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ANALYSIS OF DEBRIS FROM SPACELAB SPACE LIFE SCIENCES-1

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Airborne microbiological and particulate contamination generated aboard Spacelab modules is a potential safety hazard. In order to shed light on the characteristics of these contaminants, microbial and chemical/particulate analyses were performed on debris vacuumed from cabin and avionics air filters in the Space Life Sciences-1 (SLS-1) module of the Space Transportation System 40 (STS-40) mission 1 month after landing. The debris was sorted into categories (e.g., metal, nonmetal, hair/fur, synthetic fibers, food particles, insect fragments, etc.). Elemental analysis of particles was done by energy dispersive analysis of x rays (metals) and Fourier transform infrared spectroscopy (nonmetals). Scanning electron micrographs were done of most particles. Microbiological samples were grown on R2A culture medium and identified. Clothing fibers dominated the debris by volume. Other particles, all attributed to the crew, resulted from abrasions and impacts during mission operations (e.g., paint chips, plastic, electronic scraps, clothing fibers). All bacterial species identified are commonly found in the atmosphere or on the human body. *Bacillus* sp. was the most frequently seen bacterium. One of the bacterial species, *Enterobacter agglomerans*, could cause illness in crew members with depressed immune systems.

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TECHNICAL MEMORANDUM

ANALYSIS OF DEBRIS FROM SPACELAB SPACE LIFE SCIENCES-1

I. INTRODUCTION

Airborne particulate contamination generated aboard the Spacelab life sciences module is a potential safety hazard for crews. Both microbiological and inanimate particles are of concern. Microbial contamination can lead to infection and disease; abiotic particles within a certain size range can enter respiratory passageways and impede breathing. The presence of abiotic particles can also indicate degradation of materials.

A specific concern is microbial contamination of the orbiter and lab modules arising from animal housing. Photographs of filter debris from previous missions show evidence of particles assumed to be animal feces, hair, bedding, and food. One photograph included a piece of a large cockroach. Although micro-organisms associated with these particles may have included human pathogens, neither particulate nor microbial analyses were performed.

Two sample collections were taken from the Space Transportation System 40 (STS-40) mission. Marshall Space Flight Center (MSFC) Structures and Dynamics Laboratory personnel first gained access to the STS-40 shuttle on June 16, 1991, within 48 hours of its landing at Edwards Air Force Base. They collected debris from cabin and avionics filters on the Space Life Sciences-1 (SLS-1) module for microbiological and particulate/chemical analysis.

This report discusses a second collection that was taken a month later. On July 16, a week after STS-40 returned to Kennedy Space Center (KSC), MSFC Materials and Processes Laboratory personnel obtained particles from the air filters, the debris that had fallen into troughs below the filters during the landing, and swab samples of the module wall and filter frames.

II. METHODS

A. Collection

1. KSC. KSC personnel vacuumed debris from the two cabin filters, one avionics filter, and the troughs below. This debris was placed in two plastic receptacles, one for each filter type (fig. 1).

MSFC representatives used sterile cotton-tipped applicators to swab the frames of the cabin filters, the avionics filter, and a seal on the cabin wall. The swab samples were placed in sterile peptone water.

2. MSFC. Upon arrival at MSFC, debris was shaken out of each receptacle and placed in two sterile plastic bags (figs. 2*a* and 2*b*). Total debris weight was recorded for each type of filter.

The debris was sorted visually and aseptically into categories such as fibers, metallic particles, and nonmetallic materials; weighed; and placed in sterile test tubes. Each sample was suspended in 4 mL sterile water, sonicated 15 minutes, and allowed to settle for 1 minute. The liquid layer was removed,

placed in a sterile tube containing 3-percent brain heart infusion broth, and incubated at 28 °C for 1 week. Debris that remained in the tubes was resuspended in 10 to 15 mL sterile water and filtered across 0.45 μm cellulose acetate membranes. These membranes were placed in plastic holders and dried at 35 °C, in preparation for chemical analysis.

Swab samples were incubated at 28 °C for 1 week.

B. Microbiological Analysis

One week later, 20 μL of each broth solution and the swab samples were plated on R2A agar, using the spread plate technique. The plates were incubated at 28 °C and observed daily. All colony and culture types were described and identified, where possible. The Biolog and Minitek identification systems were used for bacteria. Fungal classification was based on cellular and colonial morphological observations, using dissecting and compound microscopes.

C. Chemical Analysis

1. Debris Sorting. Initially, the debris was grouped into 13 samples for microbiological analysis. Individual particles were then sorted out, using microtweezers and a stereomicroscope at × 8 to × 64 magnification. Whenever practical, each visually identifiable particle was segregated and placed in a clean 47-mm Millipore filter holder.

Most particles were interspersed in a fiber mass that came from the astronauts' clothing. Each particle was removed, placed in a holder, and photographed at approximately × 3 magnification. Selected fibers were analyzed, since separating the entire mass was not practical.

2. Particulate Analysis. Chemical analysis was performed on 75 particles. Metallic particles were qualitatively analyzed, using a Cambridge Stereoscan 250 Mk2 scanning microscope (SEM) and energy dispersive analysis of x rays (EDAX). SEM photos were taken at × 10 to × 50, depending on the size of the particle.

Nonmetallic particles comprised most of the debris. They were analyzed, whenever possible, using a Perkin-Elmer 1800 Fourier transform infrared (FTIR) spectrophotometer after being mounted on a Spectra-Tech microscope attachment.

III. RESULTS

A. Microbiological Results

Figures 2*a* and 2*b* show debris from the cabin and avionics filters. It was visually sorted by material type. Nine cabin and four avionics samples resulted (figs. 3*a*, 3*b*, and 4), containing items such as peanut pieces and earplugs, abundant fibers including synthetics and hair, chips and flecks of metallic and nonmetallic materials, and a common flea from the Pulicidae family (fig. 5).

More than four times as much debris (with greater diversity of materials) was recovered from the cabin filters as from the avionics filter. The cabin filter debris weighed a total of 1.47 grams, and the

sorted materials weighed a total of 1.41 grams, representing a 96-percent recovery efficiency. The avionics filter debris weighed a total of 0.37 grams, and the sorted materials weighed a total of 0.42 grams. This increase was attributed to resuspension of sample 13 in sterile water to allow removal of minute particles from the plastic bag prior to placement in the test tube (table 1).

1. Cabin. Bacteria were isolated from seven samples of cabin filter debris (table 2). Three of these samples, the peanuts, the plastic plug, and the elliptical plastic (samples 5 to 7), contained more than one bacterial genus. No bacteria were found on the earplug or the sample of large debris that remained after sorting.

The cabin bacteria identified were primarily those commonly found in the air or on the body. The most frequently isolated bacterium was *Bacillus* sp., a spore-forming organism widely distributed in nature. This organism was found in four of the nine cabin debris samples. Three bacterial colonies could not be classified by the identification methods used. Four Deuteromycetes and two Ascomycetes fungal species were isolated from six cabin debris samples.

2. Avionics. *Bacillus* sp. appeared in all four avionics samples. Only sample 11, the nonmetallic particles, gave rise to a second bacterial type, *Pseudomonas paucimobilis*. No fungi were isolated (table 2).

3. Swabs. Bacteria were found on only the sample from the seal on the wall of the cabin module; one species, *Staphylococcus capitis*, was isolated. This organism was not found in any of the filter debris samples. Deuteromycetes fungi were found in all samples; a Zygomycetes, not found in any of the debris samples, was isolated from the swab of a cabin filter frame (table 2).

B. Chemical Results

Cabin filter debris was separated into 49 particles and avionics filter debris into 26 particles. A list of particles with their sample codes is given in the appendix. Figures 6 through 76 show particles selected for analysis. Each particle's visual description, filter source, and FTIR or EDAX identification are given in tables 3 through 5. The identification of each material (shown in parentheses) is speculative, based on FTIR or EDAX composition and a general knowledge of the hardware and materials used in NASA spacecraft.

Metallic particles were found in five samples from the cabin filters and two from the avionics filter. Most were aluminum, iron, chromium, and nickel, with traces of molybdenum and silicon (table 5). SEM views were taken (figs. 77 through 85) of all but sample A-14, which included a collection of metallic flecks not individually observed by SEM (fig. 76). X-ray spectra were made of all metallic particles (figs. 86 through 105).

The chemical structure of 68 nonmetallic particles from the filters was analyzed by FTIR, except for two bits of black plastic. In the cabin filter debris, 20 out of 43 particulate samples were identified positively. The chemical structure of some remaining samples led to speculation about their sources (table 3, in parentheses). Many organic compounds were found in nonmetallic particles from the avionics filter (table 4).

IV. DISCUSSION

Debris was collected from SLS-1 cabin and avionics filters on June 16, shortly after shuttle landing. Another collection was made on July 16, which was expected to confirm the earlier results, yield information about the persistence of micro-organisms in space modules on Earth, and perhaps contribute biological or chemical/physical data not gained from the first sample.

Large volumes of debris were not anticipated, but a great diversity of material types was collected. The cabin filters contained a larger volume of debris and consisted of greater diversity of materials than the avionics filter, which was not surprising. The cabin contained two filters, and human activity there might be expected to generate more particles.

A. Discussion of Microbiological Analysis

All bacterial genera found (except *Methylobacter* sp. and *Moraxella* sp.) have been isolated from air, surfaces, and/or crew members during previous shuttle missions. However, little is known about events that intervened between shuttle landing and the July 16 debris collection, making effective data comparison impossible. Changes in microbial populations and communities may have occurred, and postflight contaminants could have included many organisms.

Since debris was collected in bulk from each filter, correlation of microbial type with specific debris materials was difficult and microbial cross-contamination possible. These conditions may explain why *Bacillus* sp. was isolated from all sorted samples which contained any bacteria, although it was the only bacterium that occurred in more than one sample. Other isolated species were unique to their samples, suggesting that they may have originated there. The peanut pieces in sample 5 contained three different bacterial species that were not isolated from any other sample. One is a medically significant organism (*Enterobacter agglomerans*) recovered on previous missions. It is normally found in natural waters, on produce, and in the intestinal tract of humans and other mammals.

Clothing fibers in sample 2 contained a *Methylobacter* sp., also isolated from SLS-1 humidity condensate water. The laboratory has isolated this organism from local air and water sources, including an iodinated resin used in the environmental control and life support water recovery test at MSFC. That test showed it to be resistant to currently recommended levels of iodine.

Fungi were identified only to class level. All isolates belong to the Amastigomycota division of terrestrial fungi, with three of the four classes (Zygomycetes, Ascomycetes, and Deuteromycetes) represented. Most samples contained Deuteromycetes.

The cabin filters contained a much more diverse population of organisms than the avionics filter. The significance of this difference is debatable, because the filters' history is unknown between shuttle landing and July 16. Extremely low occurrence of fungi in the avionics filter may imply that the cabin environment is more conducive to fungal growth. However, the cabin's two-filter air system may simply retain fungi more effectively. Sampling both air supplies in flight would help resolve this question and might suggest a way to reduce air system fungal contamination.

B. Discussion of Chemical Analysis

Chemical analysis was performed using SEM and FTIR equipment on approximately 75 samples. Only a qualitative analysis could be obtained, due to the particles' minute size and a limited quantity of any particular type. Specific materials and chemical compounds were frequently identified. Fragment identification was speculative in some cases, based on visual and chemical data and general knowledge of the hardware and materials used in NASA spacecraft.

Most materials found on the cabin filters were personnel-related (human hair, food, cloth fibers, polyethylene packaging material, nylon, cotton, etc.). Nonmetallic materials consisted of aromatic and aliphatic organic structures, which probably came from paint chips and scrap from electronic components and printed wiring boards. Aromatic hydrocarbons in several particles strongly suggested electronic sources, with both primary and secondary amines found in some samples (figs. 19, 20, and 40 and table 3, C-18, C-19, C-40).

Nonmetallic debris from the avionics filter primarily consisted of organic compounds. A few particle samples, such as polyethylene (figs. 57, 61, 66 and table 4, A-10, A-16, A-22) and nylon (figs. 60, 62, 70 and table 4, A-13, A-17, A-26), were common to both filters, suggesting that debris from crew quarters and electronics can cross-contaminate all areas. The remaining particles (which may be paint chips, electronic manufacturing debris, or packaging scraps) probably lodged in the hardware and floated free under zero-g conditions.

Electronic hardware debris was indicated by samples of silver wire (fig. 75 and table 5, A-8) and lead chip (fig. 76 and table 5, A-14). Many metallic chips and particles from both filters (e.g., bits of steel, cabinet or rack material, electronic wire) are assumed to be manufacturing debris that was not removed when the hardware was installed.

V. CONCLUSIONS

1. Most filter debris appeared to be clothing fibers. The proportion of each type was not determined, however, since the total particulate mass was divided among several laboratories.

2. All contaminants could be attributed to the crew, abrasions, and impacts during mission operations (e.g., paint chips, plastic, electronic scraps, clothing fibers), and debris brought aboard in equipment and hardware. Manufacturing debris indicates that hardware needs to be more thoroughly cleaned prior to installation in the spacecraft.

3. Cross-contamination apparently occurred between the cabin and avionics duct system.

4. Metallic particles formed a very small part by volume of the total debris. Most were inert, except as possible respiratory tract irritants. A small bit of lead found in the avionics filter was probably a solder scrap from an electronic assembly or connector.

5. Of the nonmetallic particles, all but one (C-49) were organic compounds.

6. All bacterial species identified are commonly found in the atmosphere or on the human body, and most were also found on previous shuttle missions. *Bacillus* sp., a spore-forming organism widely distributed in nature, was the most frequently seen bacterium.

7. One of the bacterial species (*Enterobacter agglomerans*) associated with the peanut pieces was medically significant. Thus, this species could cause illness in crew members with depressed immune systems.

8. Fungi were found in six of nine samples taken from the cabin filters; no fungi were isolated from the avionics filter.

9. Significant changes in microbial populations may have occurred between the June 16 and July 16 debris collections. The analyses should be compared for a more complete understanding of shuttle contamination problems.

Table 1. SLS-1 cabin and avionics air filter debris characterization and weight.

Sample	Debris Type	Source	Debris Weight (g)
–	Total prior to sorting	Cabin	1.47
1	Hair	Cabin	0.00
2	Fibers (i.e., lint)	Cabin	0.09
3	Earplug	Cabin	0.36
4	Black foam	Cabin	0.02
5	Peanut pieces	Cabin	0.18
6	Electronics pieces	Cabin	0.20
7	Elliptical, flat plastic	Cabin	0.01
8	Remainder of large debris	Cabin	0.65
9	Remainder of small debris including metallics	Cabin	–0.10*
–	Total prior to sorting	Avionics	0.37
10	Hair	Avionics	–0.01
11	Nonmetallics	Avionics	0.10
12	Fibers, associated hair	Avionics	0.01
13	Remainder of debris, mostly metallics	Avionics	0.32*

* To aid in recovery of small debris, samples 9 and 13 were resuspended in 4-mL sterile water and the debris pipetted out. Weight recorded is that of debris minus weight of water (3.95 g).

Table 2. Taxonomic classification of micro-organisms from SLS-1 cabin and avionics air filter debris.

Sample	Colony Types	Bacteria/Classification	Fungi/Classification
1	1	1/could not isolate	0
2	3	1/*Methylobacter* sp.	2/Deuteromycetes Deuteromycetes
3	1	0	1/Deuteromycetes
4	2	1/could not isolate	1/Ascomycetes
5	3	3/*Bacillus* sp. *Enterobacter agglomerans* *Micrococcus luteus*	0
6	4	3/*Bacillus* sp. *Staphylococcus haemolyticus* could not isolate	1/Ascomycetes
7	4	2/*Bacillus* sp. *Moraxella* sp.	2/Deuteromycetes Ascomycetes
8	1	0	1/Deuteromycetes
9	1	1/*Bacillus* sp.	0
10	1	1/*Bacillus* sp.	0
11	2	2/*Pseudomonas paucimobilis* *Bacillus* sp.	0
12	1	1/*Bacillus* sp.	0
13	1	1/*Bacillus* sp.	0
Swab Avionic Filt.	1	0	1/Deuteromycetes
Swab Cabin Filt.	2	0	2/Deuteromycetes Zygomycetes
Swab Wall	2	1/*Staphylococcus capitis*	1/Deuteromycetes

Table 3. SLS-1 cabin filter debris.

Particulate Description—Visual	Sample	Figure	Identification
Nonmetallic Particles			
Fiber Strands	C-1	6	Human hair, multitype
Fiber, White	C-2	7	Aliphatic ester/ketone (paint chips)
Fiber, Clear	C-3	8	Nylon
Fiber, Clear	C-4	9	Nylon
Fiber, Red	C-7	10	Nylon
Lint, Blue	C-9	11	Cotton
Fiber Mass, White	C-11	12	Cotton
Chip W/Adhesive	C-12	13	Cotton
Foam, Yellow	C-13	14	Silicone adhesive/tape
Foam, Gray	C-14/C-15	15, 16	Insulation
Brown Scraps	C-16	17	Food, peanut scraps
Plastic "Sleeve," Clear	C-17	18	Ear plugs, human
Plastic-Like, Clear/Amber	C-18/C-19	19, 20	Organic polymer(s)
Foam, White	C-20	21	Teflon-TFE
Fabric, Woven Appearance	C-21	22	Fabric (clothes)
Plastic Chip, Blue	C-22/C-25	23,26	Silicone compound
Plastic Chip, Translucent	C-23	24	Synthetic fiber (clothes)
Foam, Rigid	C-24	25	Insulation
Chip, Clear/Yellow	C-26	27	Electronic coating material
Misc. Scraps, White	C-27	28	Paper
Fiber, Blue	C-28	29	Fabric (clothes)
Fibers, Translucent	C-29	30	Polyethylene-low density
Chip, Green	C-30	31	Organic esters (paint)
Fiber, Blue	C-31	32	Nylon
Chip, Cream	C-32	33	Aromatic amine compound (paint chip)
Chip, Ivory	C-33	34	Aliphatic alcohol/cyclic hydroxy compound(s)
Chip, Clear	C-34	35	Aromatic hydrocarbon compound
Scrap, Fiberglass Appearance	C-35	36	(Fiberglass PWB chip-electronic)
Chips, Blue	C-36	37,38	(Paint chips)
Flakes, Orange	C-37	39	Aromatic organic ester/acid (paint)
Nonmetallic Particles			
Chip, Blue/Gray	C-40	40	Aromatic organic ester/amine
Chip, Black	C-41	41	Not analyzed by FTIR
Chip, Yellow/Green/White	C-42	42	Aromatic organic compound
Chip, Cream	C-43/C-44	43,44	Inorganic compounds (sand, dirt)
Fiber	C-46	45	Aliphatic organic polymer
Foam, Black	C-47	46	Foam insulation
Chip, Yellow/Clear	C-48	47	Aromatic organic ester (paint)
Chips, Miscellaneous	C-49	48	Inorganic/boron compound

NOTES:
1. Visual identification performed with a stereomicroscope at × 8 to × 64 magnification.
2. Chemical analyses performed by Fourier transform infrared spectroscopy.
3. Identifications in parentheses are speculative.

Table 4. SLS-1 avionics filter debris.

Particulate Description—Visual	Sample	Figure	Identification
			Nonmetallic Particles
Clear, Rubbery Chip	A-1	49	Silicon compound
Brown, Thin Flake	A-2	50	Mixed organic compounds
Reddish Rubbery Chips	A-3	51	Silicone compound
Tan Pliable Flakes	A-4	52	Organic aromatic compound (paint)
Red/Cream Chip	A-5	53	Aromatic compound (paint chip)
Yellow/White, Thin Honeycomb	A-6	54	Amide compound (tape/adhesive)
Yellow/White Opaque Chip	A-7	55	Aliphatic ester (paint chip)
Reddish/Brown W/Yellow Flake	A-9	56	Polyfouro-substituted/ester (Teflon with paint)
Translucent Mass of Fibers	A-10	57	Polyethylene-low density
Straight, White Opaque Fibers	A-11	58	Organic compounds (synthetic fabric)
Translucent, Yellow Fibrous Chip	A-12	59	Aliphatic ketone/formaldehyde (paint)
Multicolor Fibers	A-13	60	Nylon fibers
Clear, Plastic-Like Scrap	A-16	61	Polyethylene-high density
Short Multicolor Fibers	A-17	62	Nylon
Opaque, Crystalline Chips	A-18	63	Aromatic/phenolic polymer (electronic material–potting, etc.)
Green/Gray Grainy Chips	A-19	64	Silicone compound
Green/Glassy Texture Chips	A-21	65	Dially phthalate (electronic packaging material)
Red/Waxy Scrap	A-22	66	Polyethylene-high density
Gray/White Foam	A-23	67	Silicone compound
Gray, Semi-Hard Foam	A-24	68	Aromatic acid w/amine (electronic packaging, coating material, etc.)
Pink Foam/Fiberglass	A-25	69	Silicone compound w/fibers
Amber Flakes	A-26	70	Nylon

NOTES:
1. Visual identification performed with a stereomicroscope at × 8 to × 64 magnification.
2. Chemical analyses performed by Fourier transform infrared spectroscopy.
3. Identifications in parentheses are speculative.

Table 5. SLS-1 cabin and avionics filter debris.

Particulate Description Visual	Sample	Figure	Identification
		Metallic Particles	
Metallic Sliver	C-6	71	Ti, Al, Cr
Metallic Scraps	C-10	72	Al, Cr, Fe, Cu (wire braid)
Metallic Chip	C-38	73	Fe, Cr, Ni, Si (steel chip)
Metallic Chip	C-45	74	Al (cabinet or rack chip)
Metallic Scraps	C-49	48	Al, Fe (steel, aluminum chips)
Wire	A-8	75	Ag, Mo, Si (electronic wire)
Metallic Bits	A-14	76	Pb, Fe, Ni, Al (solder, steel, Al chips)

NOTES:
1. Particulate separation and visual identification performed with a stereomicroscope at × 8 to × 64 magnification.
2. Chemical analyses performed by SEM with an EDAX analytical attachment.
3. Identifications in parentheses are speculative.
4. C = cabin, A = avionics.

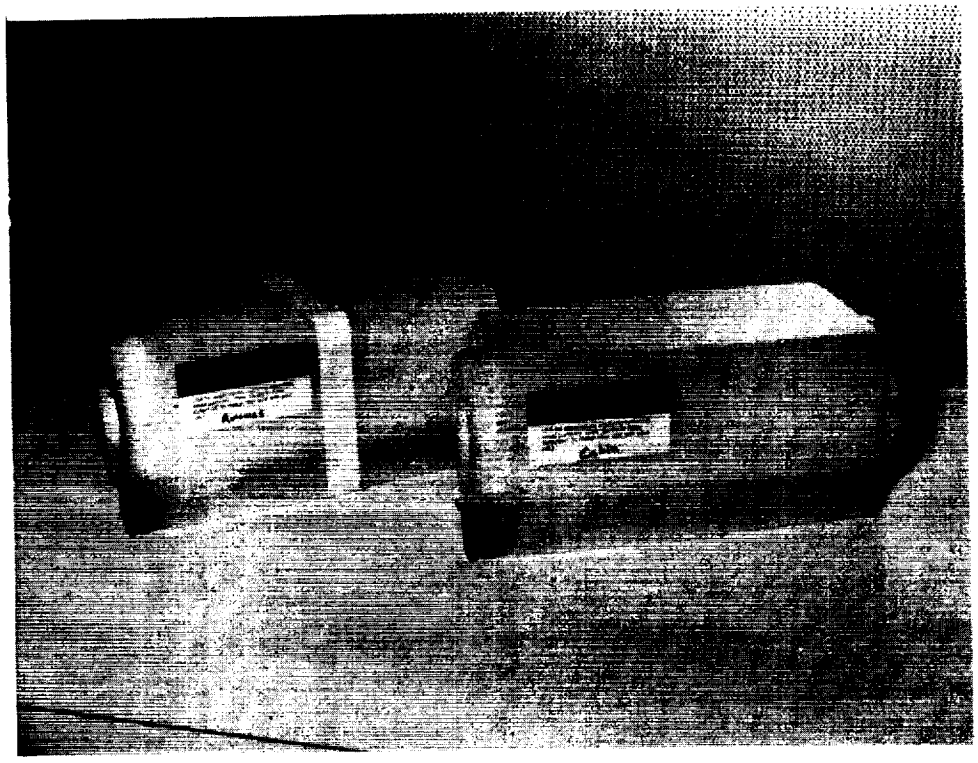

Figure 1. Vacuum receptacles used in collection of debris from cabin and avionics filters at KSC.

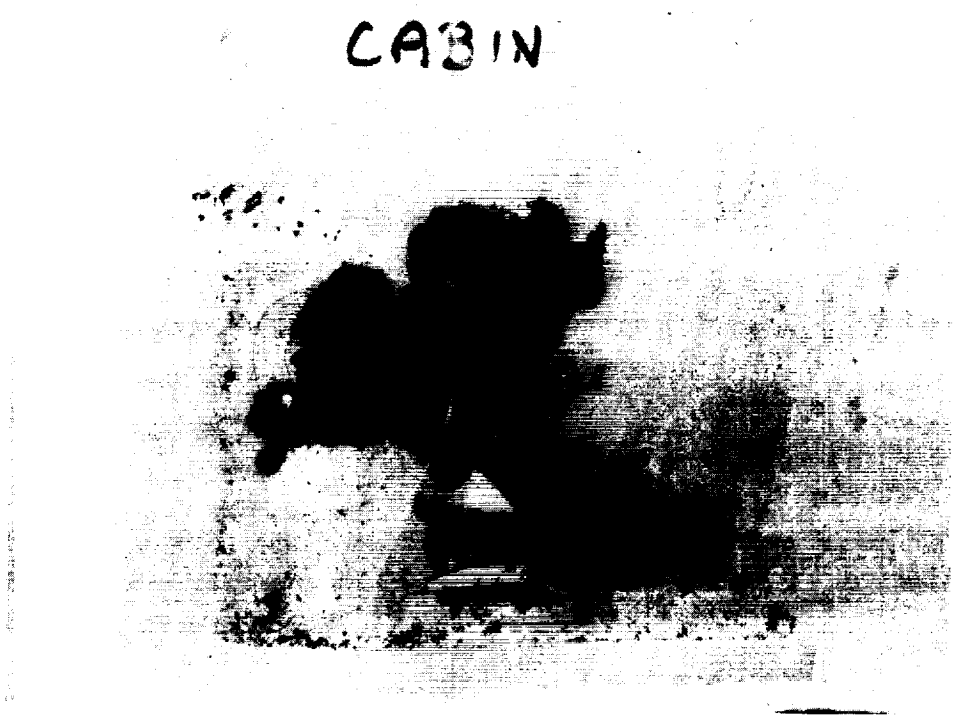

Figure 2*a*. Debris from cabin filters prior to sorting.

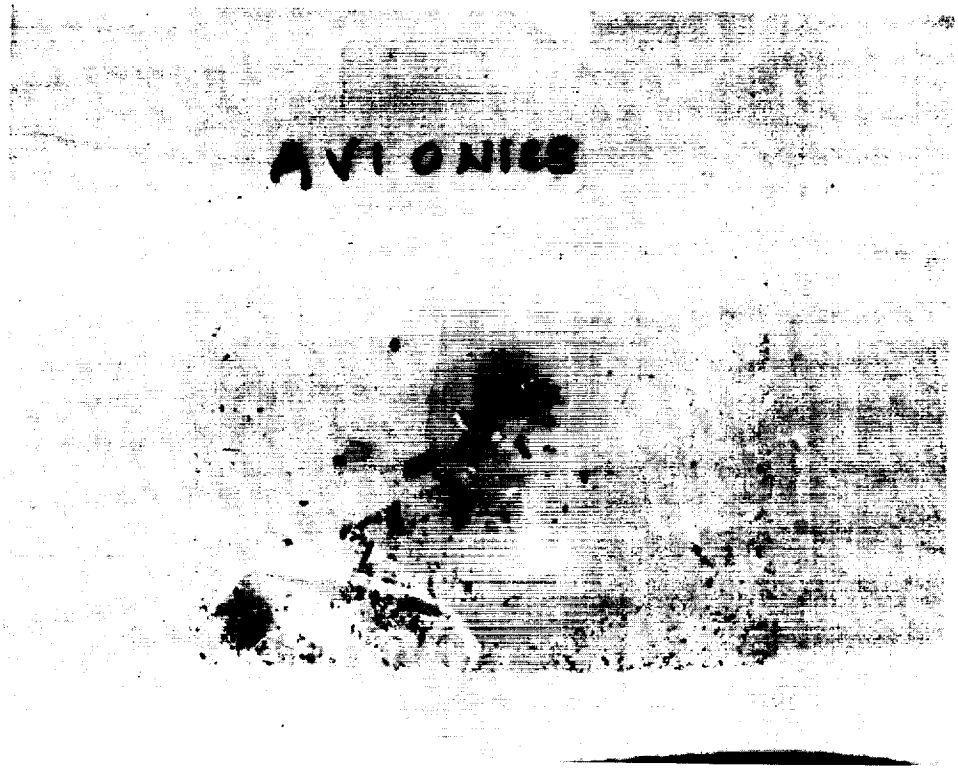

Figure 2*b*. Debris from avionics filter prior to sorting.

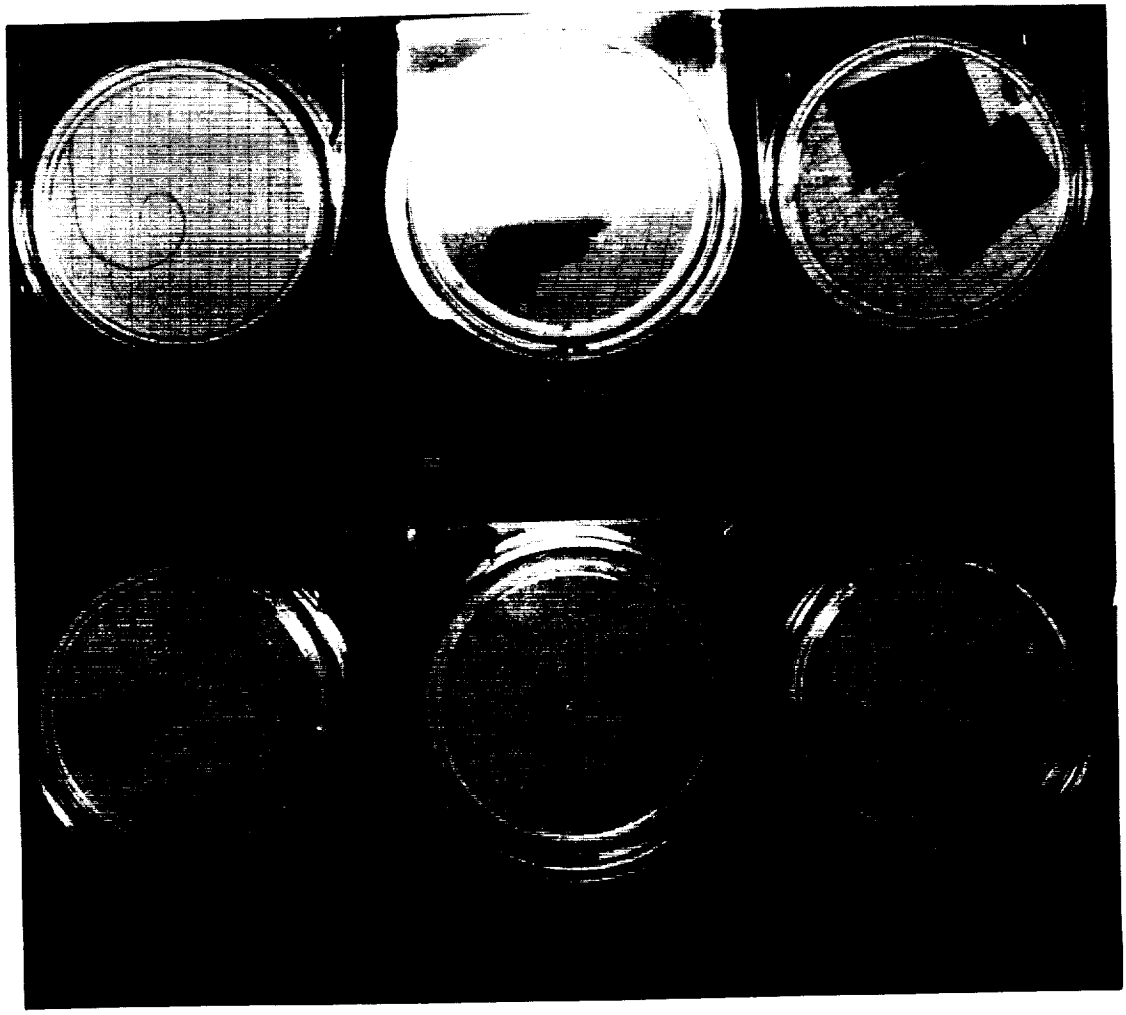

Figure 3*a*. Debris from cabin filters sorted by material type for microbiological analysis.

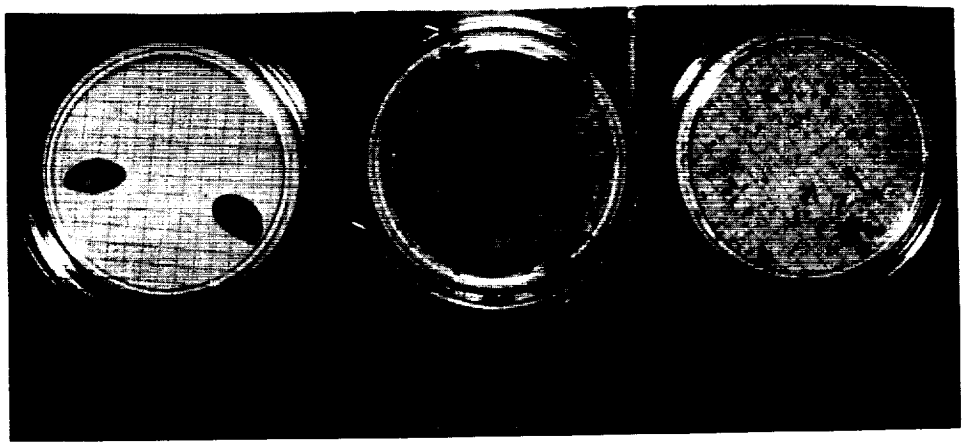

Figure 3*b*. Debris from cabin filters sorted by material type for microbiological analysis.

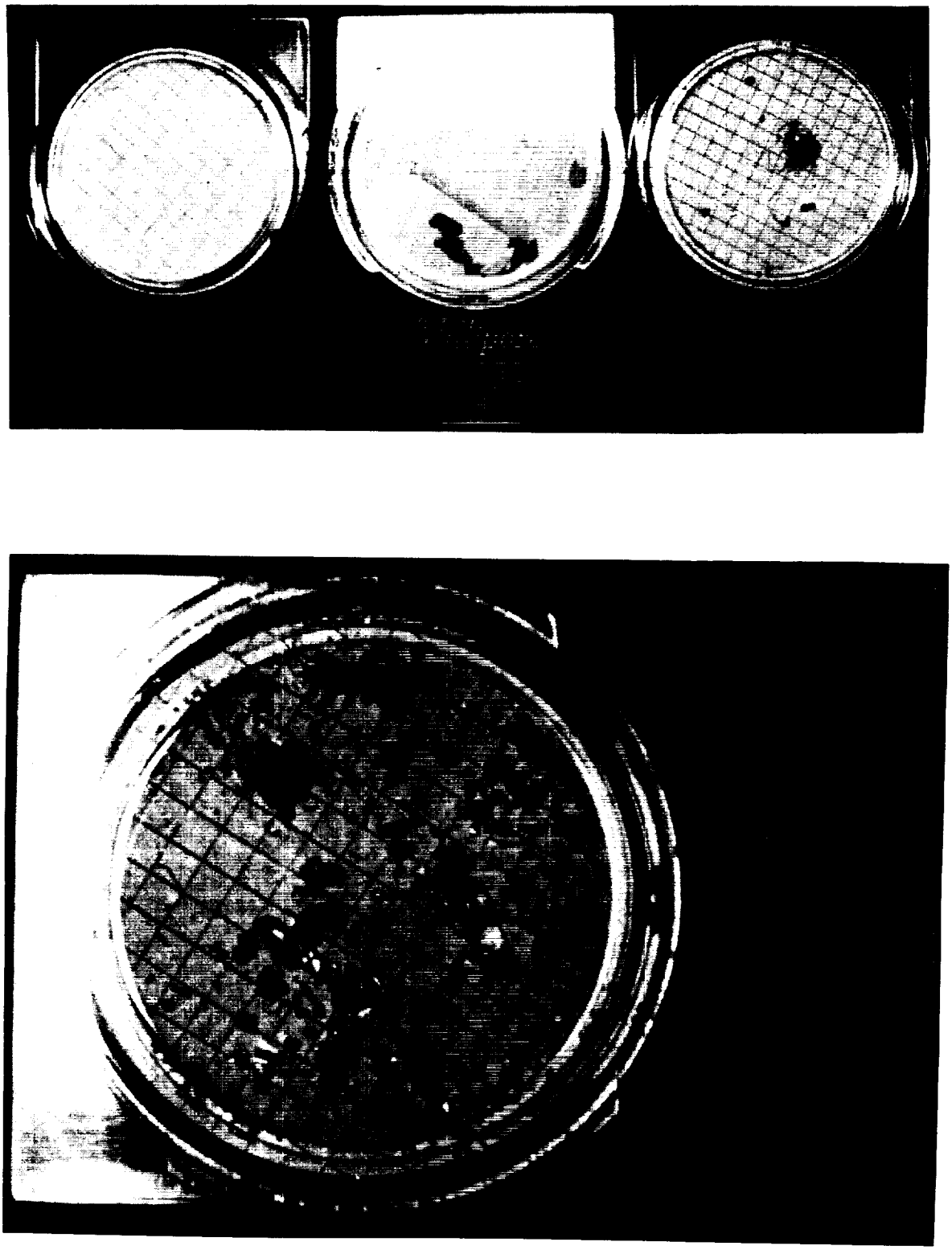

Figure 4. Debris from avionics filter sorted by material type for microbiological analysis.

Figure 5. SEM of common cat/dog flea (family pulicidae), × 80 magnification.

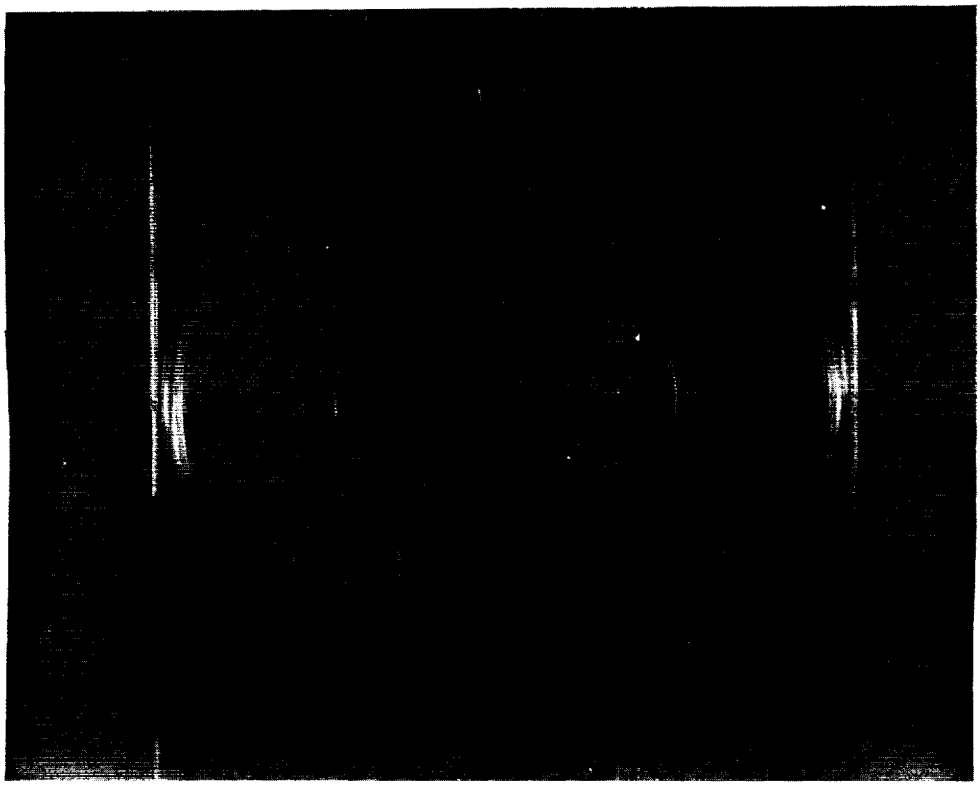

Figure 6. Sample C-1, fiber strands.

Figure 7. Sample C-2, white fiber.

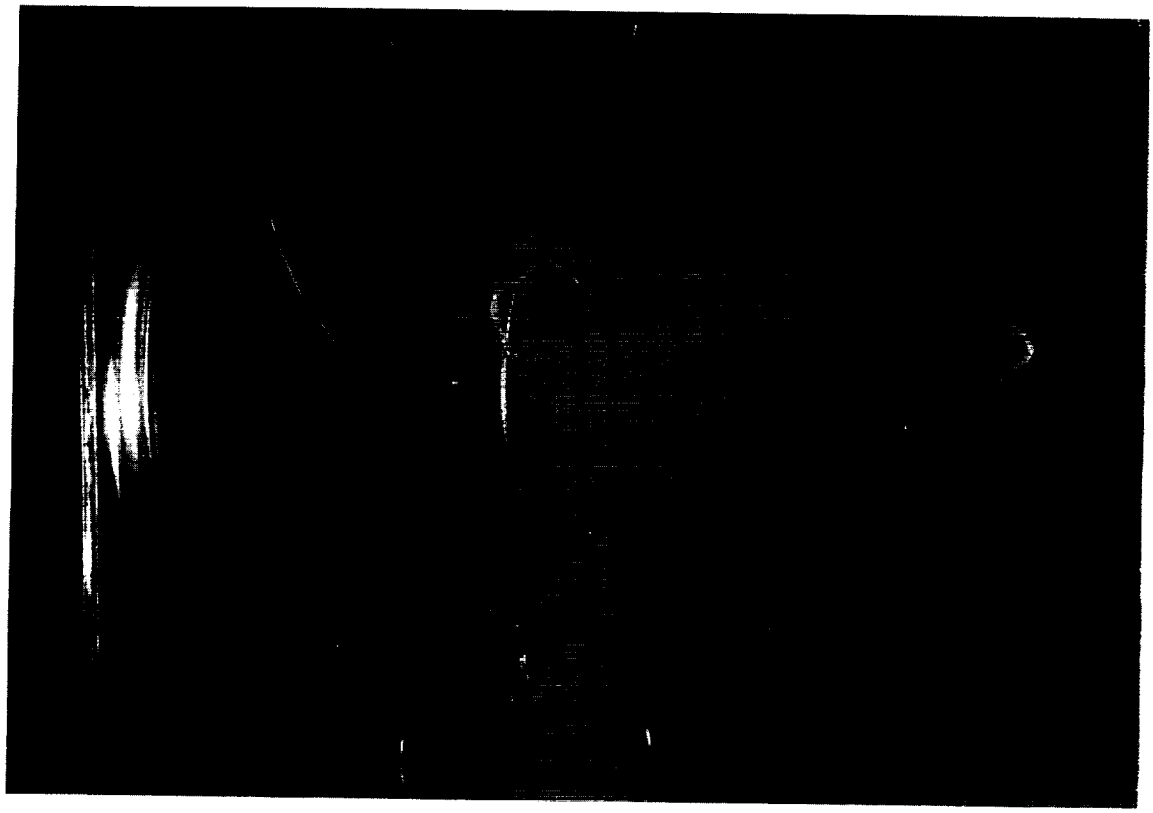

Figure 8. Sample C-3, clear fiber.

Figure 9. Sample C-4, clear fiber.

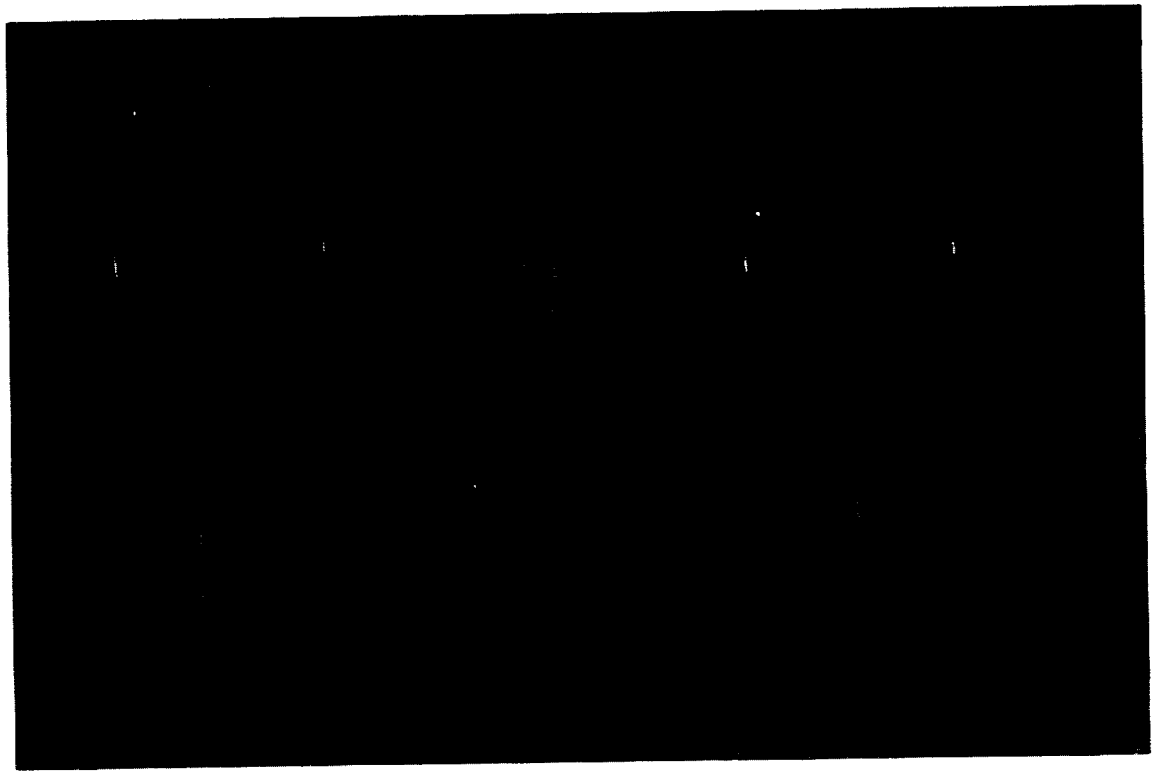

Figure 10. Sample C-7, red fiber.

Figure 11. Sample C-9, blue lint.

Figure 12. Sample C-11, white fiber mass.

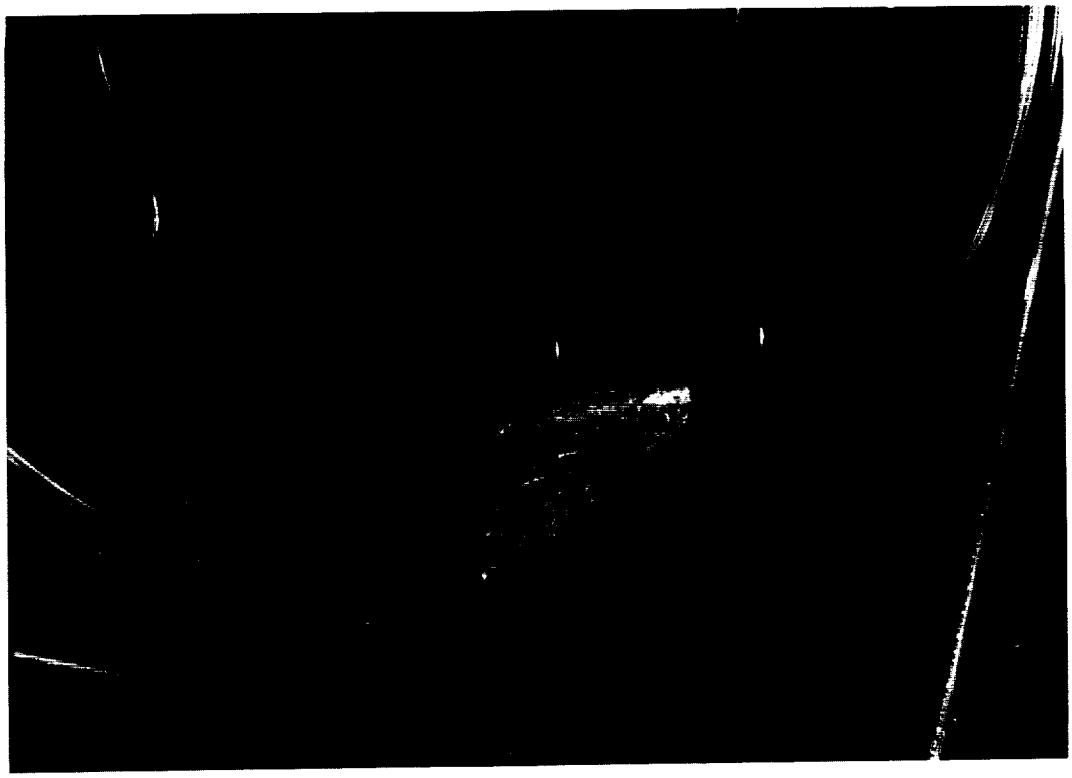

Figure 13. Sample C-12, chip with adhesive.

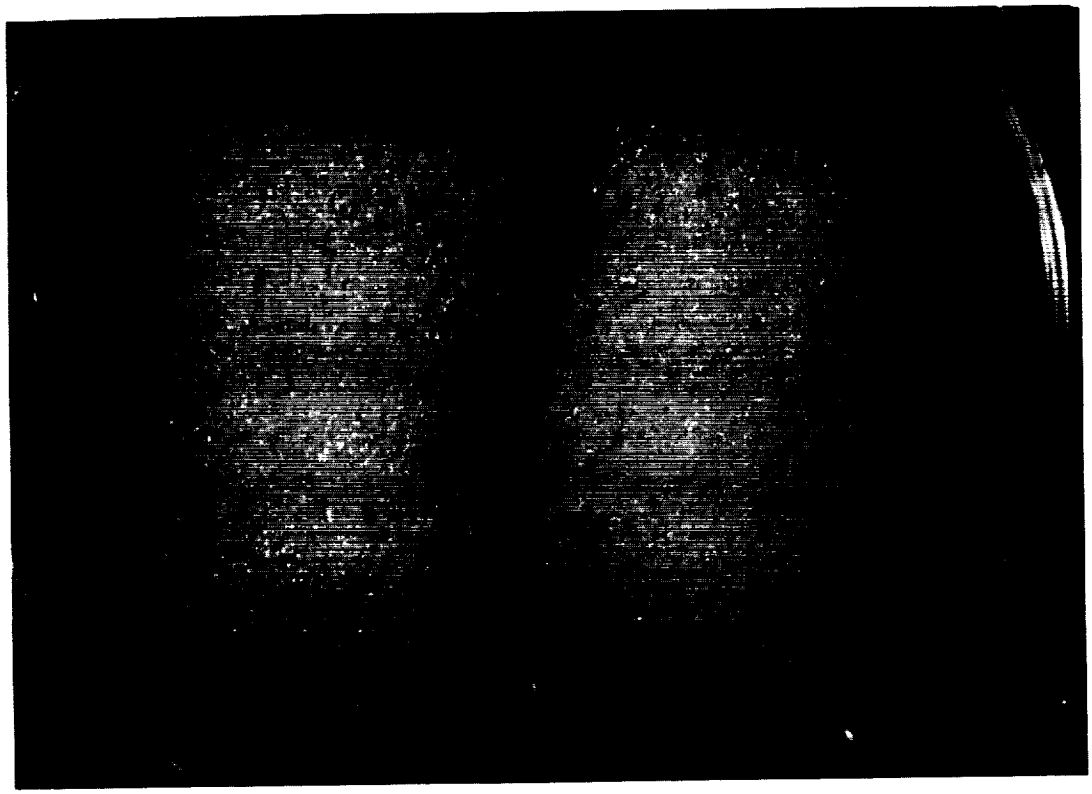

Figure 14. Sample C-13, yellow foam.

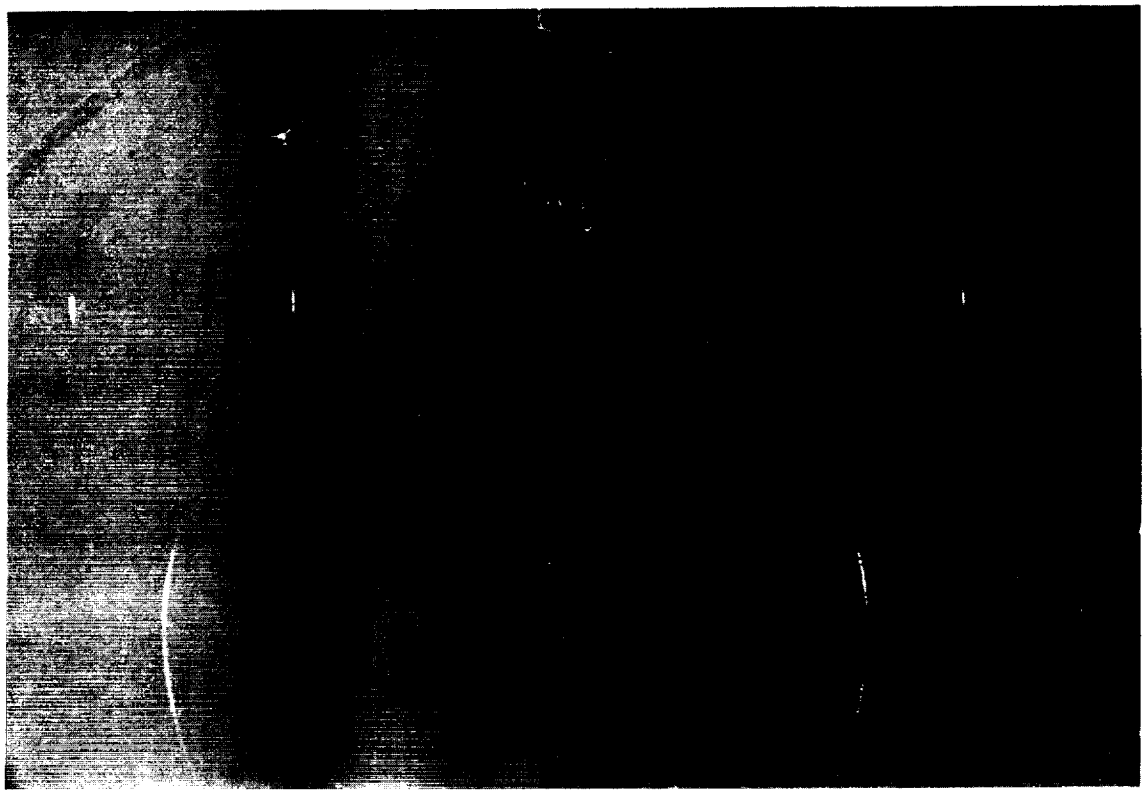

Figure 15. Sample C-14, gray foam.

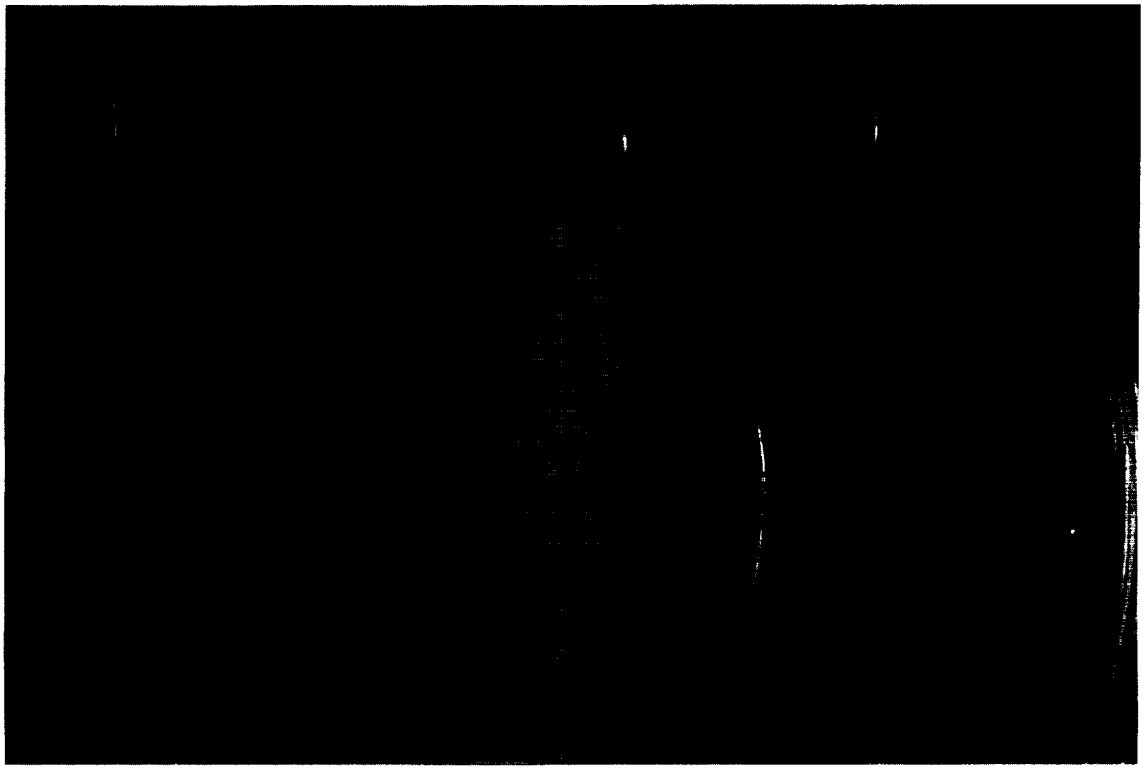

Figure 16. Sample C-15, gray foam.

Figure 17. Sample C-16, brown scraps.

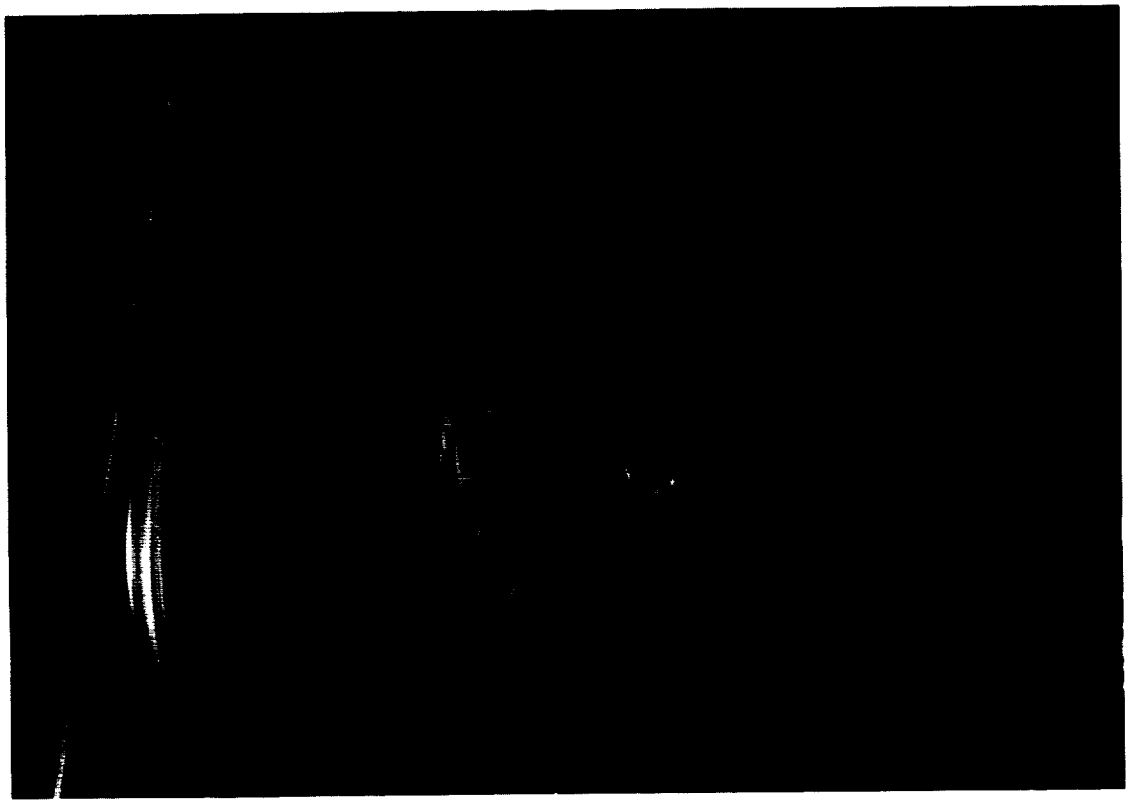

Figure 18. Sample C-17, clear plastic "sleeve."

Figure 19. Sample C-18, clear/amber, plastic-like.

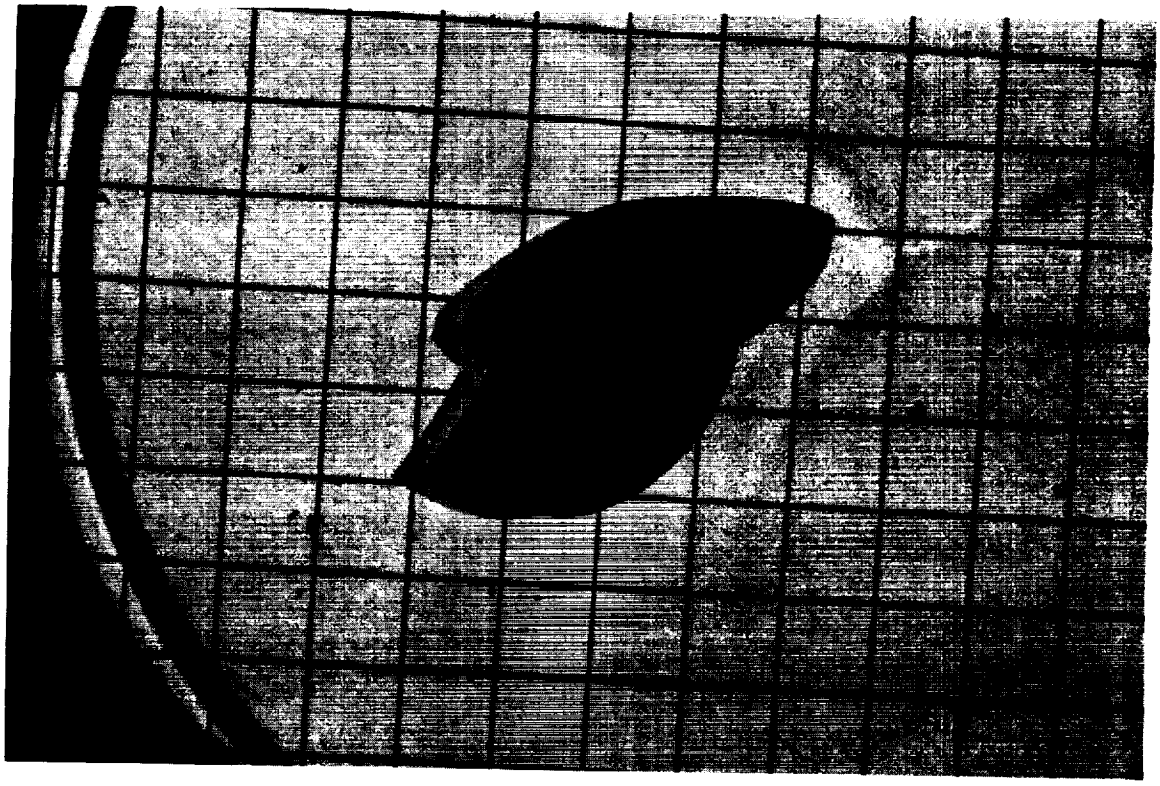

Figure 20. Sample C-19, clear/amber, plastic-like.

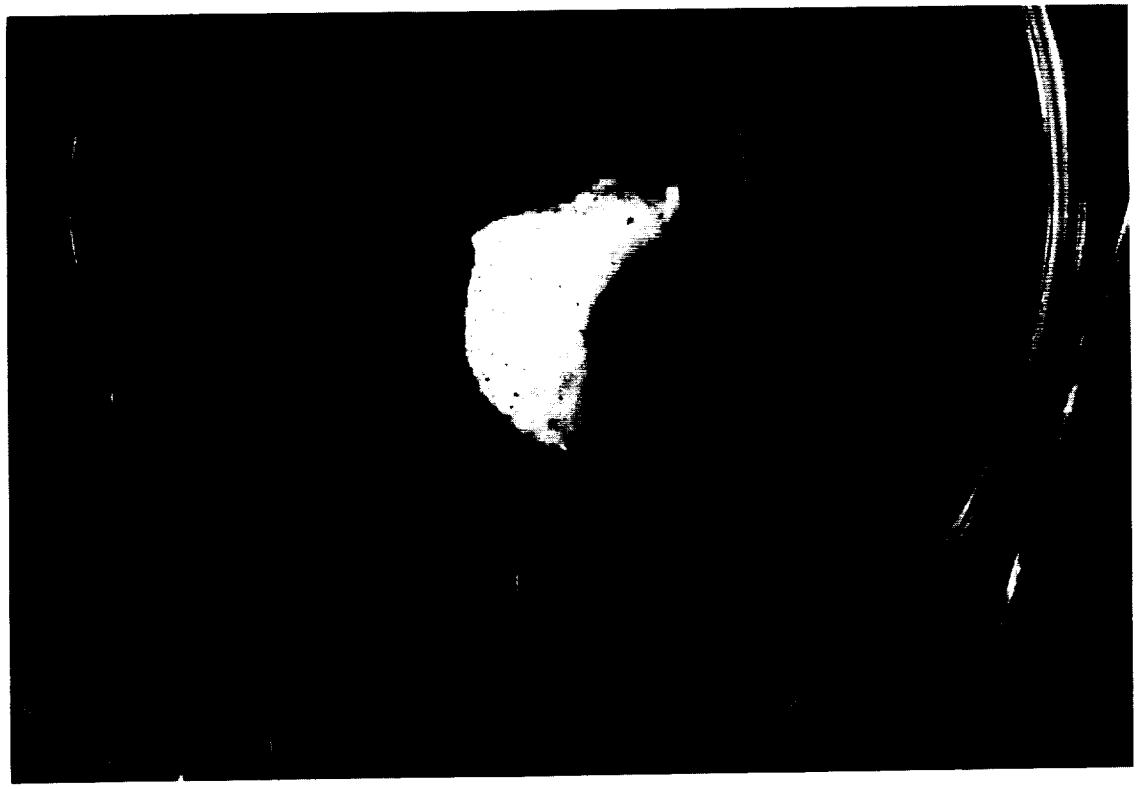

Figure 21. Sample C-20, white foam.

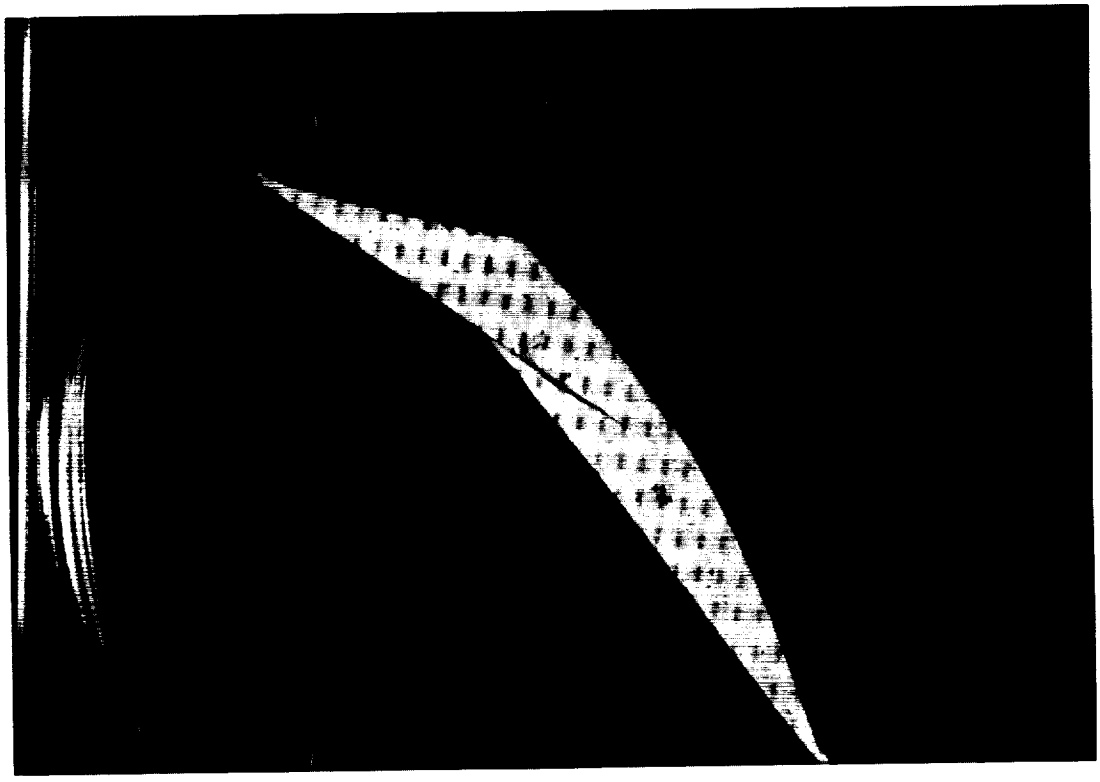

Figure 22. Sample C-21, fabric with woven appearance.

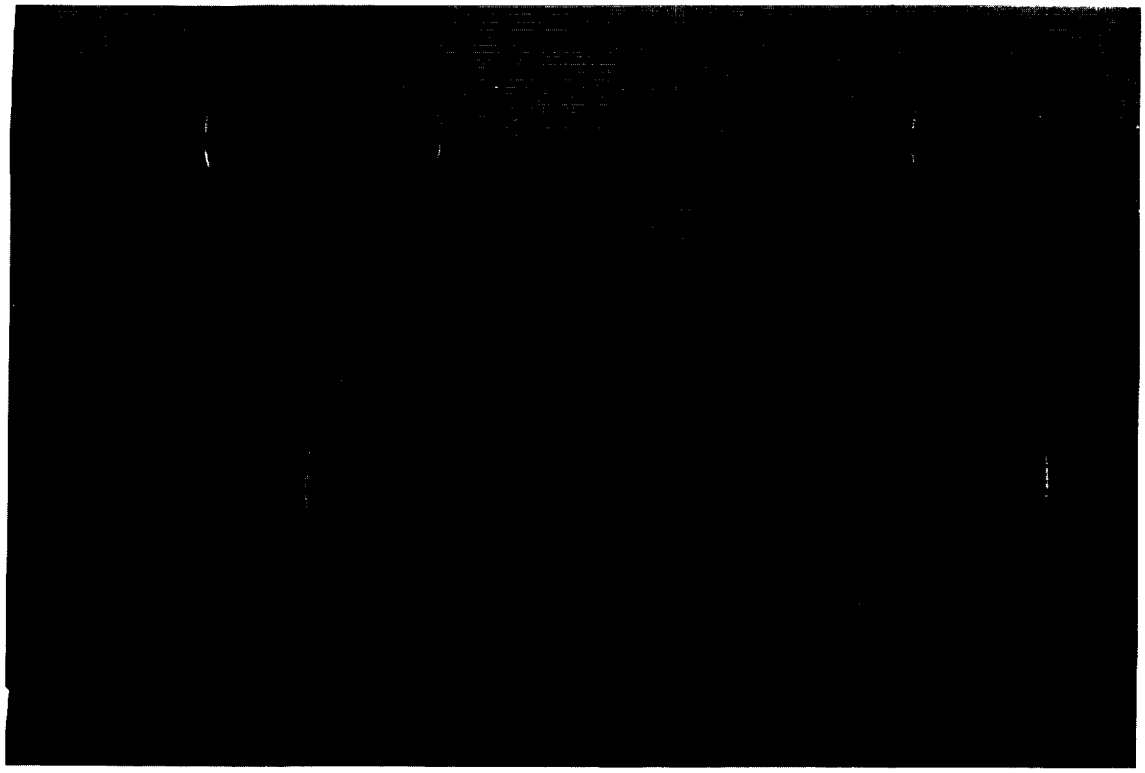

Figure 23. Sample C-22, blue plastic chip.

Figure 24. Sample C-23, translucent plastic chip.

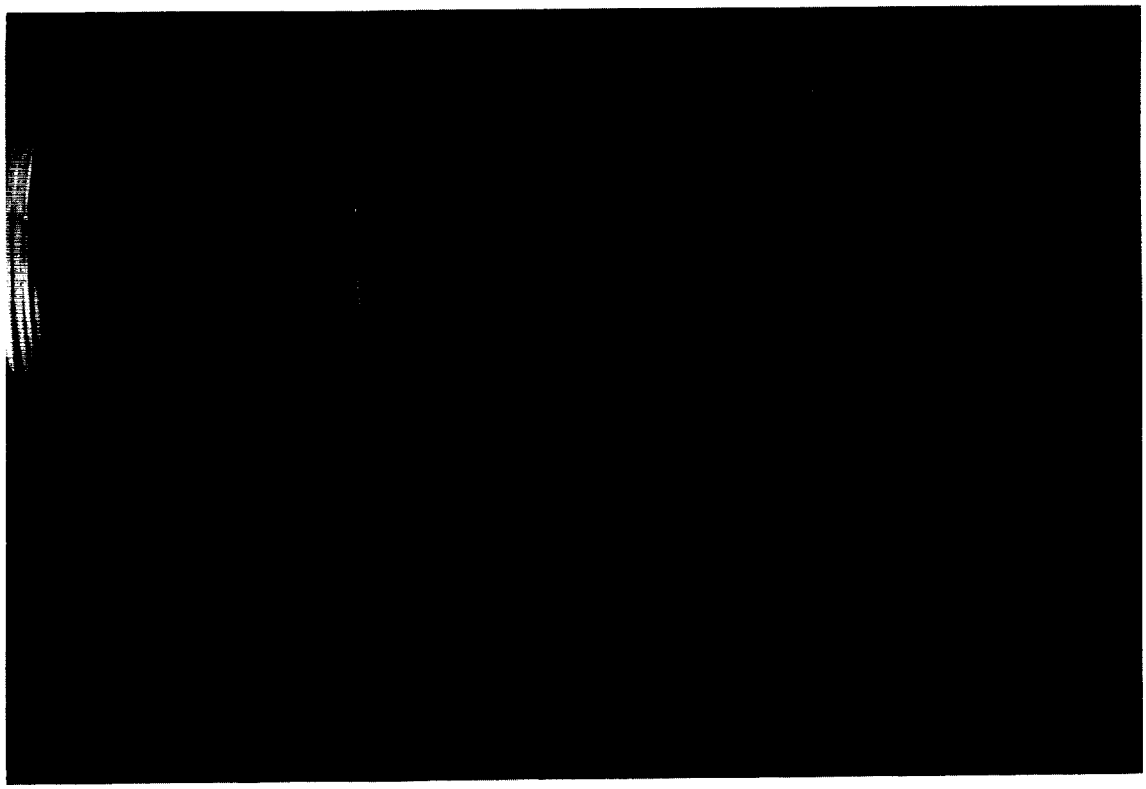

Figure 25. Sample C-24, rigid foam.

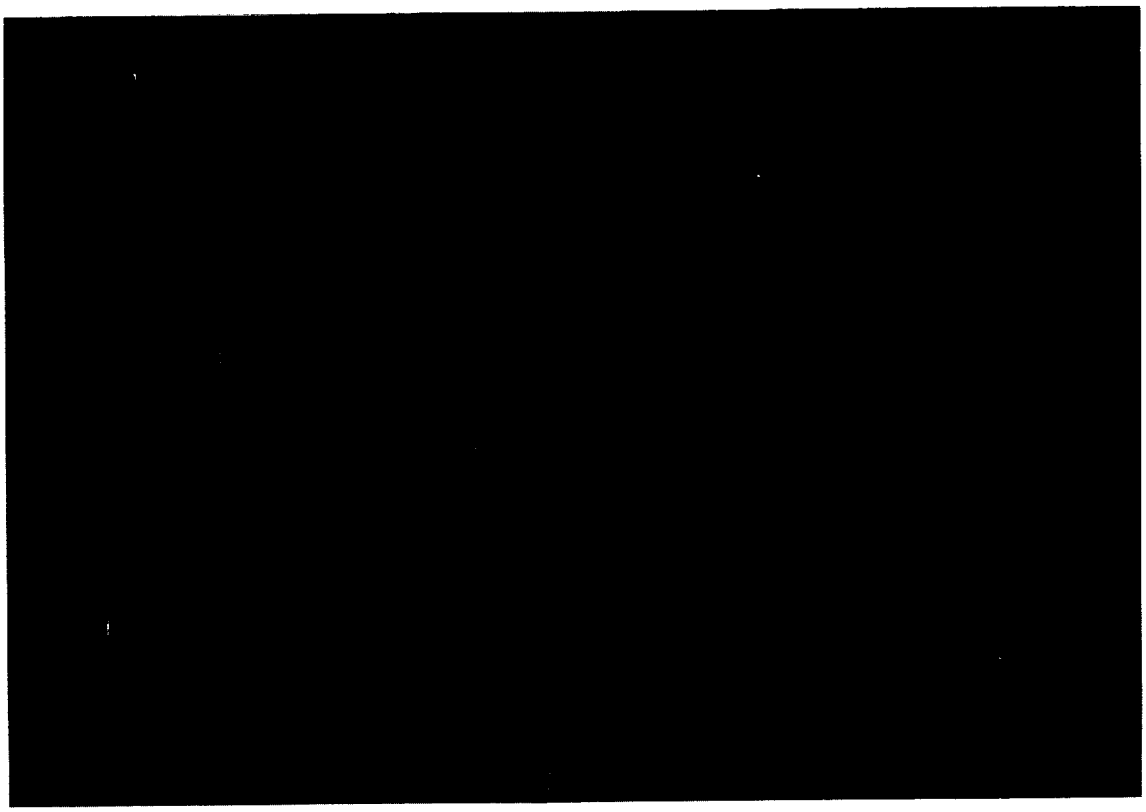

Figure 26. Sample C-25, blue plastic chip.

Figure 27. Sample C-26, clear yellow chip.

Figure 28. Sample C-27, miscellaneous white scraps.

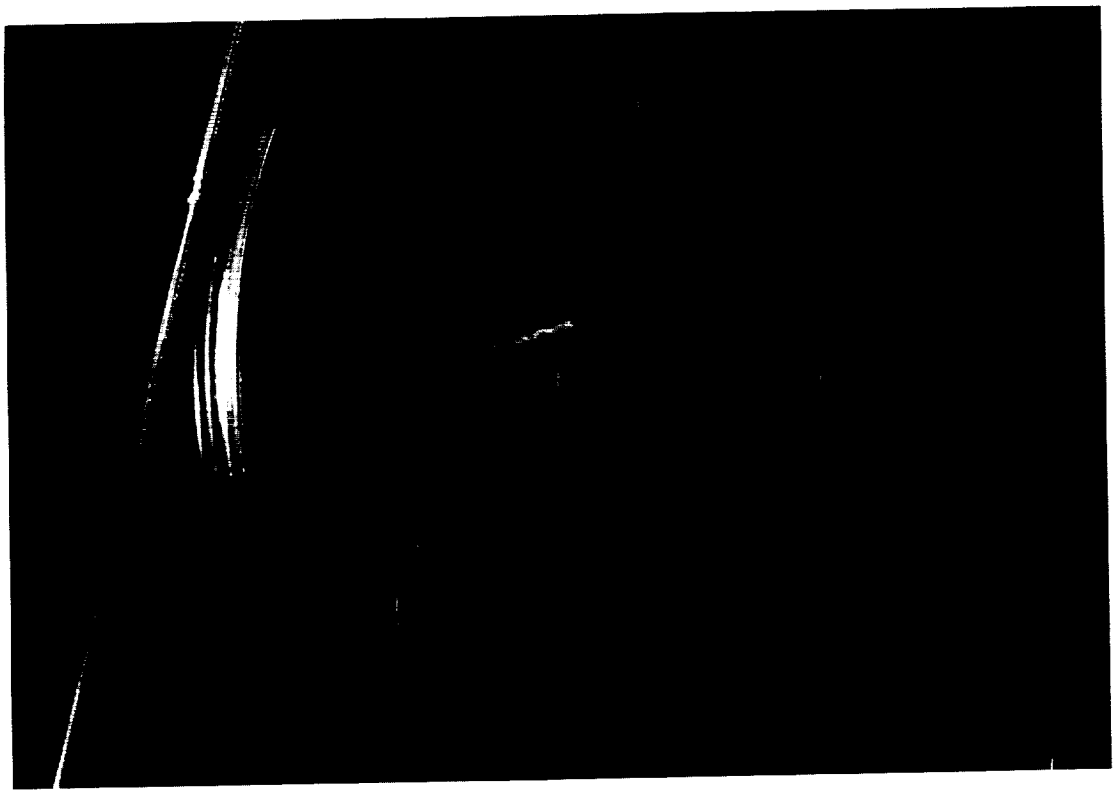

Figure 29. Sample C-28, blue fiber.

Figure 30. Sample C-29, translucent fibers.

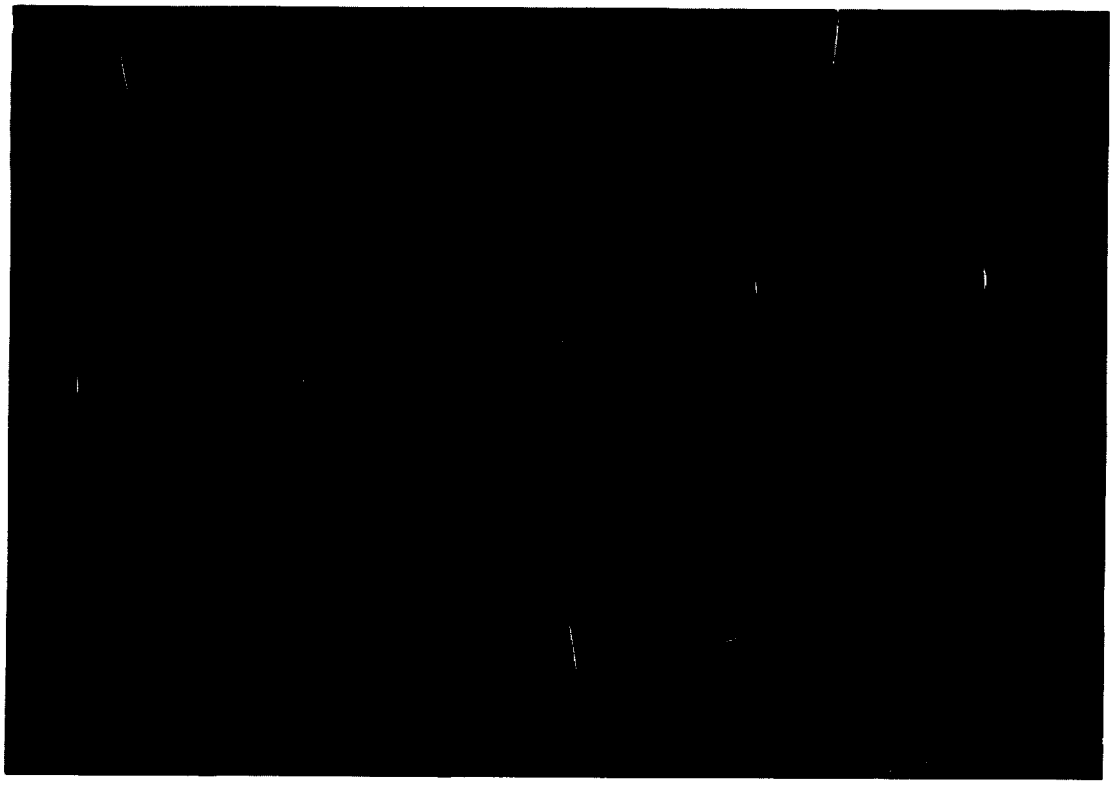

Figure 31. Sample C-30, green chip.

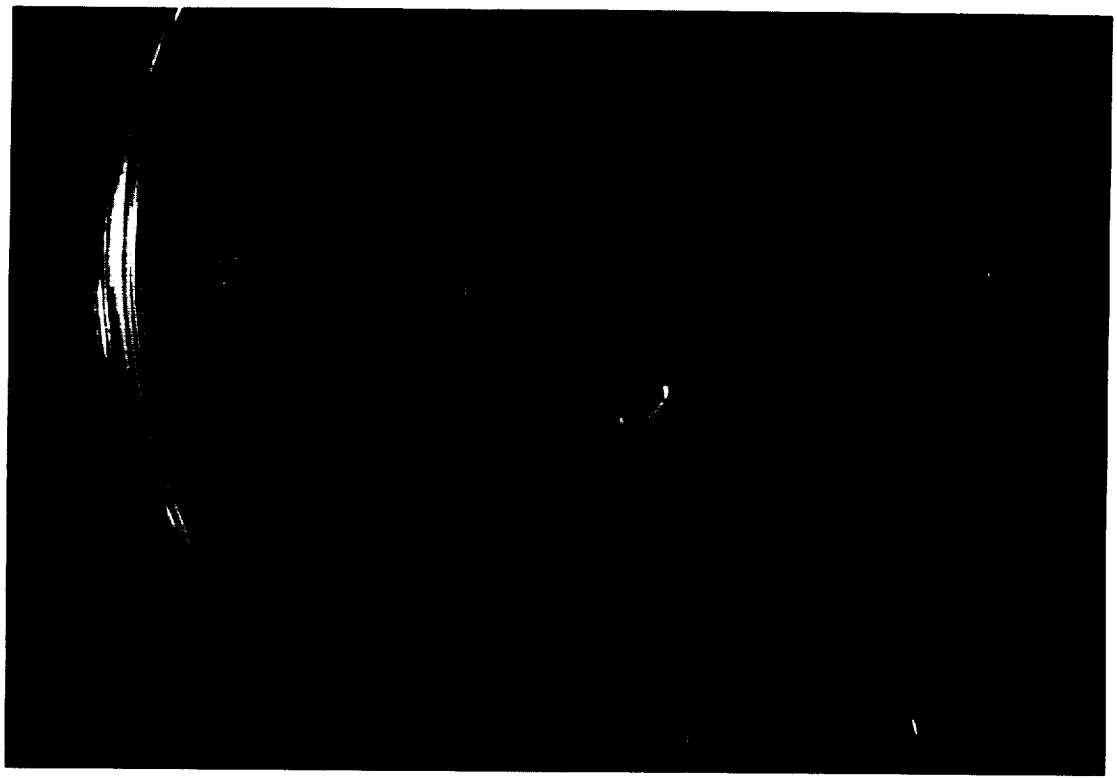

Figure 32. Sample C-31, blue fiber.

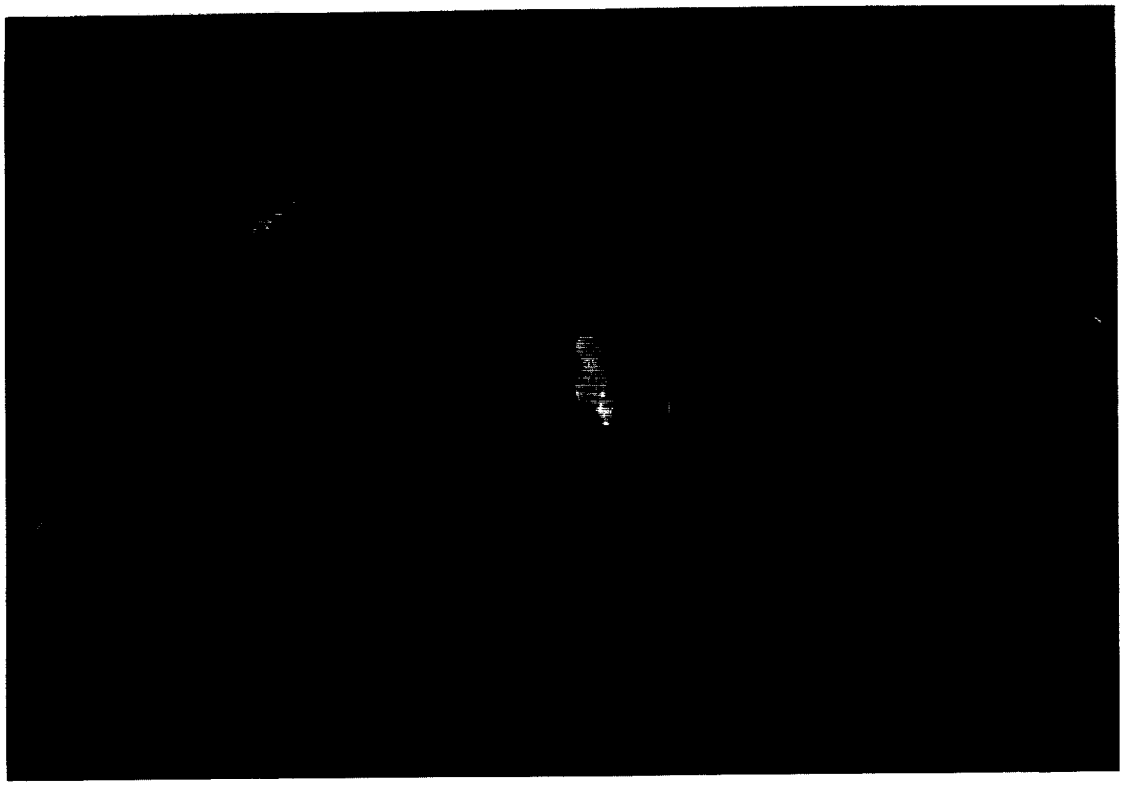

Figure 33. Sample C-32, cream chip.

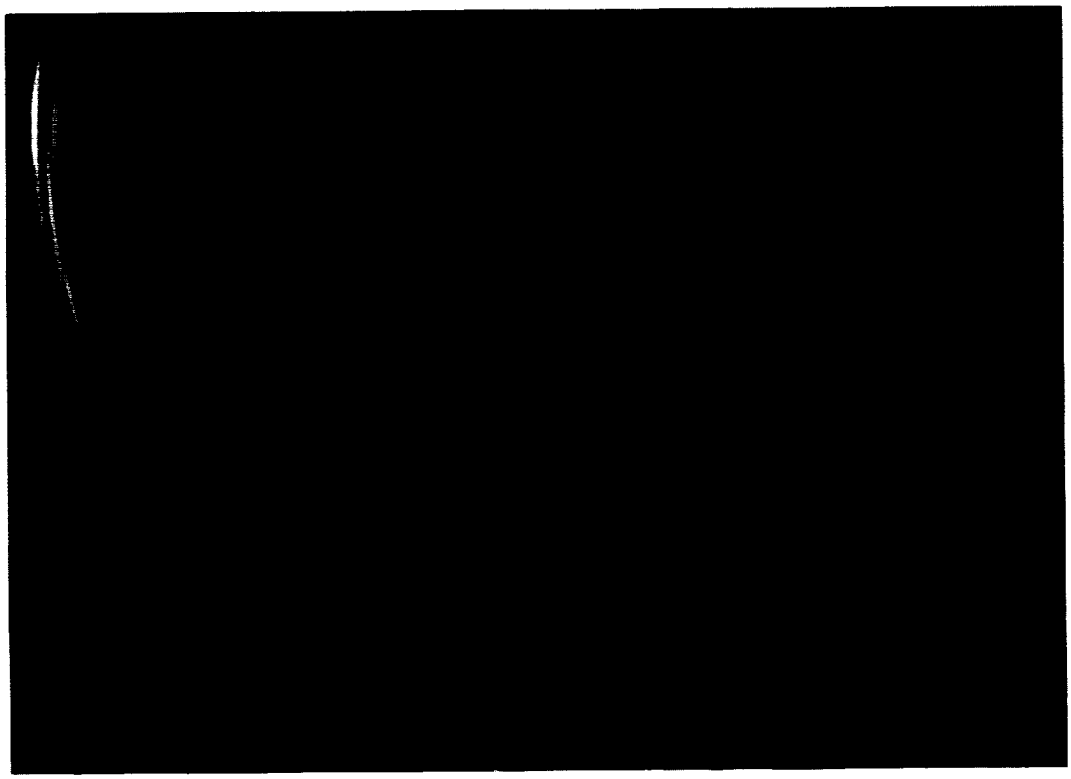

Figure 34. Sample C-33, ivory chip.

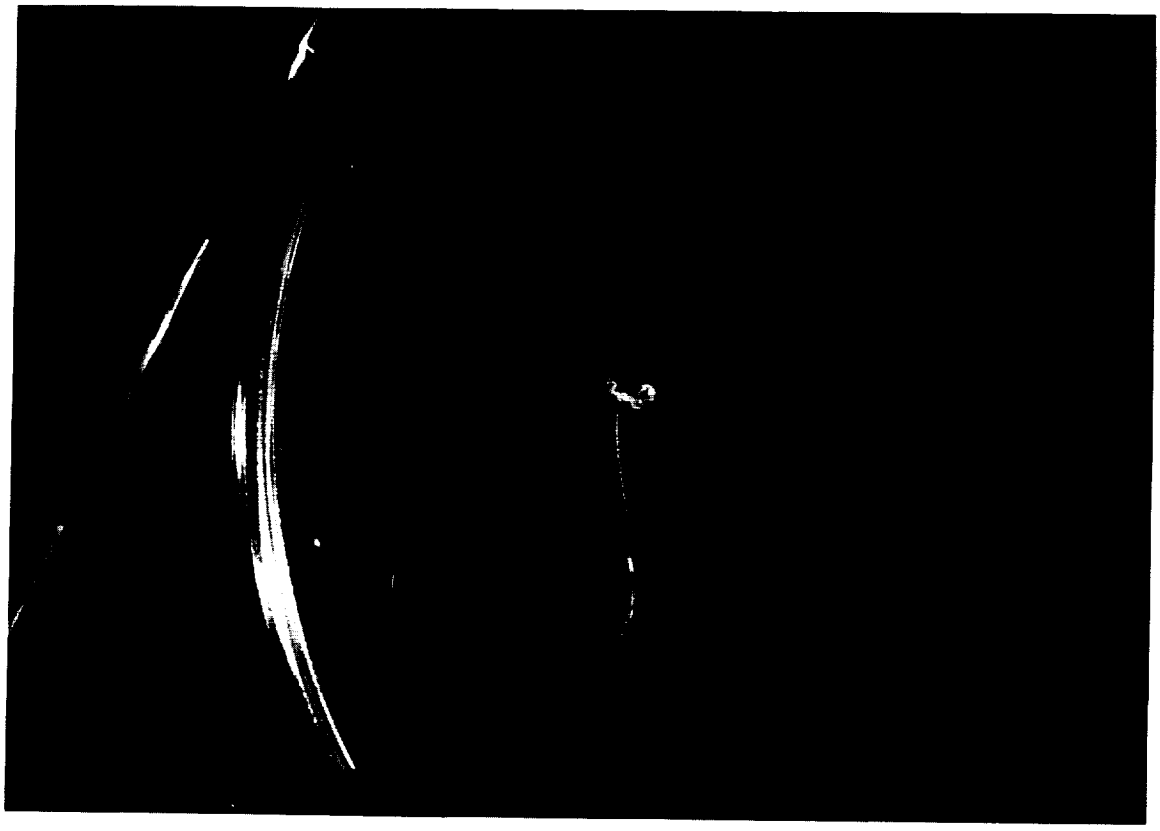

Figure 35. Sample C-34, clear chip.

Figure 36. Sample C-35, scrap with fiberglass appearance.

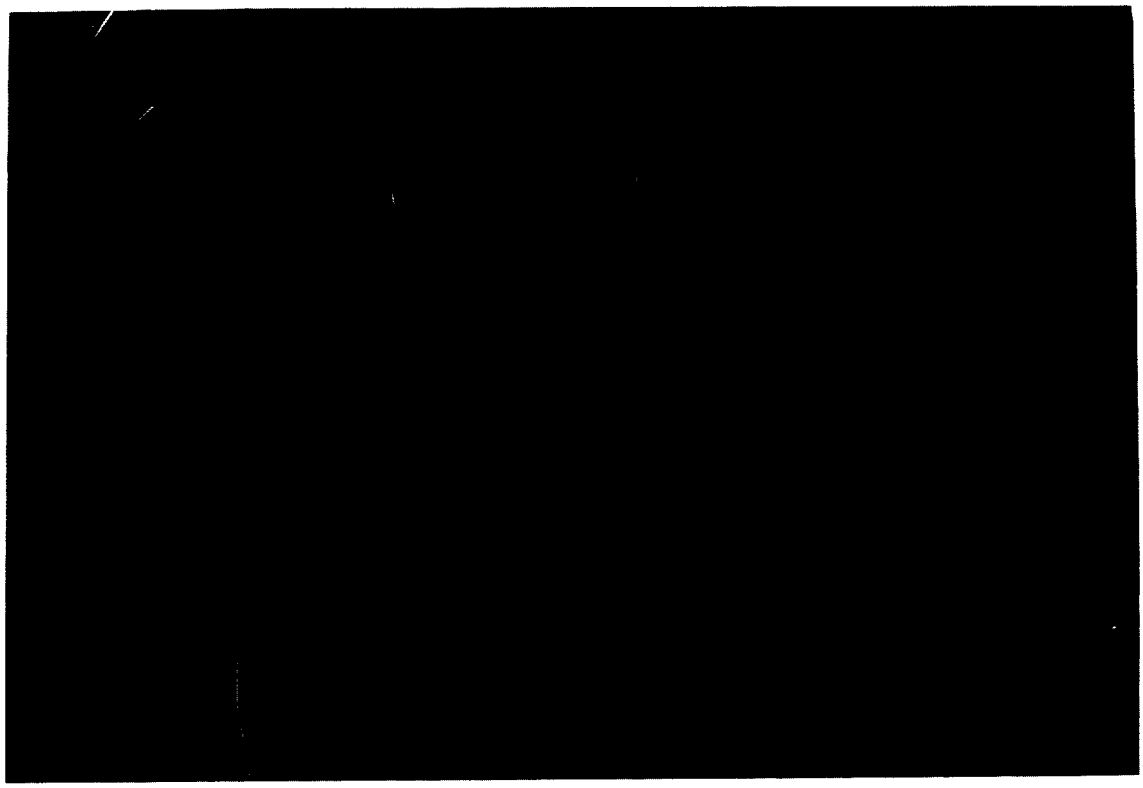

Figure 37. Sample C-36, blue chip.

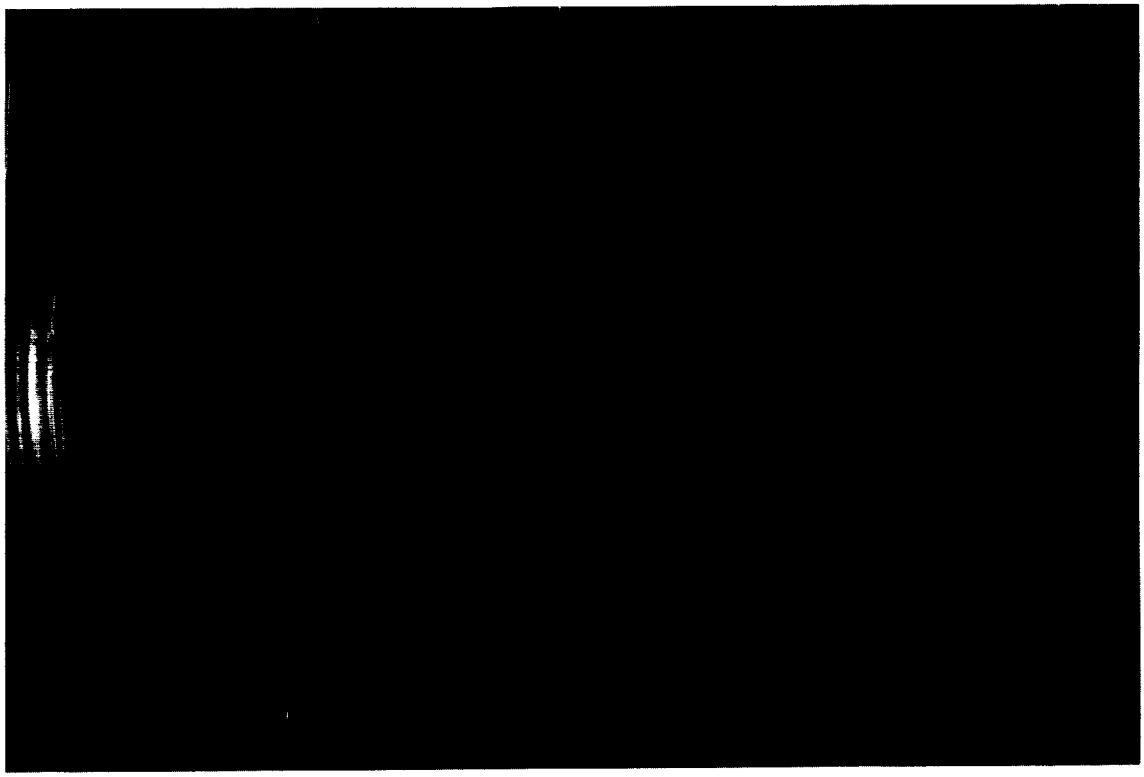

Figure 38. Sample C-36-2, blue chip.

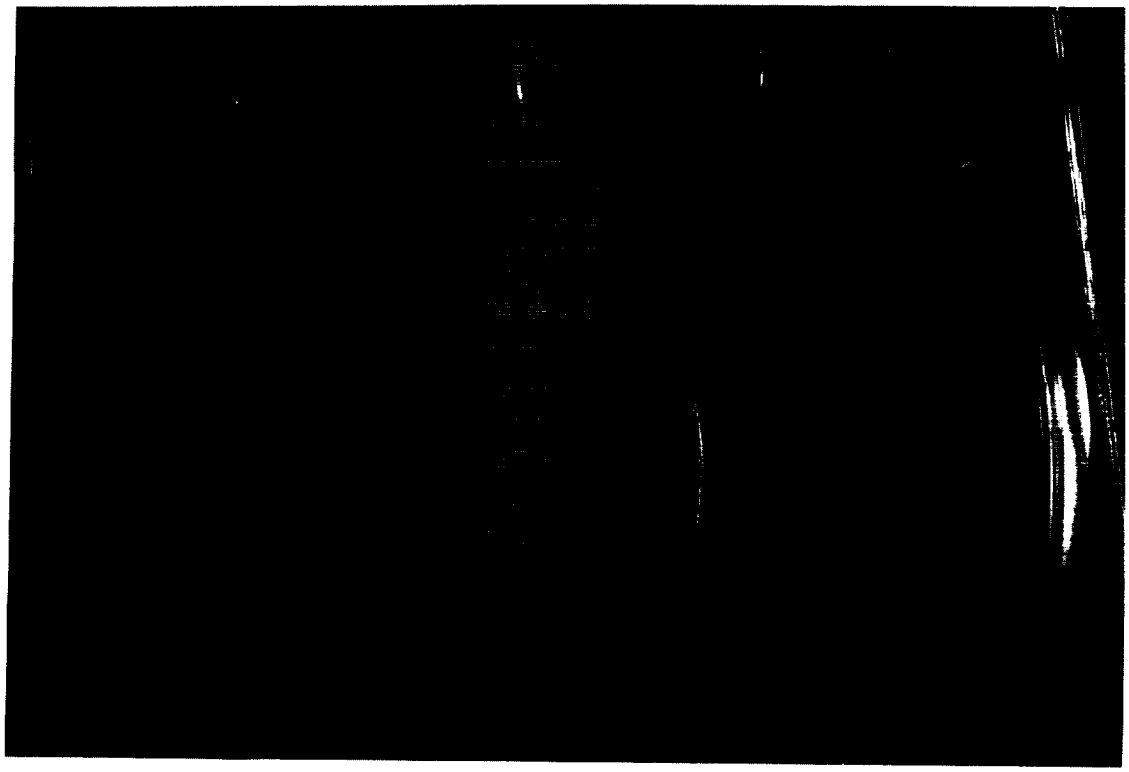

Figure 39. Sample C-37, orange flakes.

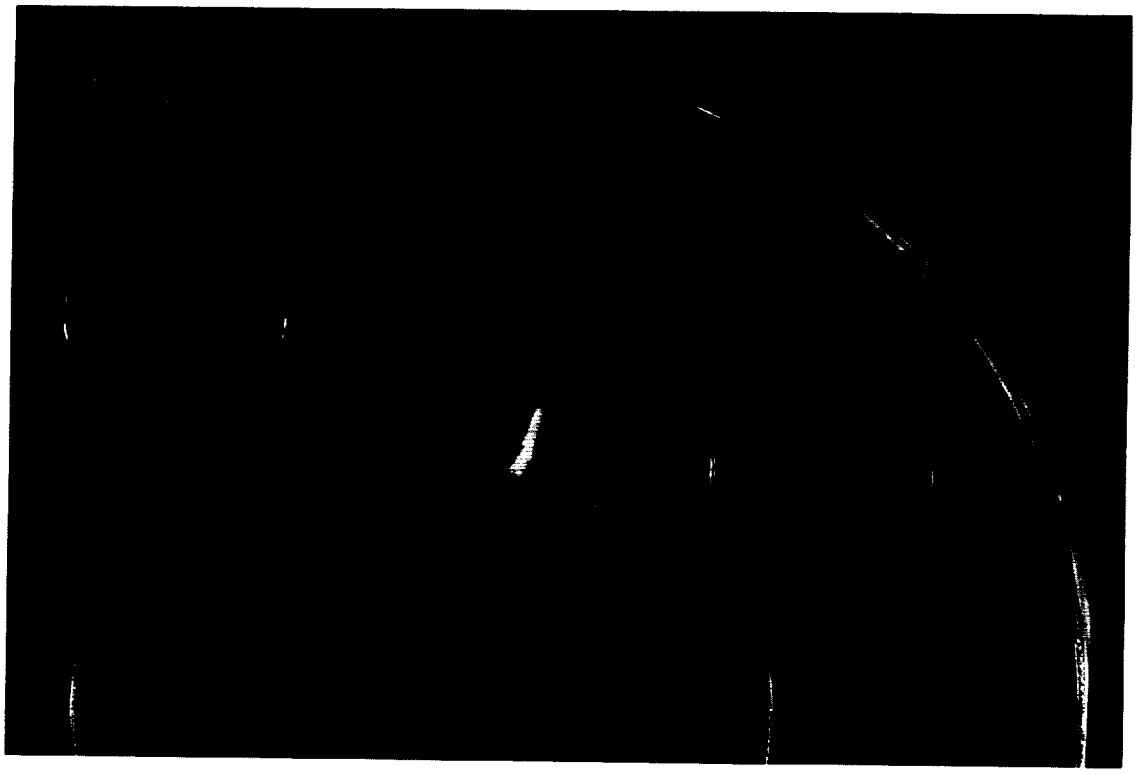

Figure 40. Sample C-40, blue/gray chip.

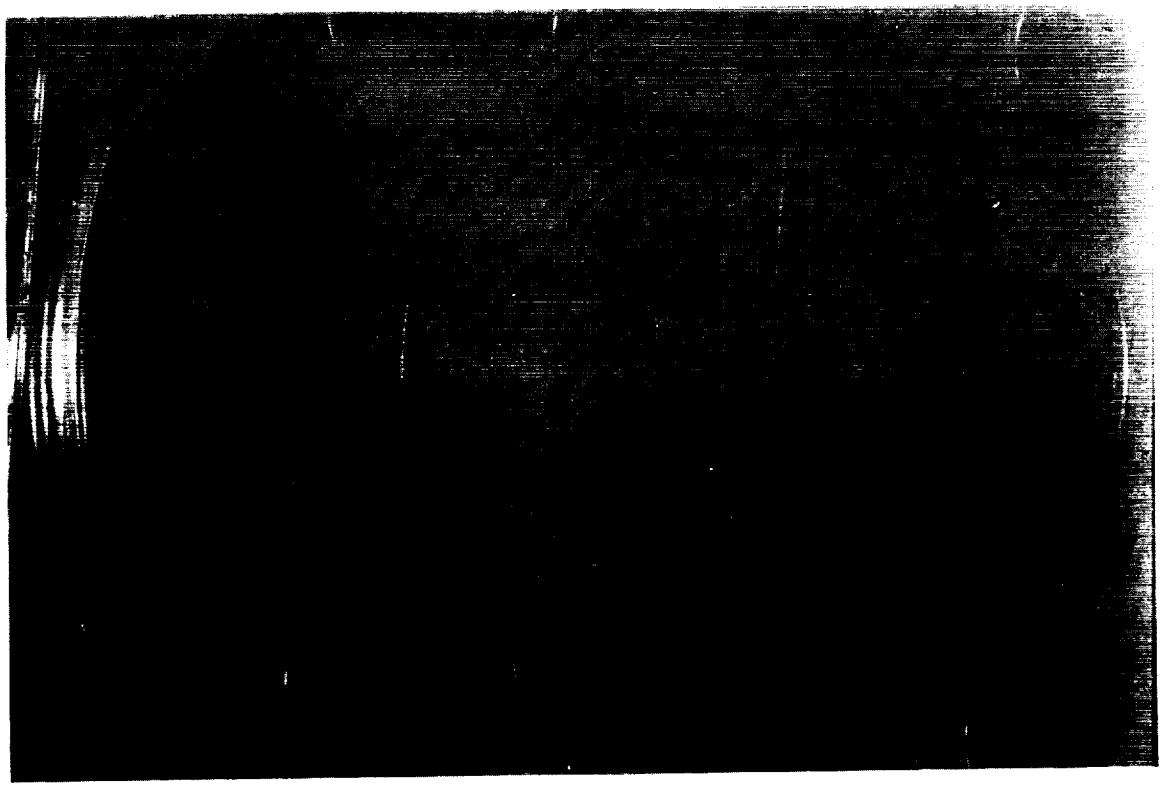

Figure 41. Sample C-41, black chip.

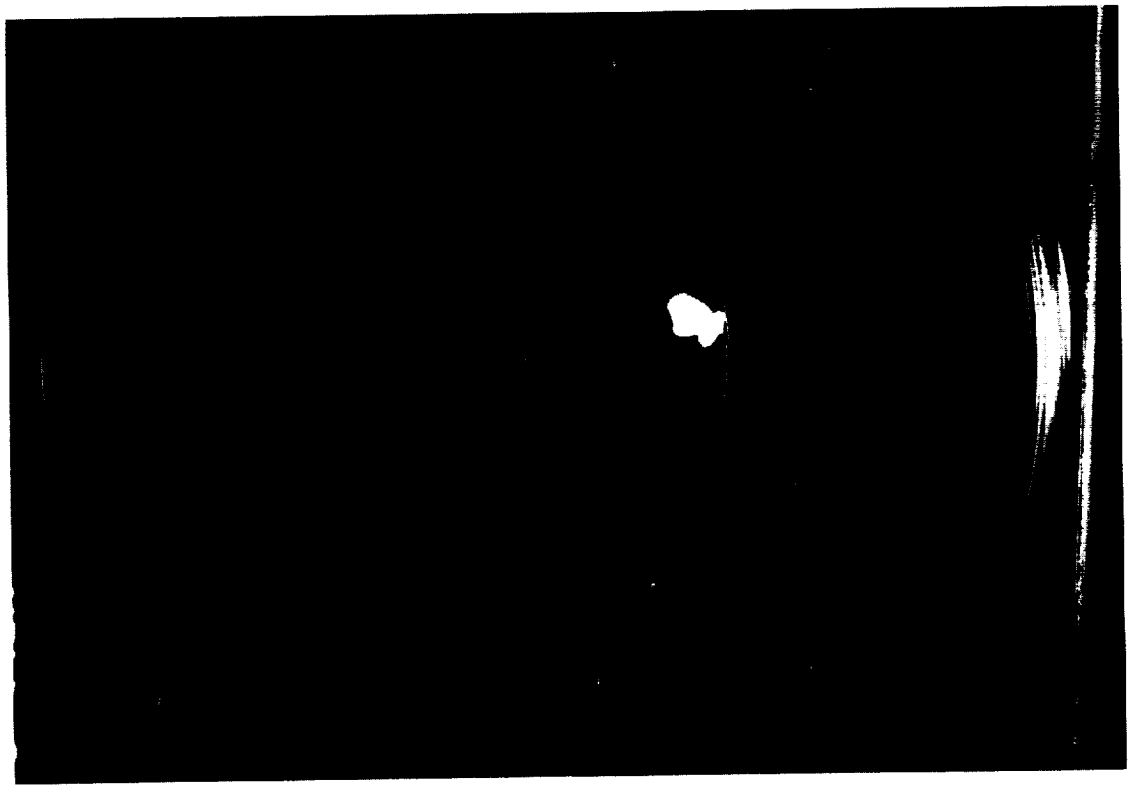

Figure 42. Sample C-42, yellow/green/white chip.

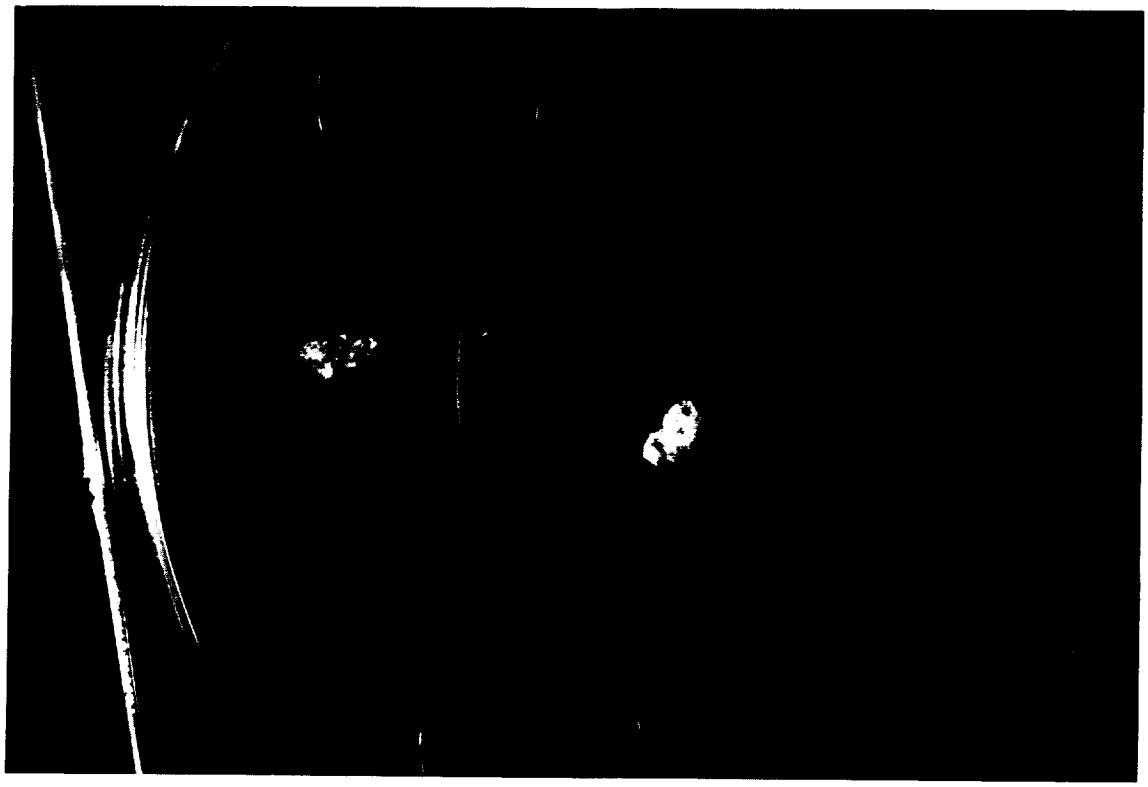

Figure 43. Sample C-43, cream chip.

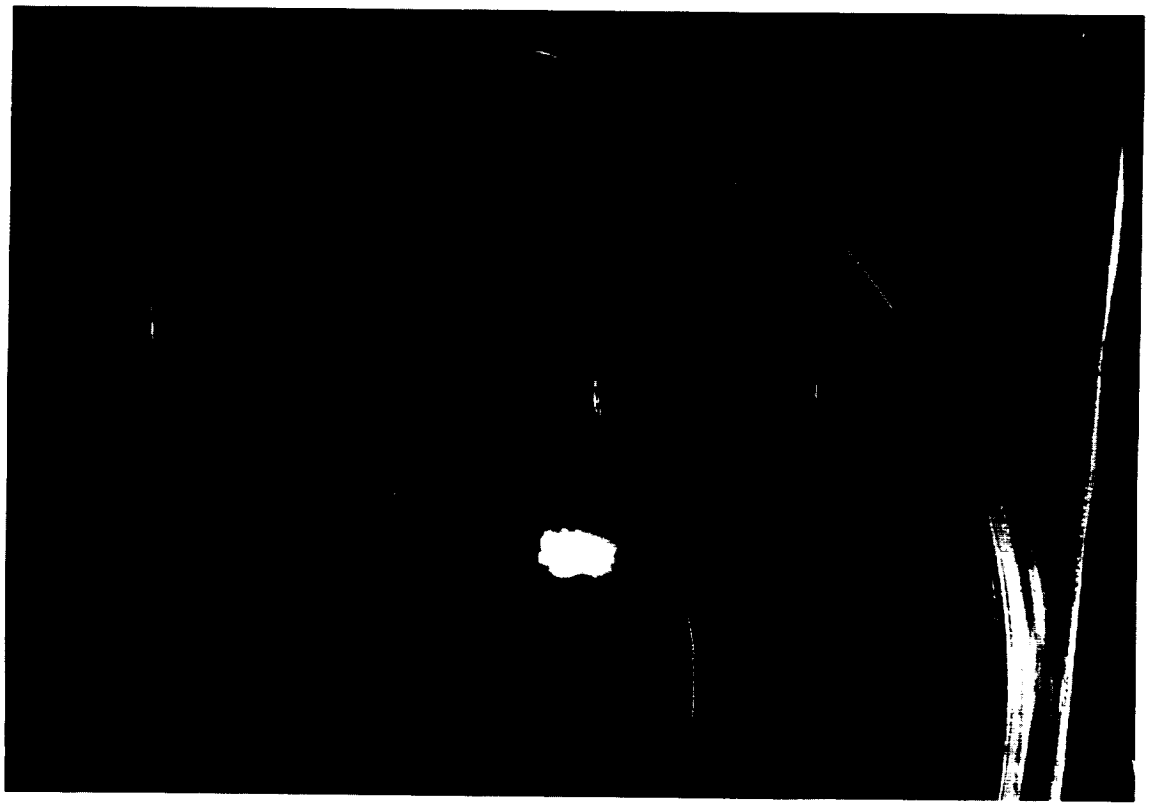

Figure 44. Sample C-44, cream chip.

Figure 45. Sample C-46, fiber.

Figure 46. Sample C-47, black foam.

Figure 47. Sample C-48, clear yellow chip.

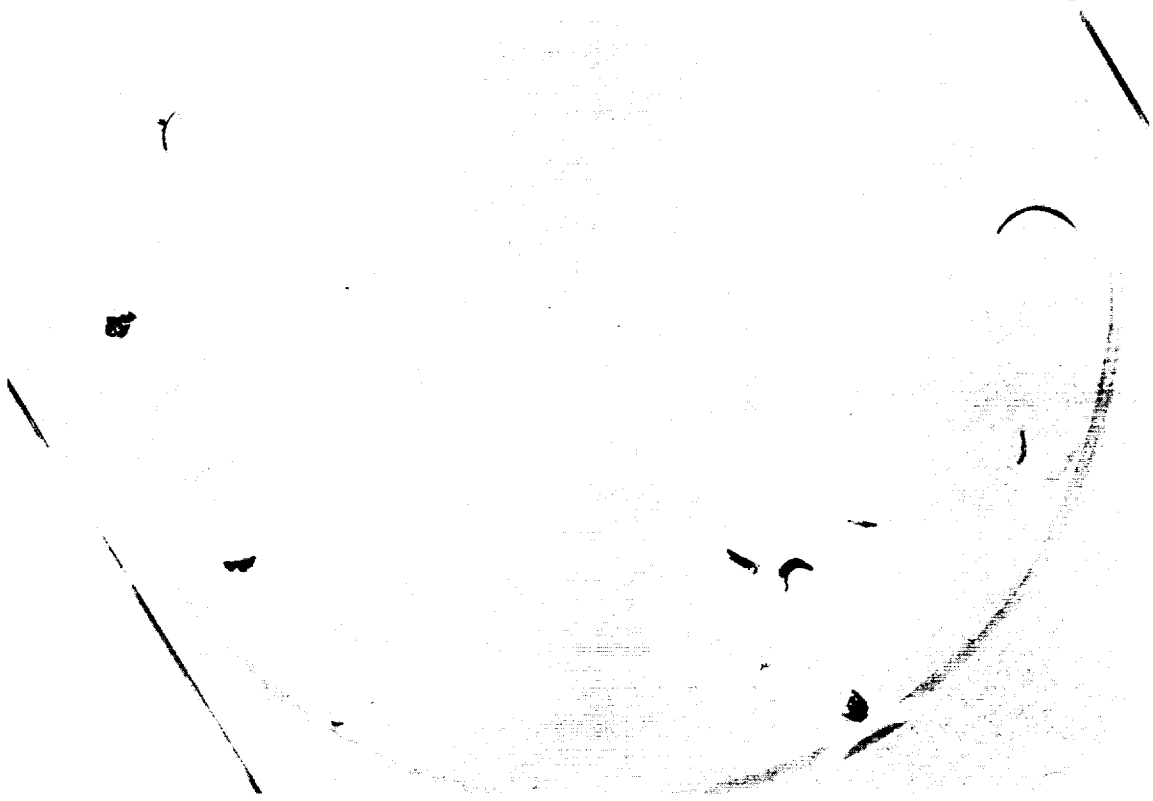

Figure 48. Sample C-49, miscellaneous chips.

Figure 49. Sample A-1, clear, rubbery chip.

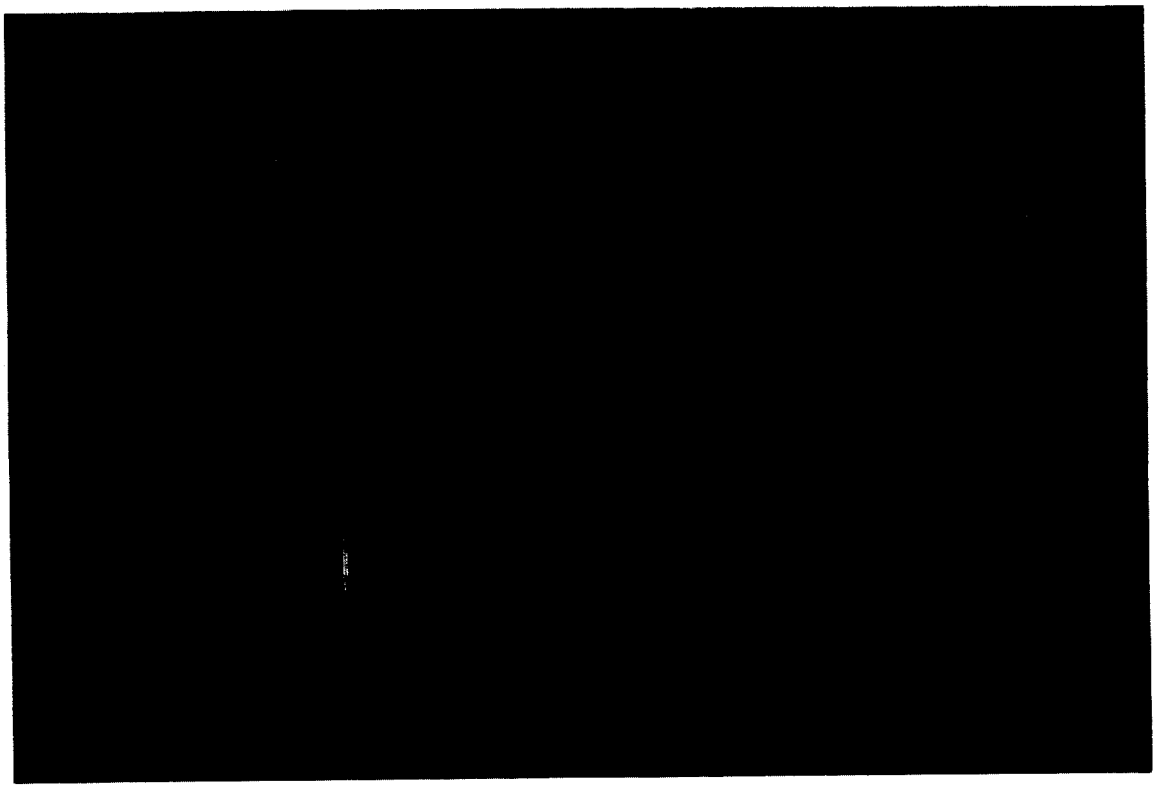

Figure 50. Sample A-2, thin brown flake.

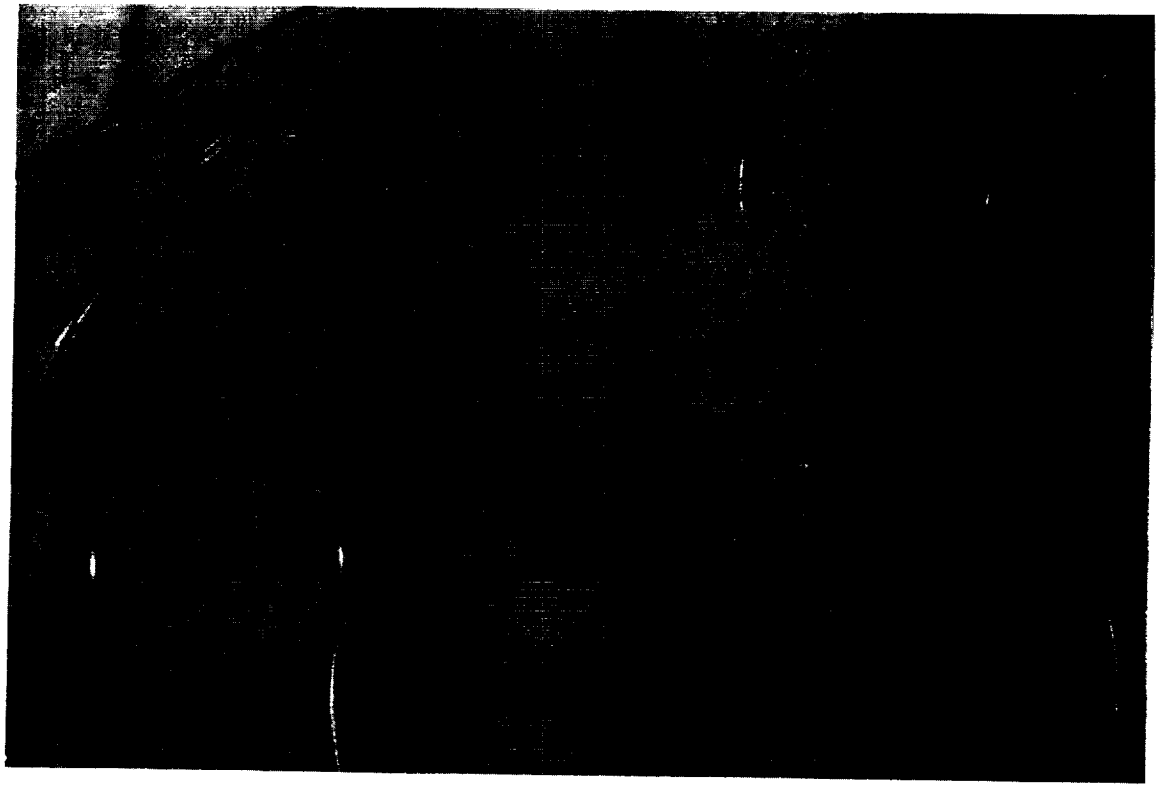

Figure 51. Sample A-3, reddish rubbery chips.

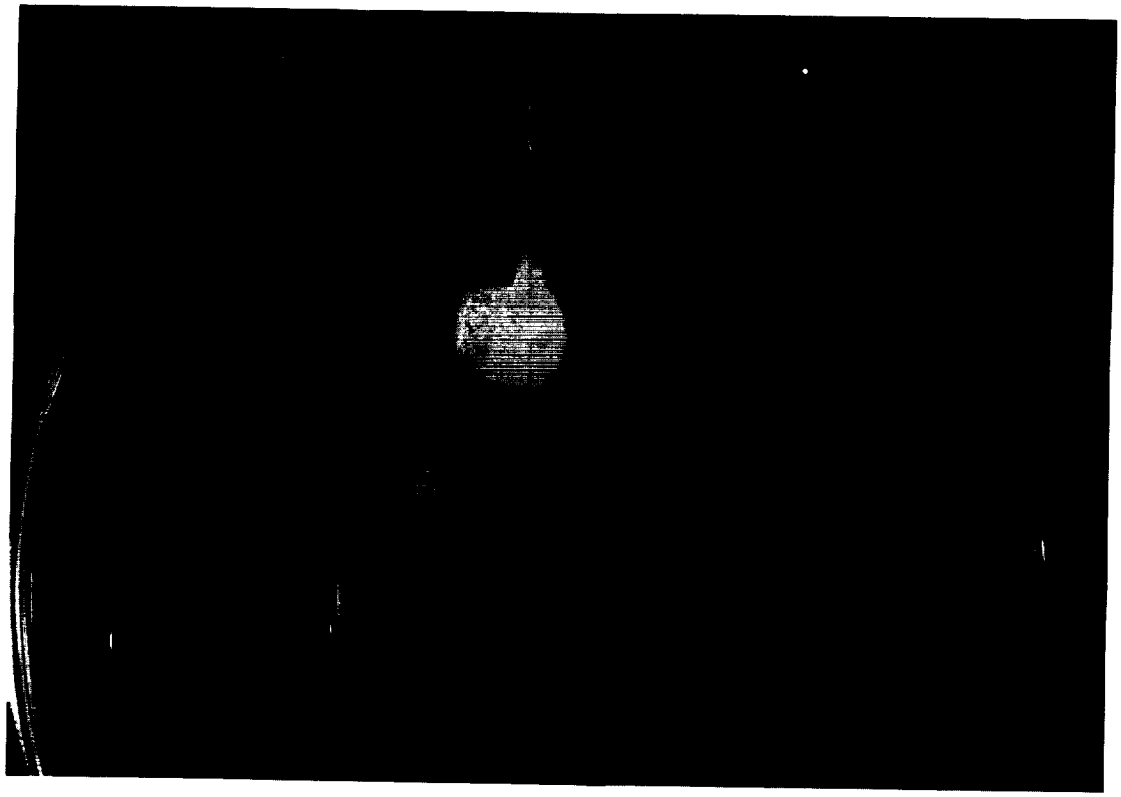

Figure 52. Sample A-4, thin pliable flakes.

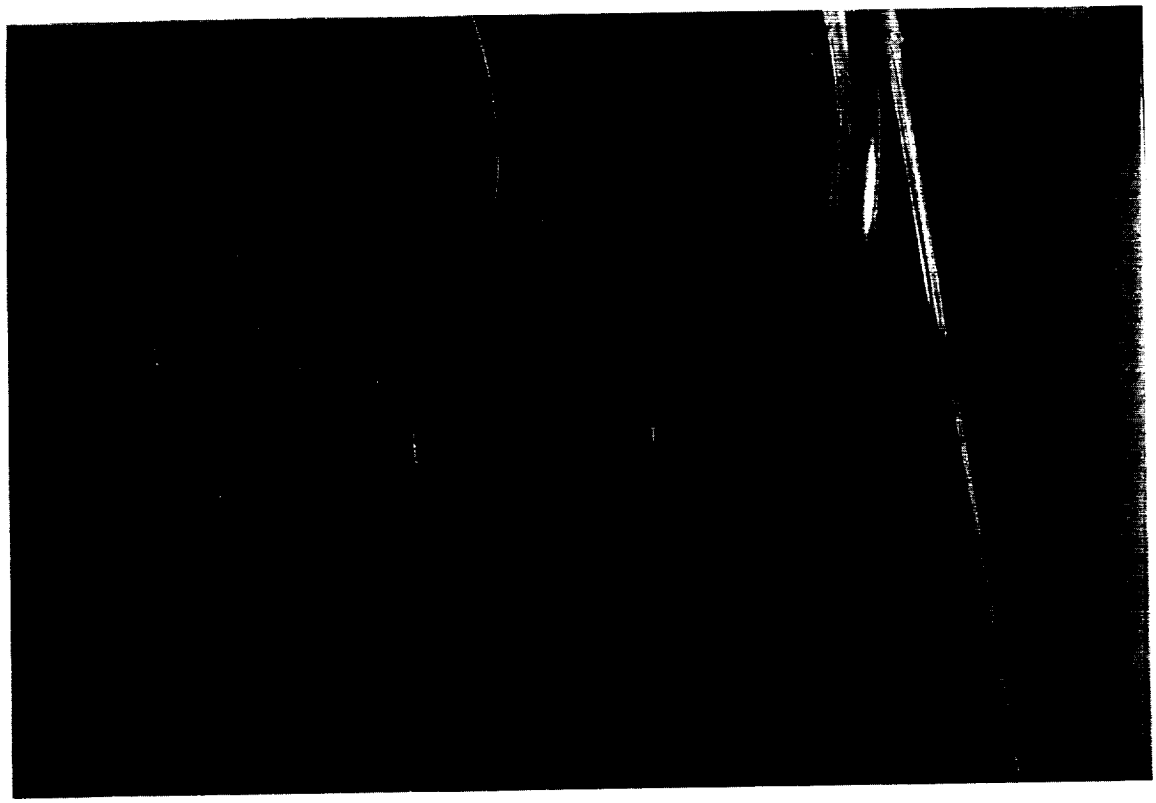

Figure 53. Sample A-5, red/cream chip.

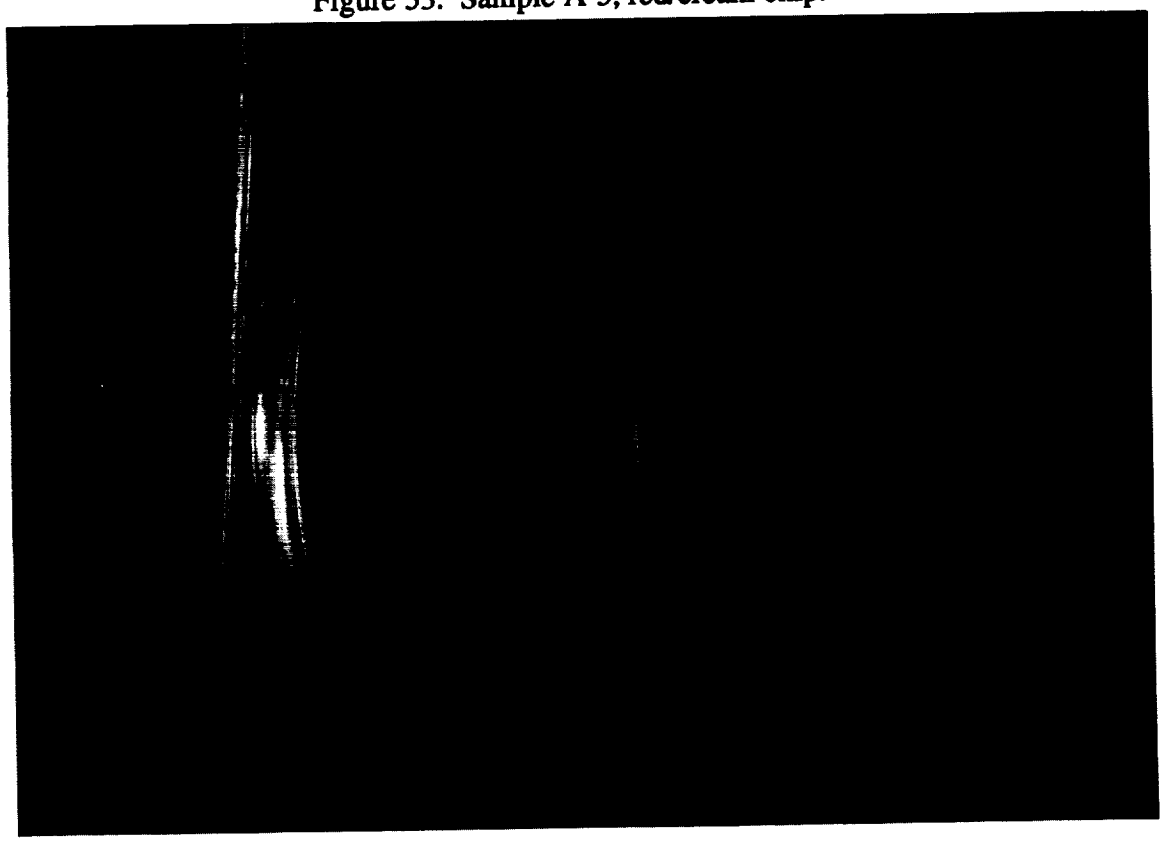

Figure 54. Sample A-6, yellow, white thin honeycomb.

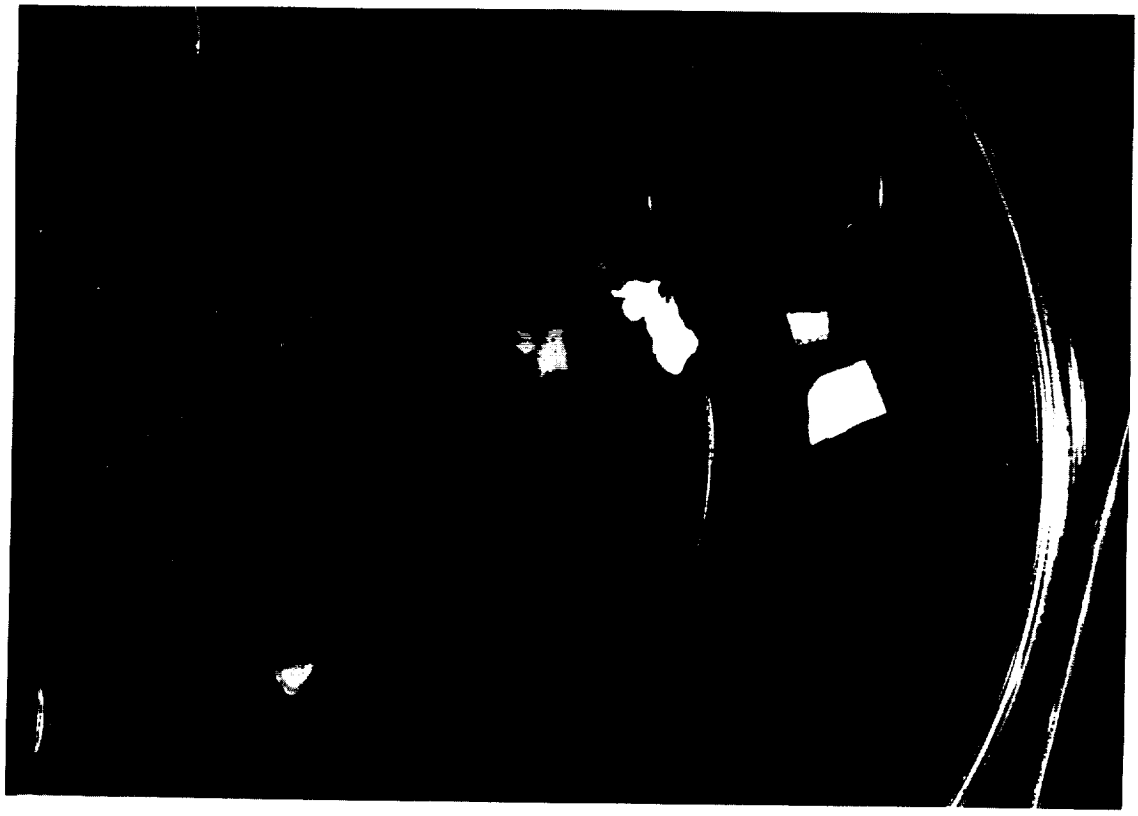

Figure 55. Sample A-7, yellow, white opaque chip.

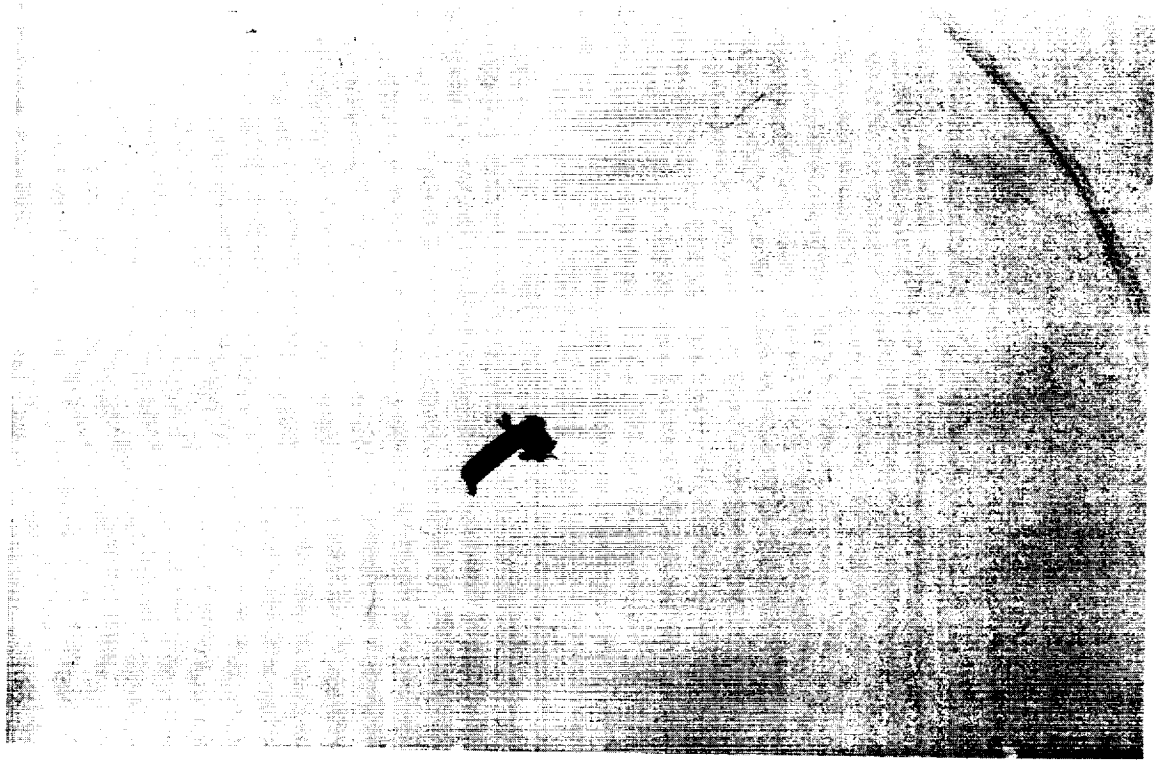

Figure 56. Sample A-9, reddish brown flake with yellow.

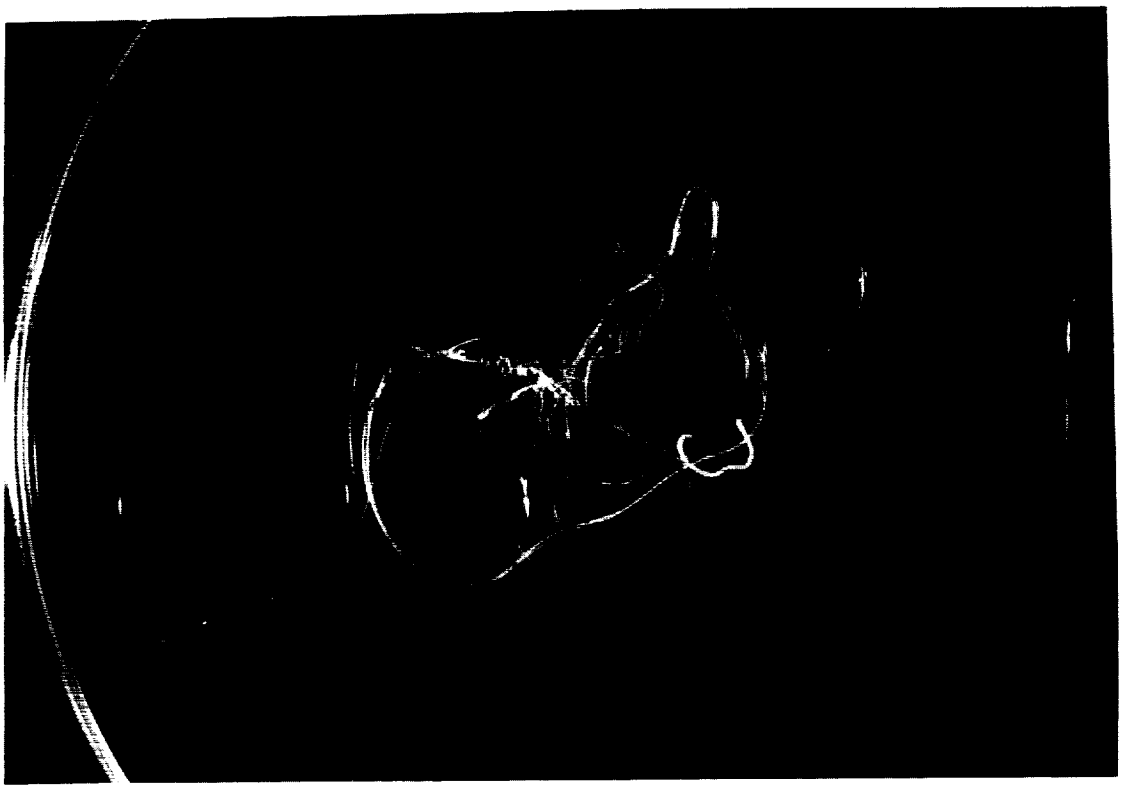

Figure 57. Sample A-10, translucent mass of fibers.

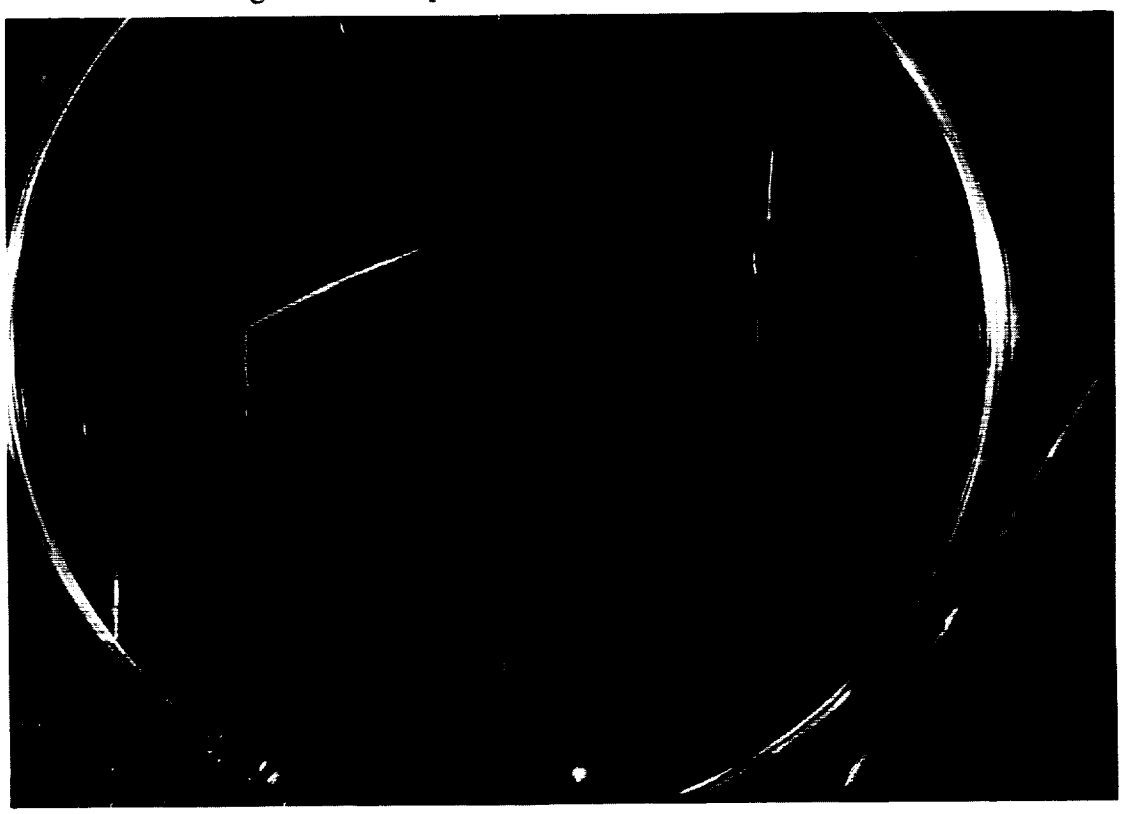

Figure 58. Sample A-11, straight, white opaque fibers.

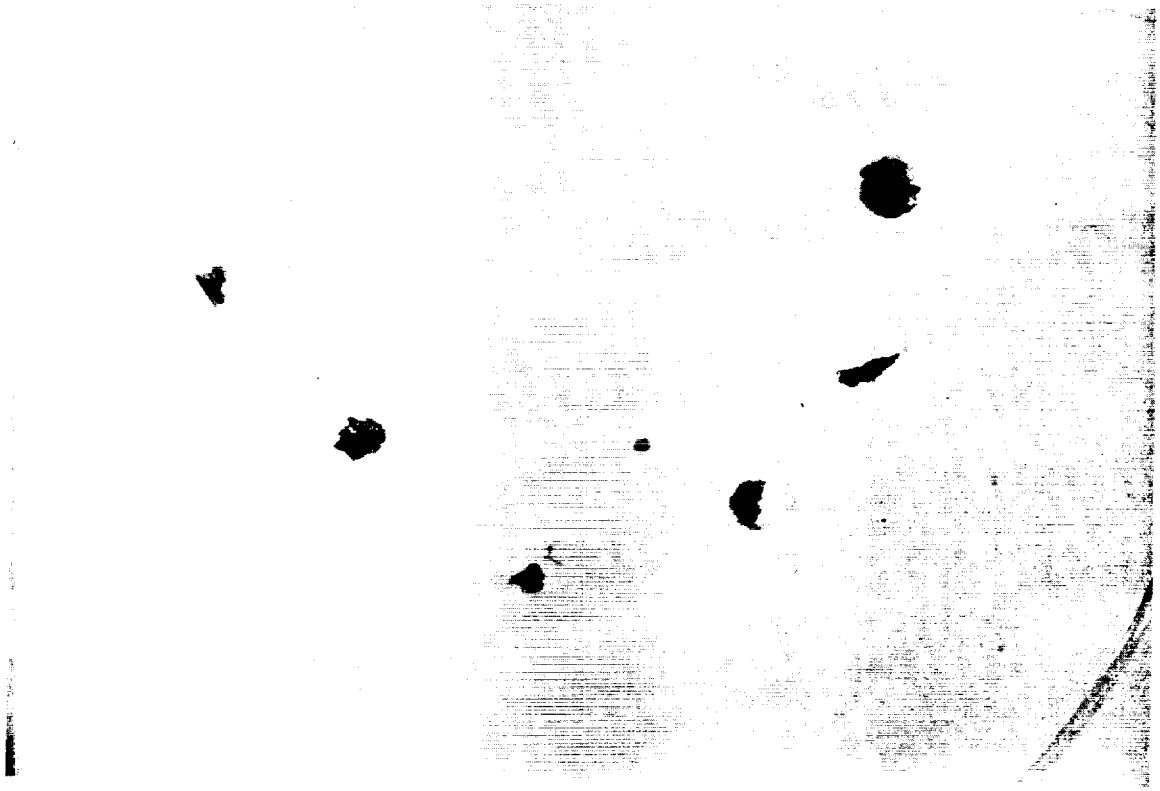

Figure 59. Sample A-12, translucent yellow fibrous chip.

Figure 60. Sample A-13, multicolor fibers.

Figure 61. Sample A-16, clear, plastic-like scrap.

Figure 62. Sample A-17, short multicolor fibers.

Figure 63. Sample A-18, opaque crystalline chips.

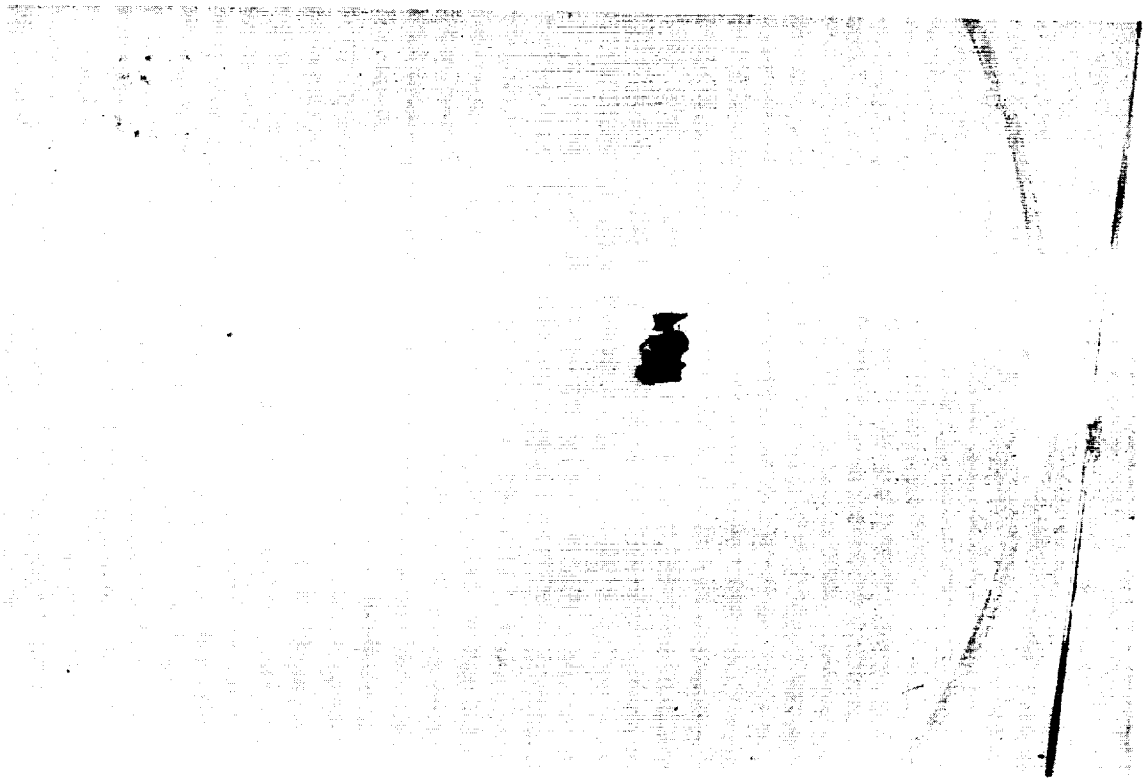

Figure 64. Sample A-19, green/gray grainy chips.

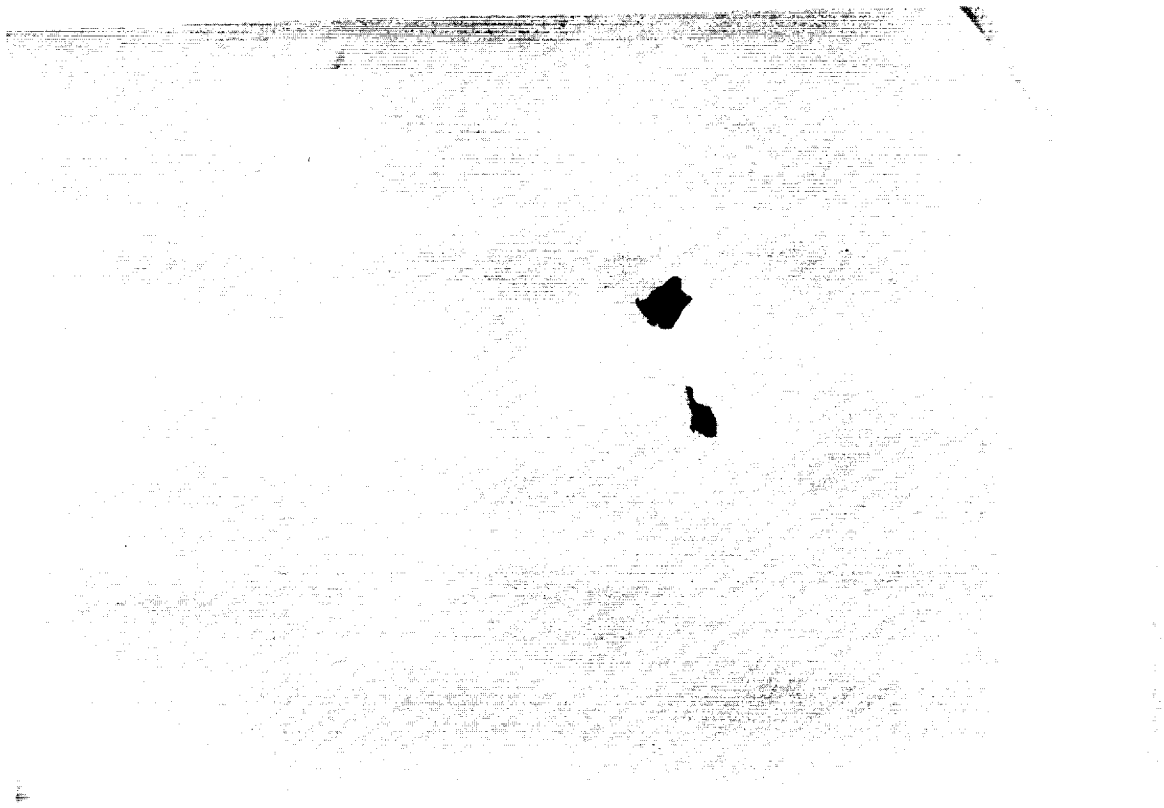

Figure 65. Sample A-21, green chips with glassy texture.

Figure 66. Sample A-22, red waxy scrap.

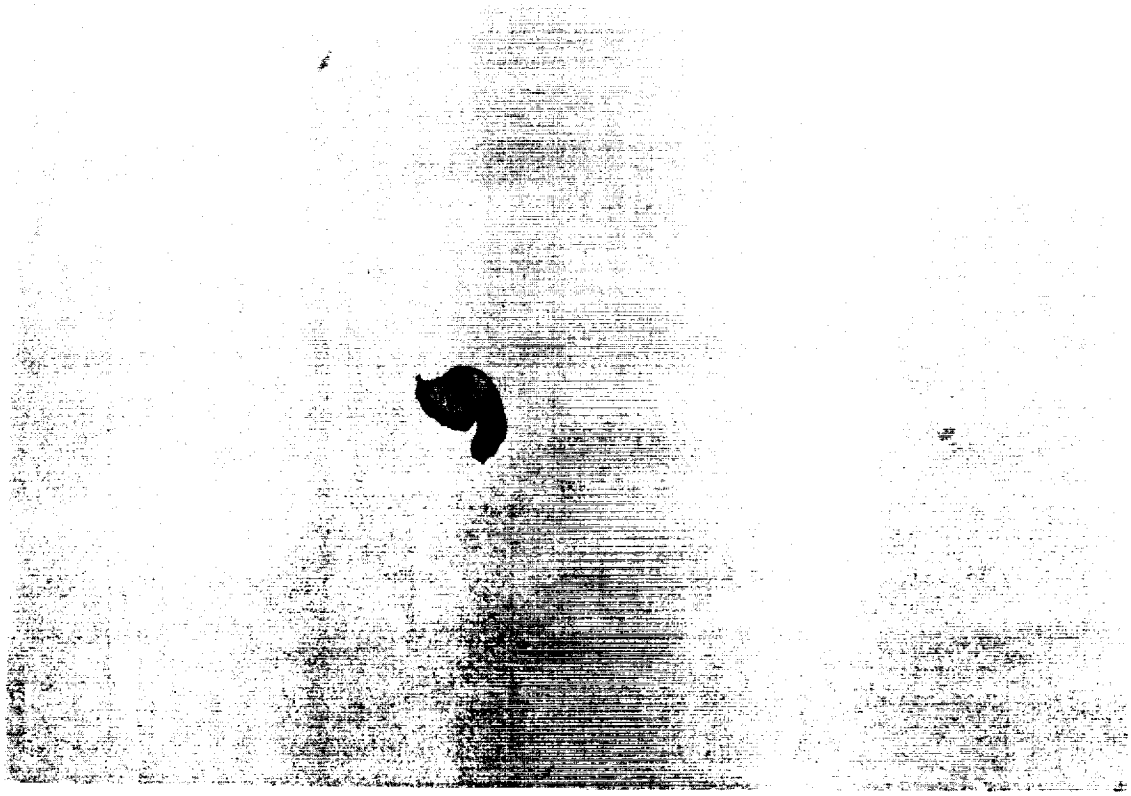

Figure 67. Sample A-23, gray/white foam.

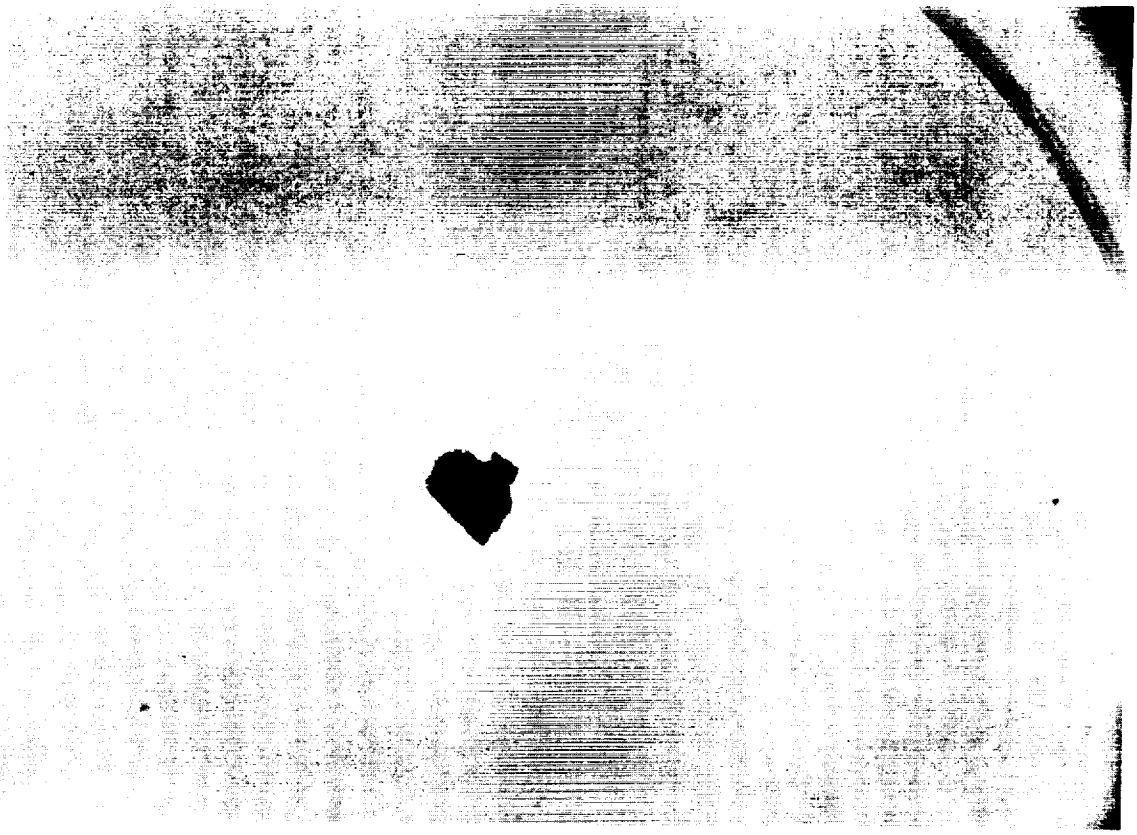

Figure 68. Sample A-24, gray, semi-hard foam.

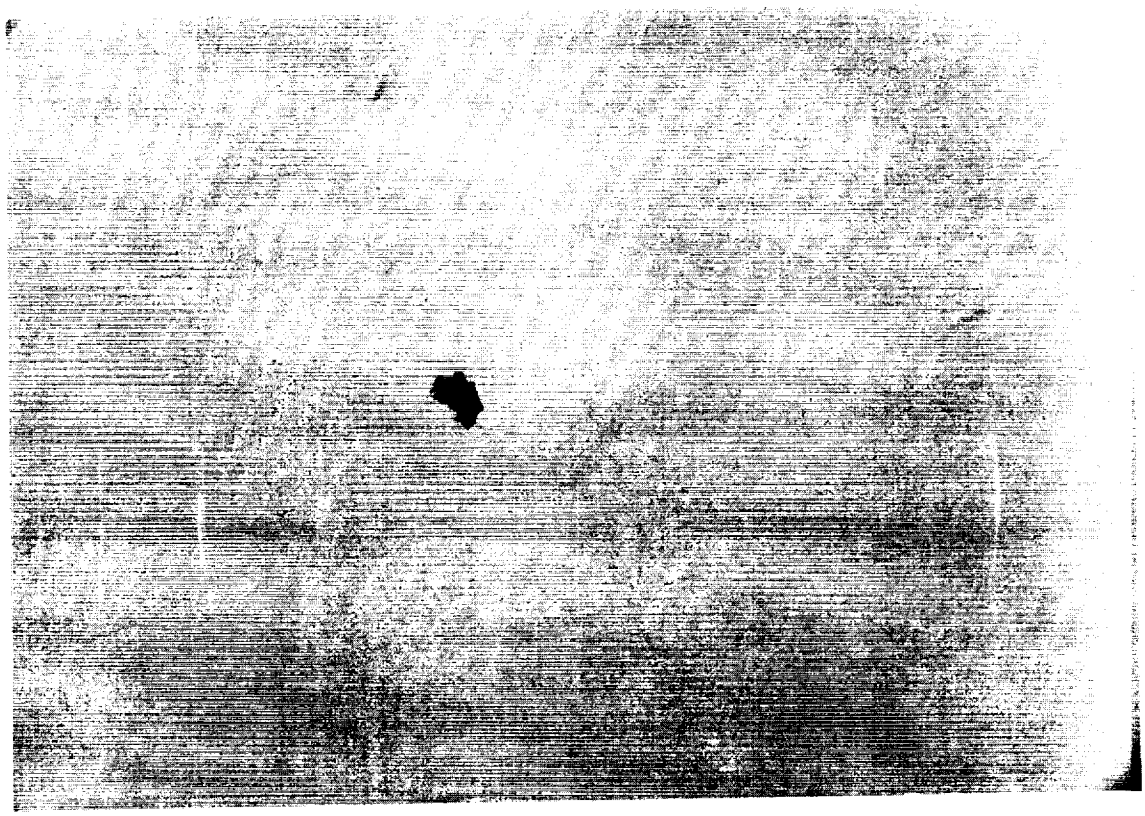

Figure 69. Sample A-25, pink foam/fiberglass.

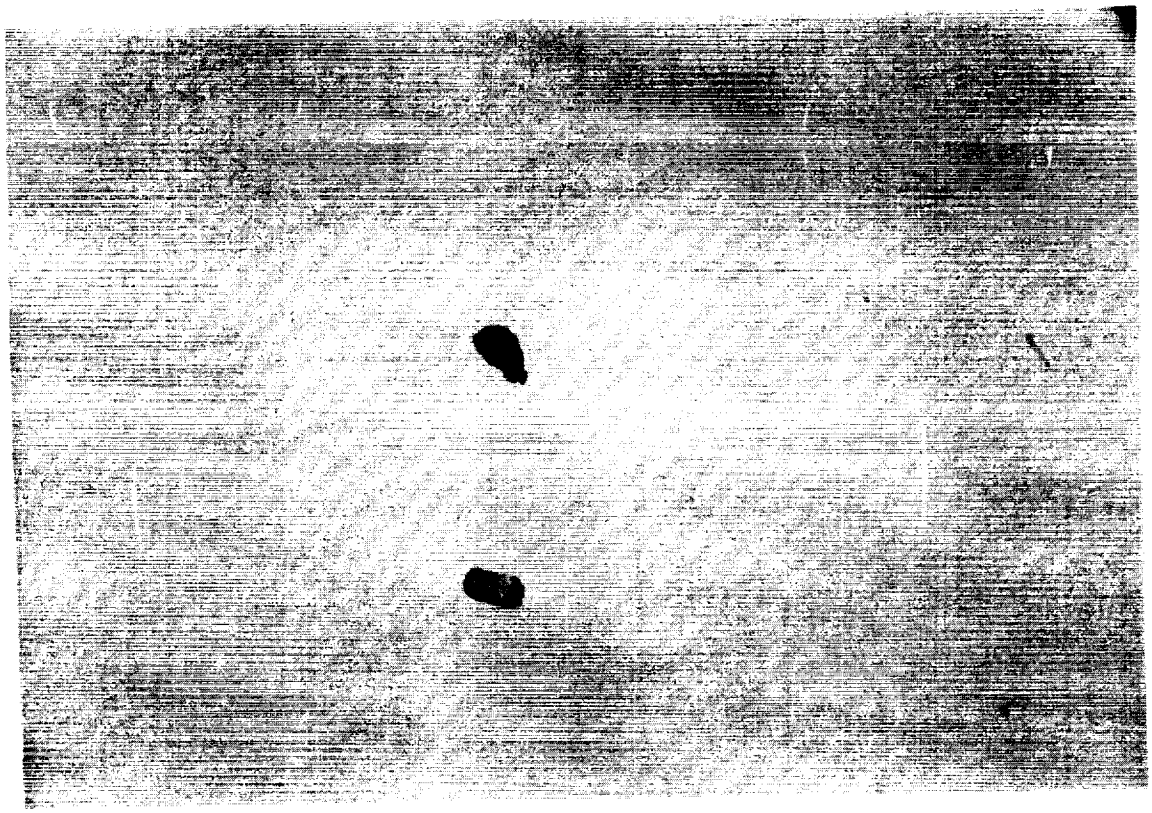

Figure 70. Sample A-26, amber flakes.

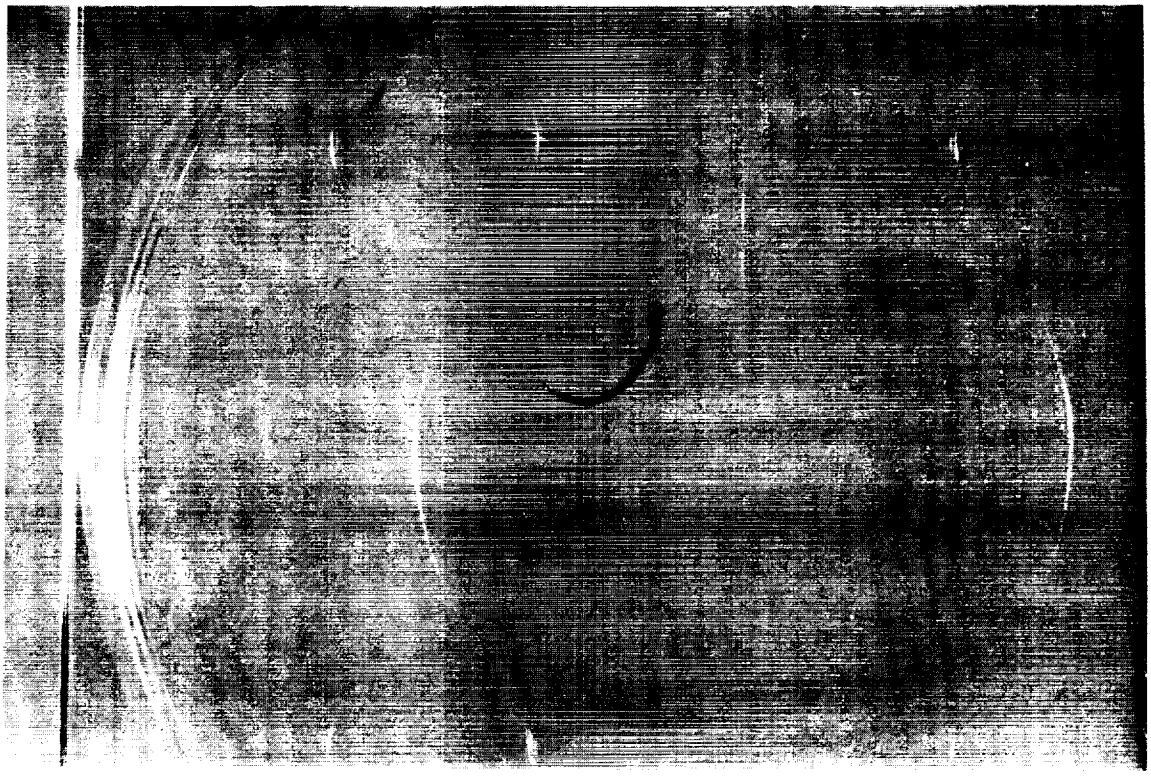

Figure 71. Sample C-6, metallic sliver.

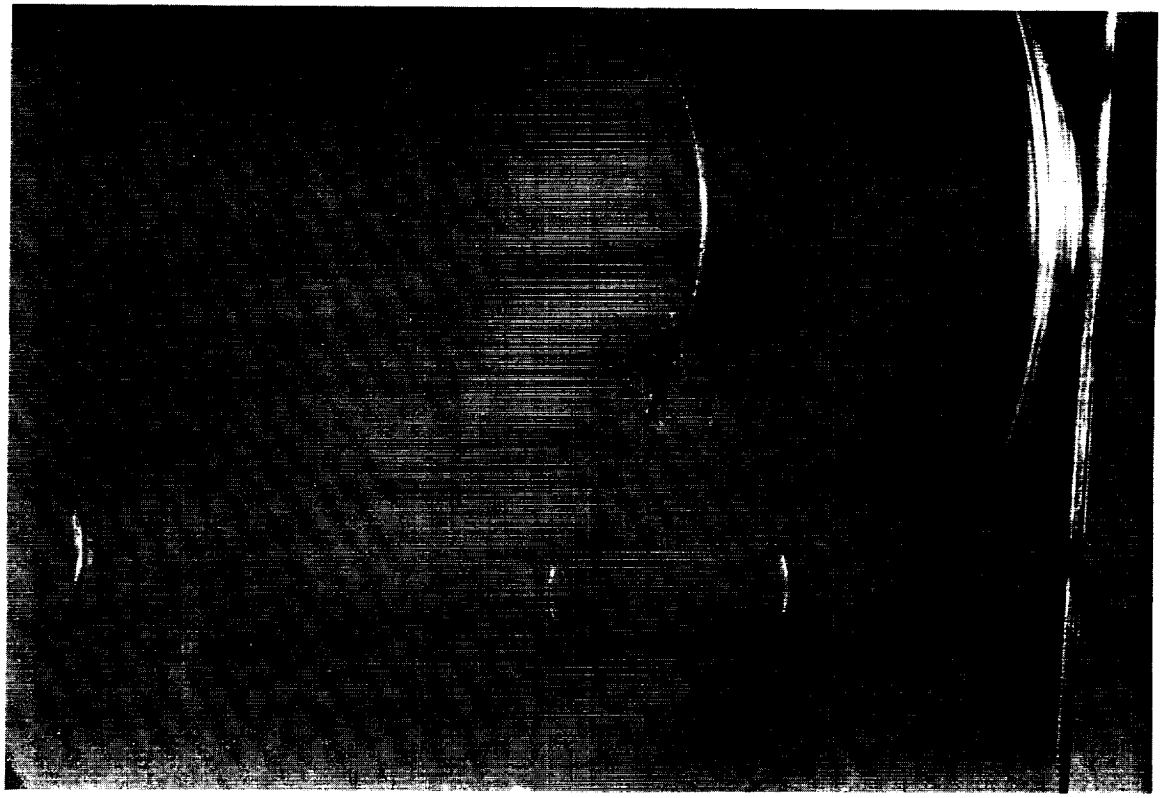

Figure 72. Sample C-10, metallic scrap.

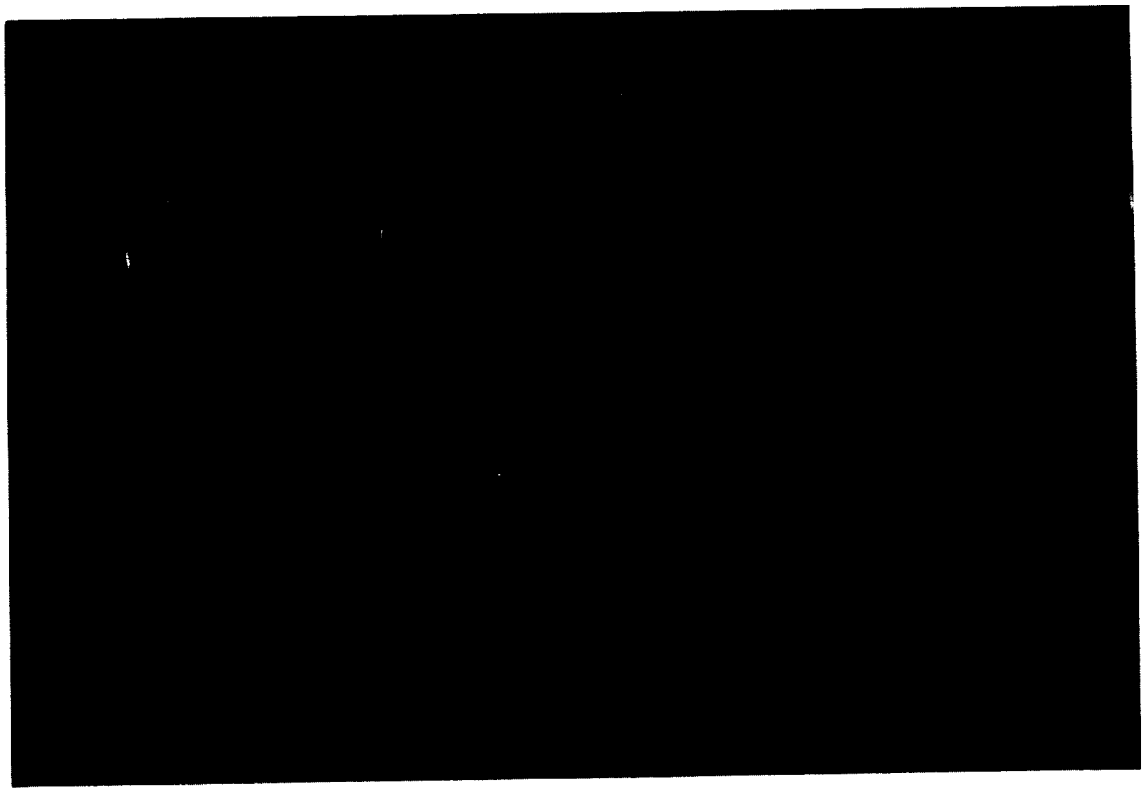

Figure 73. Sample C-38, metallic chip.

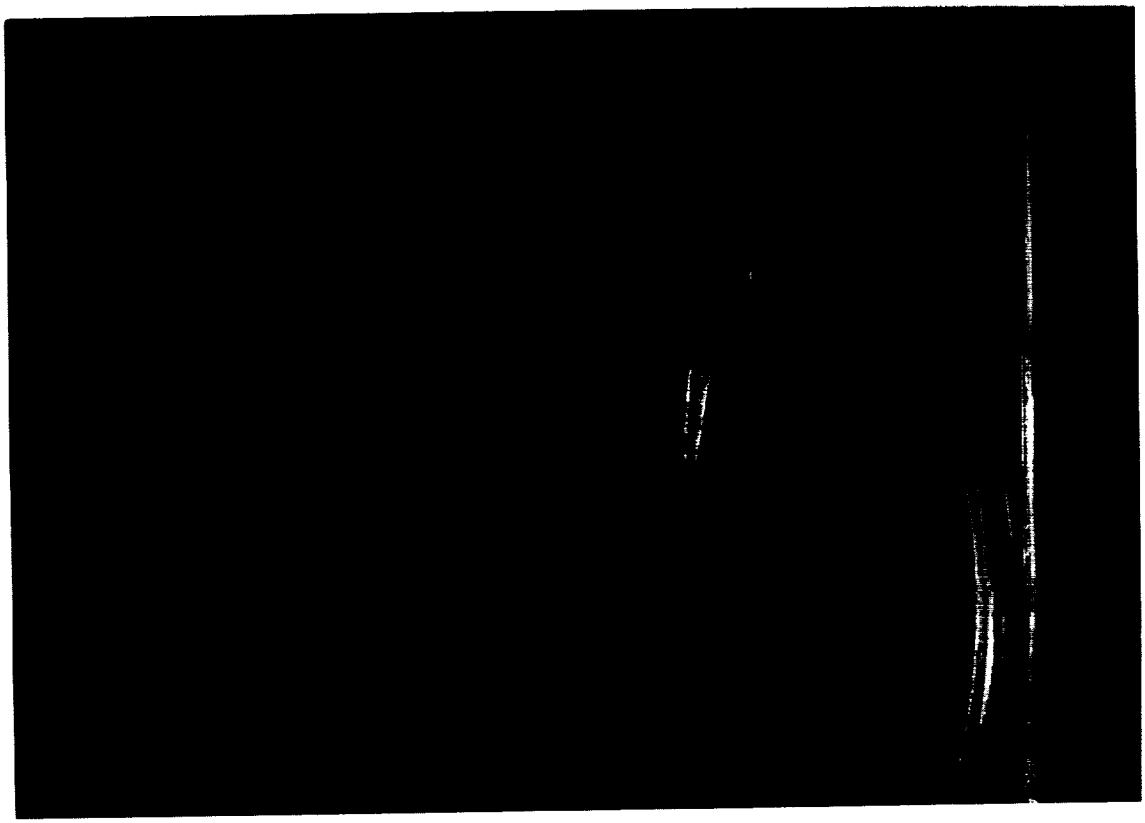

Figure 74. Sample C-45. Metallic chip.

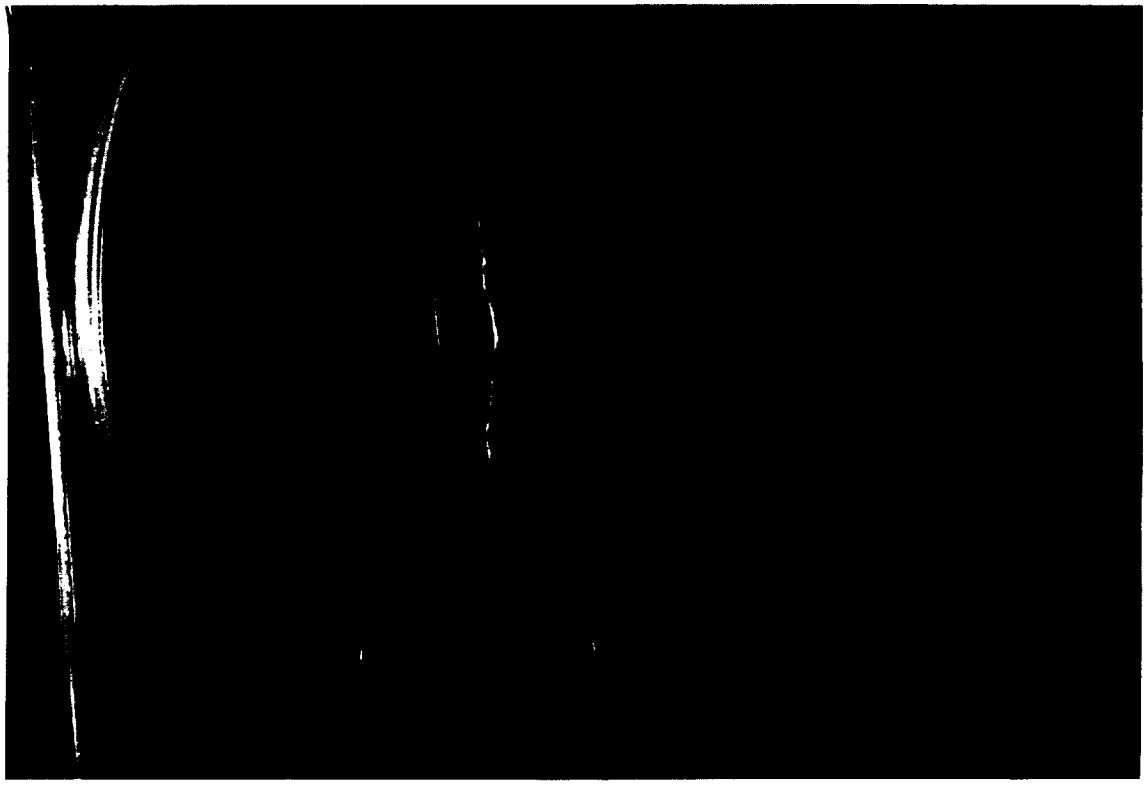

Figure 75. Sample A-8, wire.

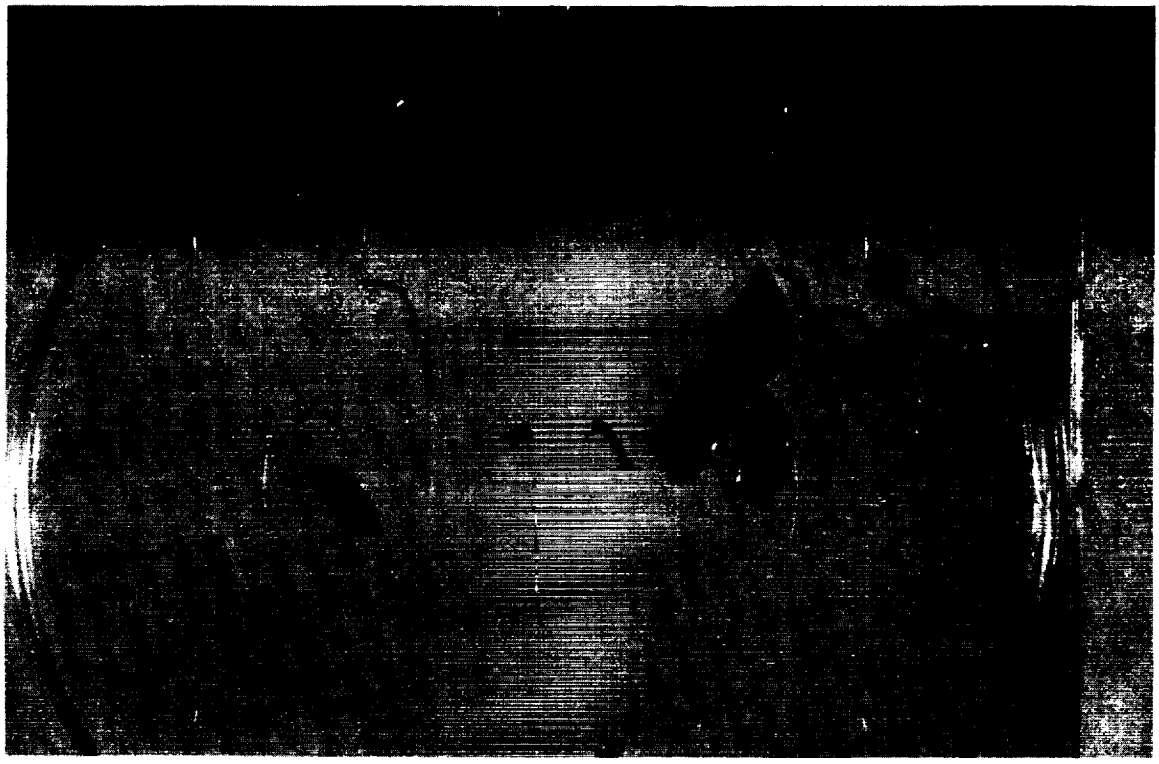

Figure 76. Sample A-14, metallic bits.

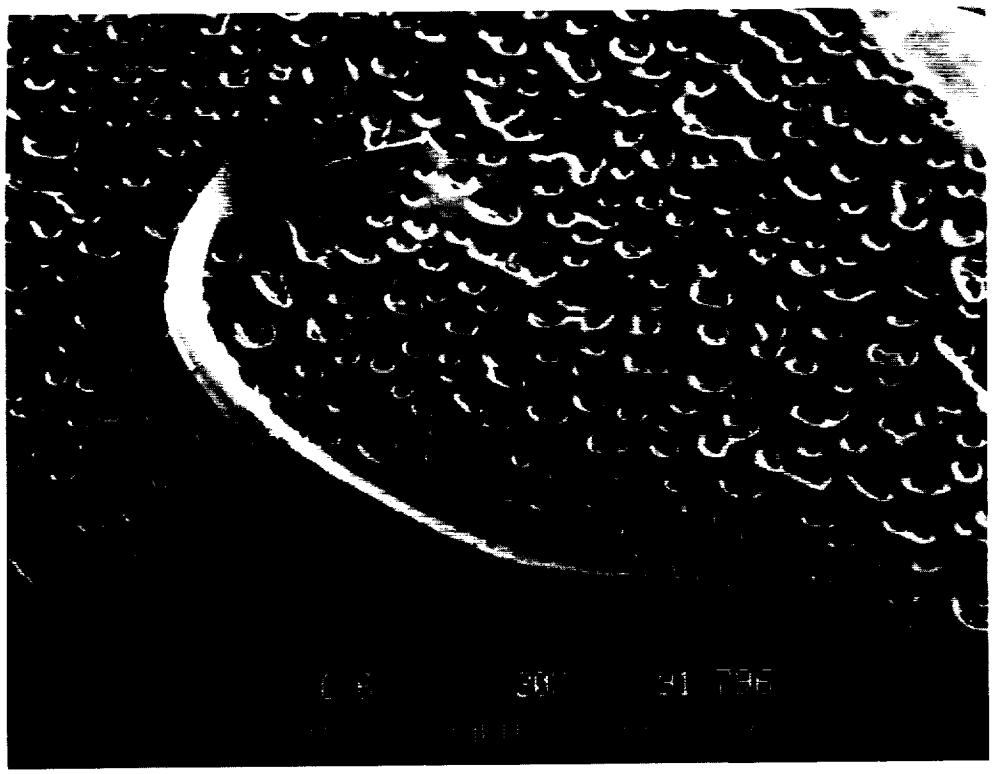

Figure 77. SEM of sample C-6, metallic sliver.

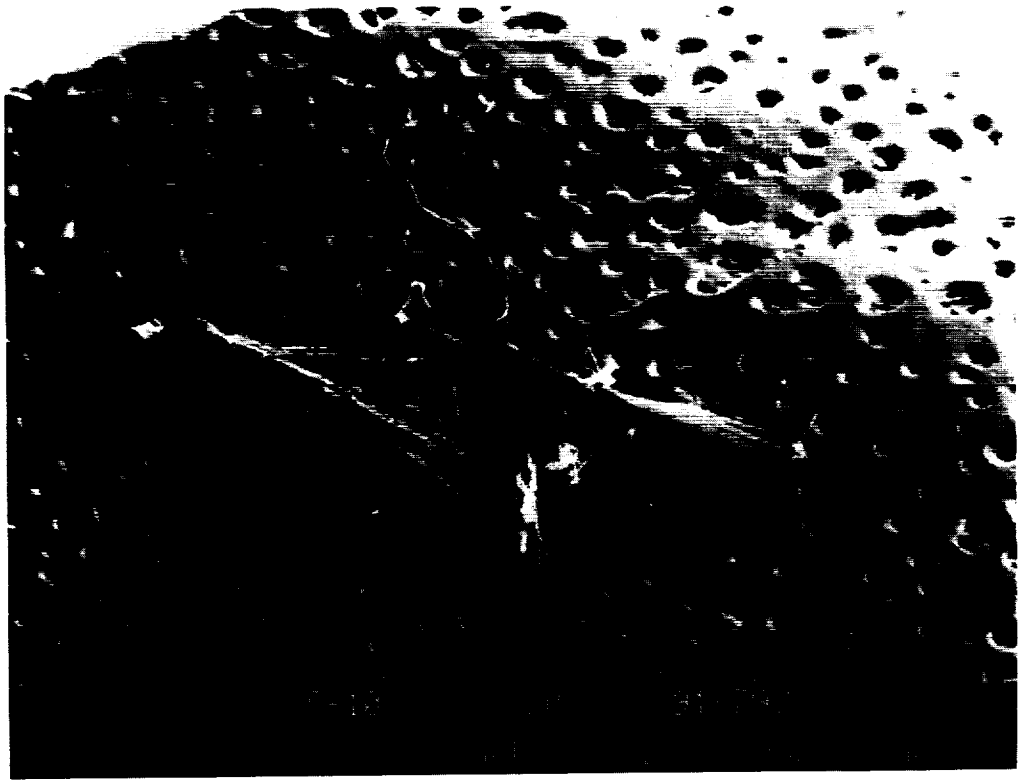

Figure 78. SEM of a sliver from sample C-10, metallic sliver.

Figure 79. SEM of sample C-38, metallic chip.

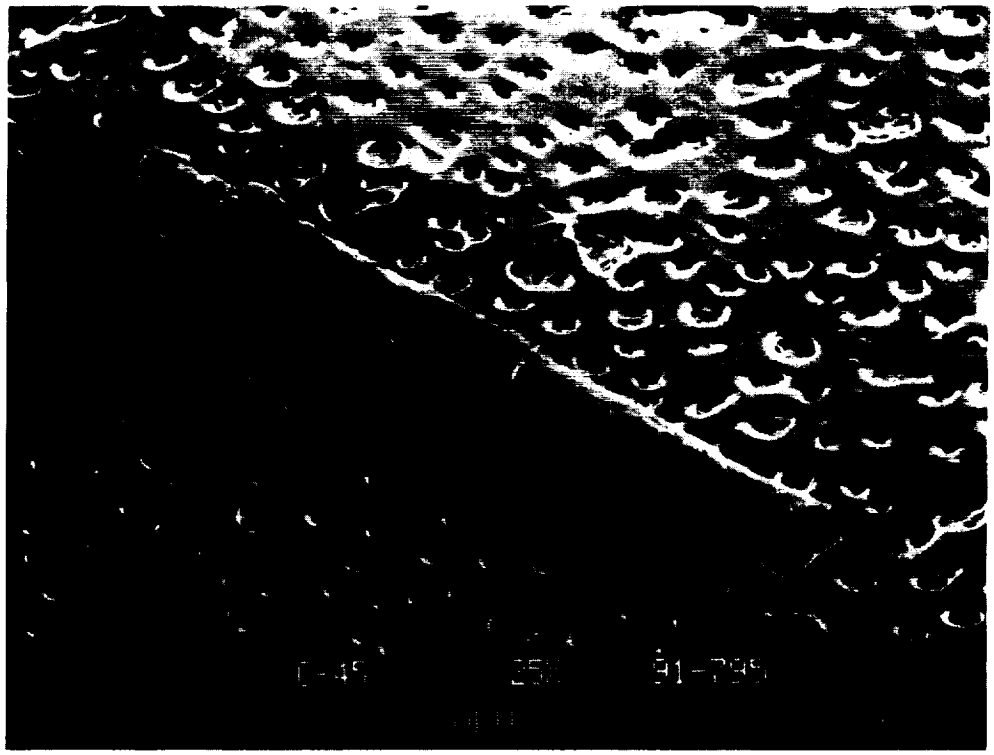

Figure 80. SEM of sample C-45, metallic chip.

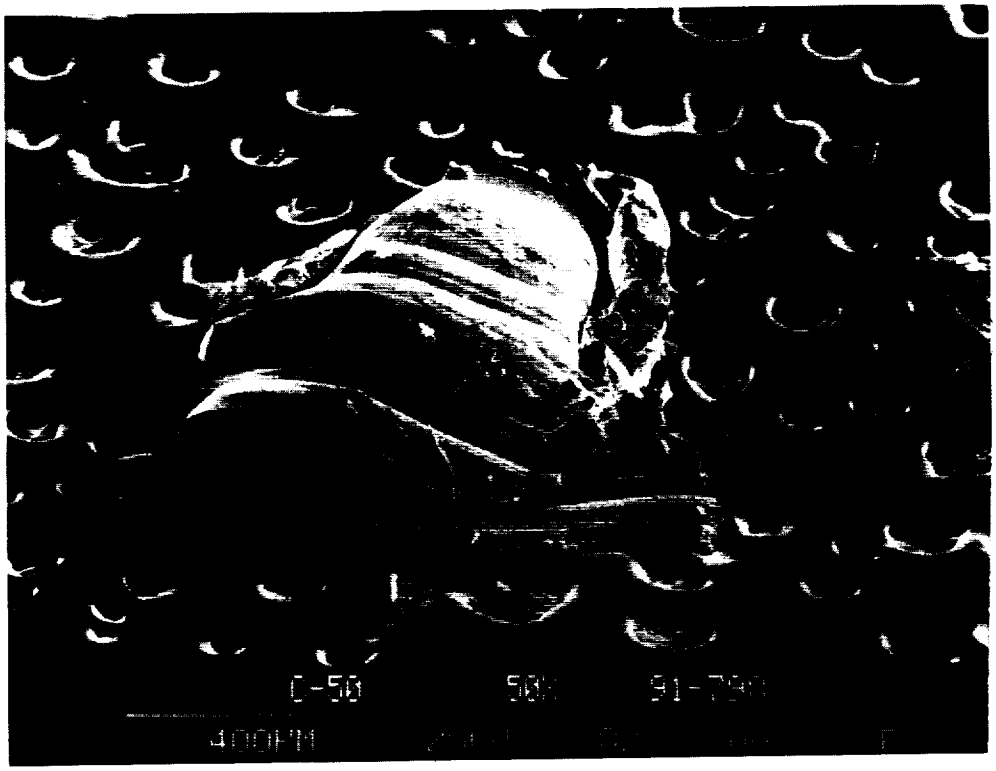

Figure 81. SEM of a sliver from sample C-49, metallic scraps.

Figure 82. SEM of a sliver from sample C-49, metallic scraps.

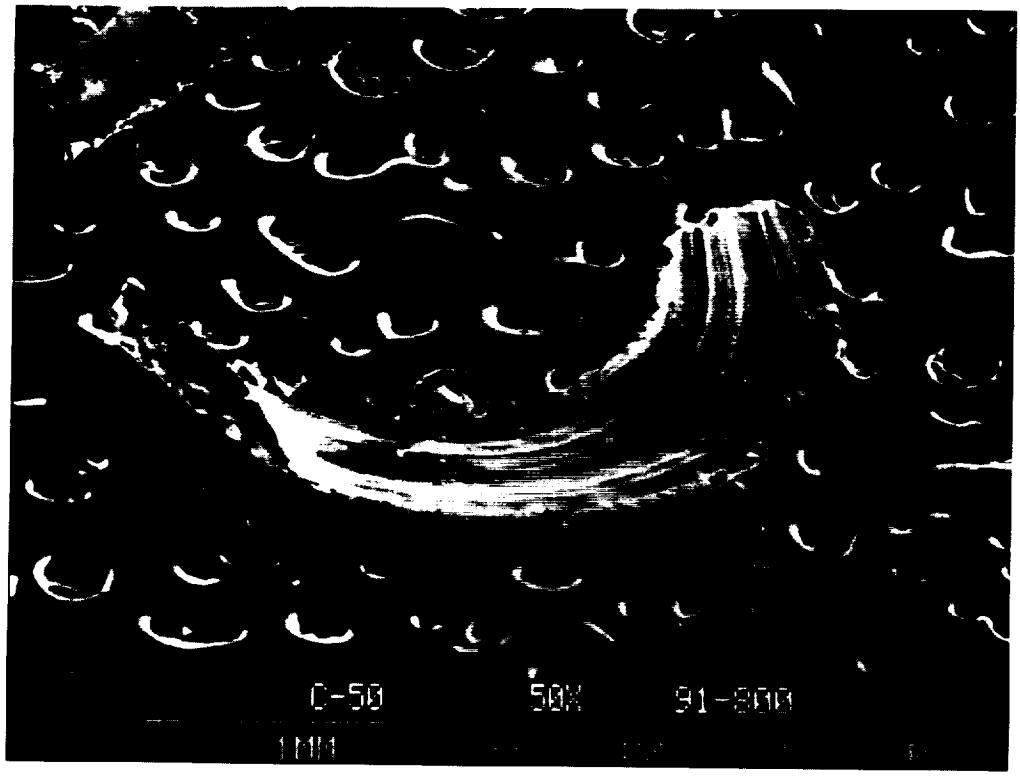

Figure 83. SEM of a sliver from sample C-49, metallic scraps.

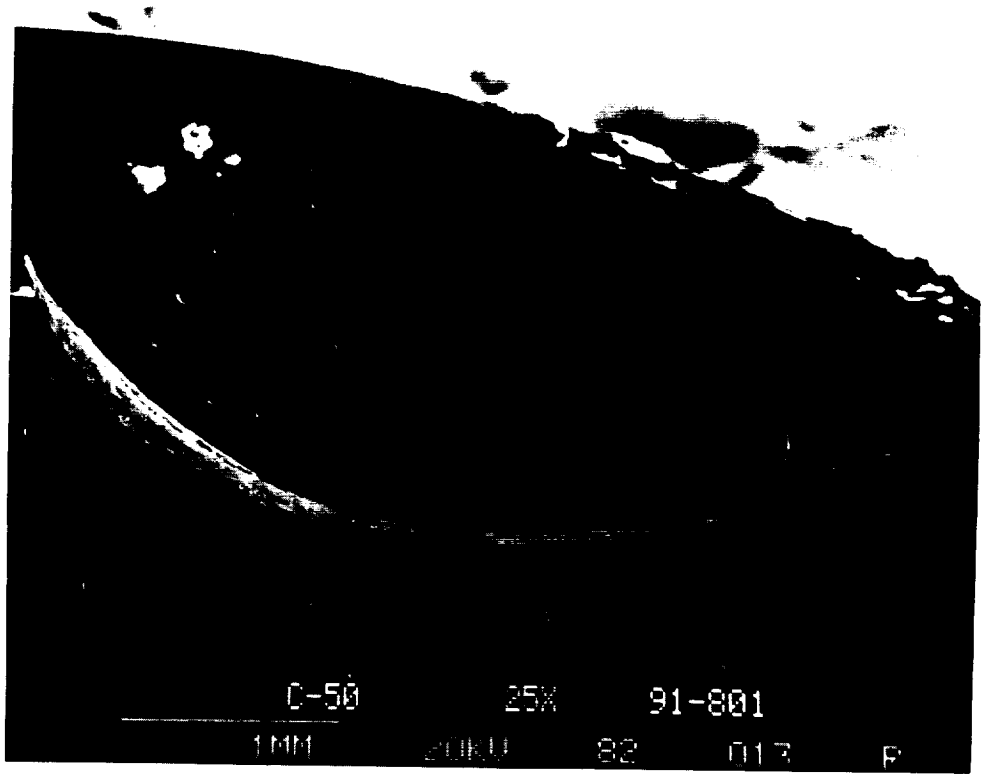

Figure 84. SEM of a sliver from sample C-49, metallic scraps.

Figure 85. SEM of sample A-8, wire.

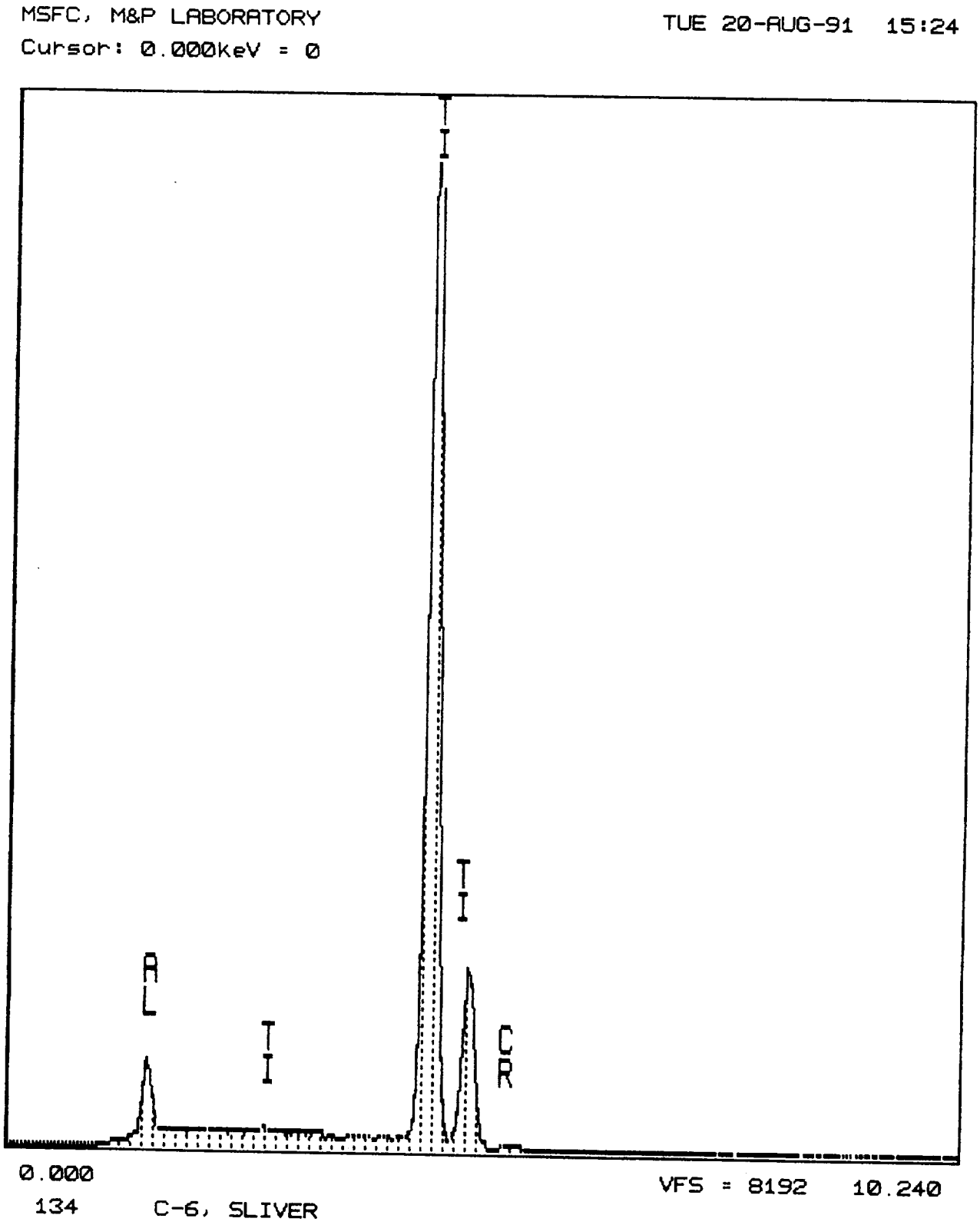

Figure 86. EDAX spectrum of sample C-6, metallic sliver.

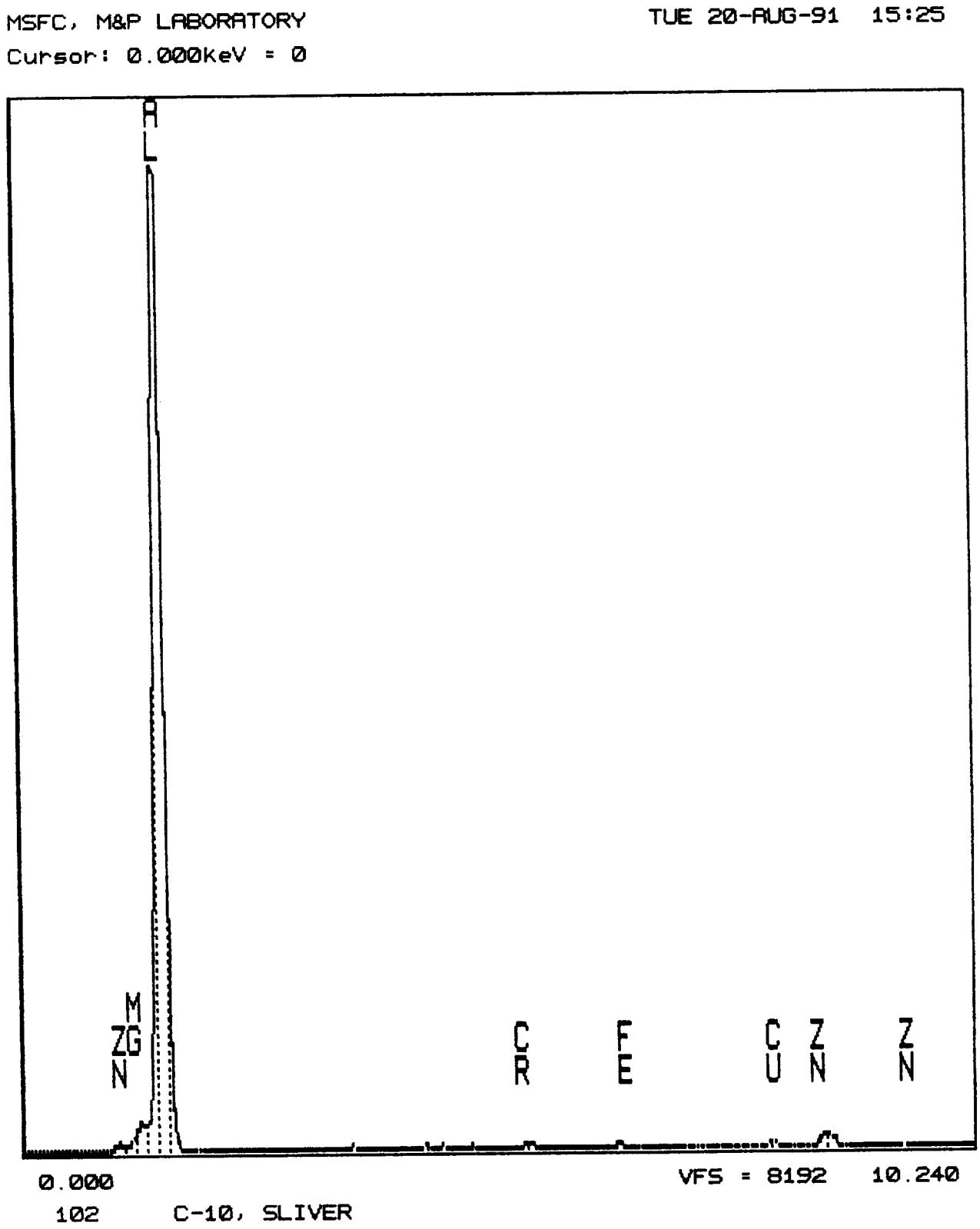

Figure 87. EDAX spectrum of a sliver from sample C-10, metallic scraps.

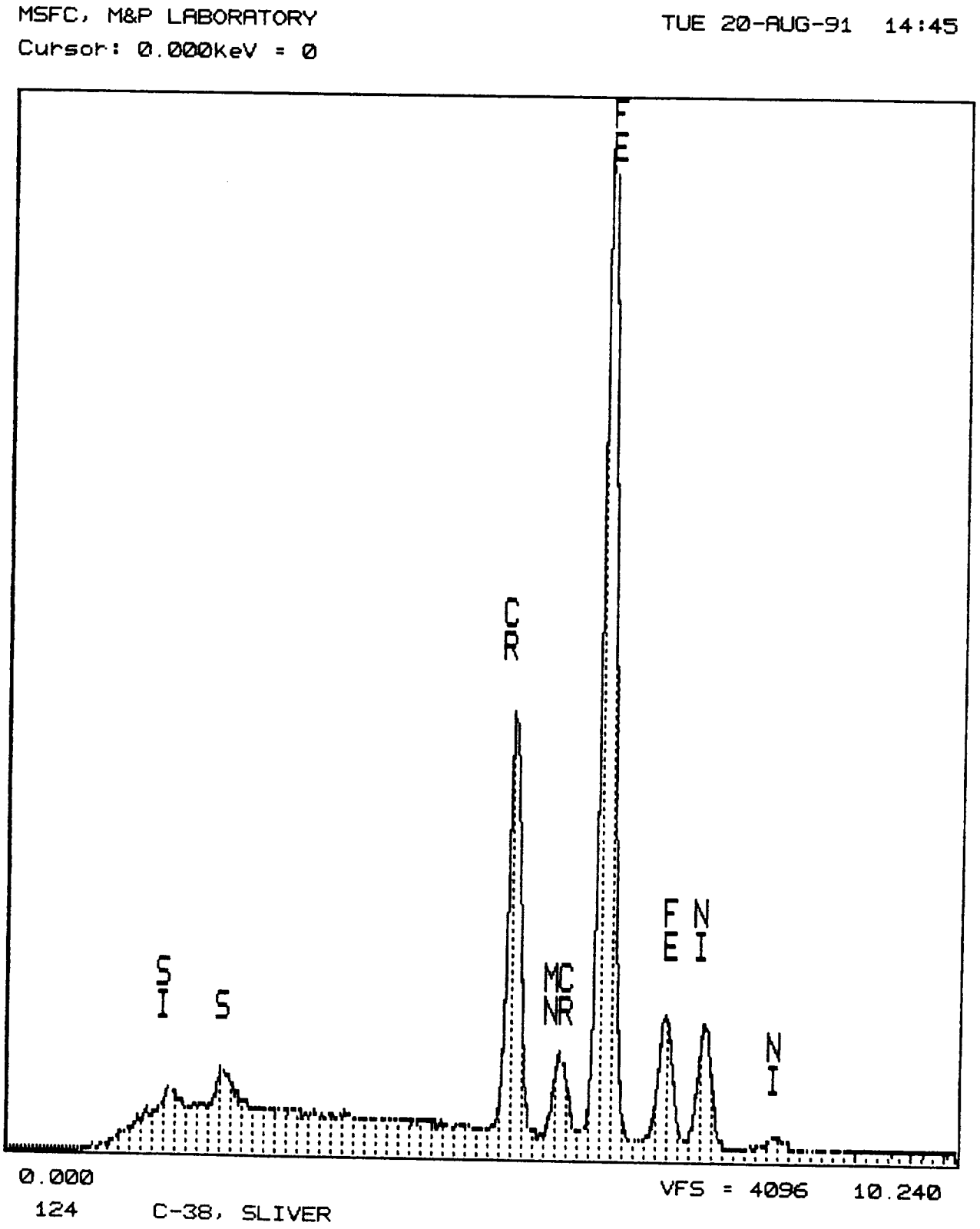

Figure 88. EDAX spectrum of sample C-38, metallic chip.

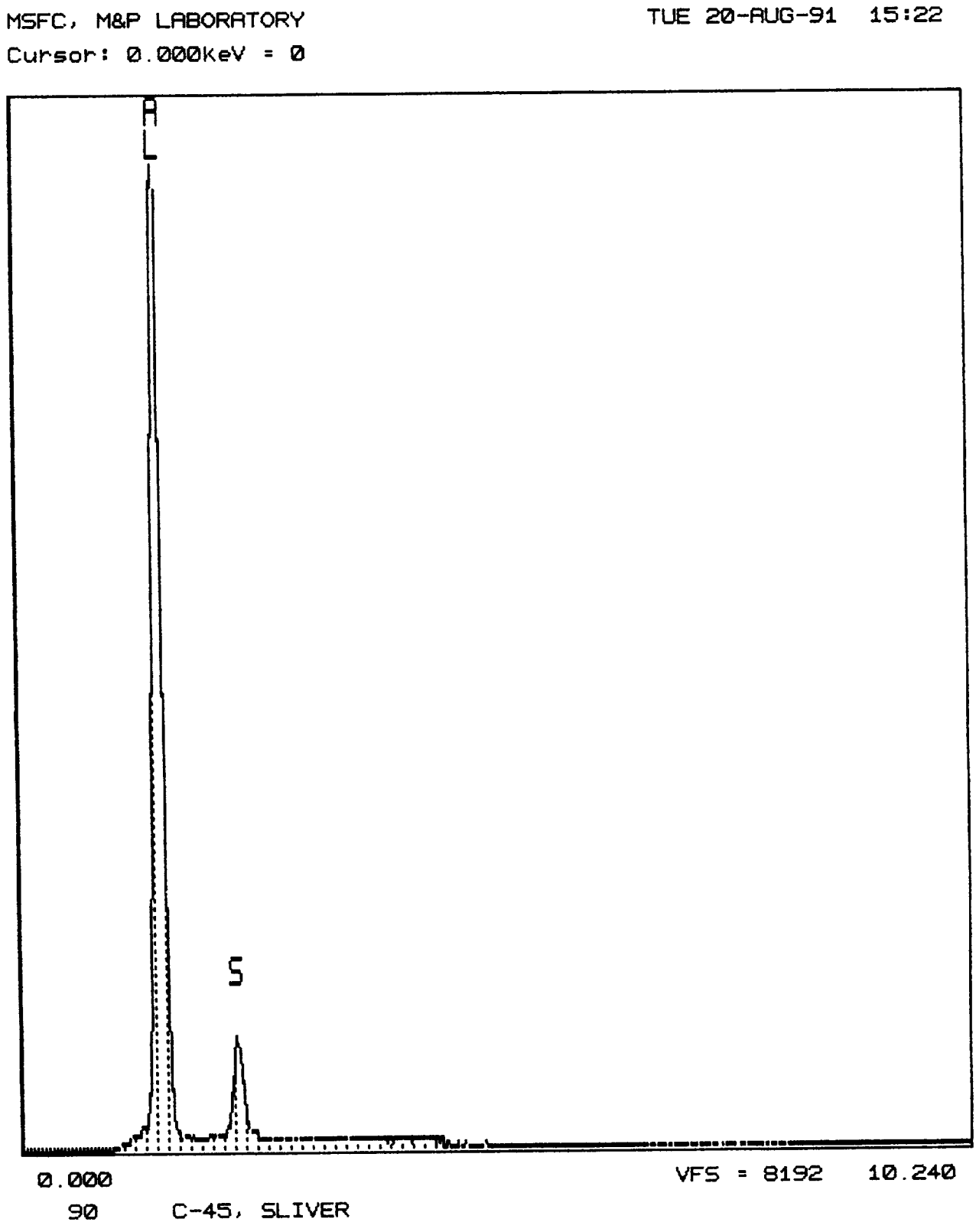

Figure 89. EDAX spectrum of sample C-45, metallic chip.

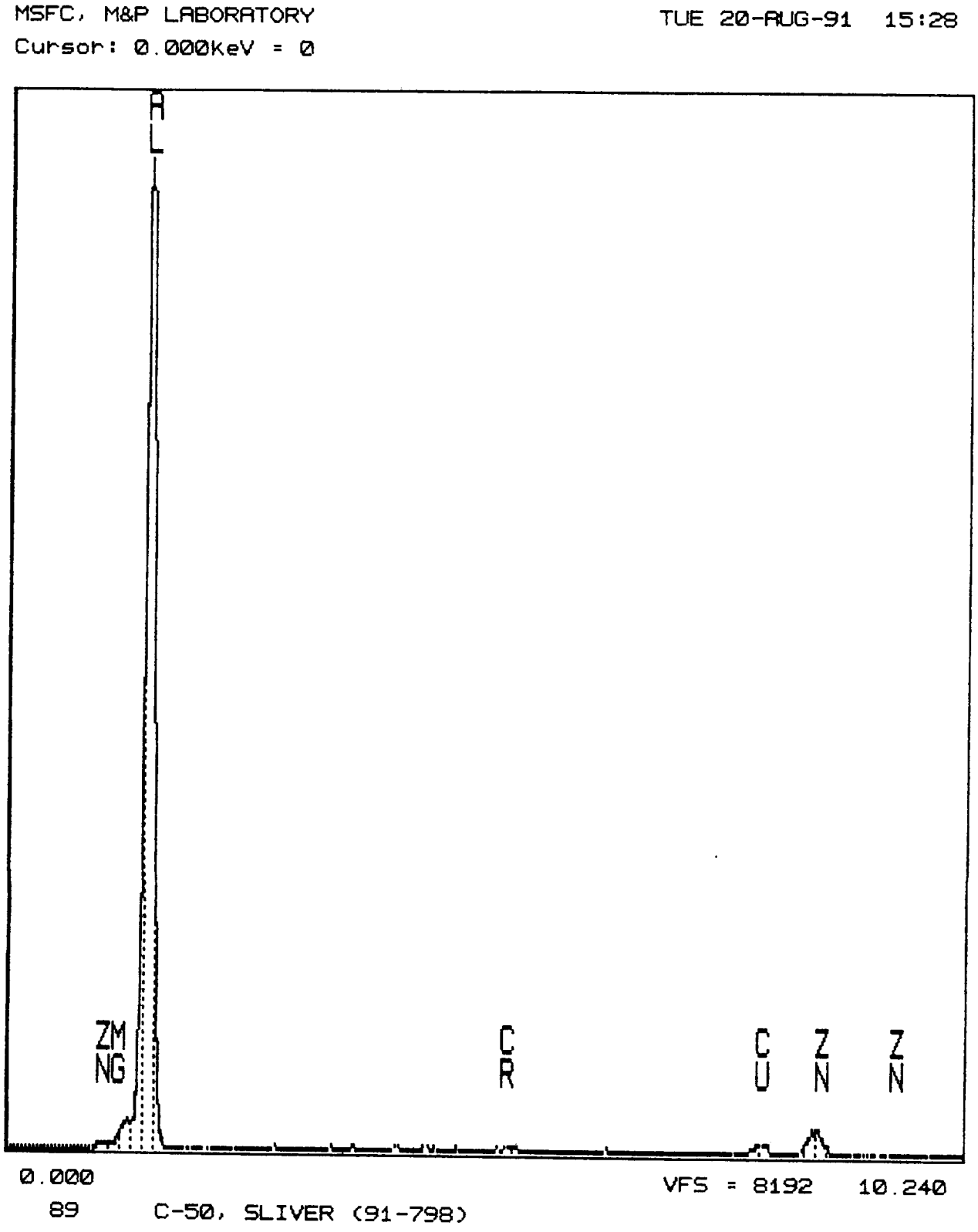

Figure 90. EDAX spectrum of a sliver from sample C-49, metallic scraps.

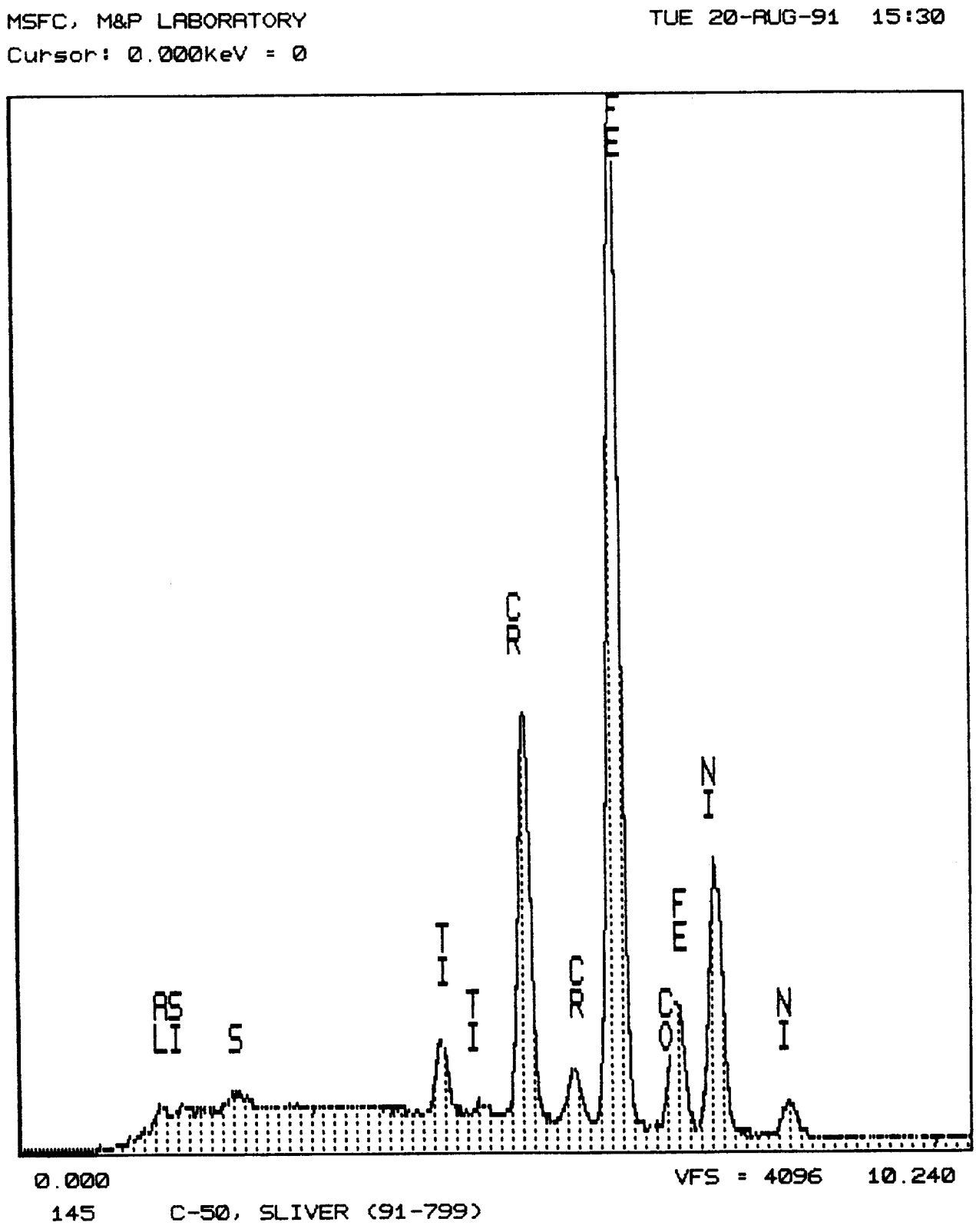

Figure 91. EDAX spectrum of a sliver from sample C-49, metallic scraps.

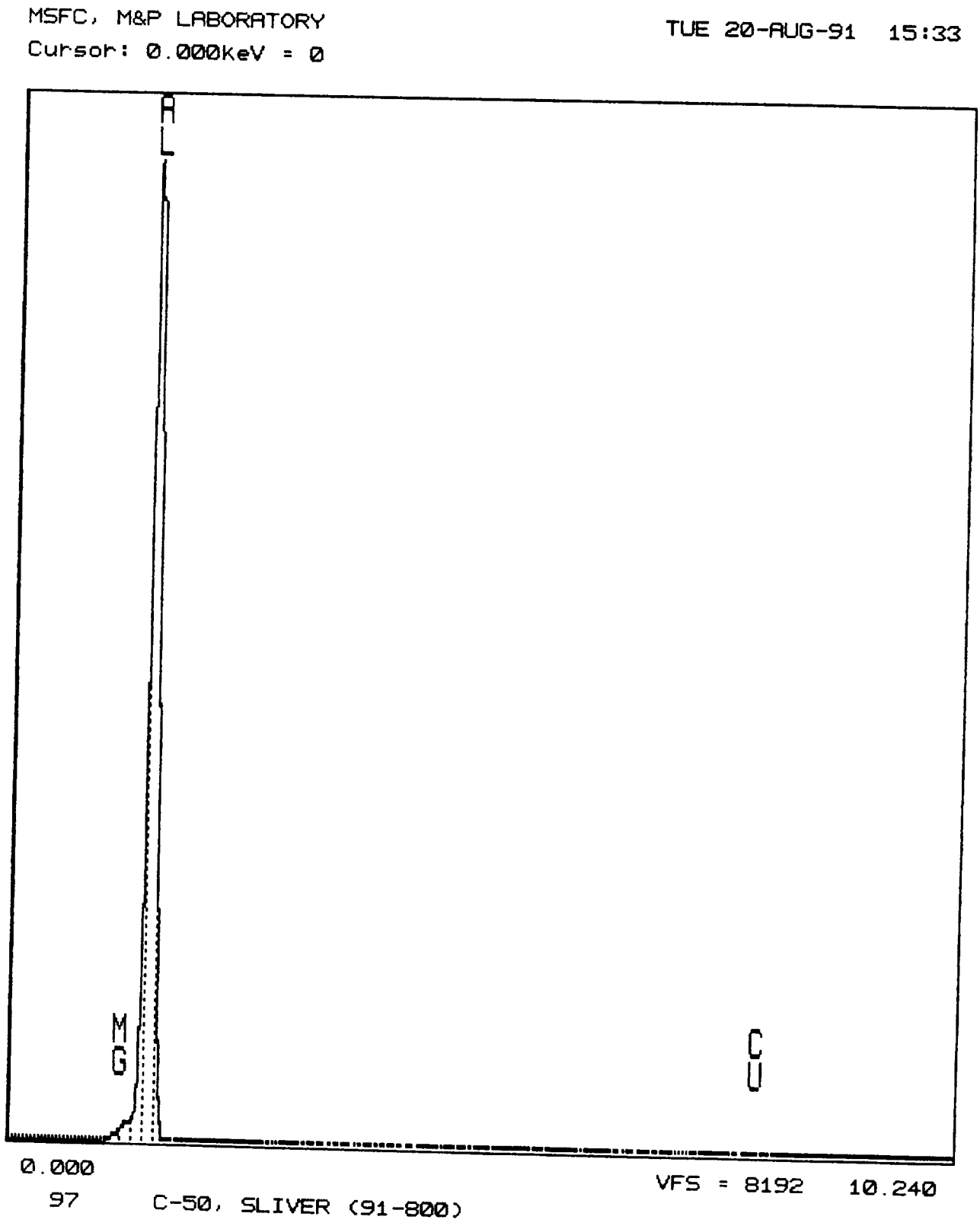

Figure 92. EDAX spectrum of a sliver from sample C-49, metallic scraps.

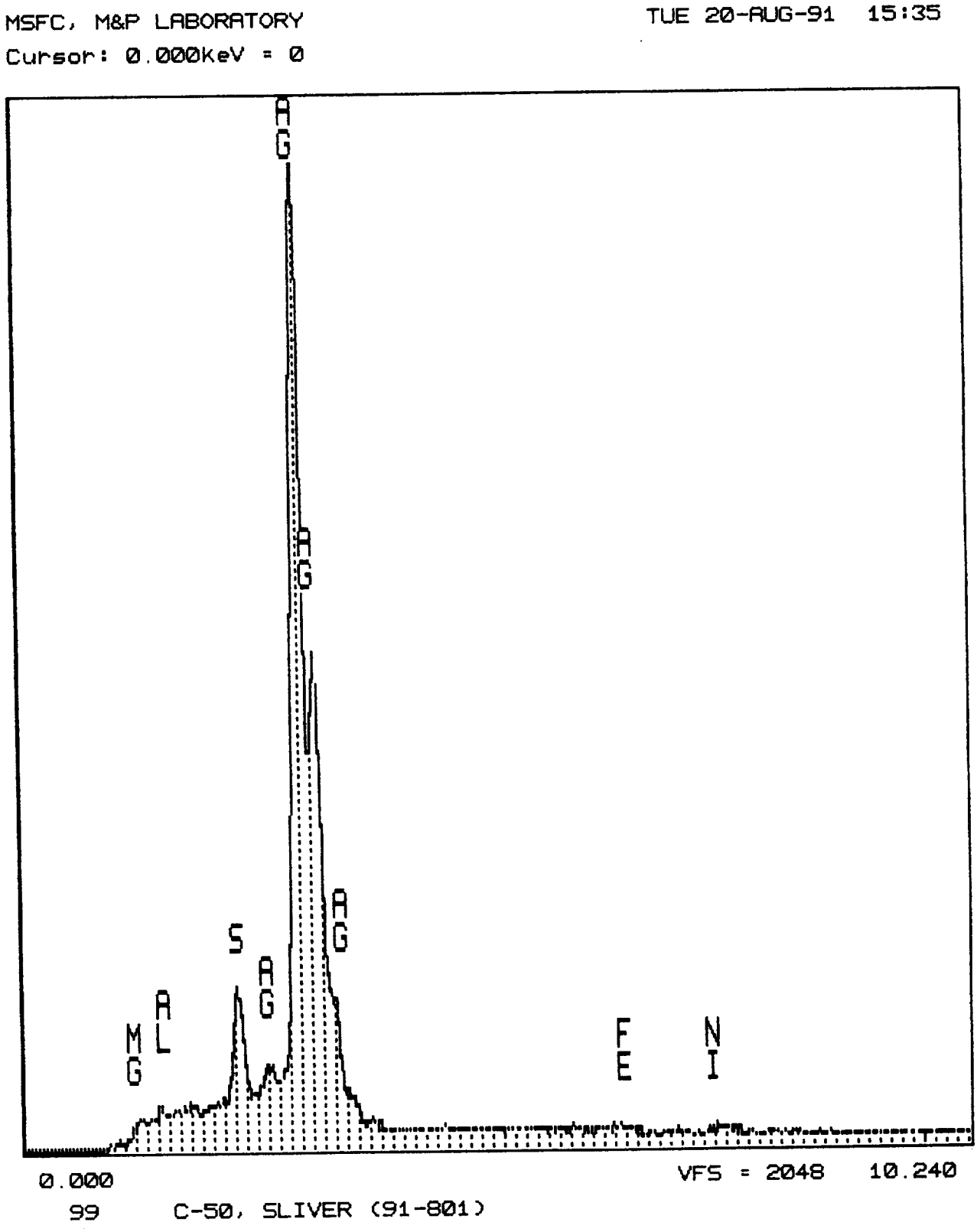

Figure 93. EDAX spectrum of a sliver from sample C-49, metallic scraps.

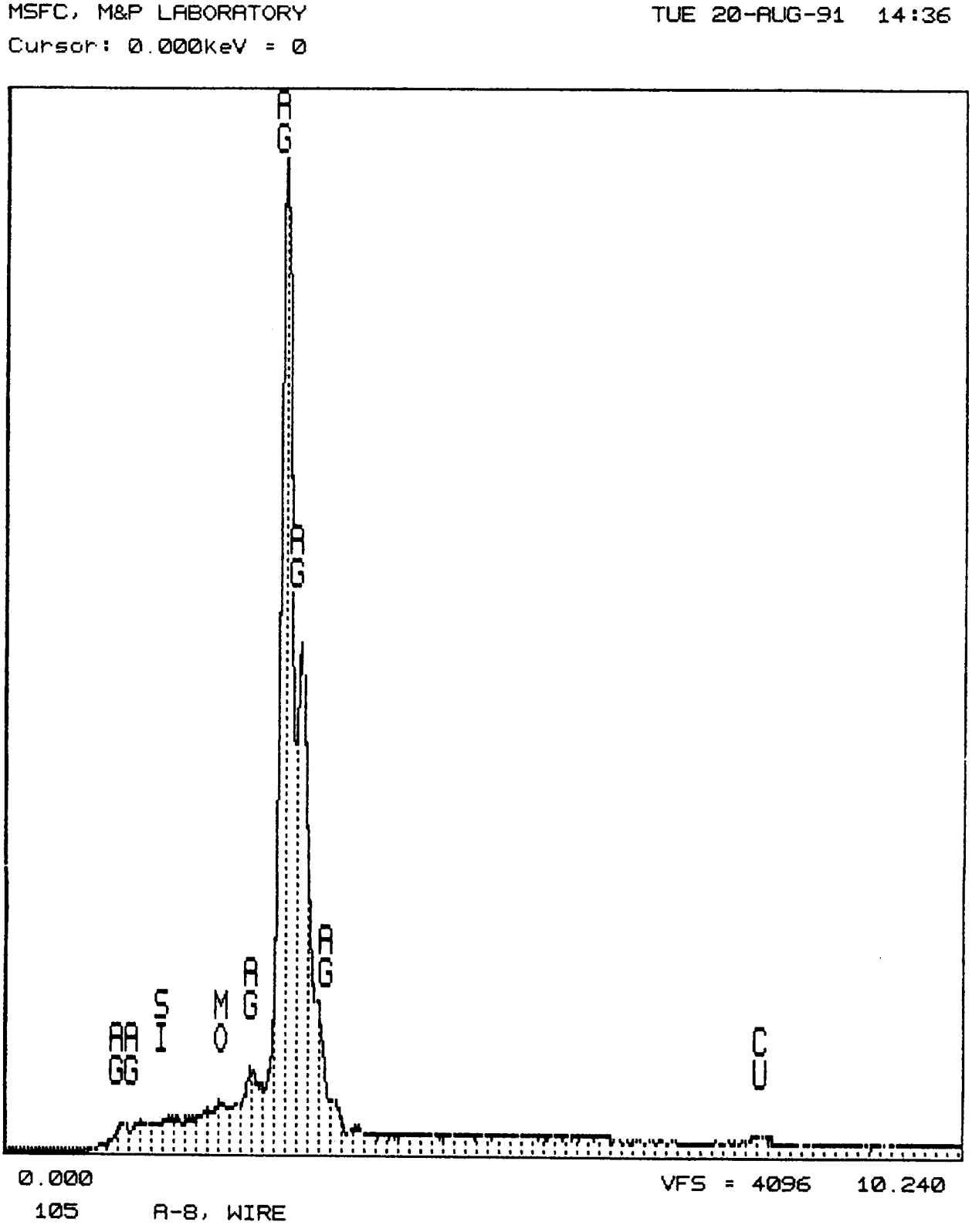

Figure 94. EDAX spectrum of sample A-8, wire.

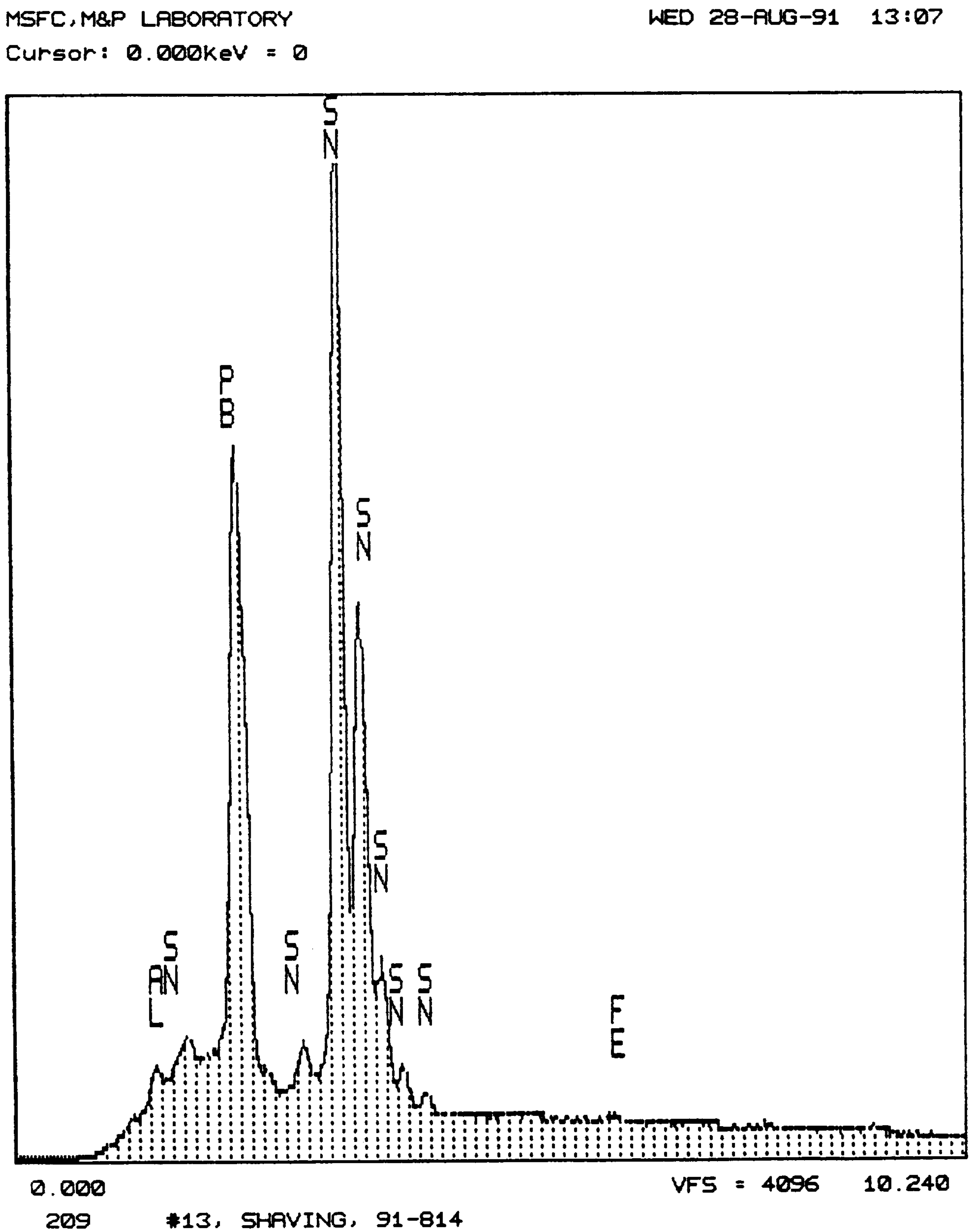

Figure 95. EDAX spectrum of a shaving from sample A-14, metallic bits.

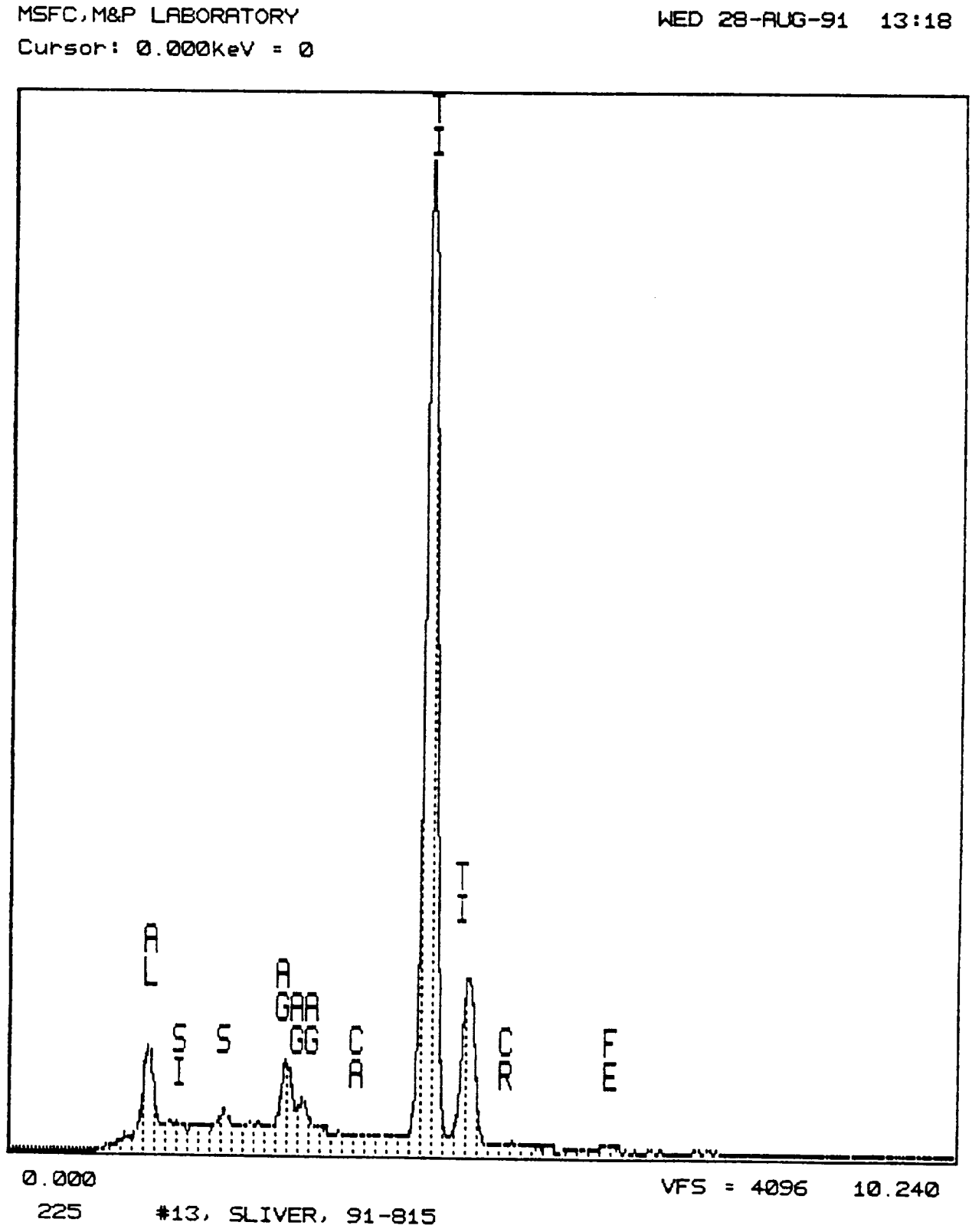

Figure 96. EDAX spectrum of a sliver from sample A-14, metallic bits.

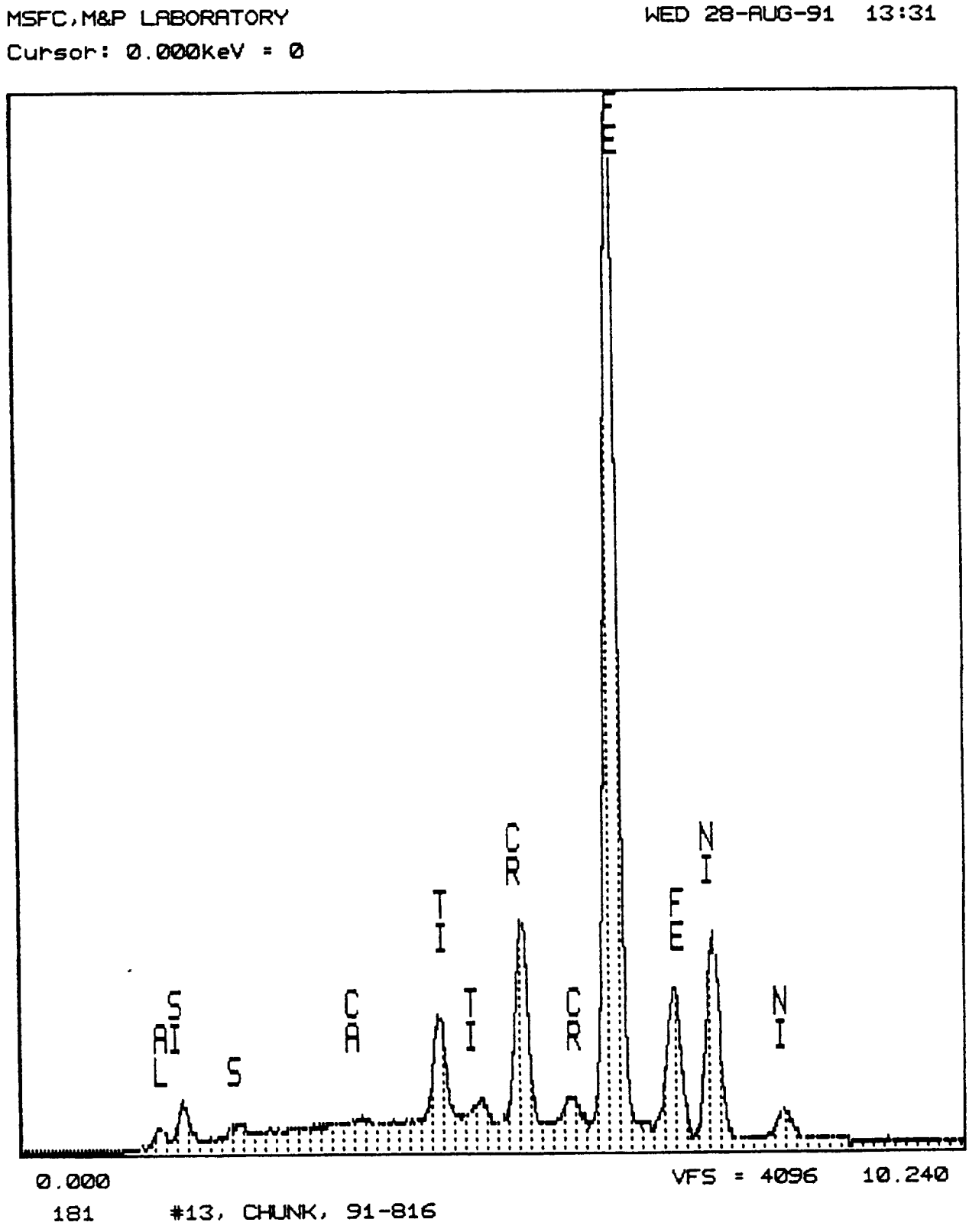

Figure 97. EDAX spectrum of a chunk from sample A-14, metallic bits.

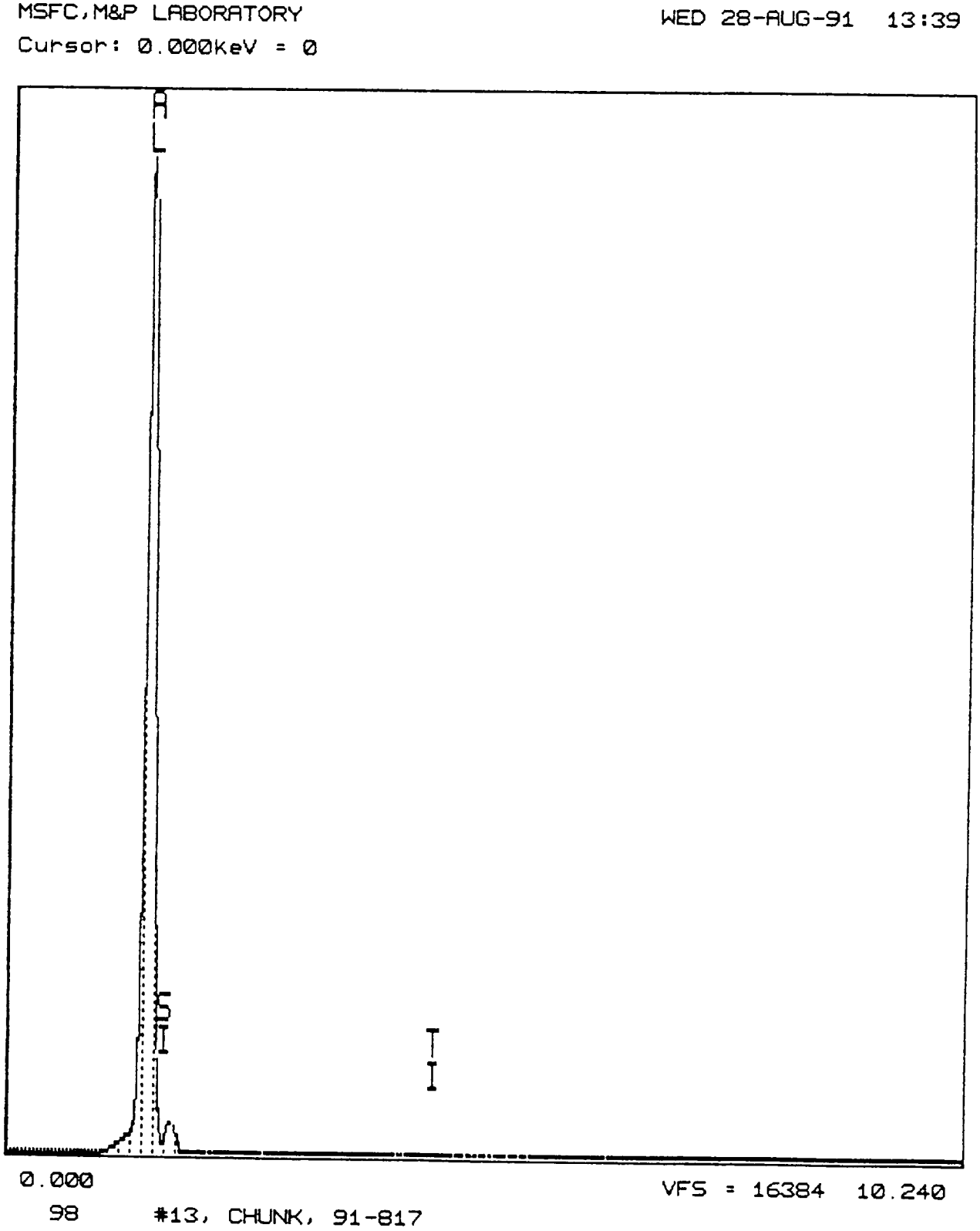

Figure 98. EDAX spectrum of a chunk from sample A-14, metallic bits.

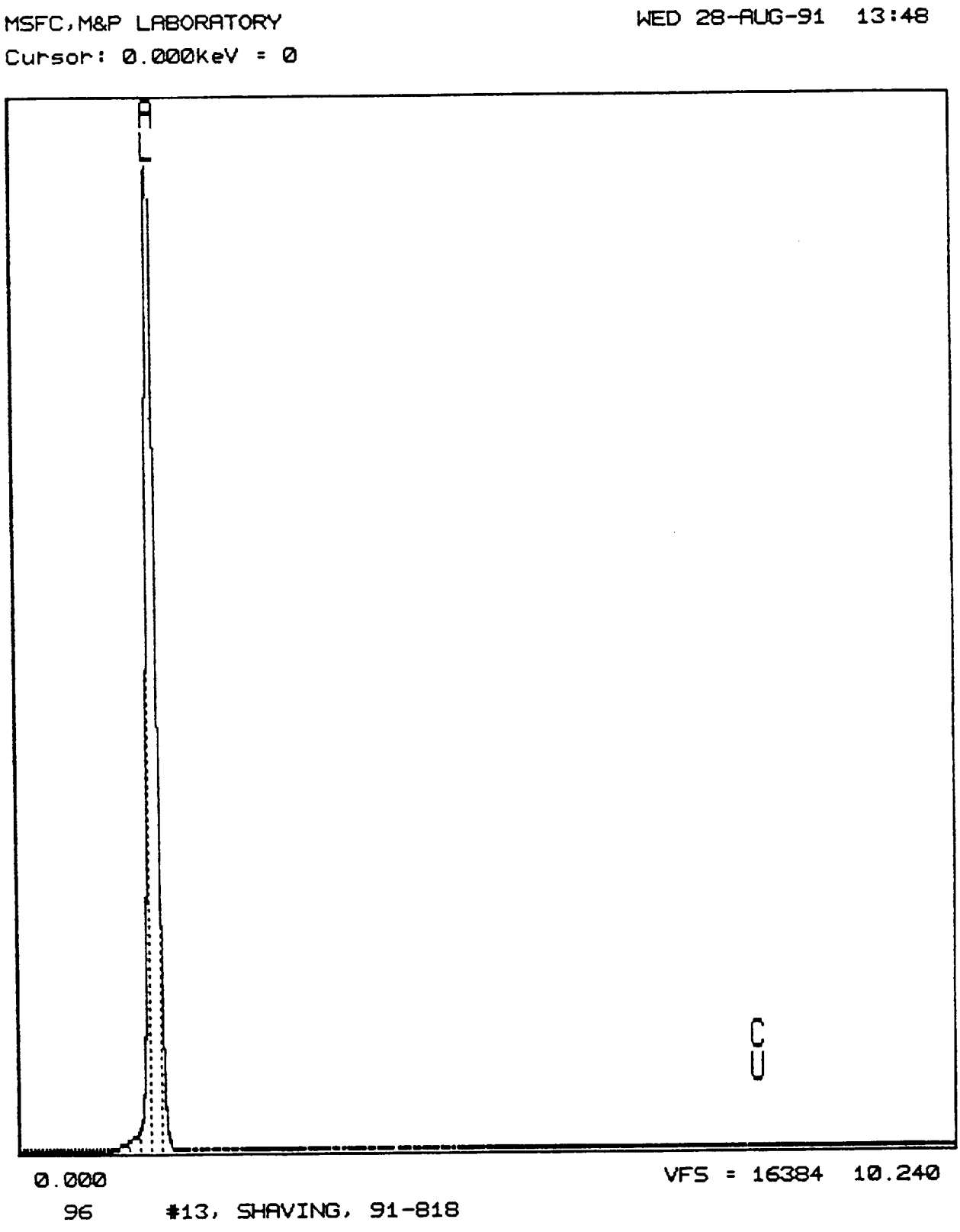

Figure 99. EDAX spectrum of a shaving from sample A-14, metallic bits.

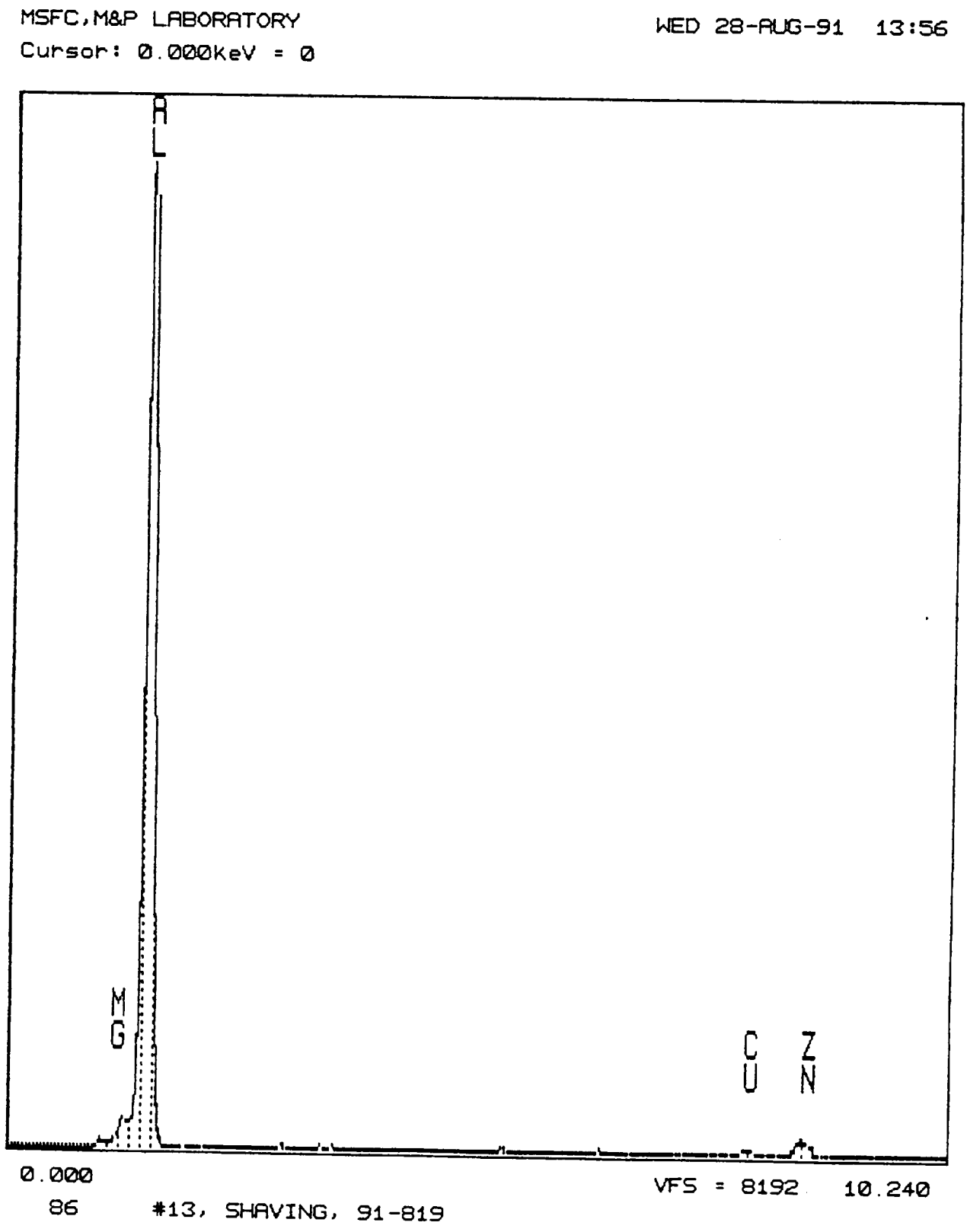

Figure 100. EDAX spectrum of a shaving from sample A-14, metallic bits.

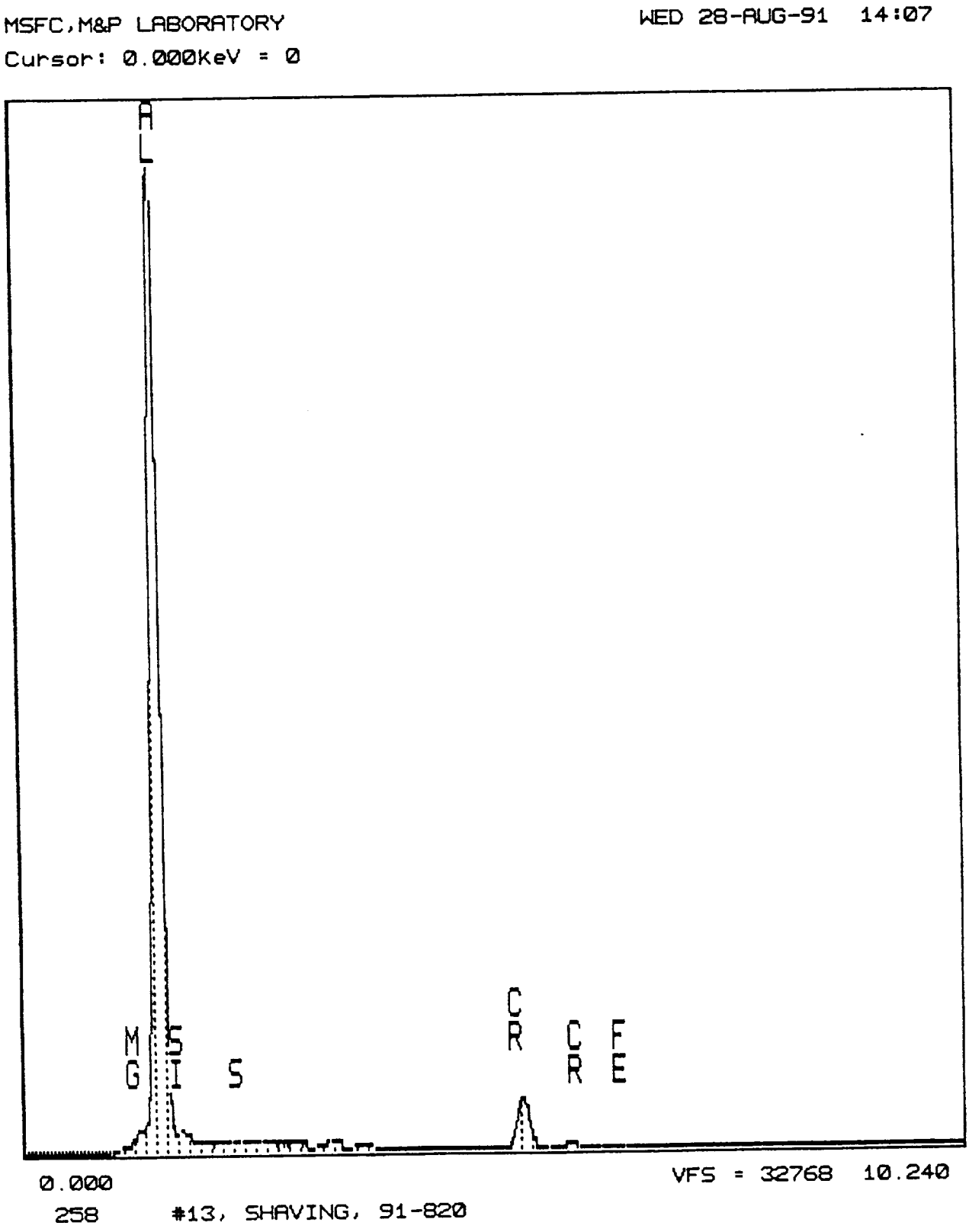

Figure 101. EDAX spectrum of a shaving from sample A-14, metallic bits.

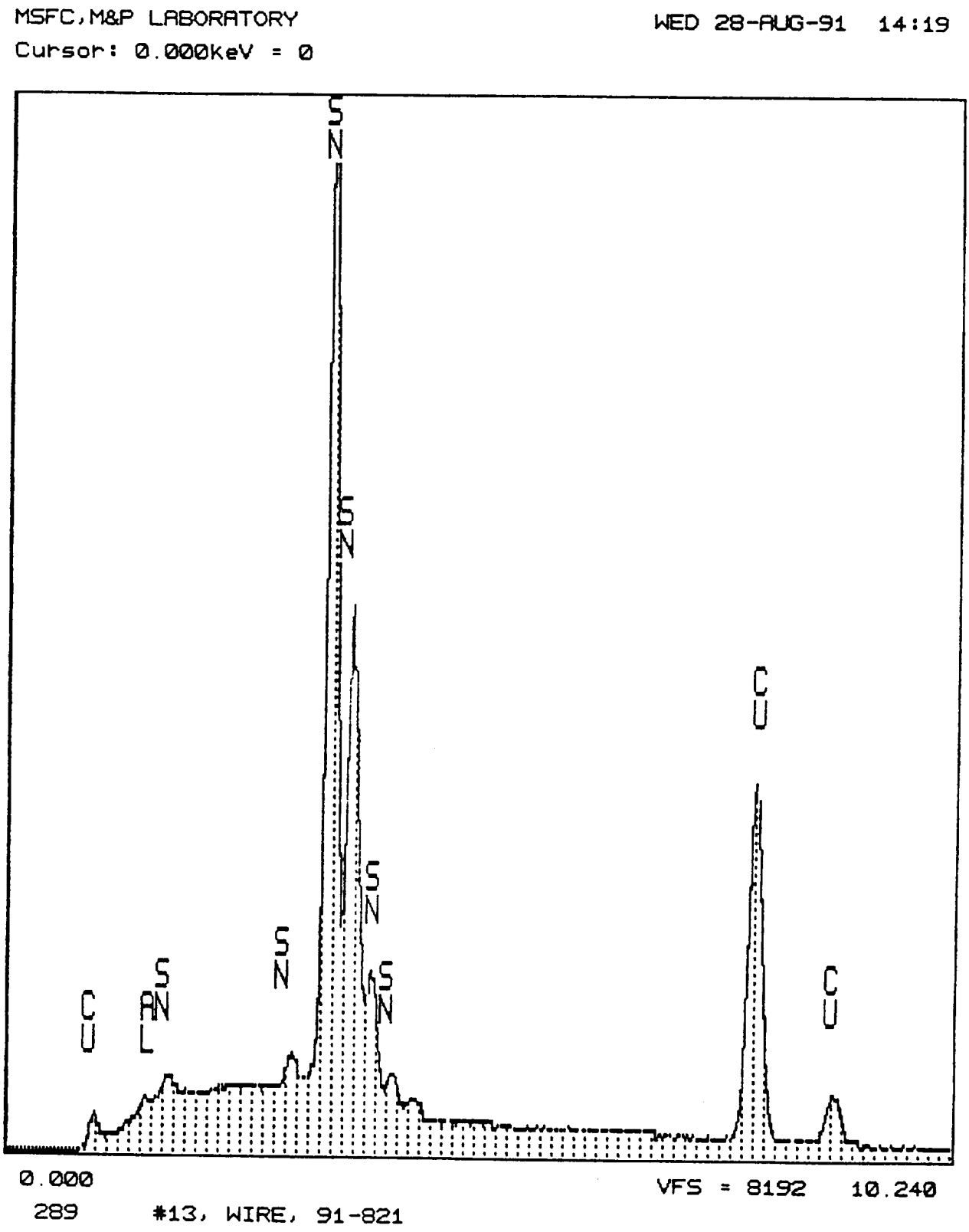

Figure 102. EDAX spectrum of a wire from sample A-14, metallic bits.

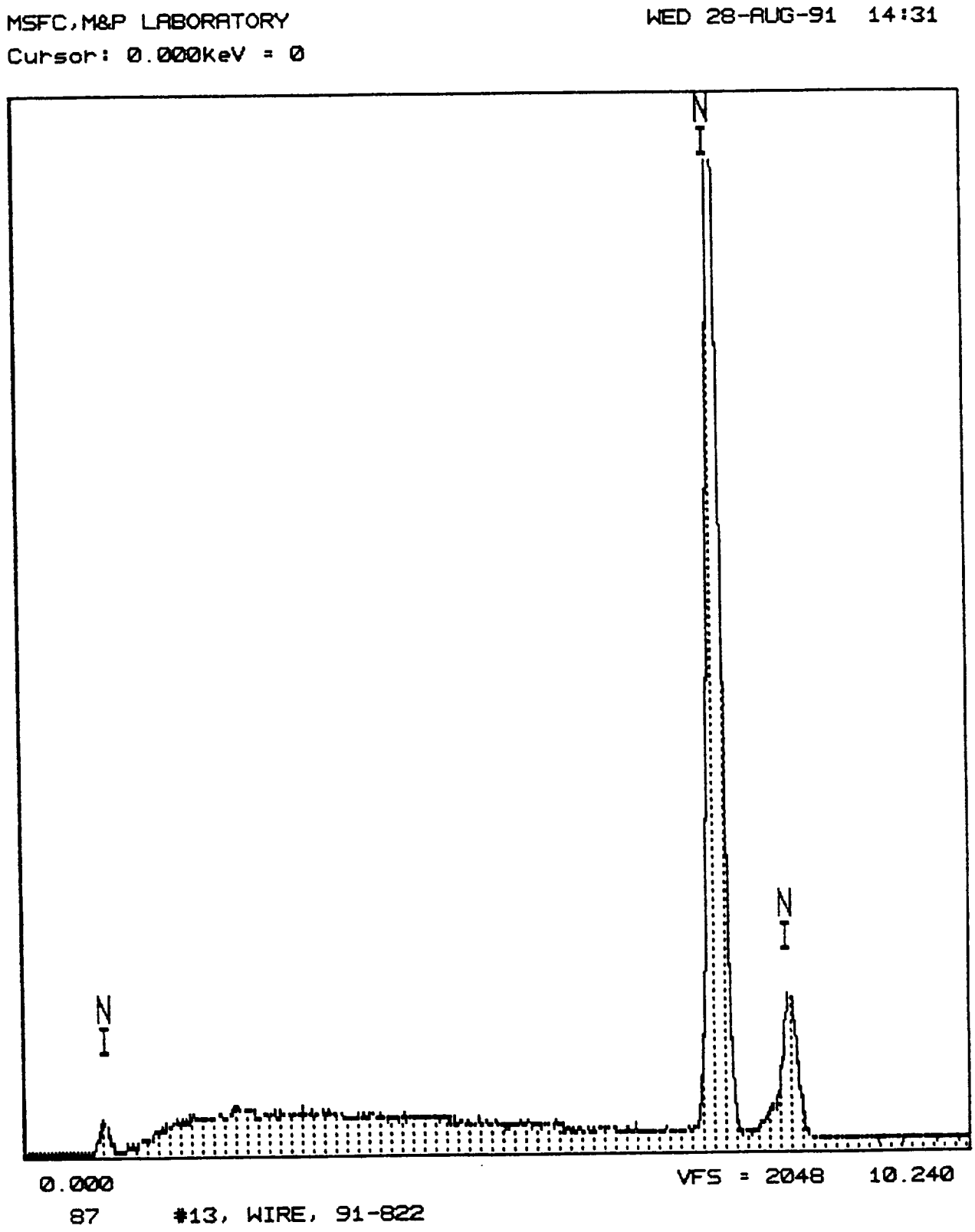

Figure 103. EDAX spectrum of a wire from sample A-14, metallic bits.

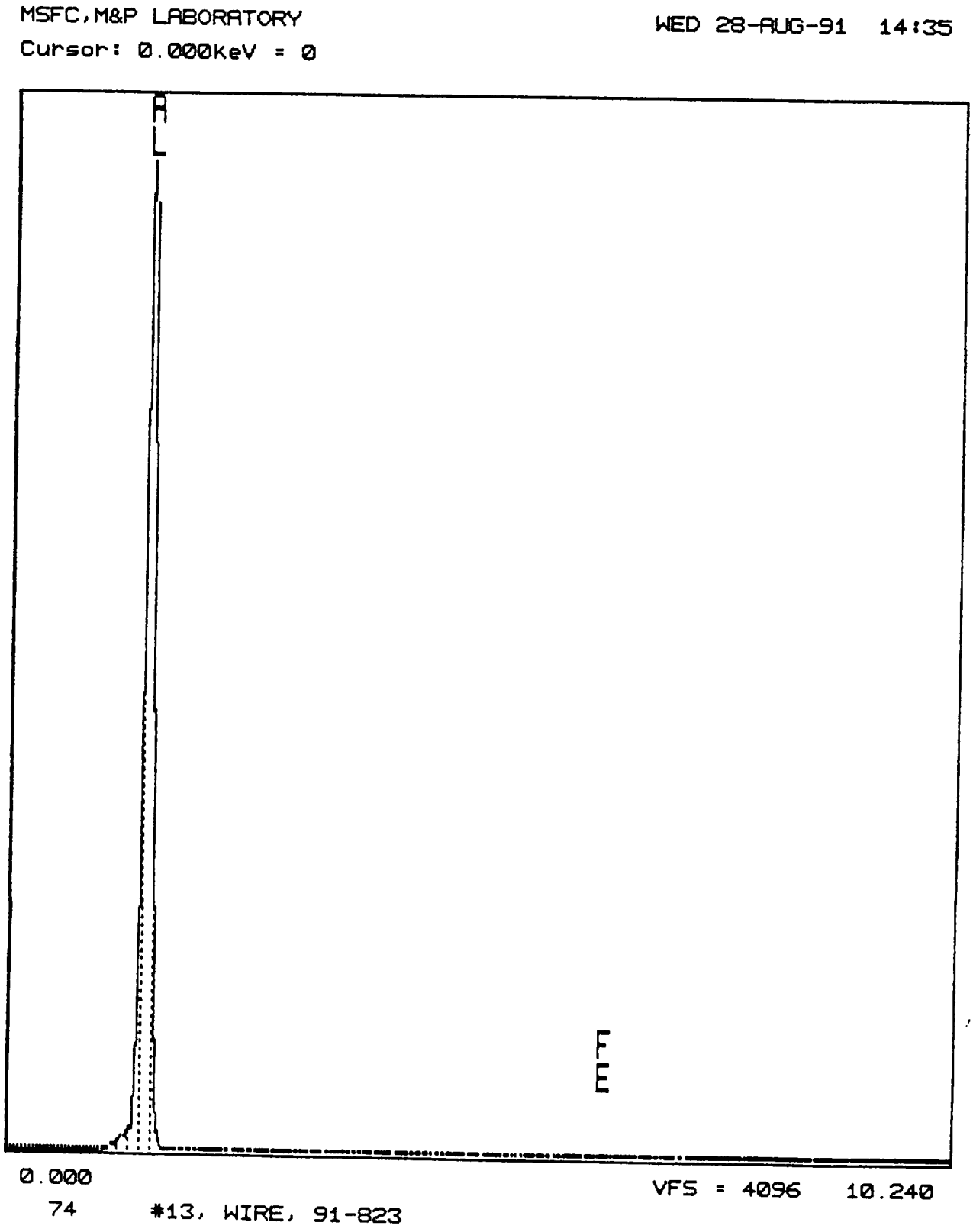

Figure 104. EDAX spectrum of a wire from sample A-14, metallic bits.

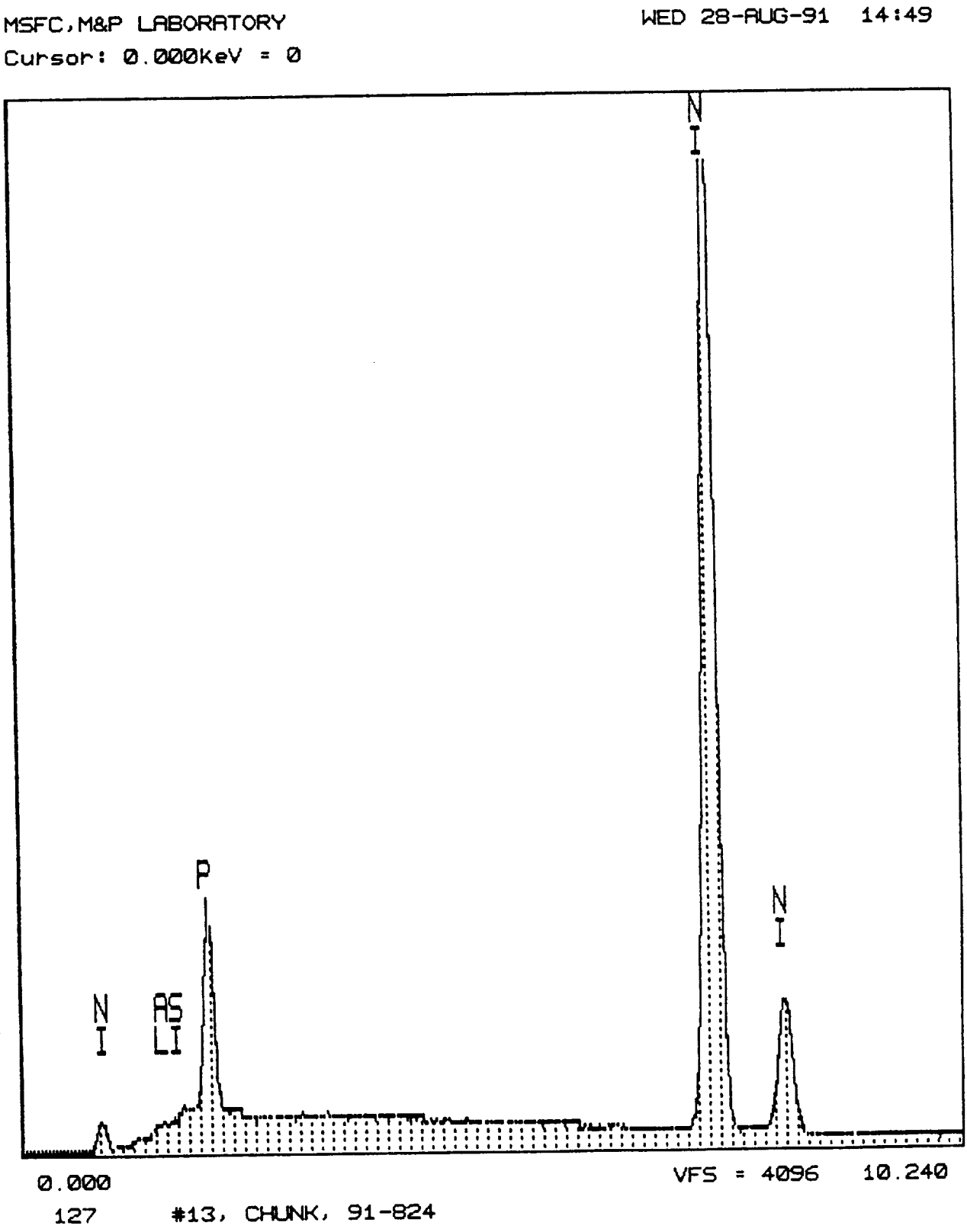

Figure 105. EDAX spectrum of a chunk from sample A-14, metallic bits.

APPENDIX A

FIGURES

43. Sample C-43, cream chip.
44. Sample C-44, cream chip.
45. Sample C-46, fiber.
46. Sample C-47, black foam.
47. Sample C-48, clear yellow chip.
48. Sample C-49, miscellaneous chips.
49. Sample A-1, clear, rubbery chip.
50. Sample A-2, thin brown flake.
51. Sample A-3, reddish rubbery chips.
52. Sample A-4, tan pliable flakes.
53. Sample A-5, red/cream chip.
54. Sample A-6, yellow, white thin honeycomb.
55. Sample A-7, yellow, white opaque chip.
56. Sample A-9, reddish brown flake with yellow.
57. Sample A-10, translucent mass of fibers.
58. Sample A-11, straight, white opaque fibers.
59. Sample A-12, translucent yellow fibrous chip.
60. Sample A-13, multicolor fibers.
61. Sample A-16, clear, plastic-like scrap.
62. Sample A-17, short multicolor fibers.
63. Sample A-18, opaque crystalline chips.
64. Sample A-19, green/gray grainy chips.
65. Sample A-21, green chips with glassy texture.
66. Sample A-22, red waxy scrap.
67. Sample A-23, gray/white foam.
68. Sample A-24, gray, semi-hard foam.
69. Sample A-25, pink foam/fiberglass.
70. Sample A-26, amber flakes.
71. Sample C-6, metallic sliver.
72. Sample C-10, metallic scrap.
73. Sample C-38, metallic chip.
74. Sample C-45, metallic chip.
75. Sample A-8, wire.
76. Sample A-14, metallic bits.
77. SEM of sample C-6, metallic sliver.
78. SEM of a sliver from sample C-10, metallic sliver.
79. SEM of sample C-38, metallic chip.
80. SEM of sample C-45, metallic chip.
81. SEM of a sliver from sample C-49, metallic scraps.
82. SEM of a sliver from sample C-49, metallic scraps.
83. SEM of a sliver from sample C-49, metallic scraps.
84. SEM of a sliver from sample C-49, metallic scraps.
85. SEM of sample A-8, wire.
86. EDAX spectrum of sample C-6, metallic sliver.
87. EDAX spectrum of a sliver from sample C-10, metallic scraps.
88. EDAX spectrum of sample C-38, metallic chip.
89. EDAX spectrum of sample C-45, metallic chip.
90. EDAX spectrum of a sliver from sample C-49, metallic scraps.
91. EDAX spectrum of a sliver from sample C-49, metallic scraps.

92. EDAX spectrum of a sliver from sample C-49, metallic scraps.
93. EDAX spectrum of a sliver from sample C-49, metallic scraps.
94. EDAX spectrum of sample A-8, wire.
95. EDAX spectrum of a shaving from sample A-14, metallic bits.
96. EDAX spectrum of a sliver from sample A-14, metallic bits.
97. EDAX spectrum of a chunk from sample A-14, metallic bits.
98. EDAX spectrum of a chunk from sample A-14, metallic bits.
99. EDAX spectrum of a shaving from sample A-14, metallic bits.
100. EDAX spectrum of a shaving from sample A-14, metallic bits.
101. EDAX spectrum of a shaving from sample A-14, metallic bits.
102. EDAX spectrum of a wire from sample A-14, metallic bits.
103. EDAX spectrum of a wire from sample A-14, metallic bits.
104. EDAX spectrum of a wire from sample A-14, metallic bits.
105. EDAX spectrum of a chunk from sample A-14, metallic bits.

APPENDIX B

LIST OF PARTICULATE MATERIALS FROM SLS-1 SORTED VISUALLY FOR CHEMICAL ANALYSIS

C samples from cabin

A samples from avionics

C-1 hair (?)
C-2 nonmetallic fiber
C-3 nonmetallic fiber
C-4 clear, nonmetallic, curled film
C-5 nonmetallic clear, flat film
C-6 metallic sliver
C-7 nonmetallic red fiber
C-8 nonmetallic greenish fiber
C-9 lint, blue
C-10 silver color metal flecks
C-11 tangled masses of white nonmetallic fibers
C-12 yellow nonmetallic fleck
C-13 ear plug, bisected
C-14 gray foam
C-15 dark gray foam
C-16 peanut pieces
C-17 clear plastic "sleeve"
C-18 plastic pieces for electronics?
C-19 elliptical "rubbery" pieces, look as if they have been poured
C-20 white foam
C-21 rigid, white woven fibers
C-22 pliable gray, blue synthetic material
C-23 nonmetallic, translucent, flat material
C-24 rigid foam, gray with brown surface
C-25 pliable gray foam, fine grain, squared shape
C-26 nonmetallic, congealed (looks as if it had been poured), clear, yellowish
C-27 paper? white and brown
C-28 blue fiber
C-29 colorless, translucent fibers, smooth, elastic
C-30 bright green pliable nonmetal
C-31 blue fiber
C-32 pliable cream-color opaque nonmetal fleck (paint?)
C-33 small flexible nonmetallic fleck, ivory color
C-34 small blob, clear, yellowish, nonmetal
C-35 nonmetallic, grayish, appears to have many fibers running linearly through it (fiberglass?, insulating or coating material?) low luster
C-36 blue "paint" chip
C-37 orange nonmetallic flecks
C-38 metallic fleck

C-39 rough, nonmetallic, flat, gray material
C-40 pale, blue-gray, nonmetal, small fleck
C-41 small black molded chunk, shiny on one side
C-42 small fleck, white on one side, yellow-green on the other, "leafy" in shape
C-43 cream colored nonmetallic nugget
C-44 white fleck, flat, thin, rough on one side, smooth on the other, nonmetal
C-45 metallic fleck, shiny on one side, black on the other
C-46 nonmetallic, fibrous (cellulose?) material
C-47 black foam, nonmetal
C-48 nonmetal, rigid fleck, yellowish, translucent, shiny
C-50 miscellaneous metal flecks and shavings

A-1 nonmetallic, translucent rubbery (silicone?)
A-2 nonmetallic, brown, thin, membranous, looks like dried scum from a surface
A-3 nonmetallic, reddish brown, rubbery as in a pencil eraser or rubber band
A-4 nonmetallic, thin, light tan, pliable, rubbery
A-5 nonmetallic, reddish color on one side with cream color on the other side, opaque, (paint chip?)
A-6 nonmetallic, grayish-green, tiny honeycomb appearance, foam material? (color, appearance similar to lichen)
A-7 nonmetallic, opaque yellow on one side with glossy white or greenish color on the other side (paint chips?)
A-8 metallic, thin piece of wire, silvery
A-9 nonmetallic, reddish-brown with some yellow markings, membranous, thin, curled, yellow material has a translucent, glassy, crystalline appearance
A-10 nonmetallic, translucent, colorless, elastic, tangled mass of fibers
A-11 nonmetallic, straight, white, opaque fibers, cellulose?
A-12 nonmetallic, translucent, tannish-yellow, rigid, some fibers of this material extending from some particles
A-13 nonmetallic, mass of fibers, some red, blue, black, clear, colorless, varying thicknesses, clear ones nylon?
A-14 metallic particles
A-15 nonmetallic, black, checkerboard structure, tiny piece of solder attached to one bit, one bit has a greenish yellow uneven crystalline coating on one side, one tiny dome-shaped piece is glossy black on both sides (no checkerboard pattern), carbon?
A-16 nonmetallic, translucent, colorless, crumpled, plastic wrap?
A-17 nonmetallic, short threads, blue, clear, yellow, nylon?
A-18 nonmetallic, opaque, grayish-green to grayish-white, crystalline, rigid
A-19 metallic, shiny, silvery with black and white specks, grainy texture
A-20 nonmetallic, translucent, glassy
A-21 nonmetallic, green, grainy texture
A-22 nonmetallic, red, waxy or plastic appearance, rigid
A-23 nonmetallic, grayish-white, foam
A-24 nonmetallic, semi-shiny, gray, semi-hard, foamy appearance
A-25 nonmetallic, pink, foam or fiberglass, glassy splinters protruding
A-26 nonmetallic, translucent amber, pliable

APPROVAL

ANALYSIS OF DEBRIS FROM SPACELAB LIFE SCIENCES-1

By S.V. Caruso, E.B. Rodgers, and T.L. Huff

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

P.H. SCHUERER
Director, Materials and Processes Laboratory

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