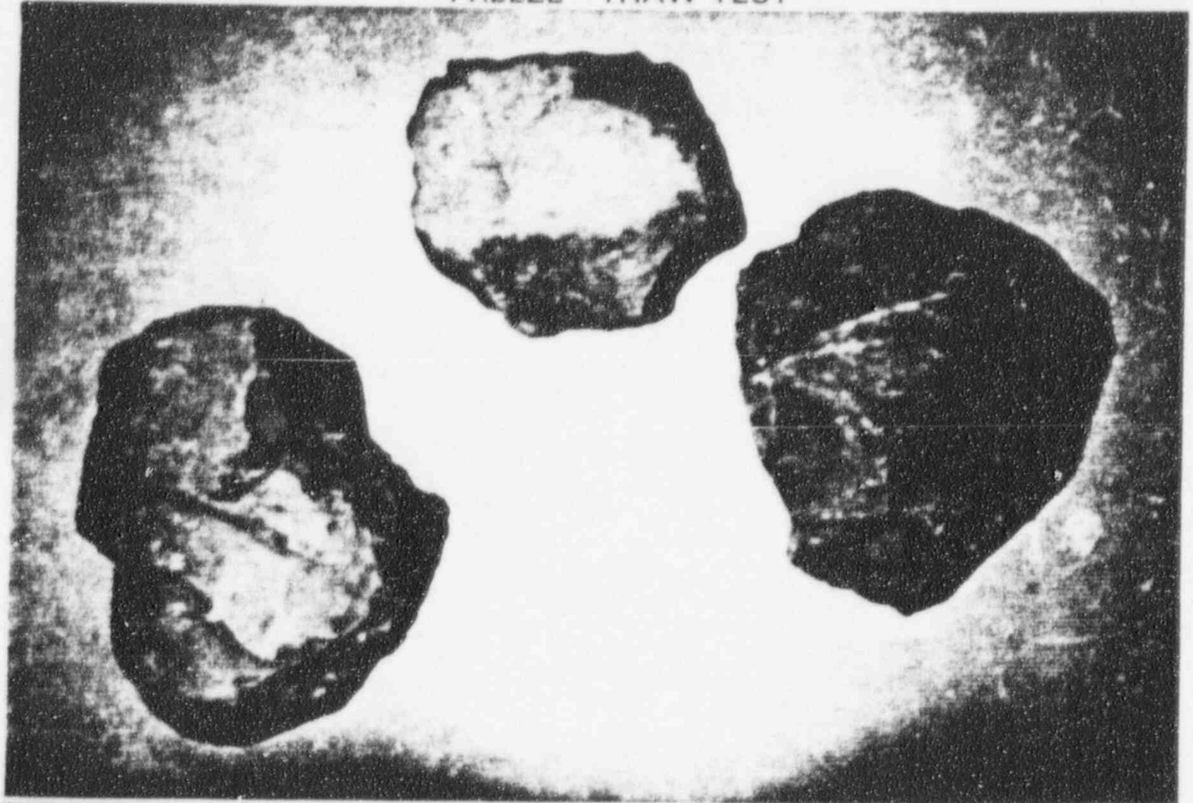


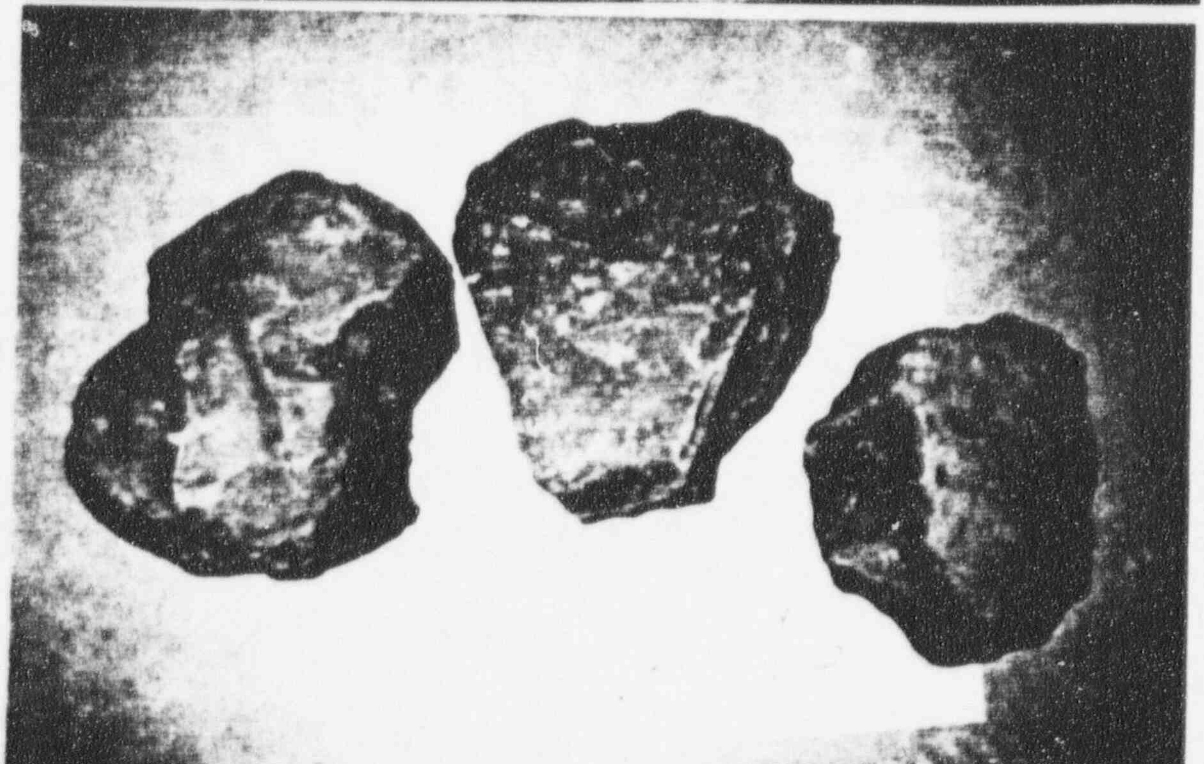
PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 35



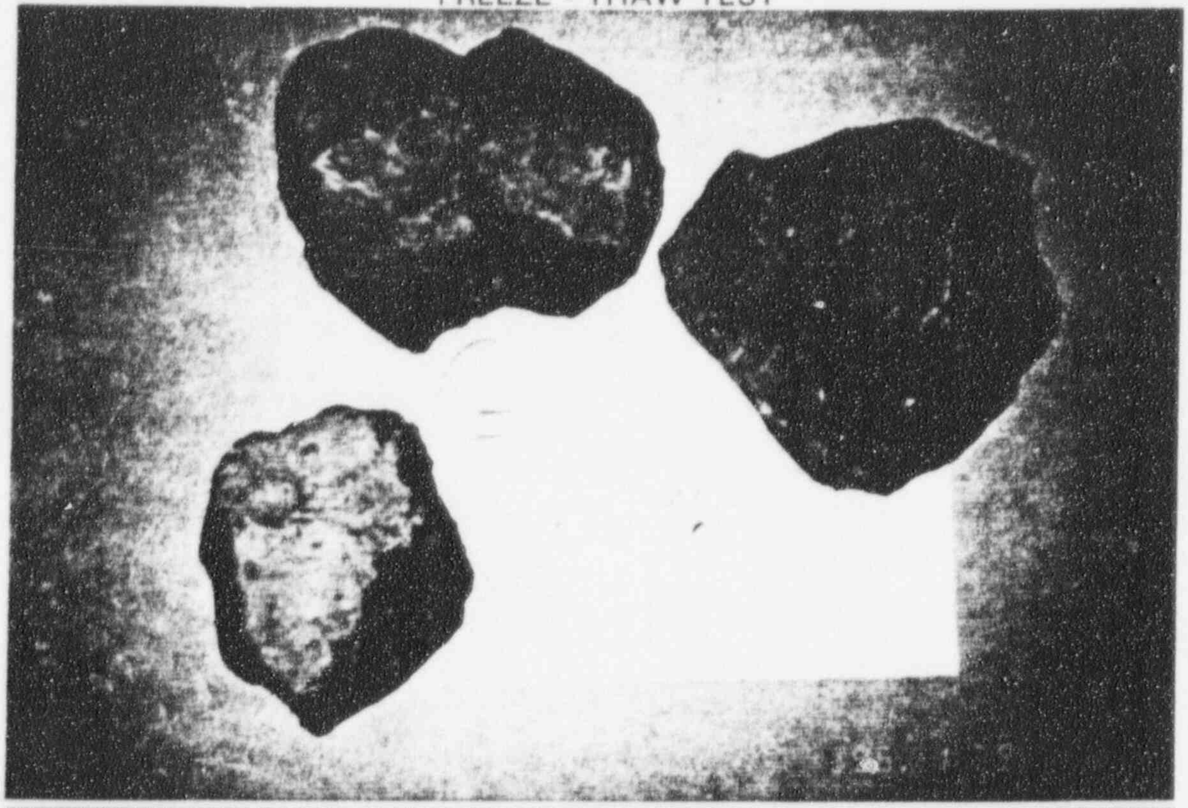
Cycle 40



PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 45



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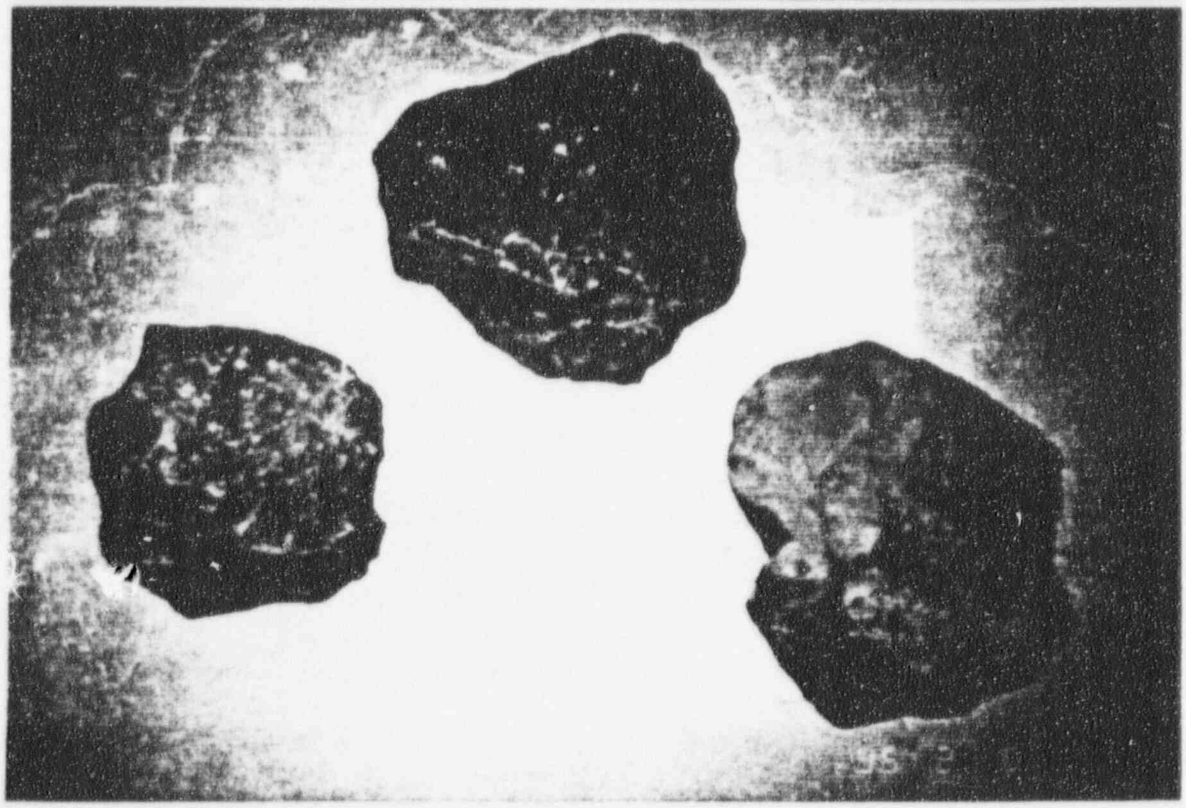
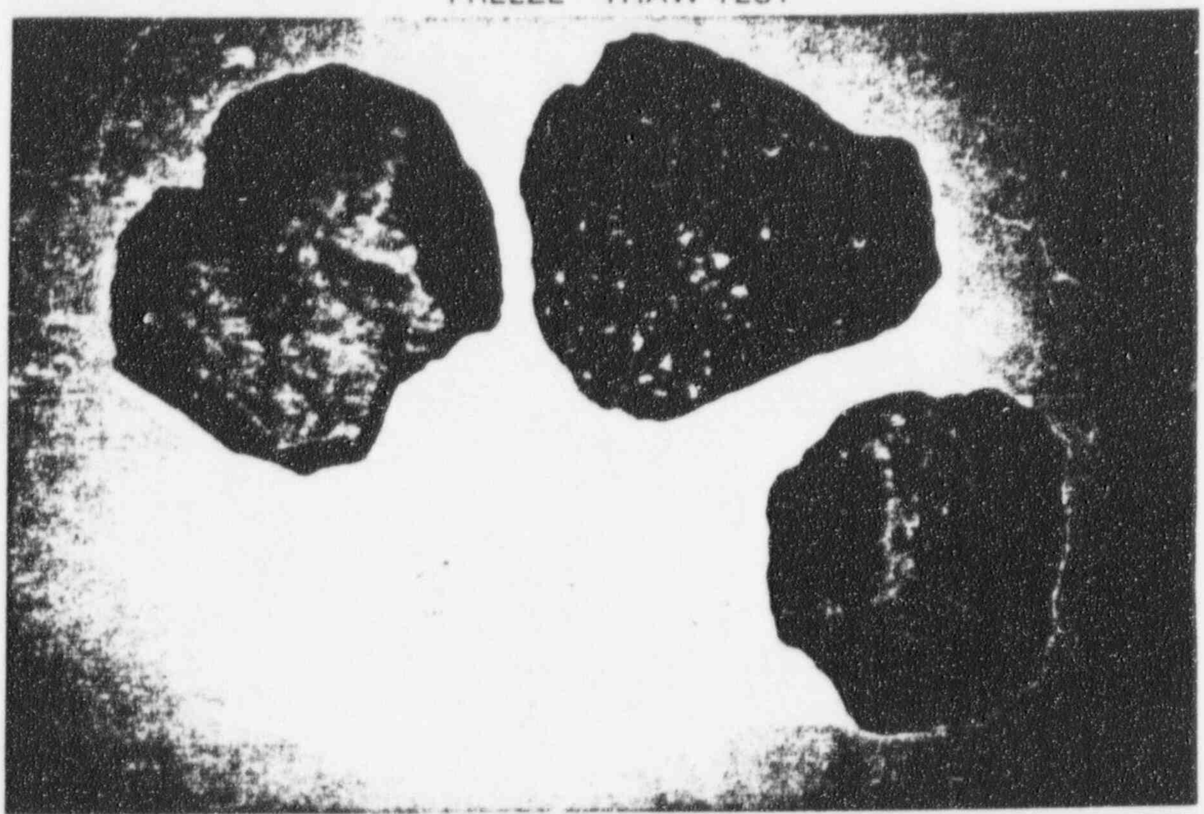


PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 55



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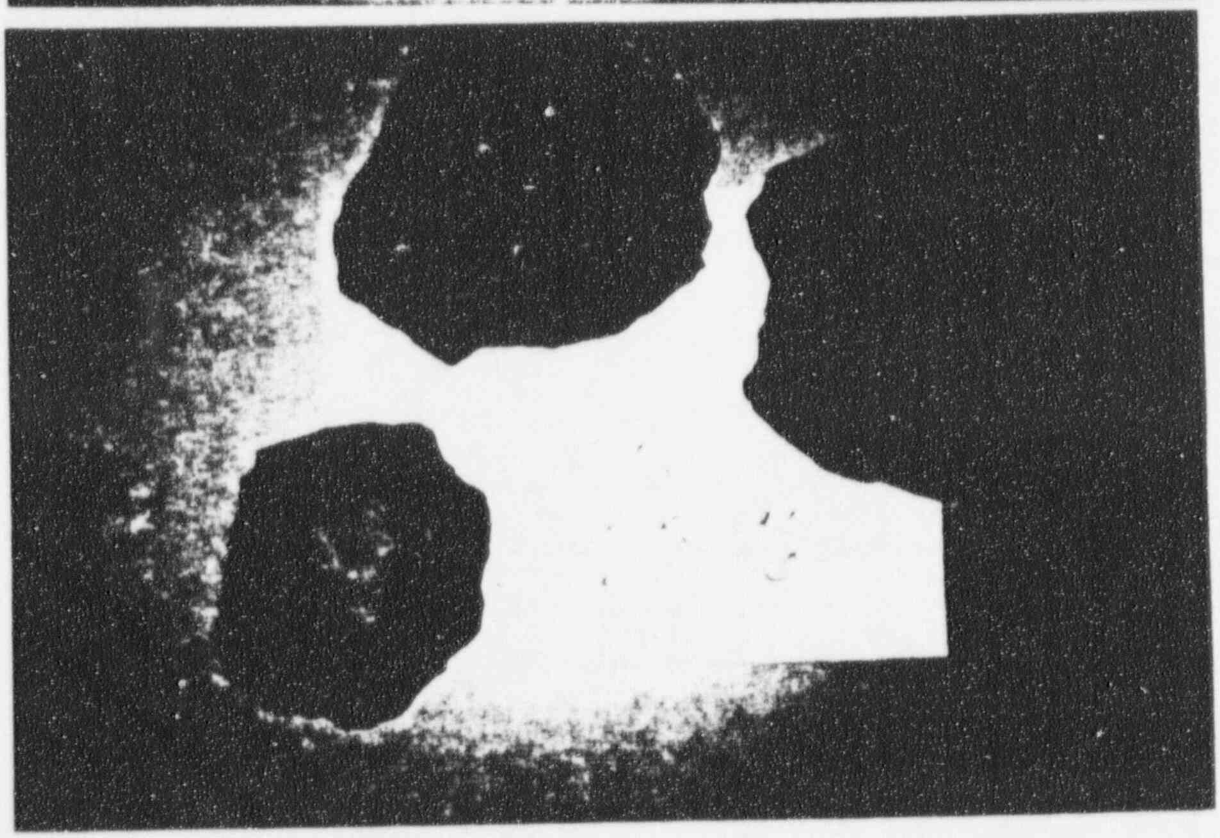
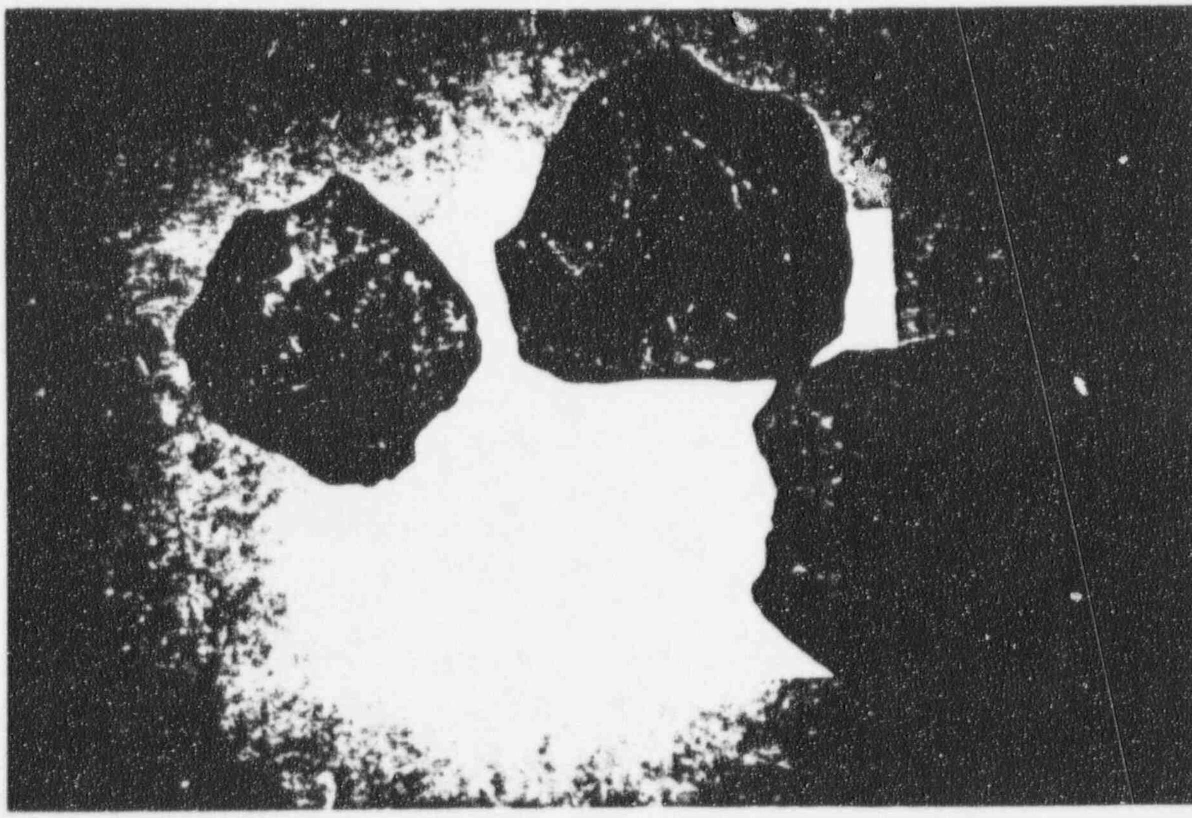


PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 65

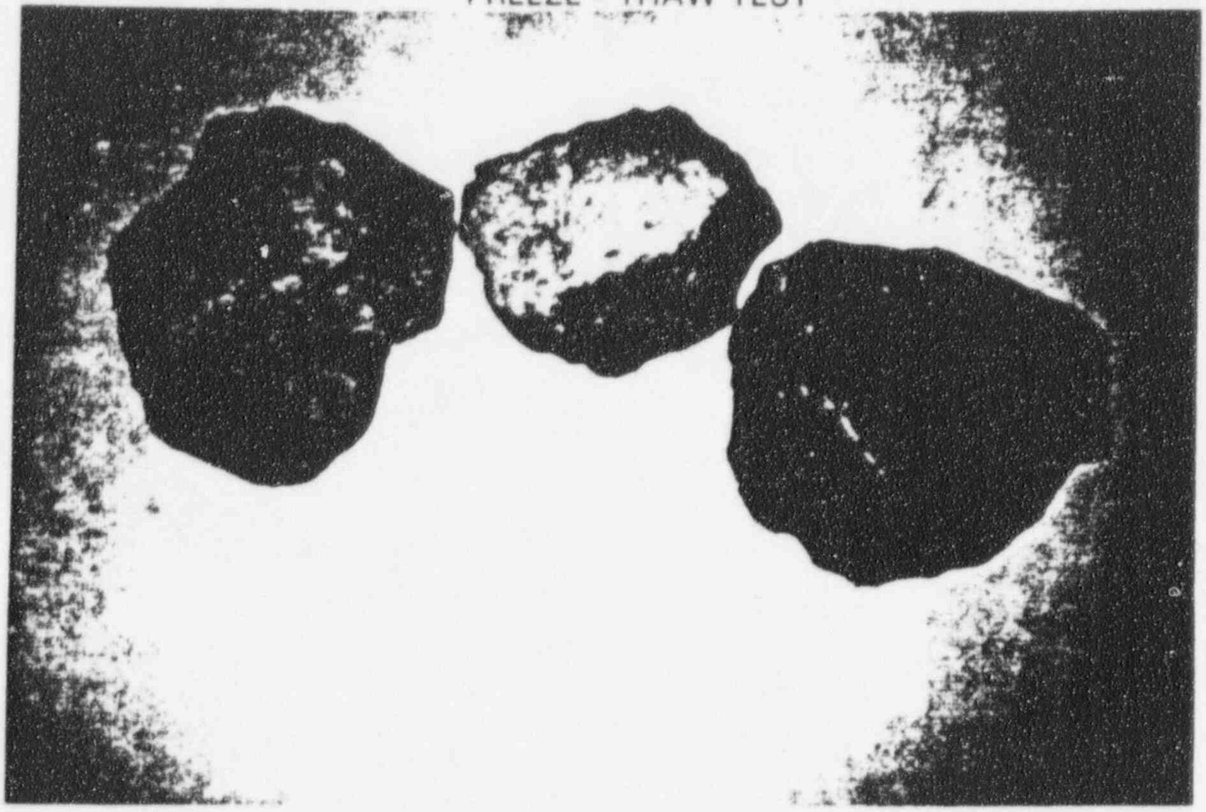
Cycle 70



PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 75

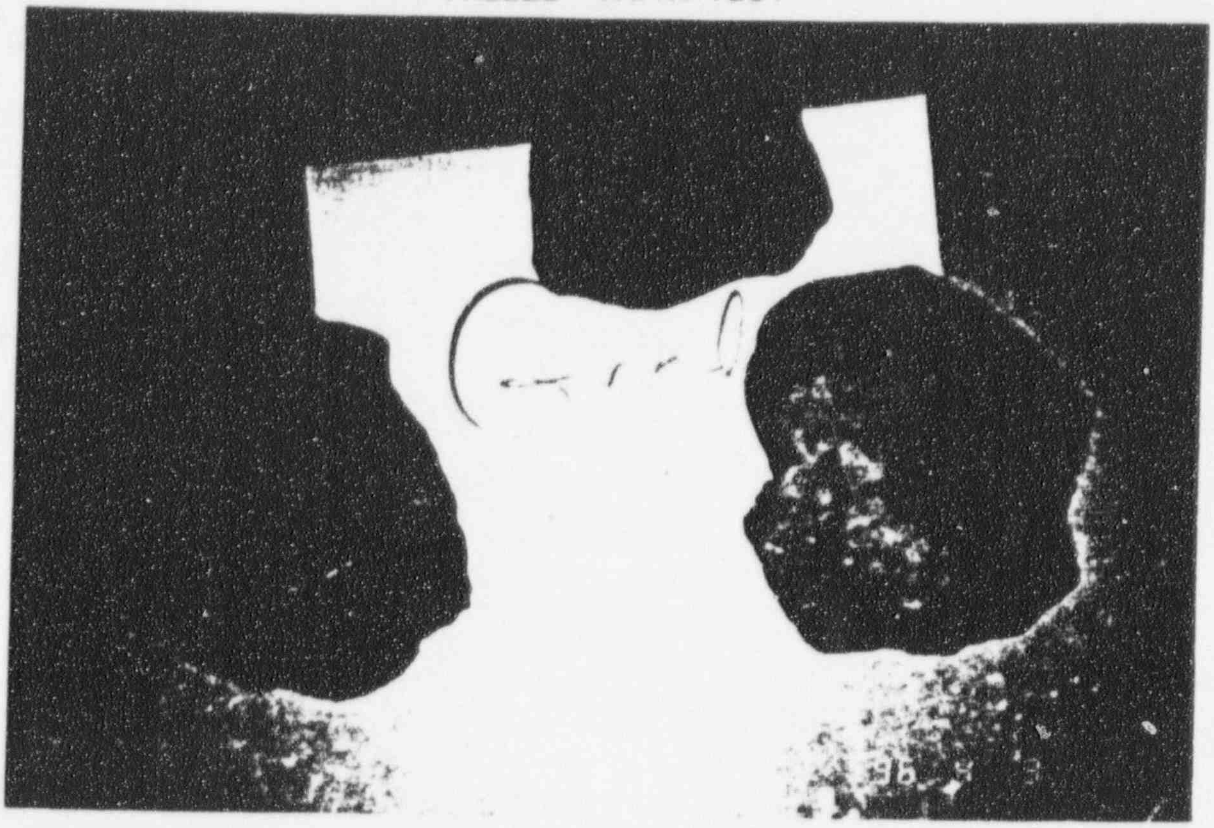


Cycle 80

PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 85

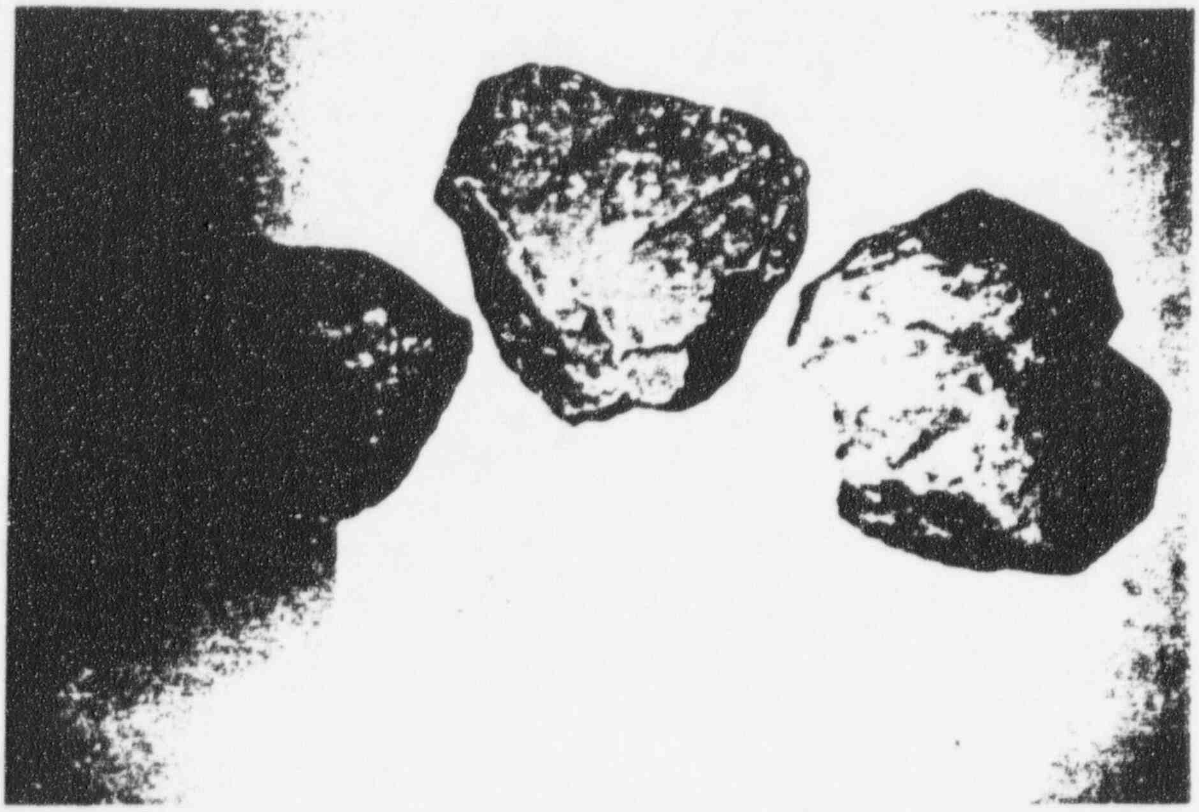


Cycle 90

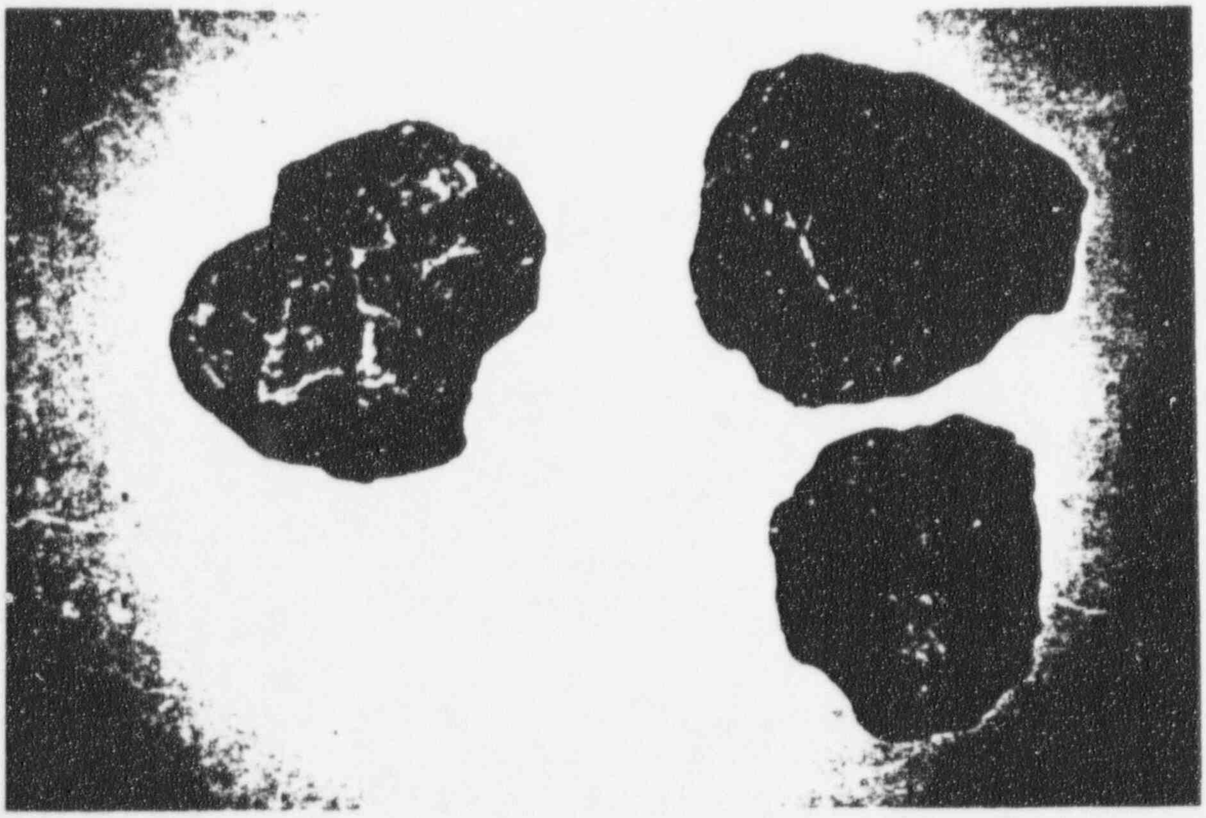
PEPPERLING GOOD

FREEZE - THAW TEST

Cycle 95



Cycle 100



NOTES OF OBSERVATION

GOOD:

OF THREE (3) PIECES, ONE (1) SHOWED SLIGHT CRACKING

PEPPERLING FAIR (MODERATE)

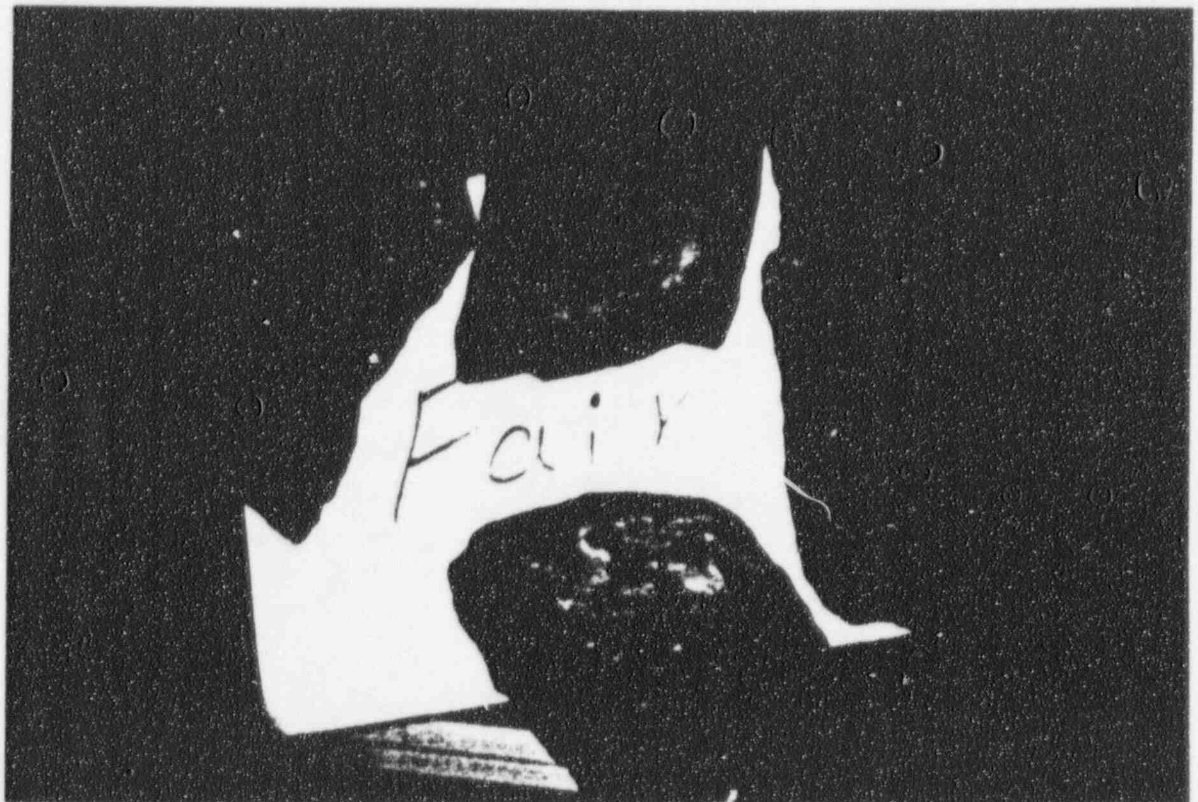
PEPPERLING FAIR (MODERATE)

Aggregate Size Distribution Prior To Testing

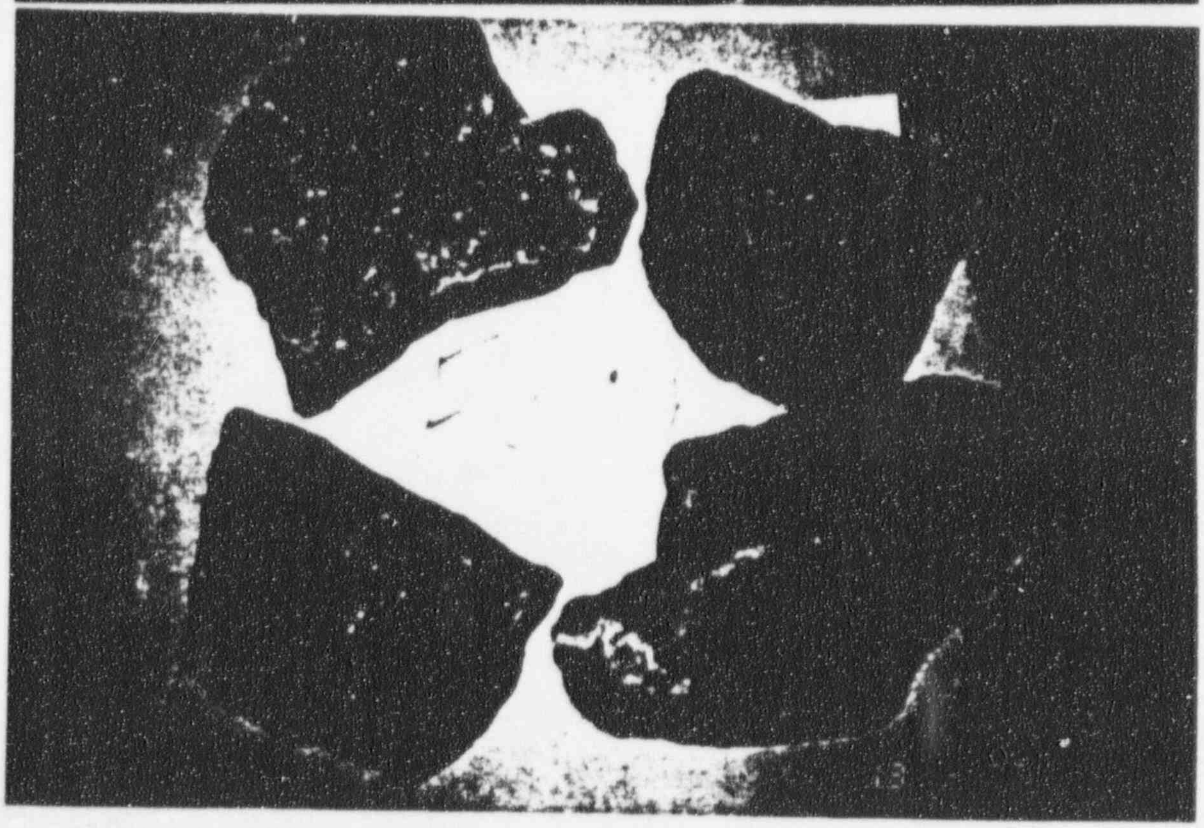
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

Cycle 5



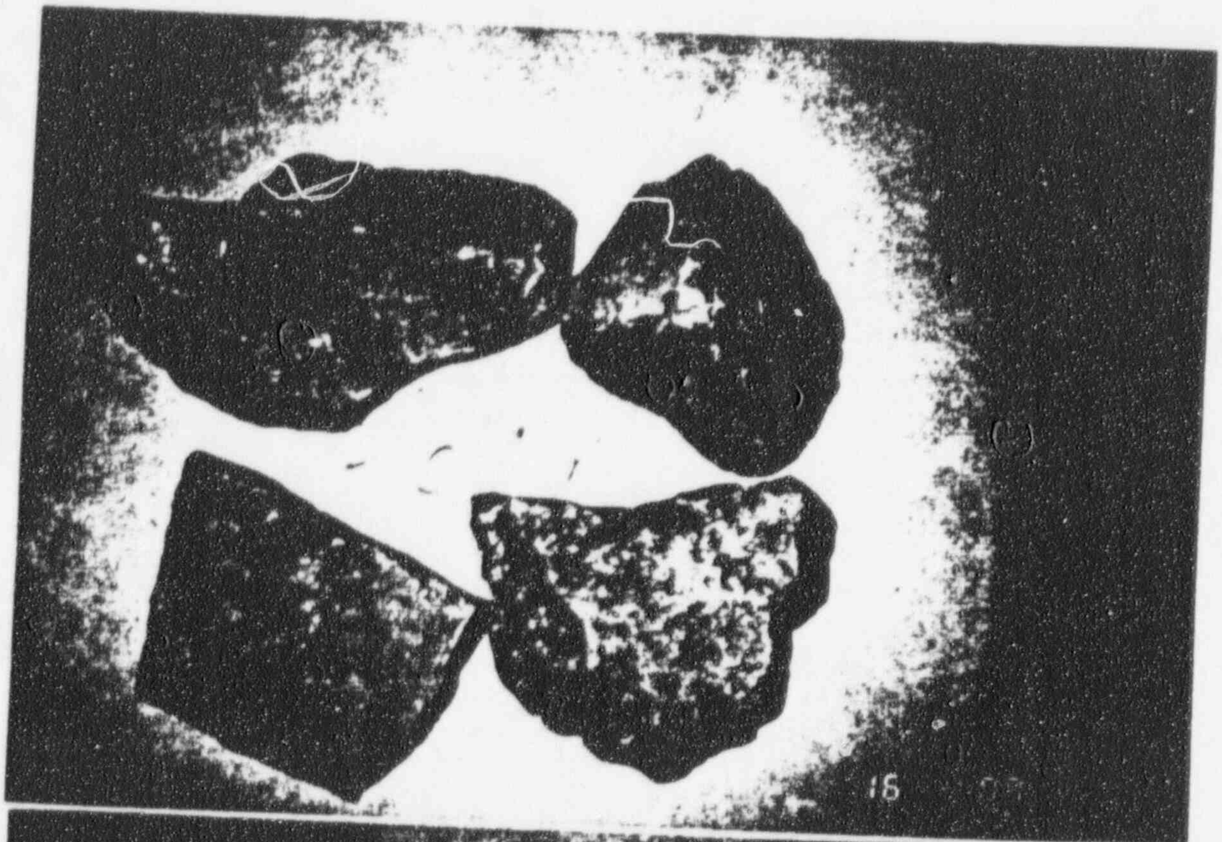
Cycle 10



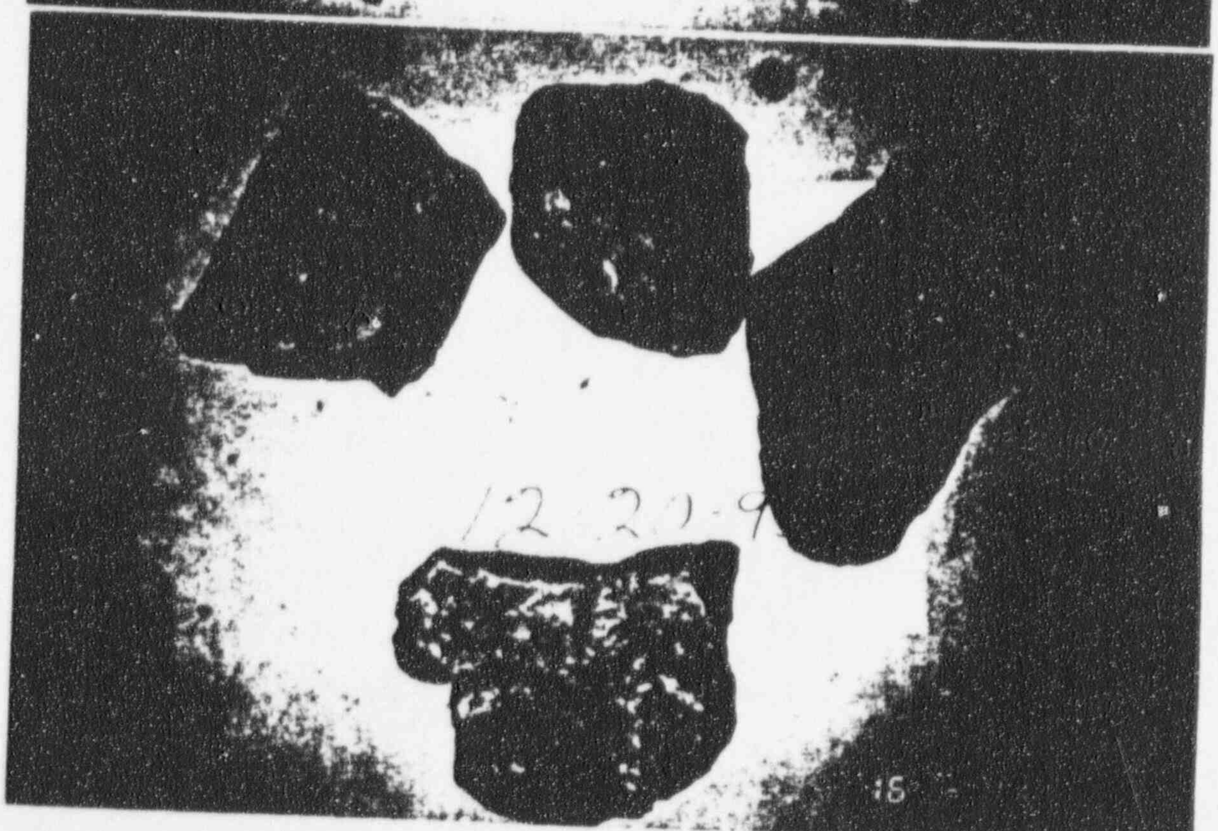
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

Cycle 15



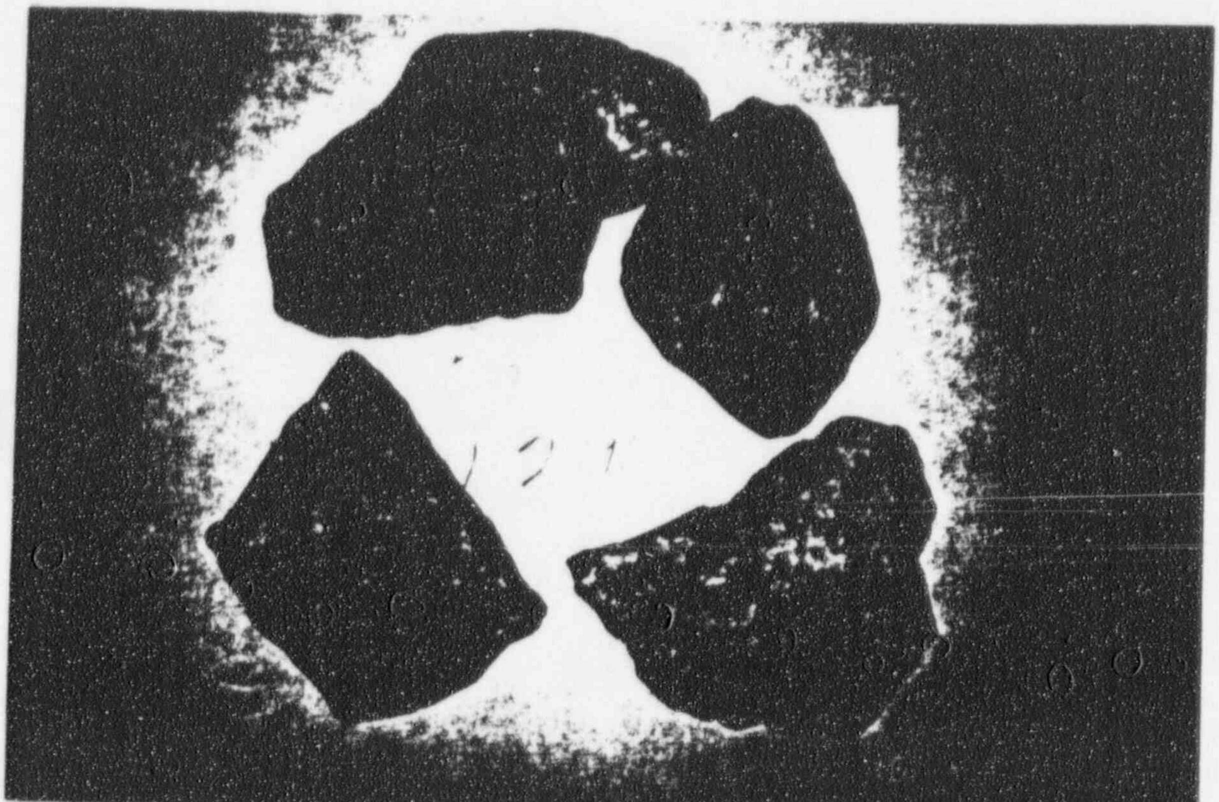
Cycle 20



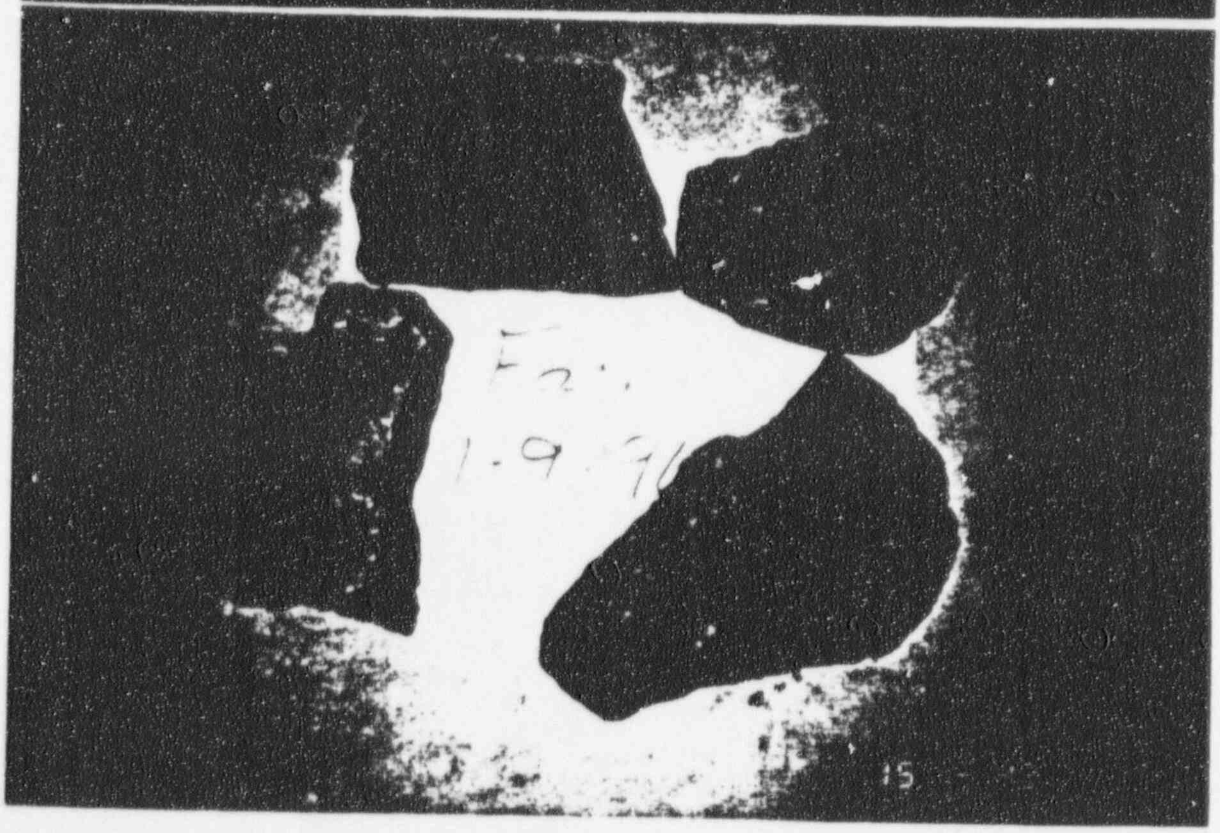
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

ycle 25



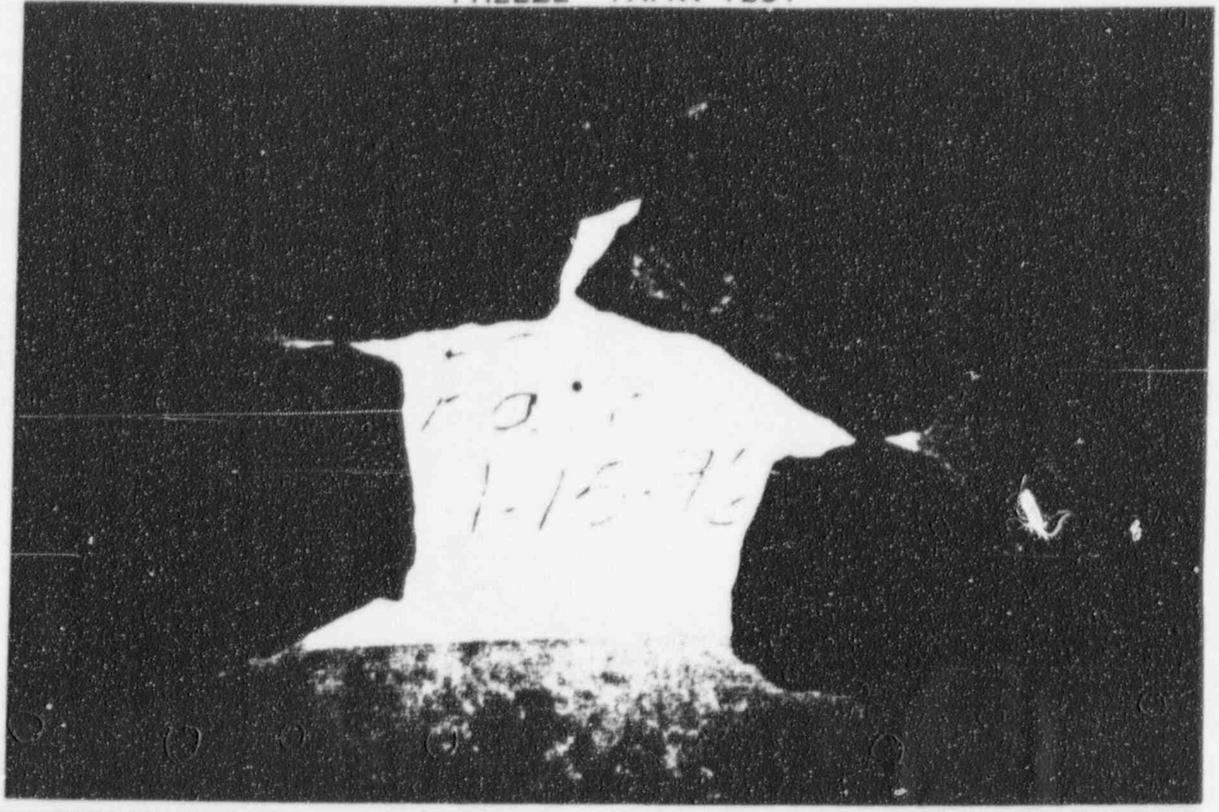
Cycle 30



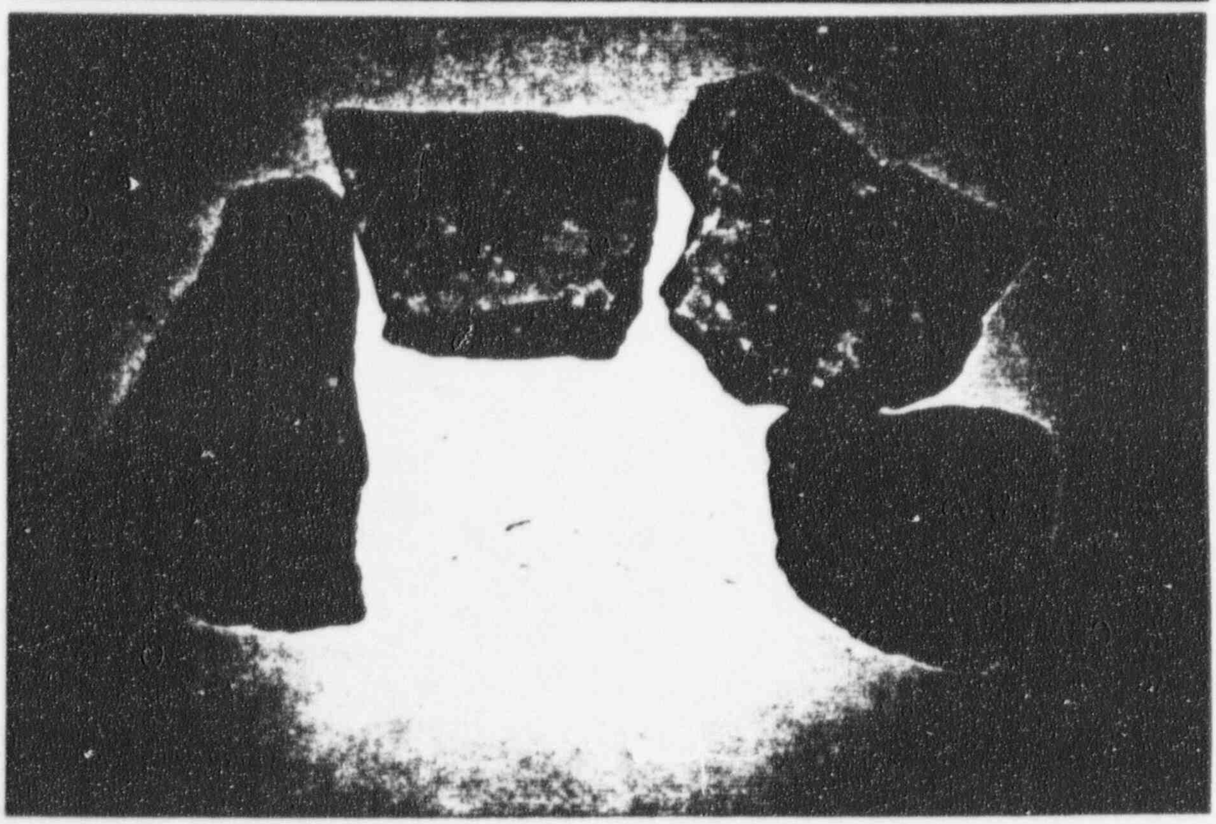
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

Cycle 35

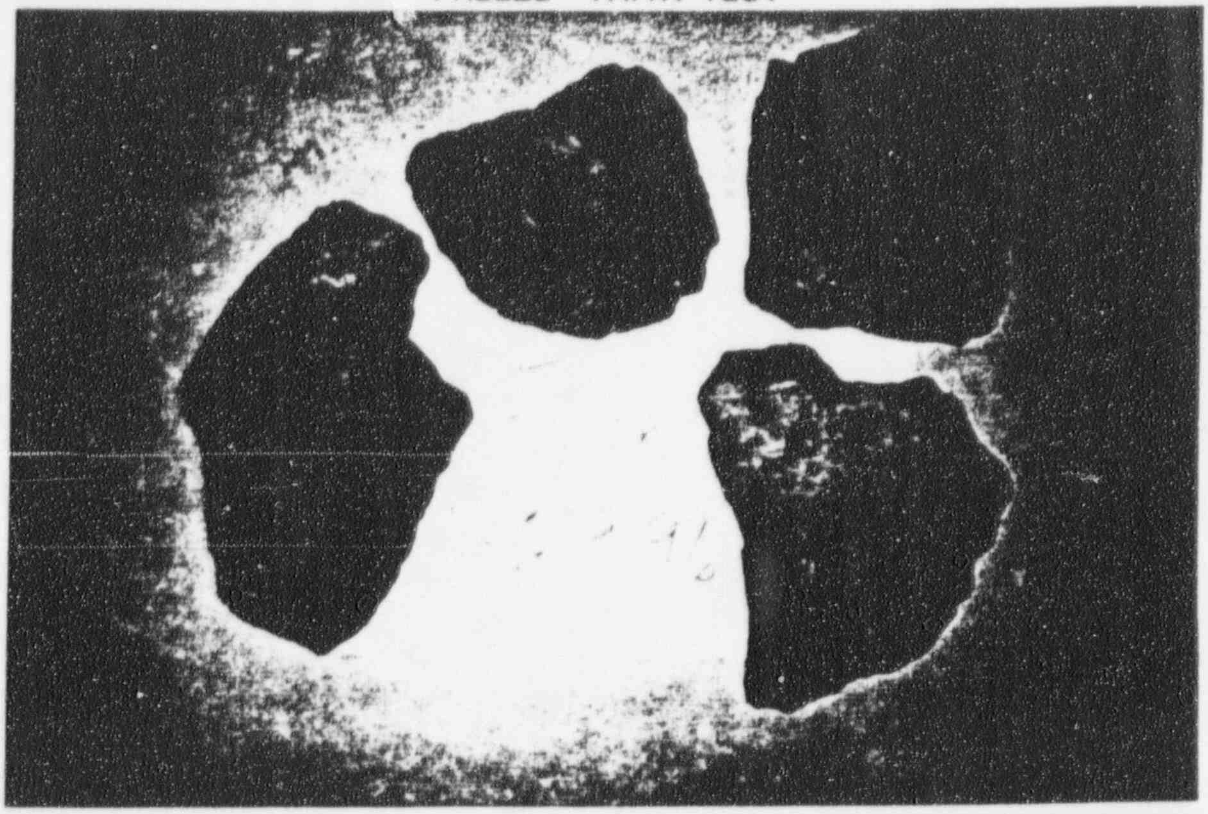


Cycle 40

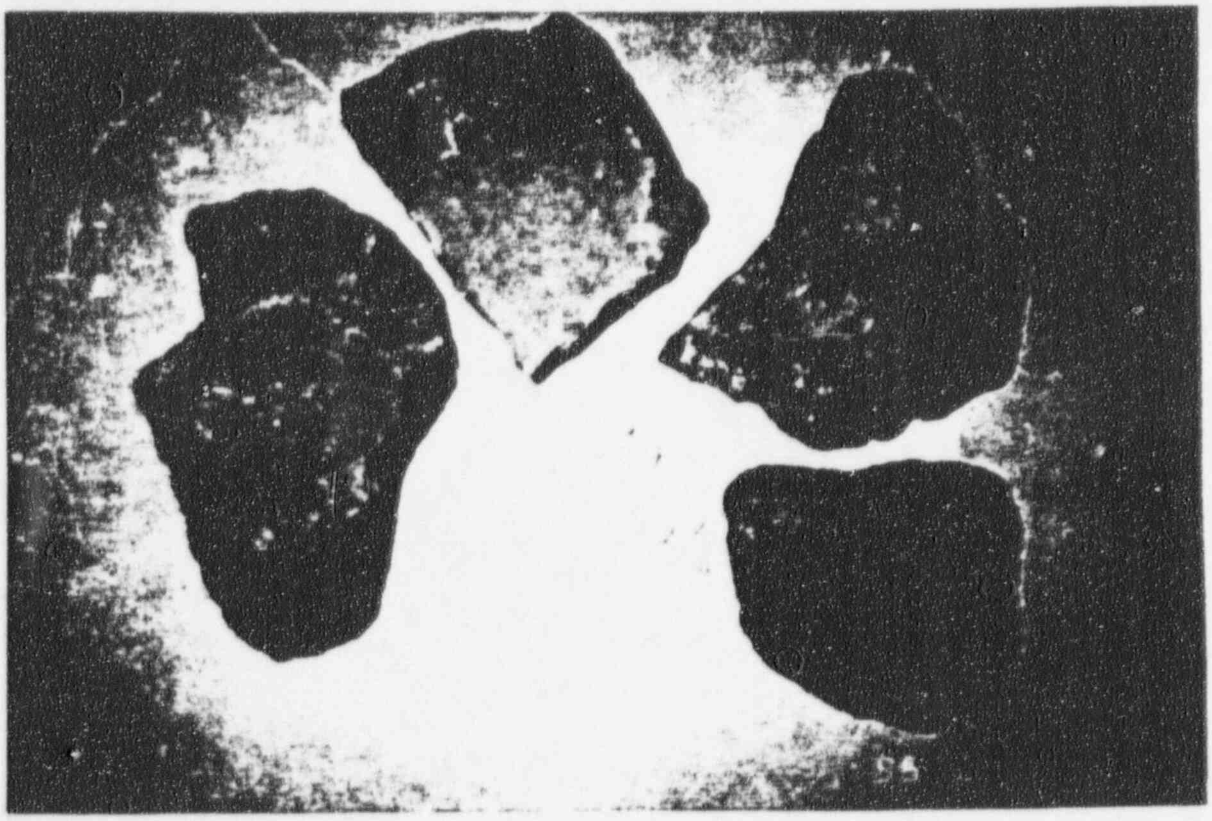


PEPPERLING FAIR (MODERATE)
FREEZE - THAW TEST

Cycle 45



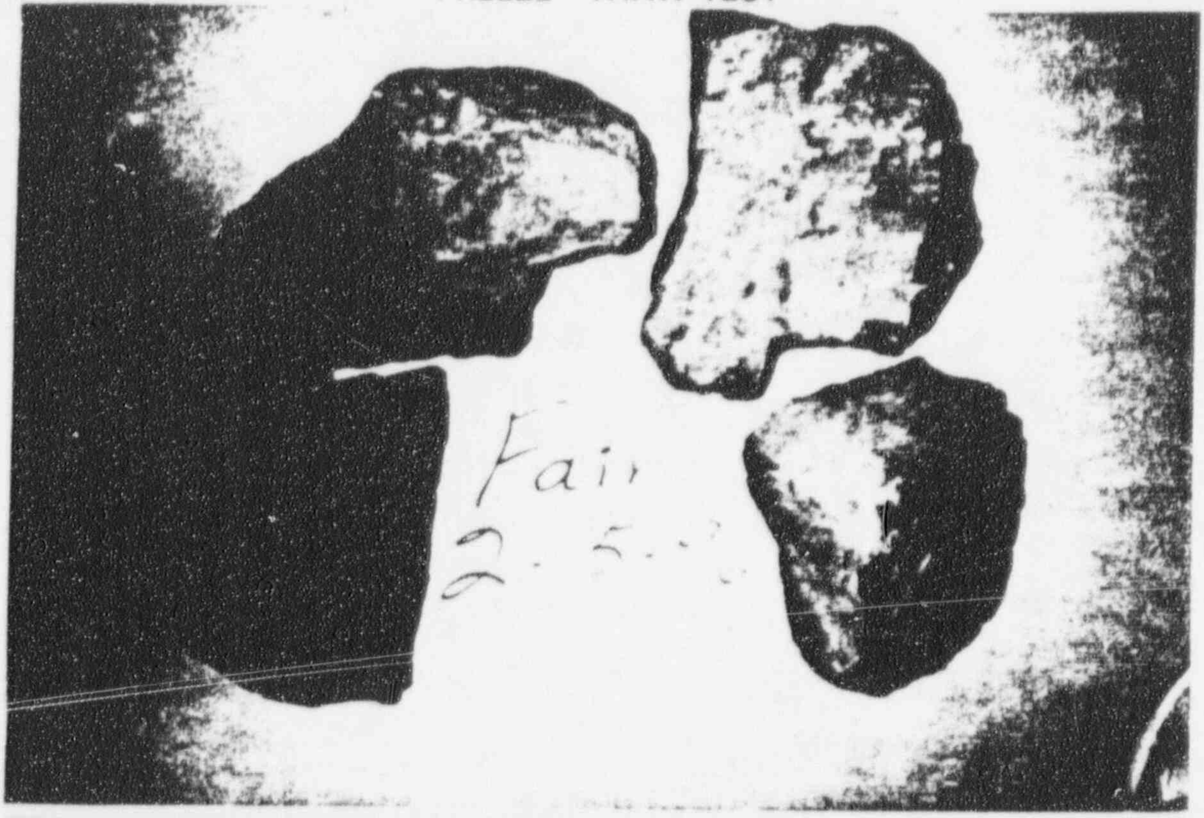
Cycle 50



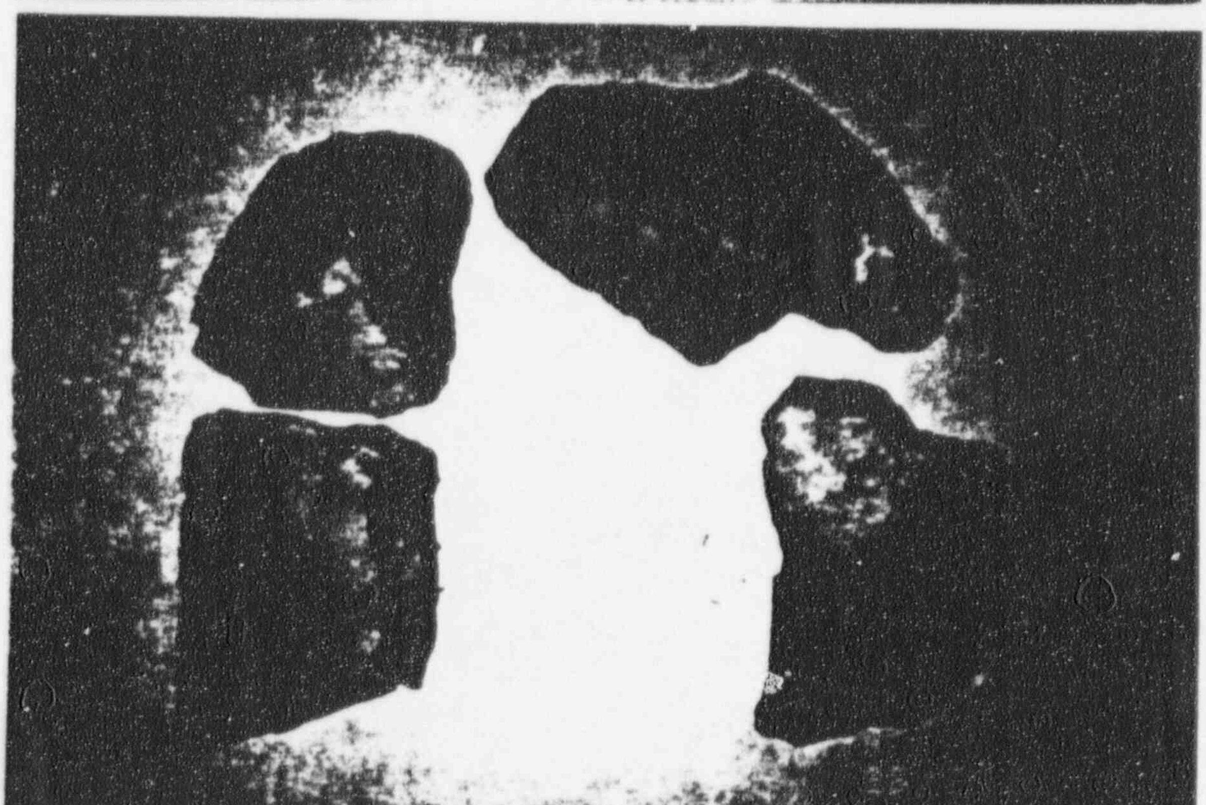
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

Cycle 55

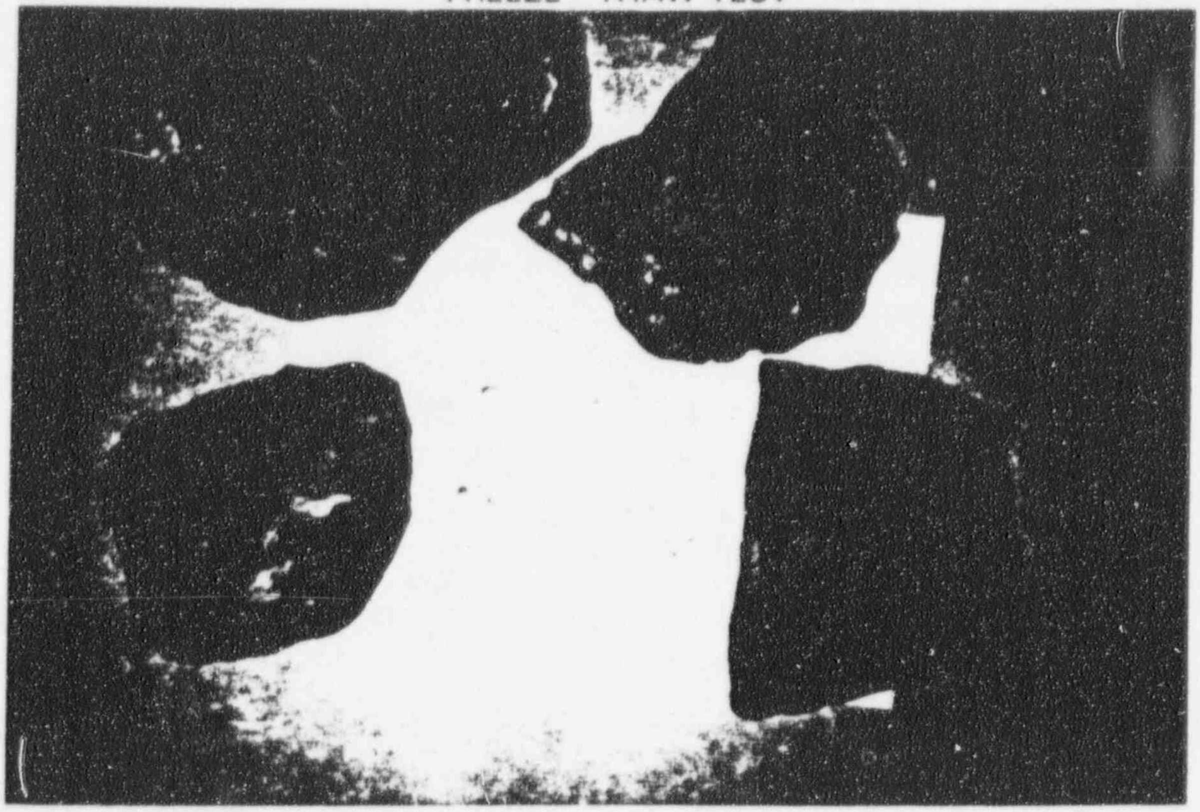


Cycle 60

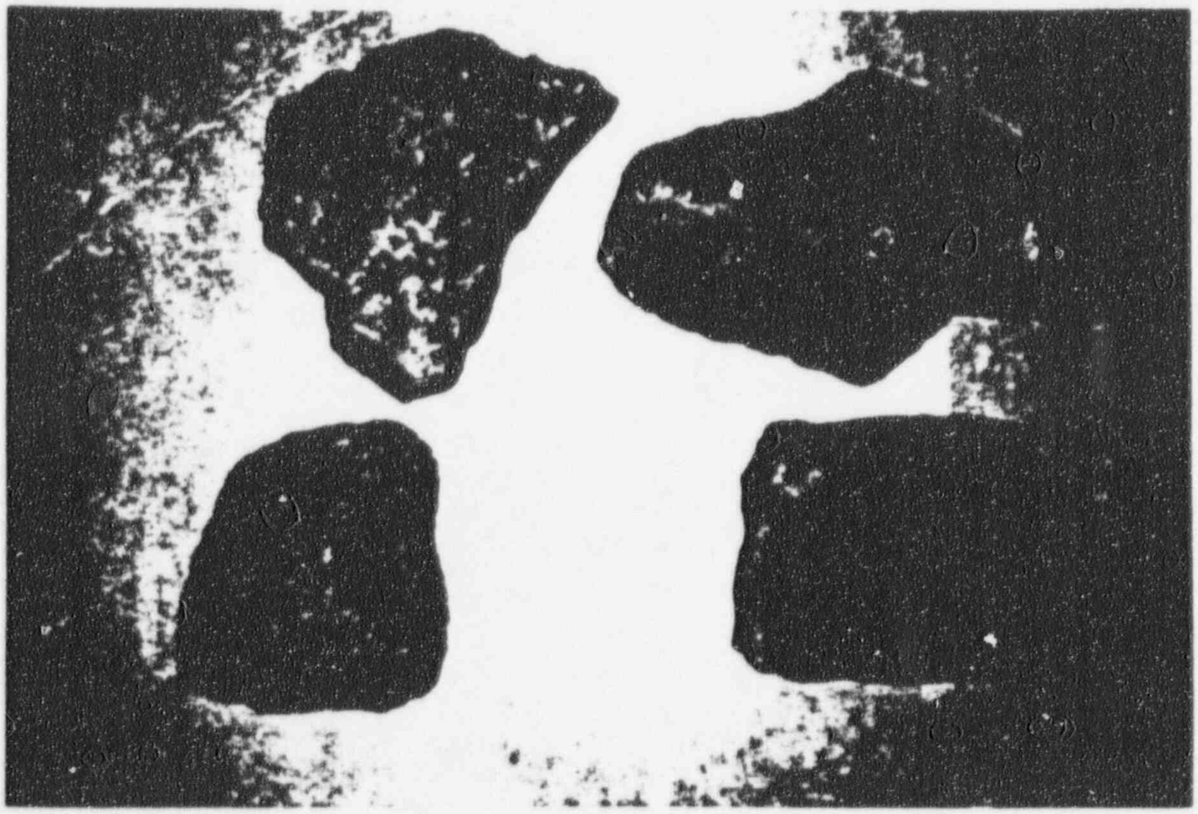


PEPPERLING FAIR (MODERATE)
FREEZE - THAW TEST

Cycle 65

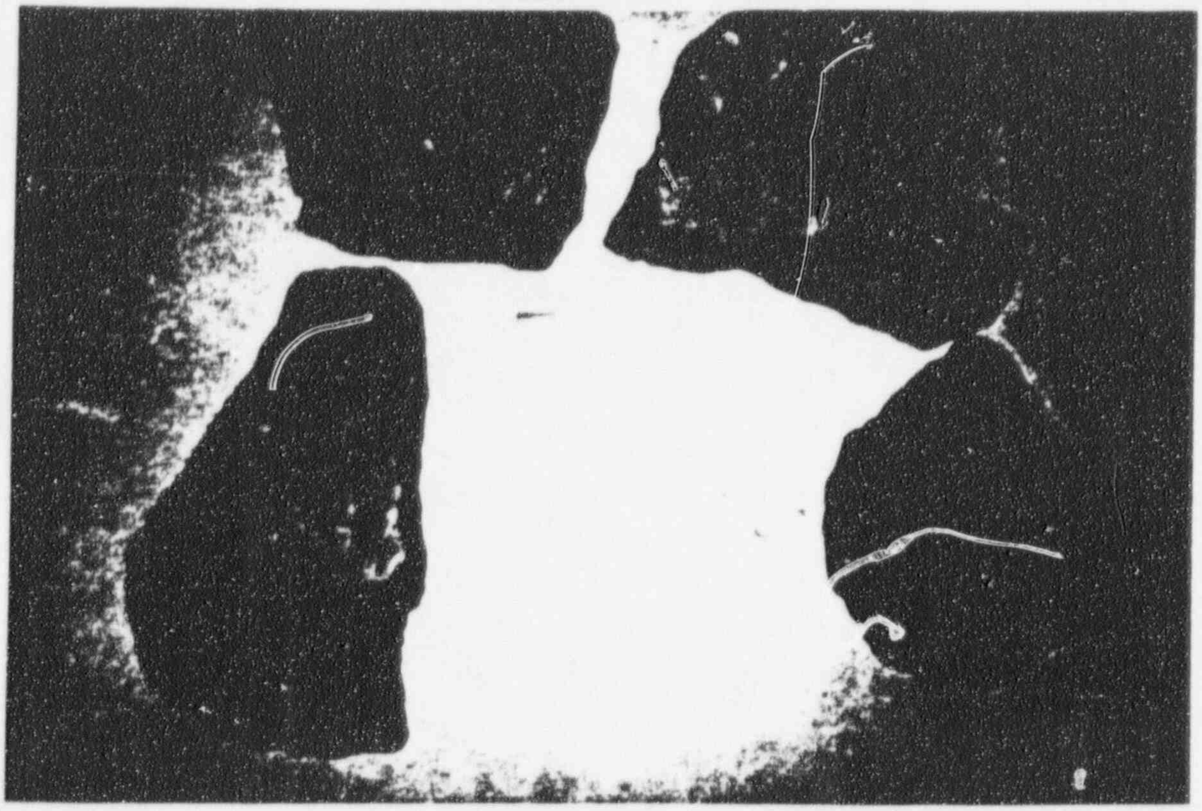


Cycle 70



PEPPERLING FAIR (MODERATE)
FREEZE - THAW TEST

Cycle 75

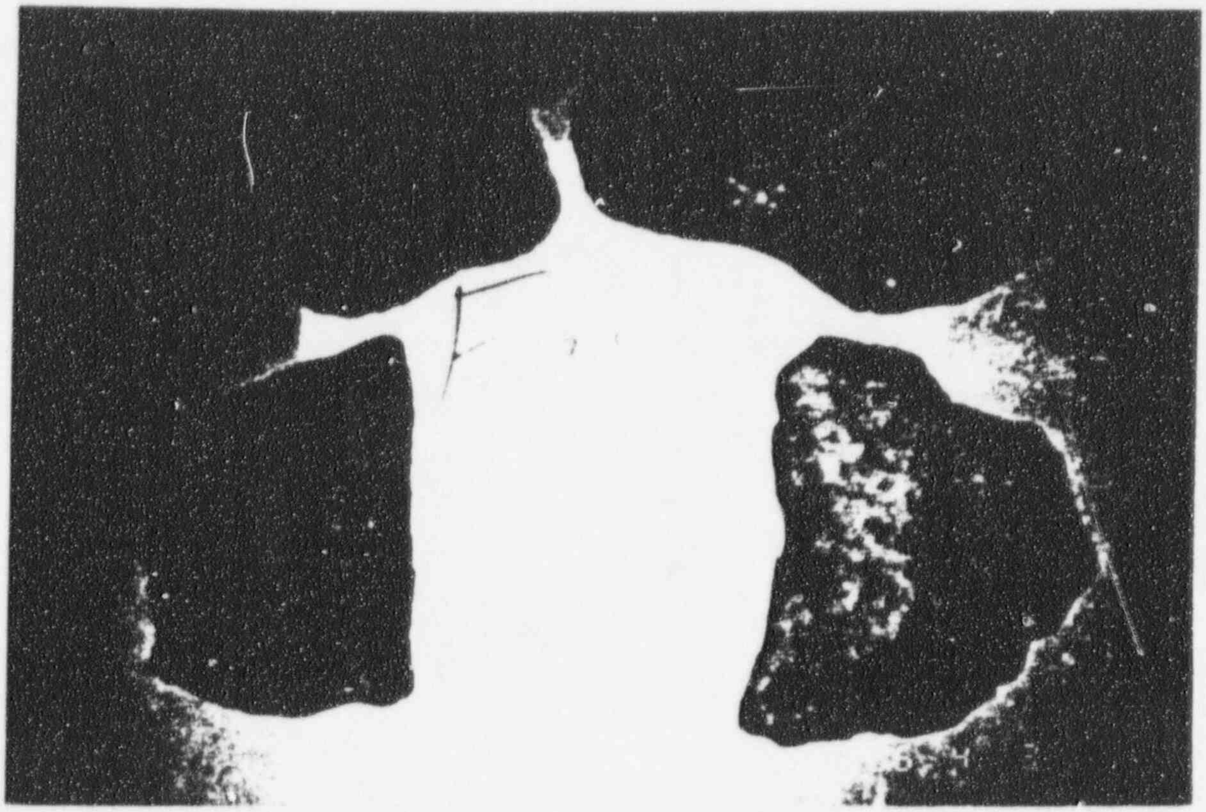


Cycle 80

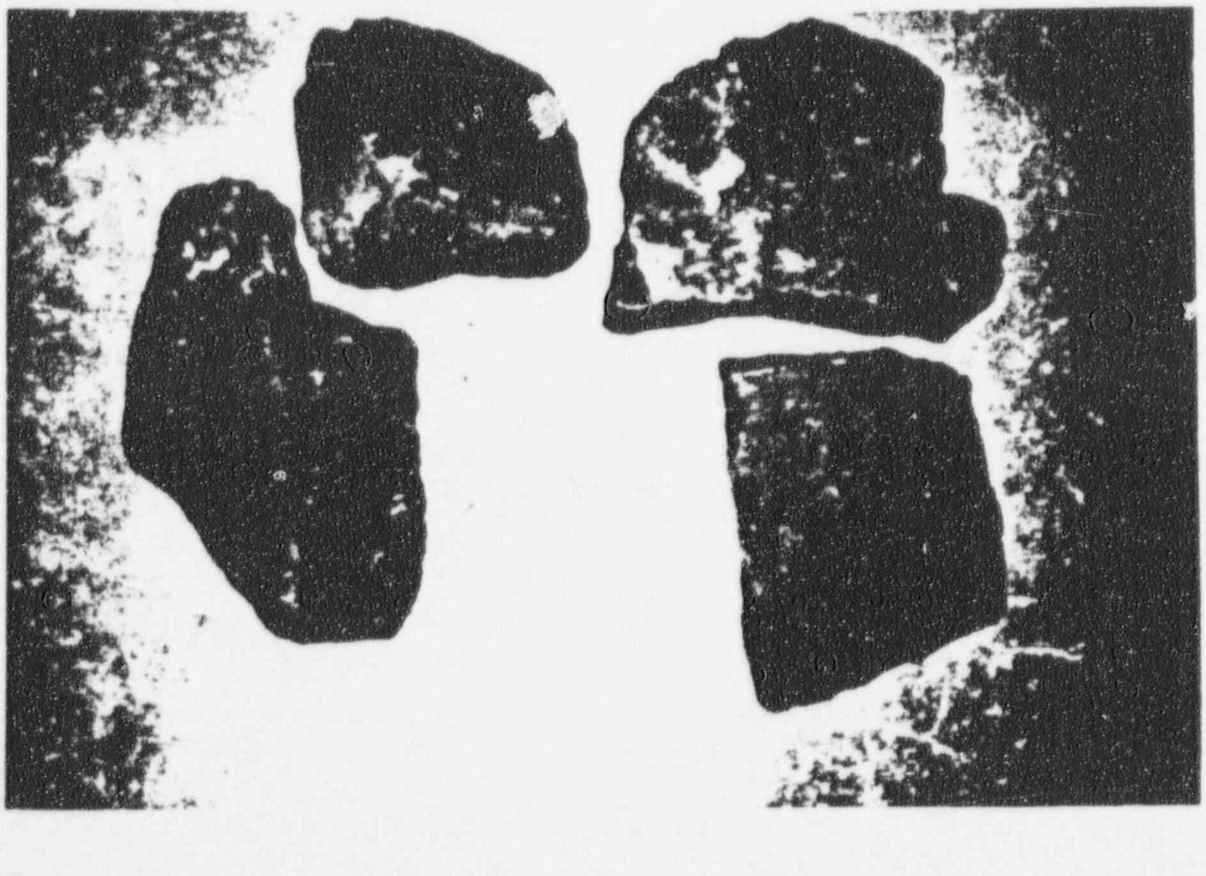
PEPPERLING FAIR (MODERATE)

FREEZE - THAW TEST

Cycle 85

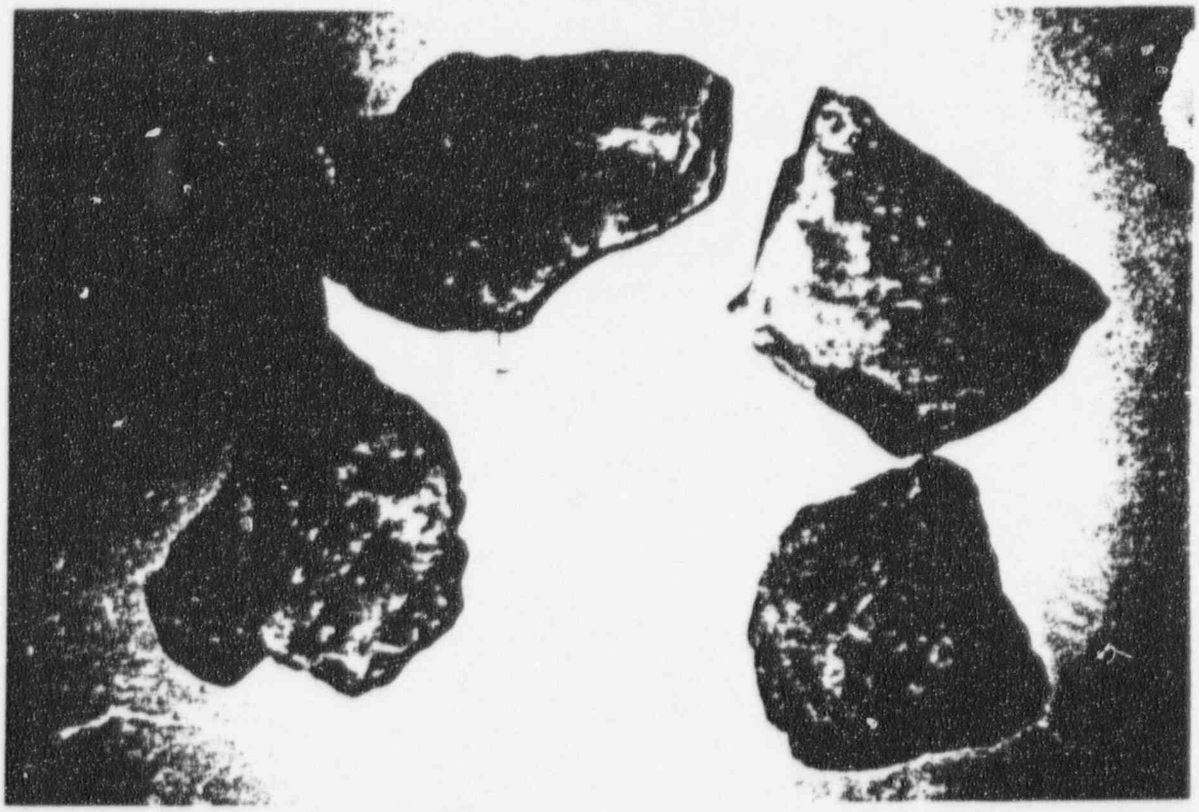


Cycle 90

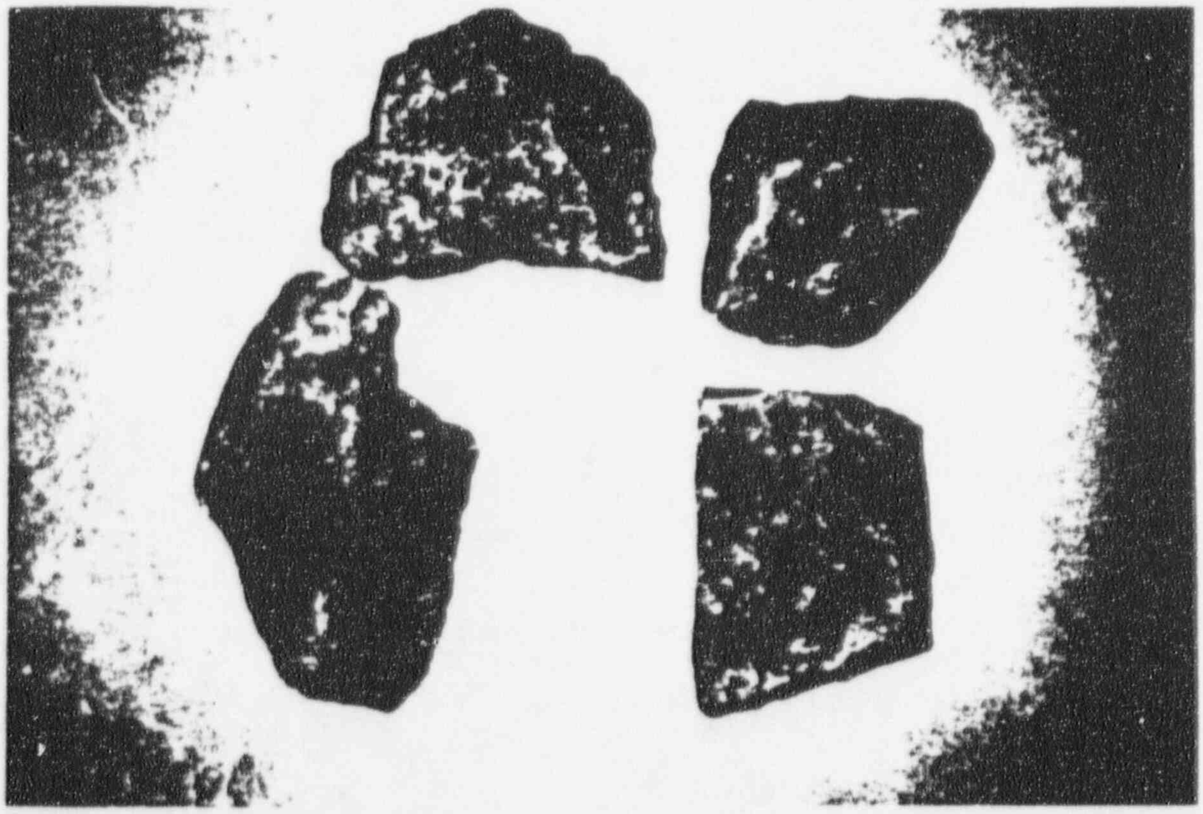


PEPPERLING FAIR (MODERATE)
FREEZE - THAW TEST

Cycle 95



Cycle 100



CSU Engineering Research Center
Uranium Mine Tailings Aggregate
Project No. 20954037

NOTES OF OBSERVATION

FAIR:

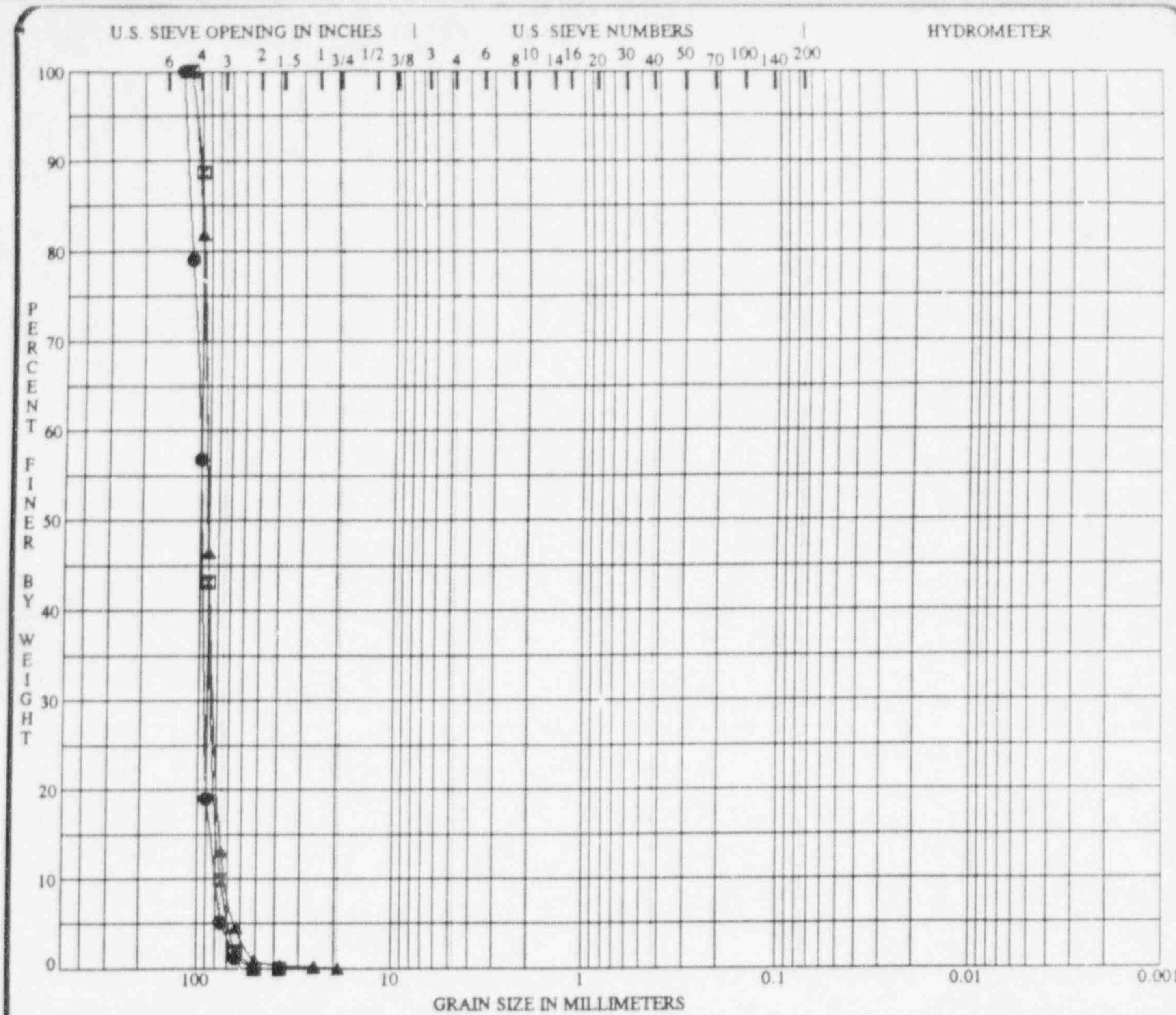
ALL FOUR (4) PIECES SHOWED SOME CRACKING BUT NO SEPARATIONS LARGER THAN 10 GRAMS

COLORADO STATE UNIVERSITY

URANIUM MINE TAILINGS FACILITY
LAKEVIEW, OREGON

AGGREGATE TESTING
PROJECT NO. 20954037

GRAIN SIZE DISTRIBUTION CURVES



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification			Classification	MC%	LL	PL	PI	Cc	Cu
●	1	0.0	Shear as received gradation						
⌧	2	0.0	Pepperling (good) as received gradation						
▲	3	0.0	Pepperling (moderate) as received gradation						

Specimen Identification			D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	1	0.0	125.00	101.70	92.800	79.9100				
⌧	2	0.0	112.50	93.59	83.750	75.0400				
▲	3	0.0	112.50	93.73	82.290	70.4700				

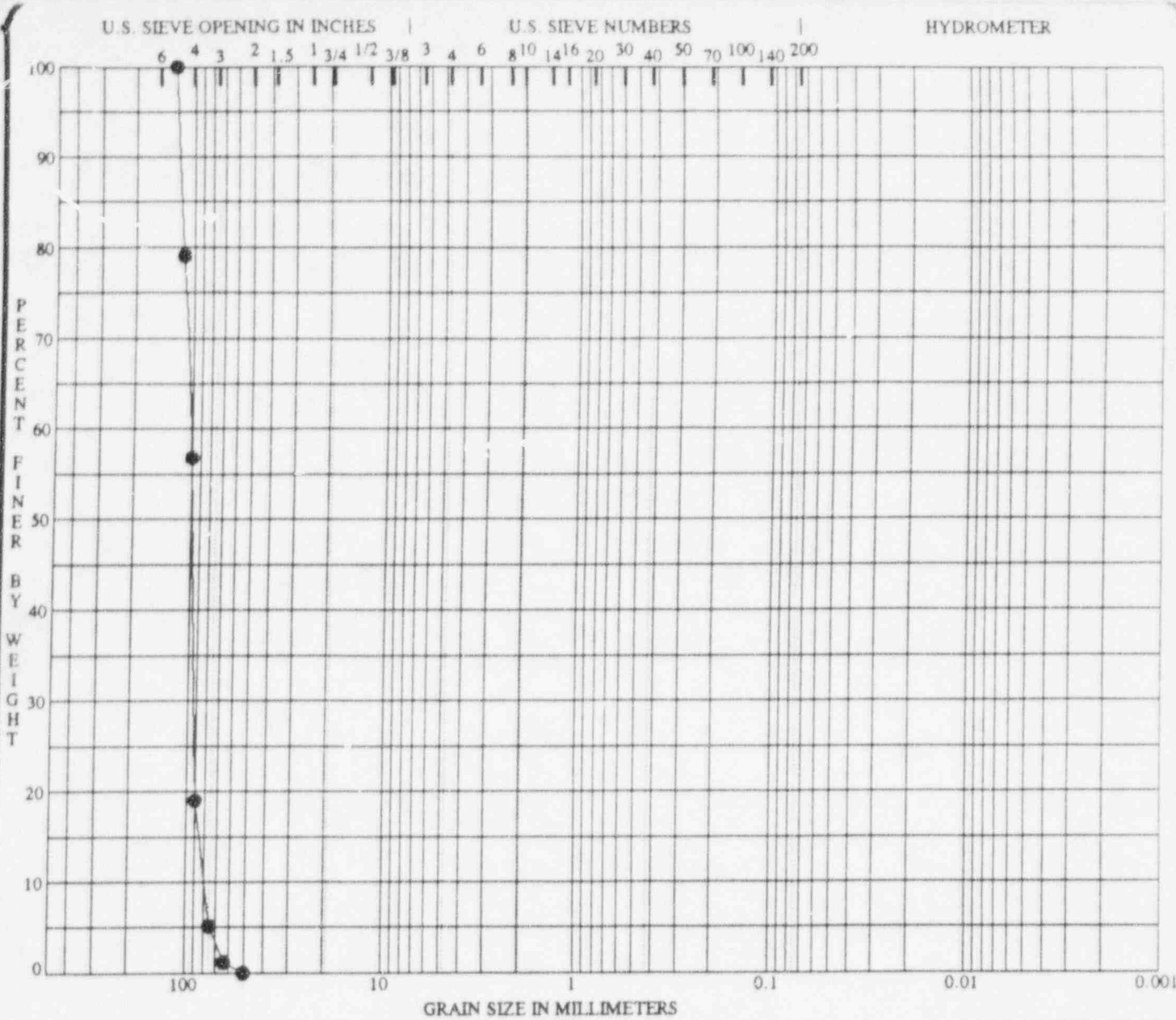
PROJECT Uranium Mine Tailings Facility -

JOB NO. 20954037
DATE 12/26/95

GRADATION CURVES

TERRACON

Consultants Western, Inc.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

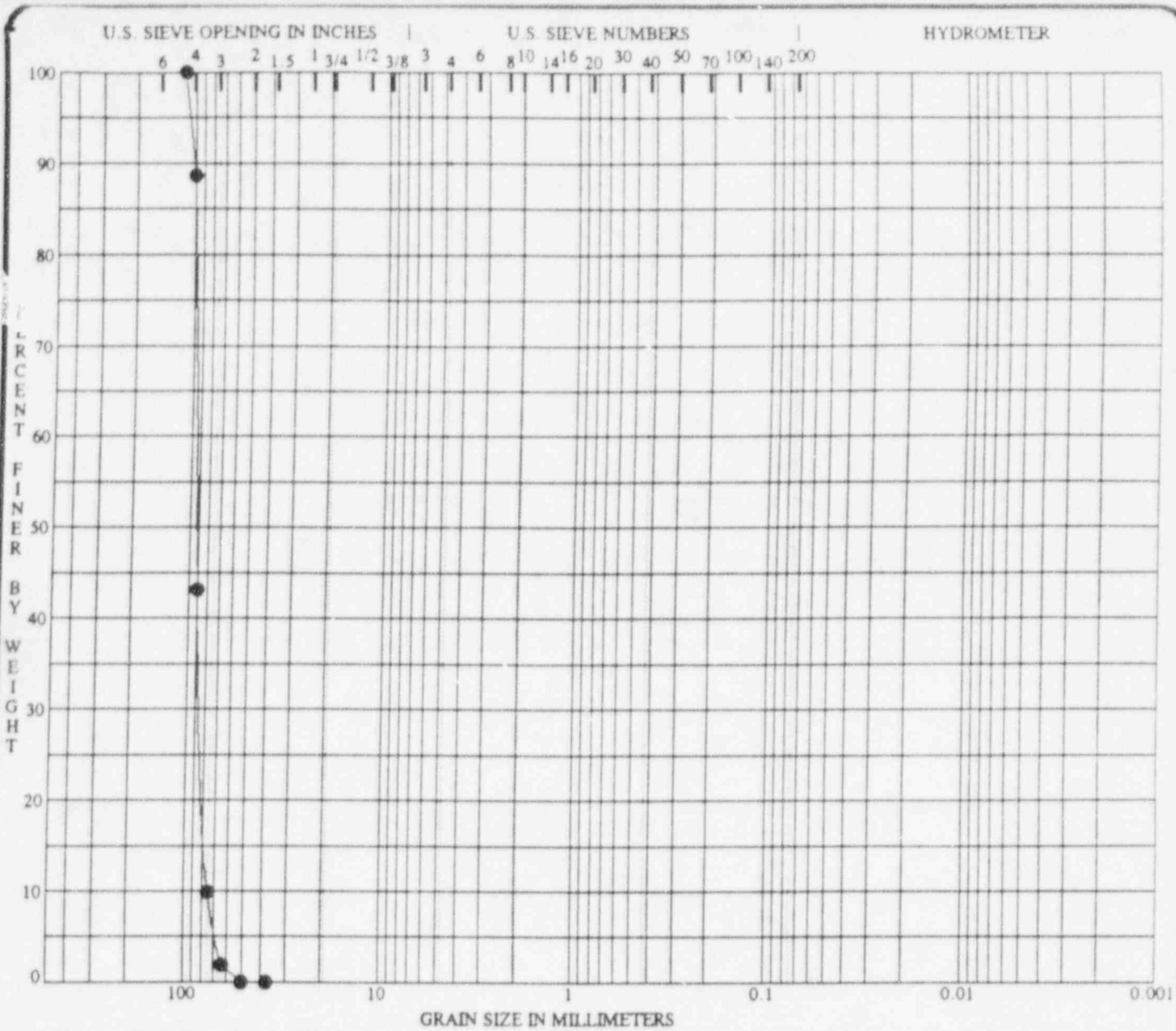
Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
● 1	0.0	Shear as received gradation						

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 1	0.0	125.00	101.70	92.800	79.9100				

PROJECT Uranium Mine Tailings Facility -

JOB NO. 20954037
DATE 12/26/95

GRADATION CURVES
TERRACON
Consultants Western, Inc.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

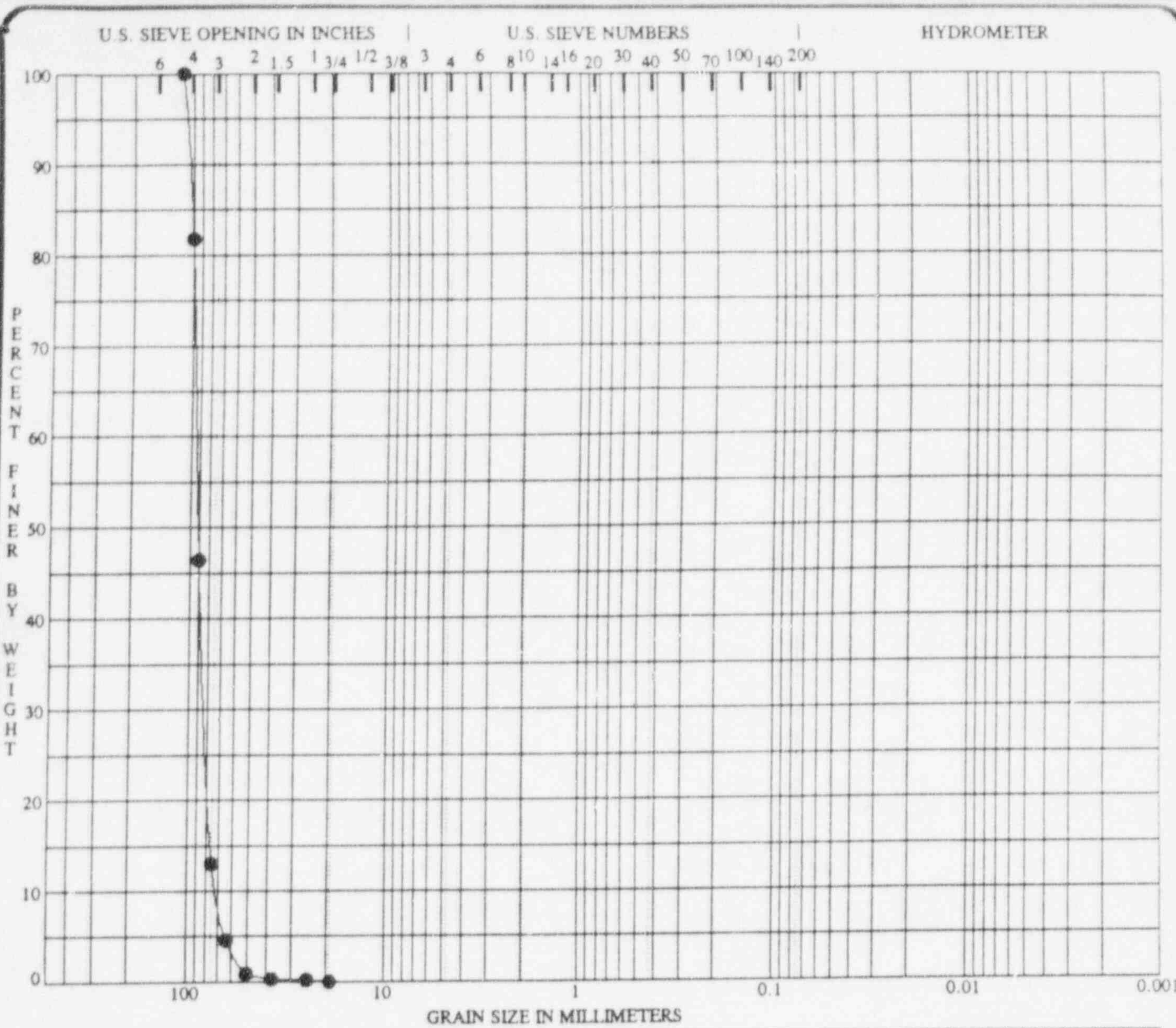
Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
● 2	0.0	Pepperling (good) as received gradation						

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 2	0.0	112.50	93.59	83.750	75.0400				

PROJECT Uranium Mine Tailings Facility -

JOB NO. 20954037
DATE 12/26/95

GRADATION CURVES
TERRACON
Consultants Western, Inc.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
● 3	0.0	Pepperling (moderate) as received gradation						

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 3	0.0	112.50	93.73	82.290	70.4700				

PROJECT Uranium Mine Tailings Facility -

JOB NO. 20954037
DATE 12/26/95

GRADATION CURVES
TERRACON
Consultants Western, Inc.

COLORADO STATE UNIVERSITY

URANIUM MINE TAILINGS FACILITY
LAKEVIEW, OREGON

AGGREGATE TESTING
PROJECT NO. 20954037

PETROGRAPHIC ANALYSIS

RICHARD C. MIELENZ, P.E., INC. – MATERIALS AND PETROGRAPHY

PETROGRAPHIC EXAMINATION OF SAMPLE

OF

COVER/PROTECTION AGGREGATE

FOR A

URANIUM TAILINGS FACILITY IN THE STATE OF OREGON

By

Richard C. Mielenz, P. E., Inc.

Gates Mills, Ohio

For

Empire Division,
Terracon Consultants Western, Inc.,
Fort Collins, Colorado

January 8, 1996

PETROGRAPHIC EXAMINATION OF SAMPLES OF COVER/PROTECTION AGGREGATE FOR A URANIUM TAILINGS FACILITY IN THE STATE OF OREGON

INTRODUCTION

In accordance with the letter of transmittal dated December 6, 1995, from Mr. Mike L. Walker, CET, Manager of Construction Services, Empire Division, Terracon Consultants Western, Inc., Fort Collins, Colorado, I have examined by petrographic methods three samples of aggregates that were placed as cover/protection to a uranium tailings facility located in the State of Oregon. The investigation is being performed at the request of Colorado State University, Fort Collins, Colorado. The work was referred to Terracon Project No. 20954037.

The shipment was received in good condition on December 12, 1995, by United Parcel Service. The samples were designated Shear, Pepperling Good, and Pepperling Moderate, respectively. The source of the samples was not stated.

It was requested that the samples be examined in accordance with standards of the American Society for Testing and Materials (ASTM) and that a professional opinion be provided on the durability of the samples.

The samples were examined visually and in detail under the stereoscopic microscope. Each piece of the aggregate was sawed across a major axis so as to provide sections showing the internal structure and composition of the rock in an undisturbed condition. Portions of the pieces were examined as grain mounts under the petrographic microscope. A microscopical thin section was obtained for each of the samples; one such section for each sample was deemed adequate because of the uniformity of the lithology. The examination was performed in accordance with ASTM C 295, Standard Guide for Petrographic Examination of Aggregate for Concrete.

CONCLUSIONS

General

1. Each of the samples consisted of ten (10) pieces of rock, the maximum dimension of which was 5 to 6-1/4 in. and the average weight being 1.4 to 2.4 lb.

a. A summary of visual examination of the pieces is presented in Table 1.

<u>"Shear" Aggregate</u>

1. The sample designated as "Shear" consisted of fragments of an olivine basalt that approaches olivine diabase in internal texture and structure.

a. All of the pieces display 1 to 6 surfaces that were exposed to weathering at the original source.

b. Six of the pieces are transected in whole or in part by natural joints, these being natural partings or fractures in the rock.

2. The basalt has been subject to minor alteration as a result of hydrothermal activity occurring in late stages of the volcanic activity and by subsequent weathering in the formation.

3. In my opinion, the aggregate is suitable for use as cover/protection aggregate from the standpoint of resistance to disintegration by weathering exposure and is expected to provide satisfactory service in this regard for 100 years and indefinitely thereafter.

<u>Pepperling Good Aggregate</u>

4. The sample designated as "Pepperling Good" consists of fragments of olivine basalt that is more fine grained than the rock constituting the Shear Aggregate and is characterized by a hyalopilitic texture.

a. The pieces display 1 to 6 surfaces that were exposed to weathering at the original source.

b. Eight of the pieces include 1 or 2 natural joints.

5. The rock has been subject to minor alteration as a result of hydrothermal activity in the formation and minimal effects as a result of weathering exposure.

6. In my opinion, the aggregate is suitable for the designated use from the standpoint of resistance to disintegration by weathering exposure and is expected to provide satisfactory service in this regard for 100 years and indefinitely thereafter.

Pepperling Moderate Aggregate

7. The sample designated as "Pepperling Moderate" consists of fragments of an olivine basalt that is more fine grained than the rock constituting the Shear Aggregate and is characterized by a hyalopilitic texture.

a. The pieces display 1 to 6 surfaces that were exposed to weathering at the original source.

b. All of the pieces include natural joints.

8. The rock has been subject to appreciable alteration as a result of deuteric activity during the latter part of magmatic processes in the lava body and by hydrothermal activity followed by weathering at the original source. Nine of the pieces include veinlets that contain varying amounts of clayey and clay-like minerals in association with analcite and calcite.

9. In my opinion, the aggregate is marginally suitable for the designated use from the standpoint of resistance to disintegration by weathering at the site of installation. Some proportion of the exposed particles are expected to exhibit splitting as a consequence of freezing and freezing and thawing when and if subjected to subfreezing temperatures while critically saturated by water. Such disintegration may require removal of near-surface portions of the cover and replacement by aggregate from another source, such as the Pepperling Good Aggregate. The main effect of such breakdown of particles will be clogging of interparticle voids within the aggregate sufficient to impair drainage of water from the cover and thus to maintain the aggregate in a saturated condition.

Evaluation of Durability (Resistance to Weathering Exposure)

10. As apart from the composition and physical characteristics of the rock, durability of a placement of aggregate depends on many factors that have not been described in correspondence accompanying the submitted samples, such as the grading of the aggregate, the dimensions and topographic relationships of the cover/protection installations, and data on weather conditions at the respective sites. Critical features of the weather include: frequency of freezing conditions, duration of freezing conditions, minimum temperature attained, and relation of onset of freezing to prior incidence of rainfall. A condition of saturation of the

particles of larger dimensions combined with freezing to low ranges of temperatures that are maintained for substantial periods of time will aggravate and promote sloughing and fragmentation of particles as a result of ice accretion and hydraulic pressure developed within finely porous or jointed rock.

11. Examination of the present installations will provide a basis for preliminary evaluation of durability of the respective aggregates. Most significant in such inspection will be observation of the occurrence and the manifestations of any breakdown of particles. Disintegration resulting from freezing of critically saturated particles will be characterized by progressive sloughing or granulation at exposed surfaces or splitting along joints or previously existing fractures. These conditions, if occurring at all, will be most frequent in placements of Pepperling Moderate Aggregate because of the frequency of internal joints, presence of fractures and vesicles containing clayey and clay-like deposits, and alteration of the matrix of the rock.

a. Being supplied is a reprint copy of a chapter by Mielenz on petrographic examination of aggregate that is part of Special Technical Publication 169B, American Society for Testing and Materials, in which Fig. 5, page 551, depicts disruption of cobbles of argillaceous limestone exposed at the surface of a deposit of sand and gravel near Charlesvoix, Michigan. This rock type is not related to the basalts that constitute the submitted aggregates but similar phenomena will occur in any rock having the necessary characteristics of porosity and jointing when exposed to freezing conditions while critically saturated. Fig. 7 also is pertinent in this regard.

b. Results of accelerated freezing and thawing tests in the laboratory must be viewed with caution if they are to provide dependable prediction of durability of aggregate to weathering exposure inasmuch as the test conditions are not likely to replicate those of the natural exposure at the installation.

(1) A paper on this subject by G. J. Verbeck and R. Landgren, "Influence of Physical Characteristics of Aggregates on Frost Resistance of Concrete," Proceedings, American Society for Testing and Materials, Vol. 60, 1960, pp. 1063-1079, provides helpful data on general principles that are applicable to frost resistance of aggregates not necessarily enclosed in concrete.

DESCRIPTION OF THE SAMPLES

Shear Aggregate

The sample designated as "Shear" consisted of ten (10) pieces of rock. The net weight of the sample was 24.3 lb. The maximum dimension of the largest piece was 6-1/4 in.

The pieces are similar in lithology. The rock type is a hard, compact, very fine-grained, dense, olivine basalt. Characteristics of the individual pieces are noted in Table 1, with regard to the presence of natural exterior surfaces, internal joints within the piece, and joints that are external surfaces of the piece and thus have influenced or determined the dimensions of the particles. Also shown in the right-hand column is a notation of the presence or absence of white deposits in the pieces, these being naturally occurring cracks that contain mineral deposits that include the zeolite mineral, analcite, with or without calcite, nontronite, or chlorite, or combinations of these minerals.

The rock is composed mainly of randomly oriented or sheaf-like arrangements of long, thin, lath-like crystals of plagioclase, stumpy prisms of pale brown augite, and scattered, subhedral phenocrysts of olivine that are typically 1 to 5 mm. in maximum dimension. The laths of plagioclase partly enclose and partly penetrate crystals of augite in a subophitic texture. The matrix of the rock is composed of microlites of plagioclase, augite, and olivine as well as an abundance of finely granular magnetite.

The olivine is altered as a result of hydrothermal activity and weathering variously to iddingsite, antigorite, chlorite, and nontronite. The secondary minerals occur at the perimeter of the crystals and invade the crystals along internal cracks. Some crystals are totally destroyed. The sites of olivine phenocrysts exposed at weathered surfaces of the pieces are demarked by irregularly shaped pits from which the altered crystal has been partly or entirely removed by chemical and physical processes of weathering.

The augite mainly is free from appreciable alteration, as is the plagioclase. The plagioclase is a highly calcic type, intermediate between labradorite and bytownite.

Natural siliceous glass was present in the original rock in minimal amounts interstitially at points of contact and surfaces of contact among the crystalline constituents. A portion of the glass was altered by hydrothermal processes to the smectite clay mineral, nontronite.

Pepperling Good Aggregate

The sample designated as "Pepperling Good" consisted of ten (10) pieces of rock. The net weight of the sample was 20.4 lb. The maximum dimension of the largest piece was 5 in.

The pieces are similar in lithology. The rock is a very hard, tough, compact, very fine-grained, dense, olivine basalt. Characteristics of the individual pieces are noted in Table 1.

The rock is composed of phenocrysts of incipiently altered olivine, smaller stumpy prisms of pale brown augite, and short laths of plagioclase that are embedded in a matrix of finely granular magnetite and meager amounts of partly altered volcanic glass. The texture of the rock is hyalopilitic.

The olivine is altered at the perimeter of the crystals and along internal microcracks to green antigorite and brown iddingsite. Sparsely distributed, small patches of brownish green nontronite may represent completely decomposed crystals of olivine. The augite and plagioclase are not altered appreciably. The composition of the plagioclase is intermediate between labradorite and bytownite.

The interstitial glass includes small patches that are composed of nontronite. Such occurrences are small and sparse, and are not significant with respect to the structural quality of the rock.

A veinlet observed in the thin section contains analcite, calcite, and nontronite.

Pepperling Moderate Aggregate

The sample designated as "Pepperling Moderate" consisted of ten (10) pieces of rock. The net weight of the sample was 13.2 lb. The maximum dimension of the largest piece was 5-1/2 in.

The pieces are similar in lithology. The rock is a moderately hard, compact to somewhat vesicular, very fine-grained, olivine basalt. The characteristics of the individual pieces are shown in Table 1.

The rock is an altered olivine basalt having a hyalopilitic texture. Rare, large phenocrysts of olivine are altered to iddingsite at the perimeter and to green antigosite along internal microcracks and also to a greenish brown, clay-like material that occurs as irregularly shaped masses within the crystals of olivine and protruding outward into the adjacent groundmass. Such phenocrysts are the origin of microcracks that radiate outward into the matrix.

The matrix of the rock is composed of crystals of olivine, augite, and altered plagioclase and includes a groundmass of finely granular to dust-like magnetite and what was originally glass but is now in large part composed of a pale greenish brown nontronite. The plagioclase crystals are albitized as a result of deuteric and hydrothermal processes during geologic time with the result that the original highly calcic plagioclase has been changed <u>in situ</u> to albite-oligoclase.

Irregularly shaped, small vesicles are present in portions of the rock. The vesicles are lined by green celadonite or lined and partly or entirely filled by brownish green nontronite.

Eight of the ten particles constituting the sample include natural fractures that contain deposits composed of varying proportions of analcite, calcite, nontronite, and chlorite.

RICHARD C. MIELENZ, P. E., INC.

Richard C. Mielenz

Richard C. Mielenz, Ph. D., P. E.
President

January 8, 1996

7483 Brigham Road
Gates Mills, Ohio 44040-9706

TABLE 1 --- VISUAL EXAMINATION OF COVER/PROTECTION AGGREGATE
Uranium Tailings Facility
Colorado State University
Fort Collins, Colorado

Aggregate Piece	Number of Natural Exterior Surfaces	Internal Joints	Joints That Are External Surfaces of Piece	Presence of White Deposits
Shear Source				
1	6	1	3	Yes
2	5	0	4	No
3	1	0	2	No
4	3	0	3	No
5	4	0	2	No
6	4	2	2	No
7	3	1	3	No
8	1	1	3	No
9	4	1	3	No
10	2	1	3	Yes
Pepperling Good				
1	2	1	1	No
2	6	1	4	No
3	4	1	3	Yes
4	5	1	4	No
5	3	1	3	No
6	2	1	2	No
7	4	0	3	No
8	2	1	2	No
9	1	0	3	No
10	2	2	2	No
Pepperling Moderate				
1	6	1	2	No
2	1	2	3	Yes
3	3	3	4	No
4	2	4	4	Yes
5	4	2	3	Yes
6	1	3	4	Yes
7	1	4	6	Yes
8	6	5	5	Yes
9	4	2	6	Yes
10	1	2	3	Yes