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Lyndon B. Johnson Space Center
Houston. Texas 77058

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COSMIC DUST CATALOG

(PARTICLES FROM COLLECTION FLAG U2015)

COMPILED BY

COSMIC DUST PRELIMINARY EXAMINATION TEAM (CDPET)

OCTOBER 1984

Volume 5
Number 1

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NASA/Johnson Space Center
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October, 1984

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1. INTRODUCTION

Since May, 1981, the National Aeronautics and Space Administration (NASA) has used aircraft to collect cosmic dust (CD) particles from Earth's stratosphere. Specially designed dust collectors are prepared for flight and processed after flight in an ultraclean (Class-100) laboratory constructed for this purpose at the Lyndon B. Johnson Space Center (JSC) in Houston, Texas. Particles are individually retrieved from the collectors, examined and cataloged, and then made available to the scientific community for research. Cosmic dust thereby joins lunar samples and meteorites as an additional source of extraterrestrial materials for scientific study.

This catalog summarizes preliminary observations on some of the particles retrieved from collection surface U2015. This surface was one of two flat plate "flags" (each with ~30 cm^2 surface area) which were coated with silicone oil and then flown aboard a NASA U-2 aircraft during a series of flights that were made mostly along the west coast of North America from June 22, 1983, to August 18, 1983. The flags were installed in specially constructed wing pylons which ensured that the necessary level of cleanliness was maintained between periods of active sampling. During successive periods of high-altitude (~20 km) cruise, the flags were exposed in the stratosphere by pilot command and then retracted into sealed storage containers prior to descent. In this manner, a total of 39.6 hours of stratospheric exposure was accumulated for flag U2015.

Flag U2015 was previously included in a broad, reconnaissance sampling of unusually large (>50 μm) particles and yielded samples of two such particles, U2015*A and U2015*B, that were described in Cosmic Dust Courier No. 5. Particle U2015*B was identified as "cosmic" (see definition in Section 4) and is not depicted in this catalog although sample U2015B9,

which was found on the flag in the vicinity of U2015*B, may be related to it. Particle U2015*A is more problematical because both the original reconnaissance samples and the samples described in this catalog (particles U2015B1-4 and U2015B6) consist of a mixture of ostensibly "cosmic" fragments (C-type) with fragments that are most readily interpreted as artificial contaminants (TCA-type).

2. PROCESSING OF PARTICLES

Particle mounts designed for the JEOL-100CX scanning transmission electron microscope (STEM) are currently the standard receptacles for CD particles in the JSC laboratory. Each mount consists of a graphite frame (size ~3x6x24 mm) onto which a Nucleopore™ filter (0.4-μm pore size) is attached. A conductive coat of carbon is vacuum-evaporated onto the mount and then a microscopic reference pattern is "stenciled" onto the carbon-coated filter by vacuum evaporation of aluminum through an appropriately sized template. CD particles are individually removed from collection flags using glass-needle micromanipulators under a binocular stereo-microscope. Each particle is positioned on an aluminum-free area of a Freon-cleaned, carbon-coated filter and washed in-place with hexane to remove silicone oil. Each mount is normally limited to 16 particles. All processing and storage of each particle is performed in a Class-100 clean room.

3. PRELIMINARY EXAMINATION OF PARTICLES

Each rinsed particle is examined, before leaving the Class-100 clean room processing area, with a petrographic research microscope equipped with transmitted, reflected and oblique light illuminators. At a magnification of 500X, size, shape, transparency, color, and luster are determined and recorded for each particle.

After optical description, each mount (with uncoated particles) is examined by scanning electron microscopy (SEM) and x-ray energy-dispersive spectrometry (EDS). Secondary-electron imaging of each particle is performed with a JEOL-100CX STEM operated in the SEM mode and at an accelerating voltage of 40 kV. Images are therefore of relatively low contrast and resolution due to deliberate avoidance of conventionally applied conductive coats (carbon or gold-palladium) which might interfere with later elemental analyses of particles. EDS data are collected with a JEOL-35CF SEM equipped with a Si(Li) detector and PGT-4000T analyzer. Using an accelerating voltage of 20 kV, each particle is raster-scanned and its x-ray spectrum recorded over the 0-10 keV range by counting for 100 sec. No system (artifact) peaks of significance appear in the spectra.

It should be pointed out that the SEM/EDS procedure used in preparing this catalog is different than that used in preparing Cosmic Dust Catalogs, Volumes 1, 2, and 3. In the earlier catalogs, both SEM imaging and EDS analysis were performed using the JEOL-100CX STEM operated at 40 kV. The procedure used for this catalog retains the superior imaging capability of the JEOL-100CX but incorporates the superior EDS capabilities of the JEOL-35CF. The new, two-step process provides the best possible preliminary-quality data while minimizing the electron-beam exposure experienced by the samples. Only the EDS spectra exhibit differences that

are likely to be noticed. However, spectra of selected comparison standards that were published in previous catalogs were re-collected under the new procedure and are included in this catalog. Please refer to Section 5 for a more complete discussion.

Following SEM/EDS examination, each particle mount is stored in a dry nitrogen gas atmosphere in a sealed cabinet.

4. CATALOG FORMAT

Each page in the main body of the catalog is devoted to one particle and consists of an SEM image, an EDS spectrum, and a brief summary of preliminary examination data obtained by optical microscopy. The unique identification number assigned to the particle appears at the top of the page. Sources of the descriptive data are as follows:

SIZE (μm) is measured using the original SEM image and its known magnification factor. For an irregularly shaped particle, the minimum dimension in the plane of the field of view is located and determined; then a second (maximum) dimension is measured at a right angle to the first. For a spherical or equidimensional particle, only a single size is recorded.

SHAPE is generalized to be spherical (S), equidimensional (E), or irregular (I). Particles having shape intermediate between S and E, or E and I, are not uncommon and may be denoted as S/E or E/I, etc.

TRANSPARENCY (abbreviated TRANS.) is determined by optical microscopy to be transparent (T), transulcent (TL), or opaque (O). Significant variations in transparency within a particle are annotated on the SEM image.

COLOR is determined by optical microscopy using oblique (fiber-optic, quartz-halogen) illumination supplemented with normal reflected (tungsten-lamp) illumination. The distinction of dark (Dk.) from light (Lt.) particles is unambiguous, although the distinction of colorless (CL) from pale-colored conditions is sometimes problematical. Complex colorations of individual particles may be noted in the "COMMENTS" column and annotated on the SEM image.

LUSTER is determined by optical microscopy using reflected normal (tungsten-lamp) illumination and supplemented with oblique (fiber-optic, quartz-halogen) illumination. Commonly applied descriptions, adopted from mineralogical usage, include dull (D), metallic (M), submetallic (SM), subvitreous (SV), and vitreous (V). Lusters transitional between categories or difficult to identify are indicated accordingly (D/SM, SV/V, etc.).

TYPE indicates a provisional first-order identification of each particle based on its morphology (from SEM image), elemental composition (from EDS spectrum), and optical properties. We emphasize that, for catalog purposes, types are defined for their descriptive and curatorial utility, not as scientific classifications. These tentative categorizations, which reflect judgements based on the collective experience of the CDPET, should not be construed to be firm identifications and should not dissuade any investigator from requesting any given particle for detailed study and more complete identification. In the absence of any generally accepted taxonomy for stratospheric dust, the precise identification of each particle in our inventory is beyond the scope and intent of our collection and curation program. Indeed, the reliable identification and scientific classification of cosmic dust is one of many important research tasks that we hope this catalog will stimulate. We indicate particle "TYPE" only to aid the users of this catalog (especially those new to small-particle analysis) in distinguishing possible cosmic dust particles from other particles which are invariably collected during stratospheric dust sampling. Categories used in this catalog are defined as follows:

AOS: Aluminum oxide sphere. An AOS is transparent, subvitreous to vitreous in luster, colorless to pale yellow and at least approximately spherical. However, shape may range from nearly perfect sphericity to pronounced ellipticity and surface texture may range from very smooth to rough. Other spheres or irregularly shaped material may be attached to its surface. Al is the distinctively dominant (or only) peak in its EDS spectrum. A sphere displaying the attributes of an AOS except with major elements in addition to Al may be listed as "AOS?" or "?". Transparent Al-rich particles of irregular shape would probably be listed as "?" or "TCA?". (AOS particles are products of solid-fuel rocket exhausts.)

C: Cosmic dust (variety unspecified) or other extraterrestrial material. In the strict sense, "cosmic dust" refers only to those particles which have not been modified during passage from interplanetary space to Earth's stratosphere. In this catalog, though, particle type "C" is used to conveniently group together all particles which are judged to be of extraterrestrial origin, including those that have apparently experienced strong ablational heating or melting. Type "C" particles are provisionally identified as those having one of the three following sets of attributes:

(a) irregular to spherical, opaque, dark-colored particles composed mostly of Fe with minor Ni or S.

(b) irregular to spherical, translucent to opaque, dark-colored particles containing various proportions of Mg, Si, and Fe with traces of Al, Ca, S, or Ni.

(c) irregular to faceted or blocky, transparent to translucent particles containing mostly Mg, Si, and Fe but with traces of Al or Ca.

Category (a) and (b) particles commonly display either complex, porous aggregate-type morphologies or distinctively spherical shapes and dull to metallic lusters which distinguish them from terrestrial minerals. Their EDS spectra are reminiscent of those exhibited by meteoritic Fe-Ni or FeS minerals, or combinations of Fe-Ni-S phases with olivine and/or pyroxene. Category (c) particles display morphologies and EDS spectra which suggest that they are fragments of olivine or pyroxene crystals, neither of which are significant components of stratospheric volcanic ash. Particles which do not fall easily into categories (a), (b), or (c) but which possess some of the same attributes may be classified here as "C?".

TCA: Terrestrial contamination (artificial or man-made). Particles included in the "TCA" category are commonly irregular in shape (though a few may be spherical) and may be transparent, translucent, or opaque. Their EDS spectra commonly show Al, Fe, or Si as the principal peaks but with a variety of minor peaks including those of Ti, V, Cr, Mn, Ni, Cu, or Zn and at abundances which are frequently much greater

than those expected in common minerals. However, such compositions are similar to those expected for certain metal alloys. In some cases, a high intensity (relative to intensities of characteristic x-ray peaks) of continuum radiation occurs in the EDS spectrum, suggesting that low atomic number elements not detectable by the EDS (e.g., H, C, N, O) are abundant in the particle. Such "TCA" particles are tacitly inferred to by synthetic carbon-based materials. (This category probably includes particles produced by or derived from aircraft operation or collector hardware, or possibly spacecraft debris. However, some of these particles are worthy of additional research and may represent true extraterrestrial "low Z" material).

TCN: Terrestrial contamination (natural). "TCN" particles may be transparent to opaque and may exhibit a variety of colors. However, they are commonly irregular in shape and distinctively rich in Si and Al with minor abundances of Na, K, Ca, or Fe. Morphologies and EDS spectra of most "TCN" particles compare favorably with respective properties of silica polymorphs, feldspar, or silicic volcanic glass, three materials which are principal components of stratospheric volcanic ash. In addition, platy or porous aggregate-type particles of light color and Si, Al-rich composition may be silicic clay minerals, common phases in Earth's surface soils. Irregular, reddish Fe-rich particles may also be products of terrestrial rock weathering. Recognition of these and other phases as "TCN" particles is based mostly on CDPET's collective miner-

alogical experience and comparison with reference samples. Less commonly, the "TCN" category may include distinctive particles with apparently non-random shapes which are rich in low atomic number elements (as inferred from their EDS spectra having high levels of continuum x-radiation and relatively small peaks for characteristic x-rays). Those rare particles are distinguished from "TCA" particles by their unusual, organized morphologies and probably represent biological contaminants.

?: Identification uncertain. This category includes particles which do not unequivocally resemble those grouped together as AOS, C, TCA, or TCN. In addition, the "?" symbol is liberally used to reiterate the tentative identifications of other types of particles.

Again, this system for provisional classification of particles is presented only as a first-order attempt to distinguish particles which are probably extraterrestrial in origin from those which are probably contaminants. Many particles, especially those cataloged as type "?", will require careful research examination before they can be satisfactorily identified.

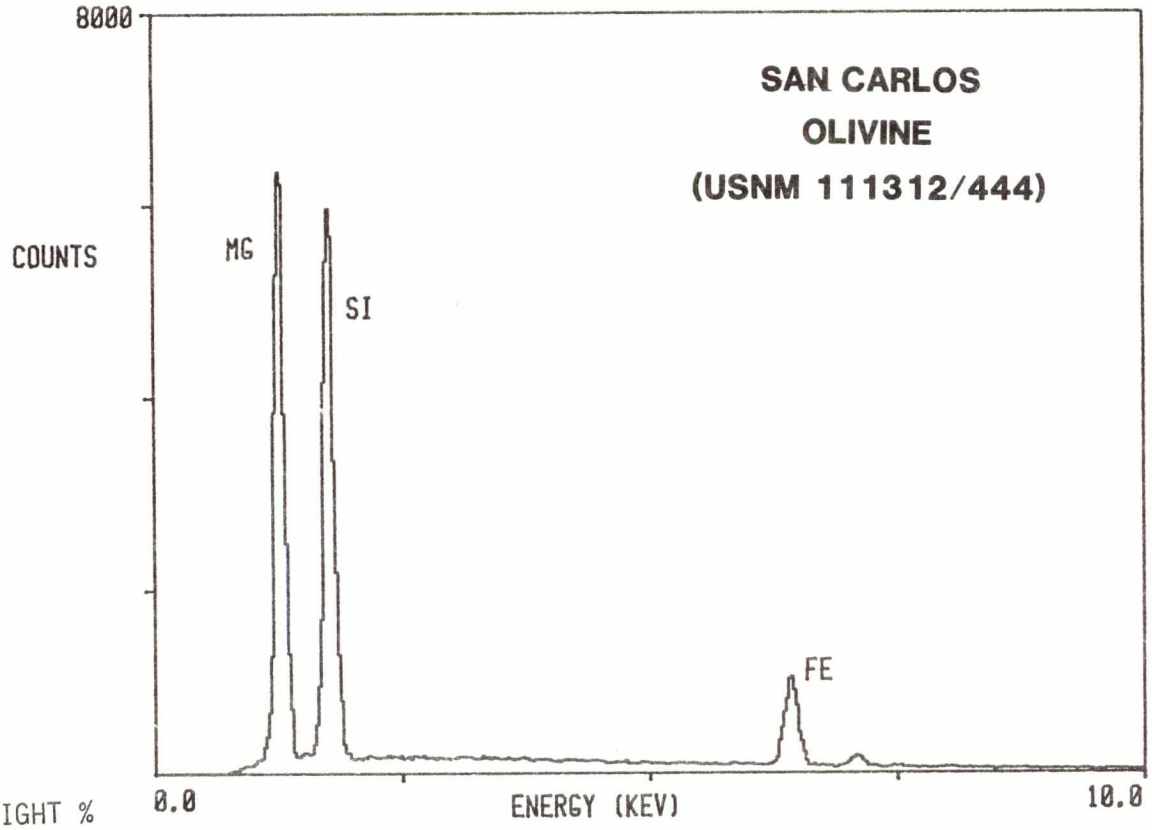
COMMENTS are included for particles with special features or histories. Particles lost during or after preliminary SEM examination, or particles with possible genetic relationships to other particles are noted here.

5. ANALYSES OF REFERENCE MATERIALS

The usefulness of the SEM images and EDS spectra provided for particles in this catalog is enhanced by comparison with similar data products obtained for mineral standards of known composition. Accordingly, a typical EDS spectrum is presented for each of three standard minerals prepared as polished grain mounts (San Carlos olivine, USNM 111312/444; diopside JLC-99-63; Kakanui hornblende, USNM 143965). Analyses of these optically flat surfaces eliminate inter-sample geometrical variations so that effects of detection limits and compositional variations, in general, on relative peak heights in the raw spectra can be more readily assessed. Even so, the polished-grain spectra should not be over interpreted because no corrections have been attempted for atomic number, absorption, or fluorescence effects. The spectra are presented simply as additional aids to the meaningful use of the sample particle EDS spectra. Investigators who might wish to compare performance characteristics of their EDS analytical systems with those of the system used by CDPET in preparing these catalog data should contact Curator/Cosmic Dust at the address given in Section 6. A short-term loan of a polished-grain mineral standard can then be arranged.

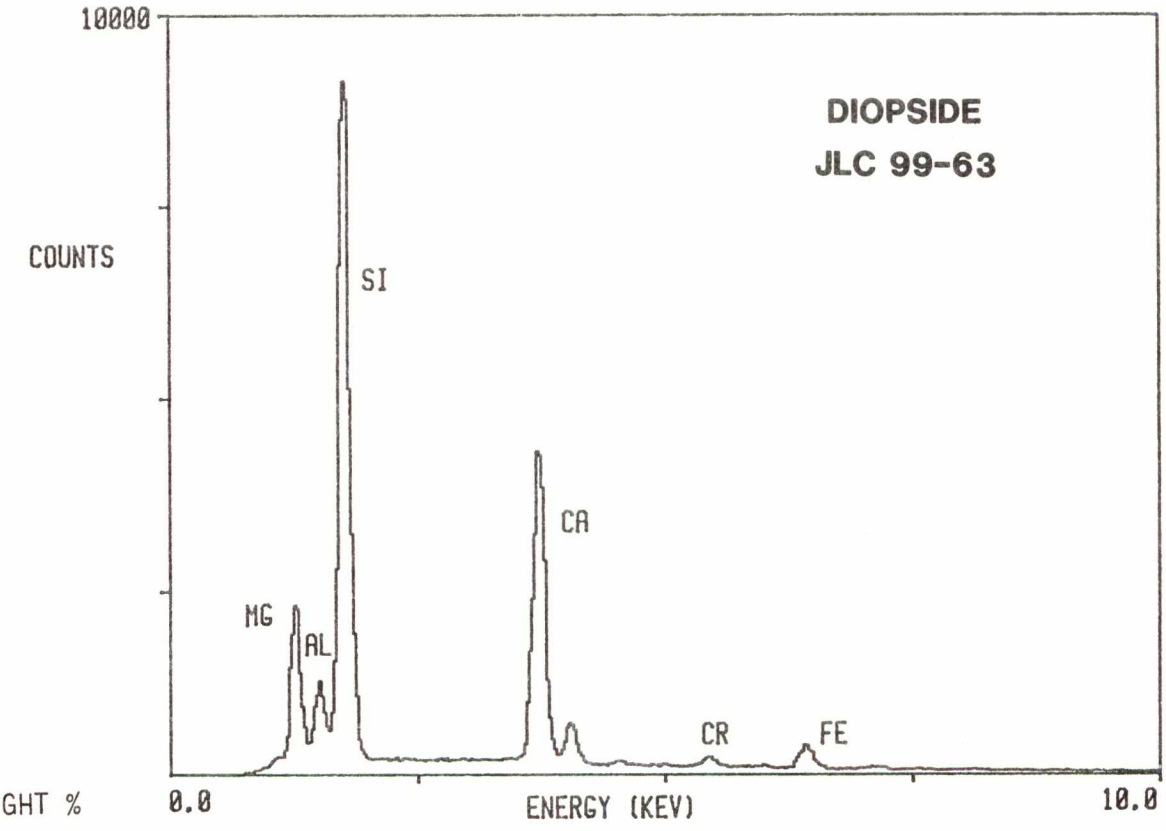
As pointed out in Section 3, the EDS spectra included in this catalog were obtained using a primary electron energy of 20 kV whereas spectra in Catalogs 1, 2, and 3 were obtained with a different instrument operated at 40 kV. Although the effects on EDS spectra to be expected from such a change are well known from x-ray spectrometric analysis, they are worth pointing out to avoid confusion among the readers of this catalog. The major effects of concern to Cosmic Dust Catalog users can be seen by comparing the two "Allende (C3) Meteorite Bulk Powder" spectra, one of

which was obtained at 20 kV and the other at 40 kV. In the 20 kV spectrum, the Si peak is more intense than the principal peak of Fe whereas the opposite is true for the 40 kV spectrum. In general, the 20 kV spectra in this catalog will show peaks of light elements enhanced relative to peaks of heavy elements when compared with 40 kV spectra published in Catalogs 1, 2, and 3. The explanation is based both on geometrical differences between x-ray paths in the two EDS systems (the JEOL-35CF system is actually more favorable for light element analysis) and on electron and x-ray physics (x-ray emission by heavy elements is more intense at 40 kV than at 20 kV). Thus, readers are cautioned against attempting to quantitatively intercompare 20 kV spectra in this catalog with 40 kV spectra in previous catalogs. Still, the spectra in each catalog should continue to serve as originally intended. Namely, the sample and standard spectra in any given catalog will represent a self-consistent data set.



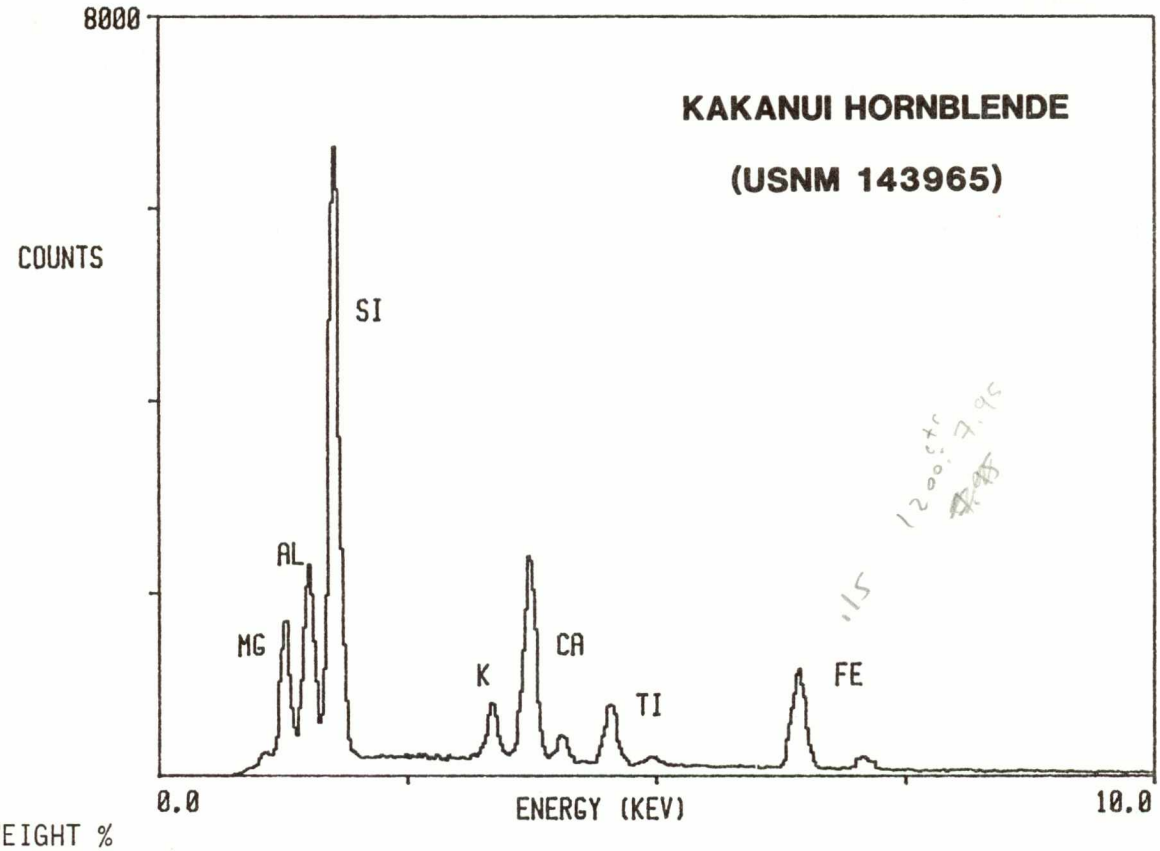
WEIGHT %

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	TOTAL
40.81	-	-	-	-	9.55	0.37	0.14	49.42	<0.05	-	-	-	100.29



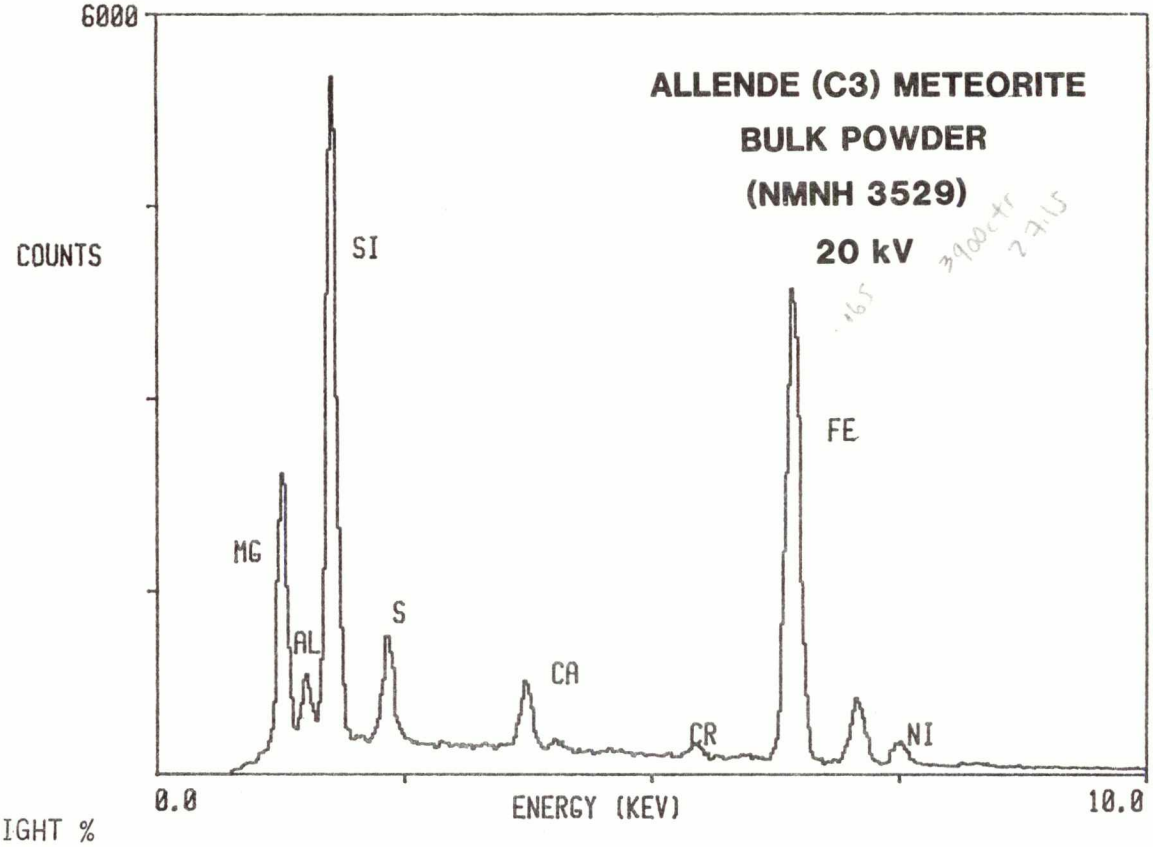
WEIGHT %

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	TOTAL
51.93	0.46	6.31	9.96	1.80	2.34	0.04	0.07	16.05	19.64	1.39	-	-	99.99



WEIGHT %

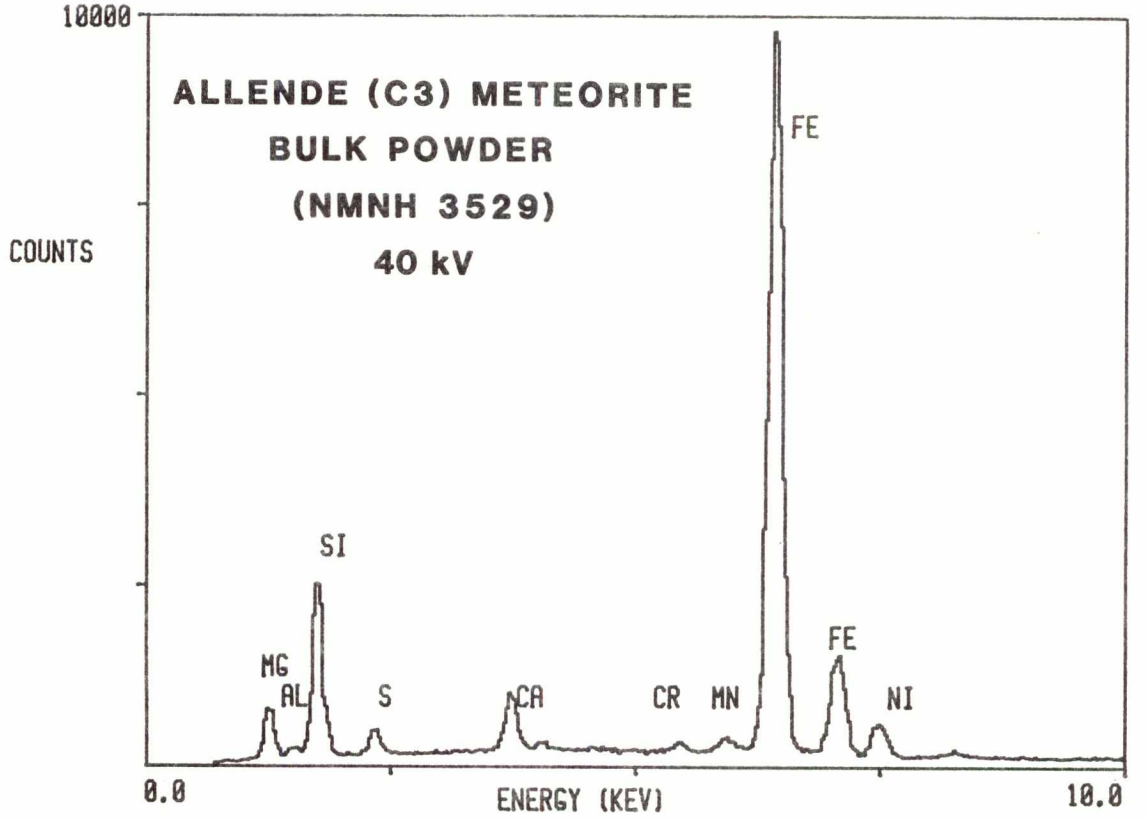
SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	TOTAL
40.37	4.72	14.90	-	3.30	7.95	-	0.09	12.80	10.30	2.60	2.05	0.94	100.02



WEIGHT %

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	C
34.23	0.15	3.27	0.52	27.15	0.18	24.62	2.61	0.45	0.03	0.23	0.29

FeS	NiS	CoS	Fe^{O}	Ni^{O}	Co^{O}	TOTAL
4.03	1.60	0.08	0.17	0.36	0.01	99.98



6. SAMPLE REQUESTS

Scientists desiring to perform detailed research on particles described in this catalog should apply in writing to:

Curator/Cosmic Dust
Code SN2
NASA/Johnson Space Center
Houston, Texas 77058
U.S.A.

Telephone: (713) 483-6241
or -3274
FTS: 525-6241
or -3274

Sample requests should refer to specific particle identification numbers and should describe the research being proposed as well as the qualifications and facilities of the investigator making the request. Additionally, requests for particles not yet passed through preliminary examination will be considered if the requester can demonstrate a strong need for them. NASA will arrange for a review of the scientific merits of each request and will inform the requester of the results. Approval of a sample request does not imply or include funding for the proposed research. Questions about NASA funding should be directed to:

Dr. Donald D. Bogard
Discipline Scientist
Planetary Materials and Geochemistry Program
Code SN-4
NASA/Johnson Space Center
Houston, TX 77058

Although foreign scientists are welcome to request samples, NASA cannot provide funds to be spent outside the U.S.A. by citizens of other countries.

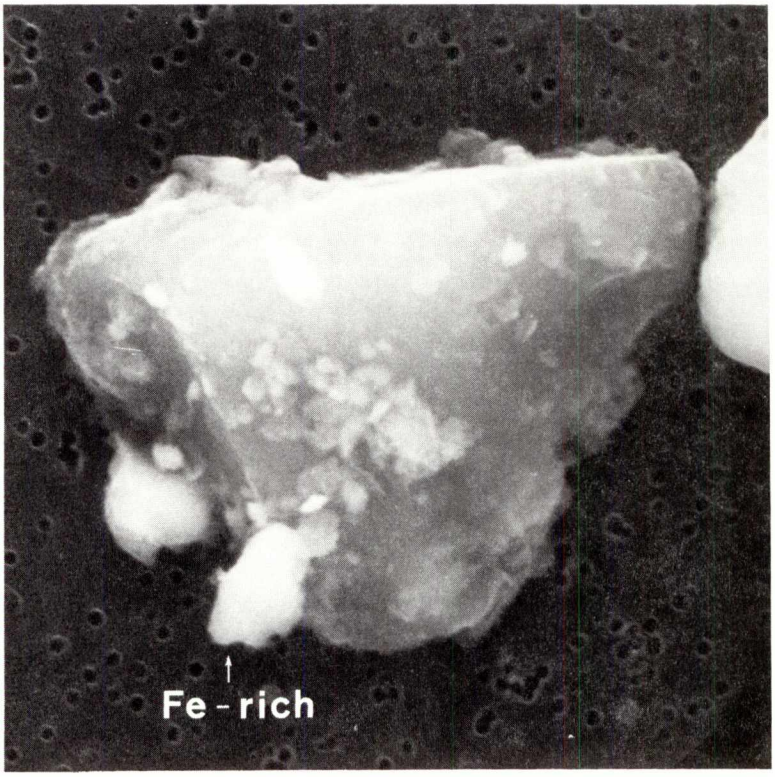
7. ACKNOWLEDGEMENTS

Guy V. Ferry and co-workers (NASA/Ames Research Center, Moffett Field, California) performed the loading and unloading of the cosmic dust collector on the U-2 aircraft and provided flight-log data.

Eugene Jarosewich (Smithsonian Institution, Washington, D.C.) kindly provided mineral standards and the Allende chondrite powder.

U2015B

U2015B1

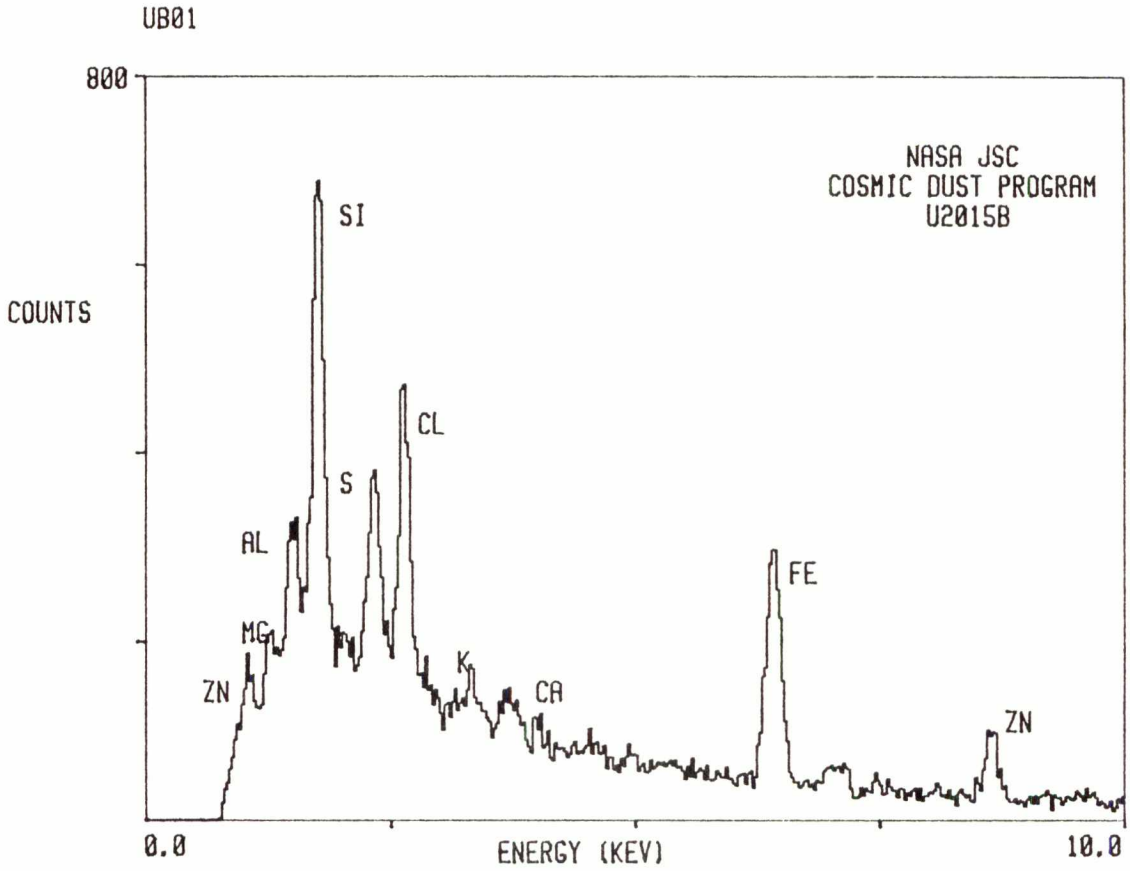


S-84-41360

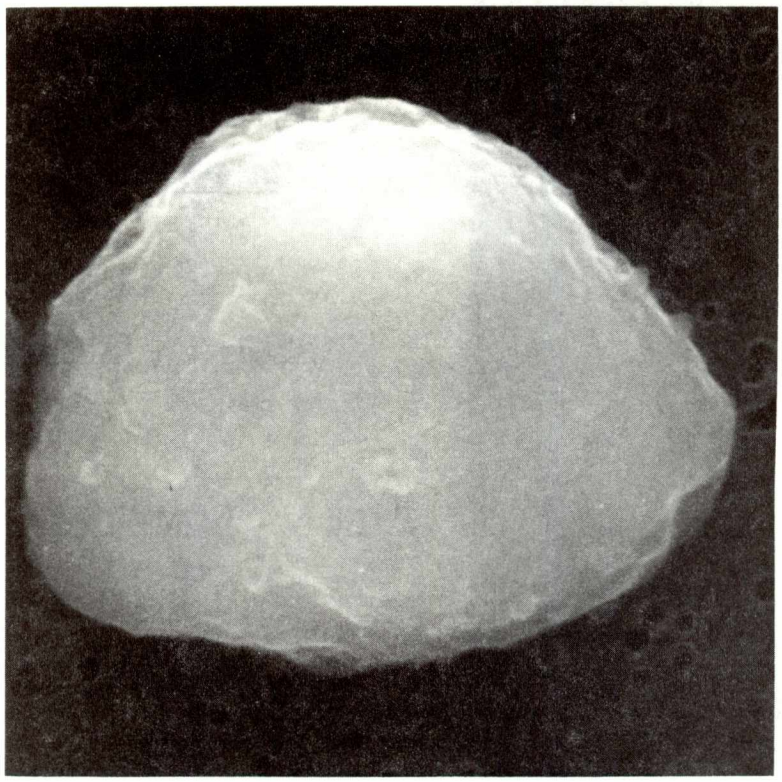
SIZE	SHAPE	TRANS.
14x17	I	T

COLOR	LUSTER
CL to pale yellow	SV

TYPE	COMMENTS
TCA?	Parent is U2015*A



U2015B2

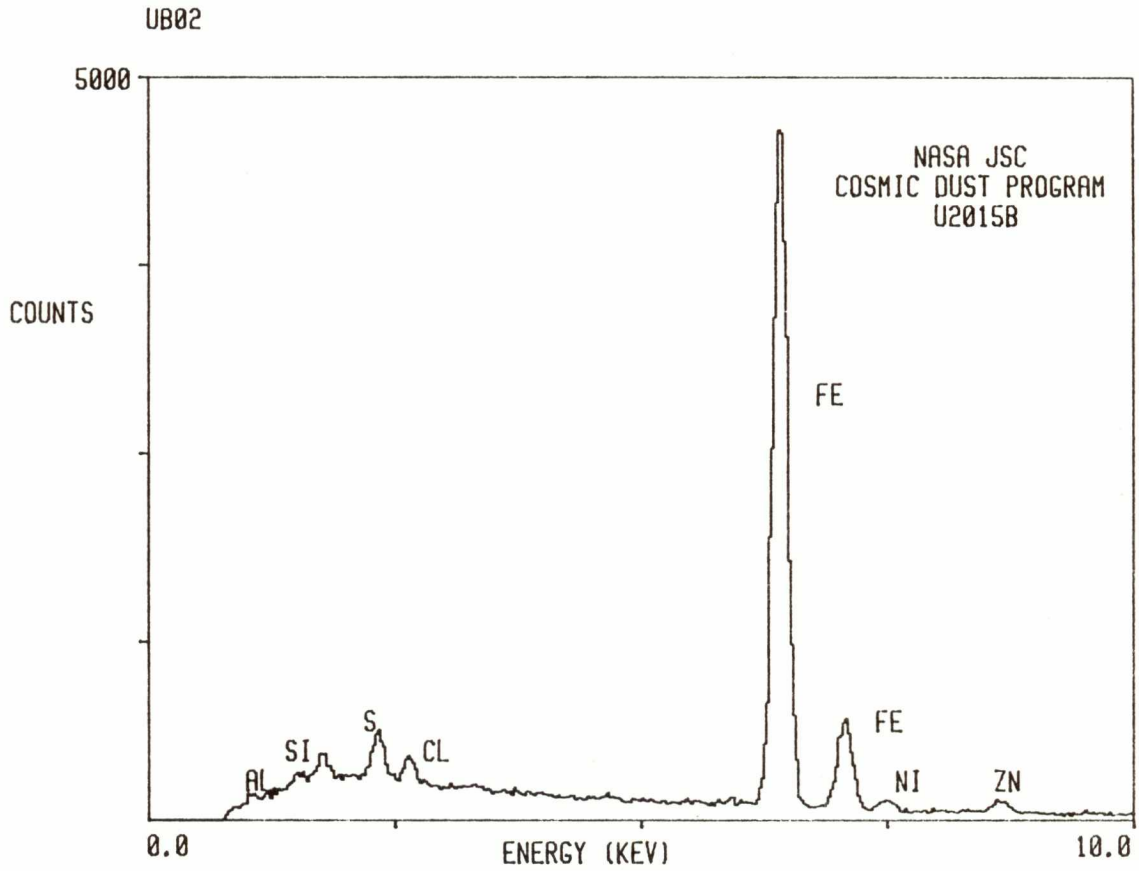


SIZE	SHAPE	TRANS.
9x11	I/E	TL

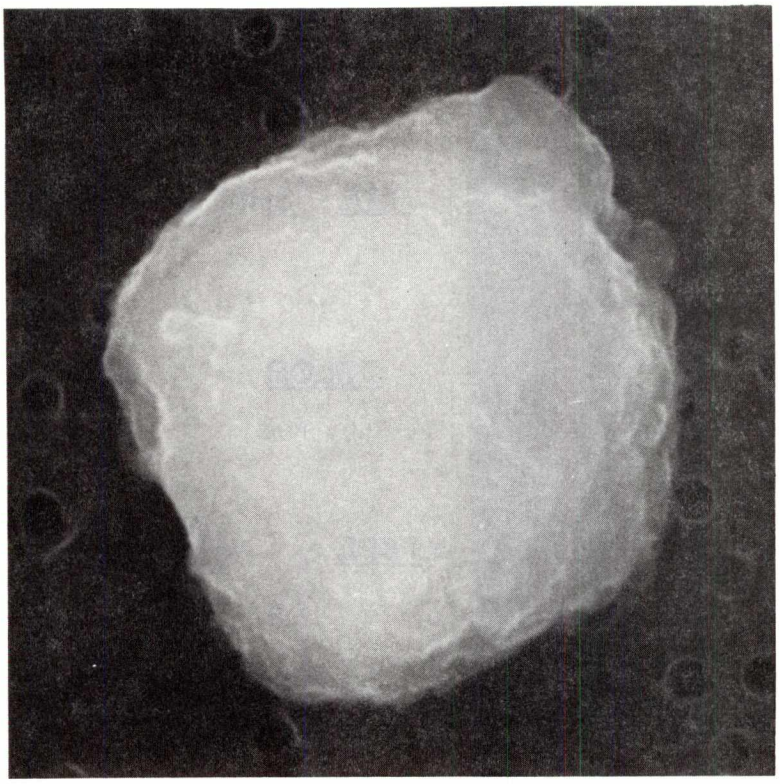
COLOR	LUSTER
Ruby red	SV

TYPE	COMMENTS
?	Parent is U2015*A

S-84-41361



U2015B3

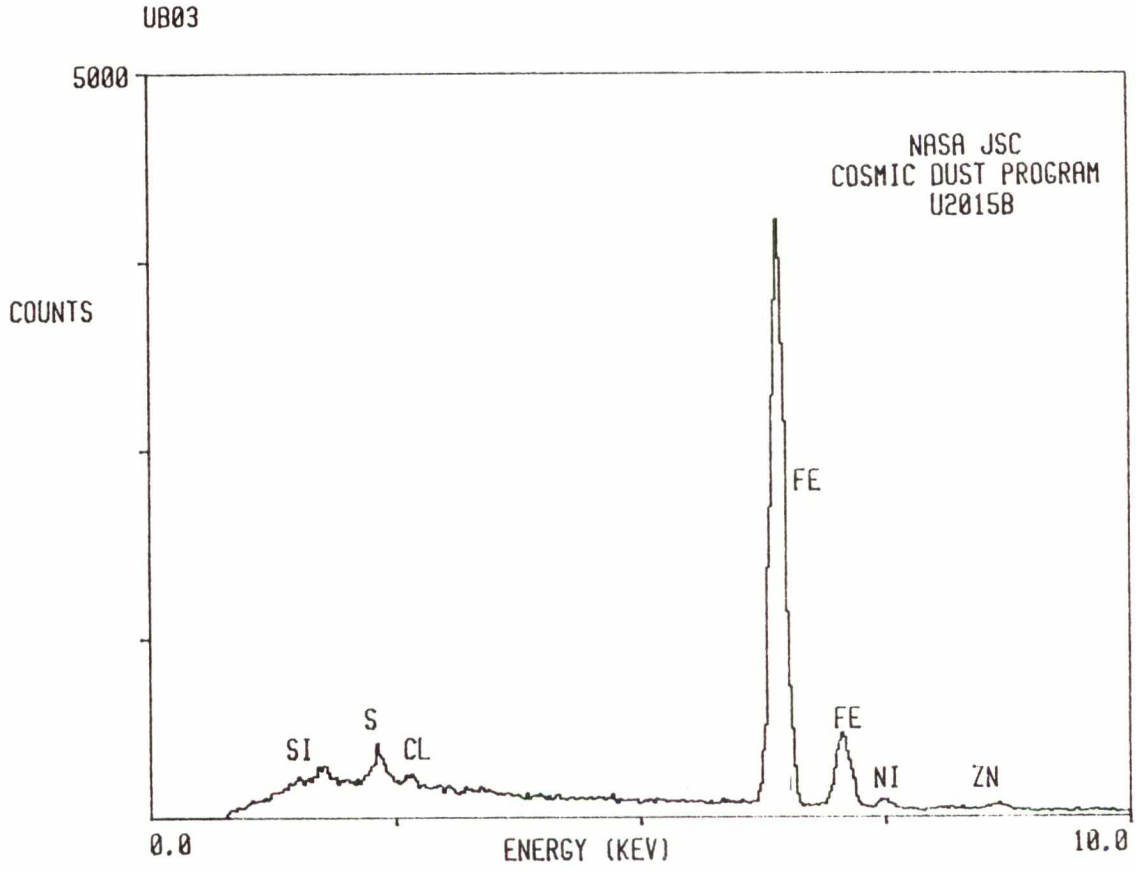


S-84-41362

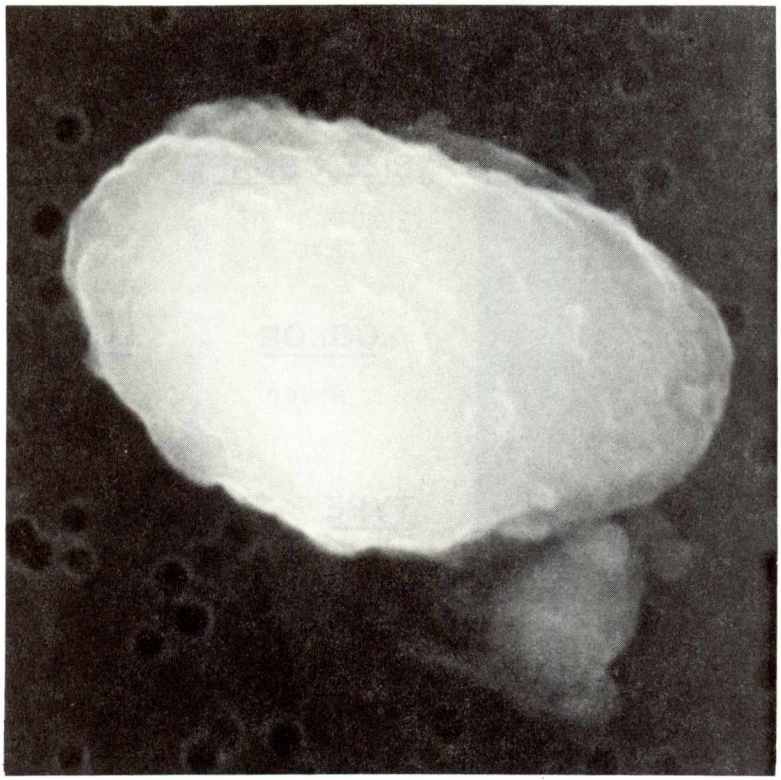
SIZE	SHAPE	TRANS.
5x6	I/E	TL

COLOR	LUSTER
Ruby red	SV

TYPE	COMMENTS
?	Parent is U2015*A



U2015B4

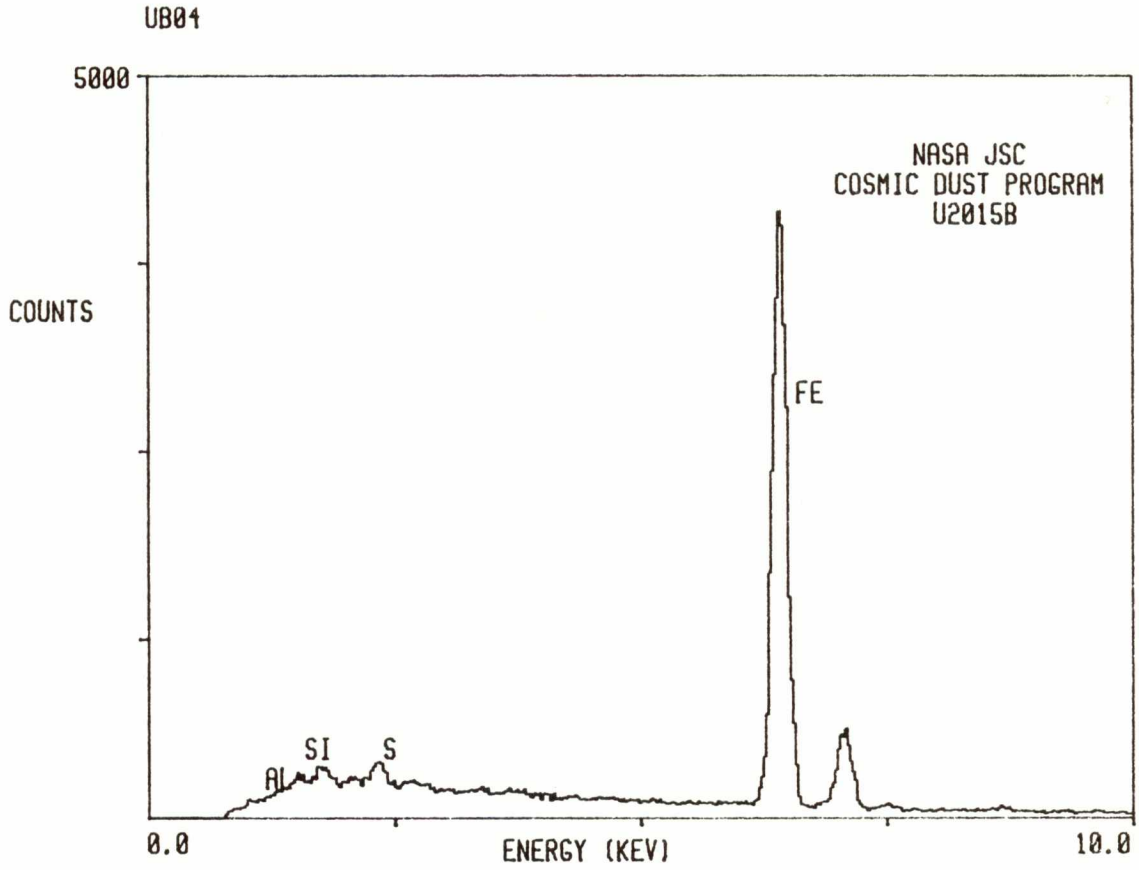


SIZE	SHAPE	TRANS.
5x7	I	0

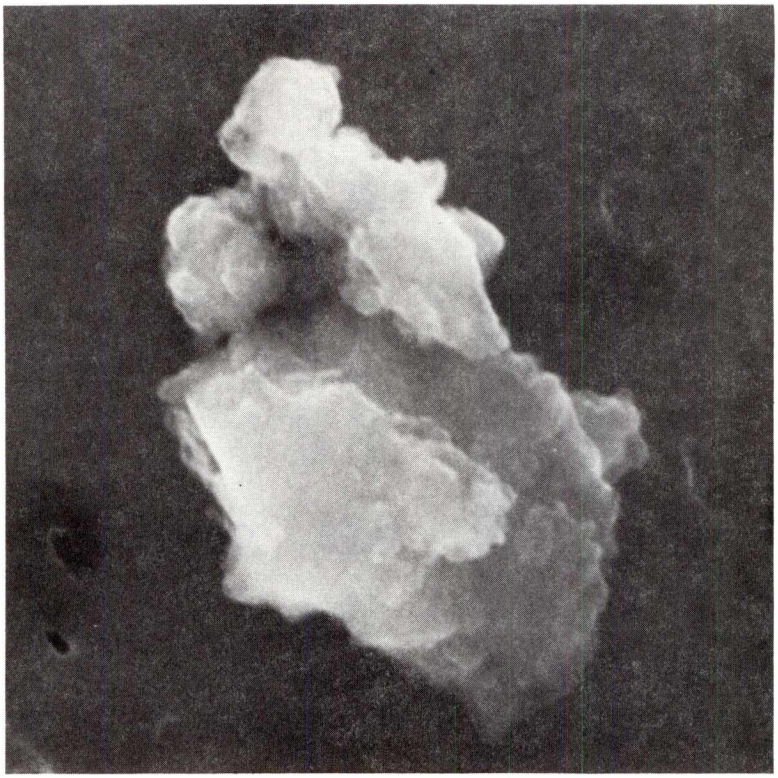
COLOR	LUSTER
Dk. gray to black	SV/SM

TYPE	COMMENTS
C?	Parent is U2015*A

S-84-41363



U2015B6

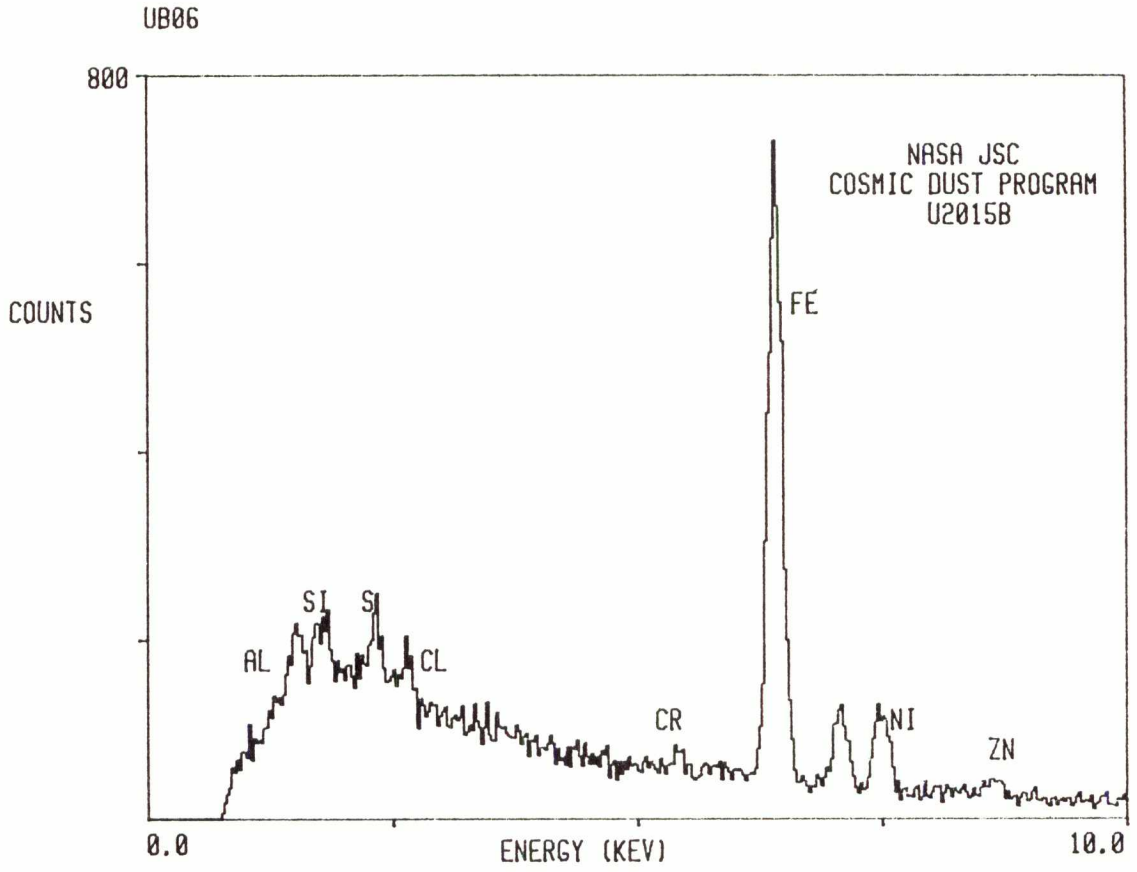


S-84-41365

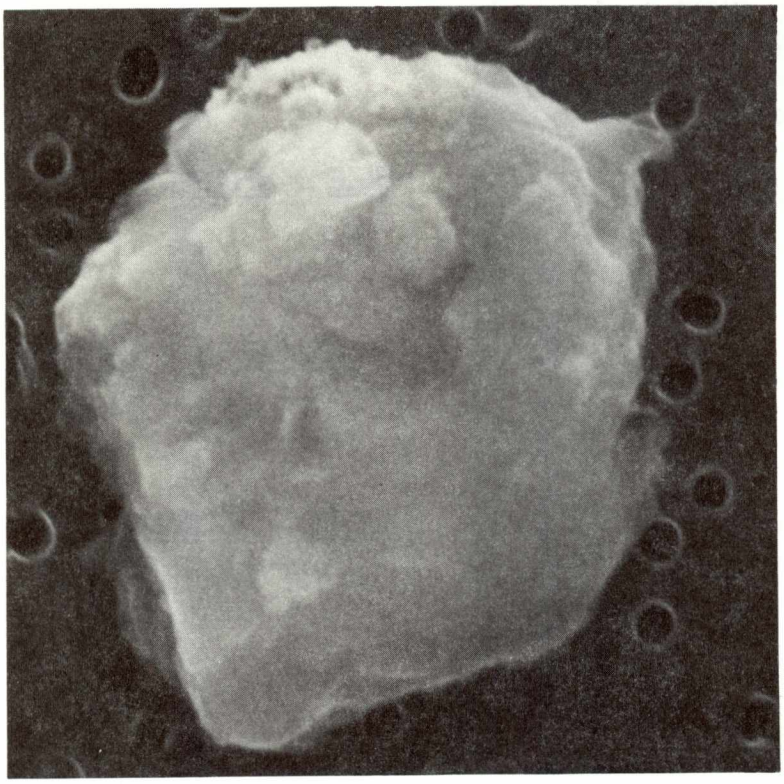
SIZE	SHAPE	TRANS.
3x4	I	TL

COLOR	LUSTER
Amber	D/SV

TYPE	COMMENTS
?	Parent is U2015*A



U2015B7

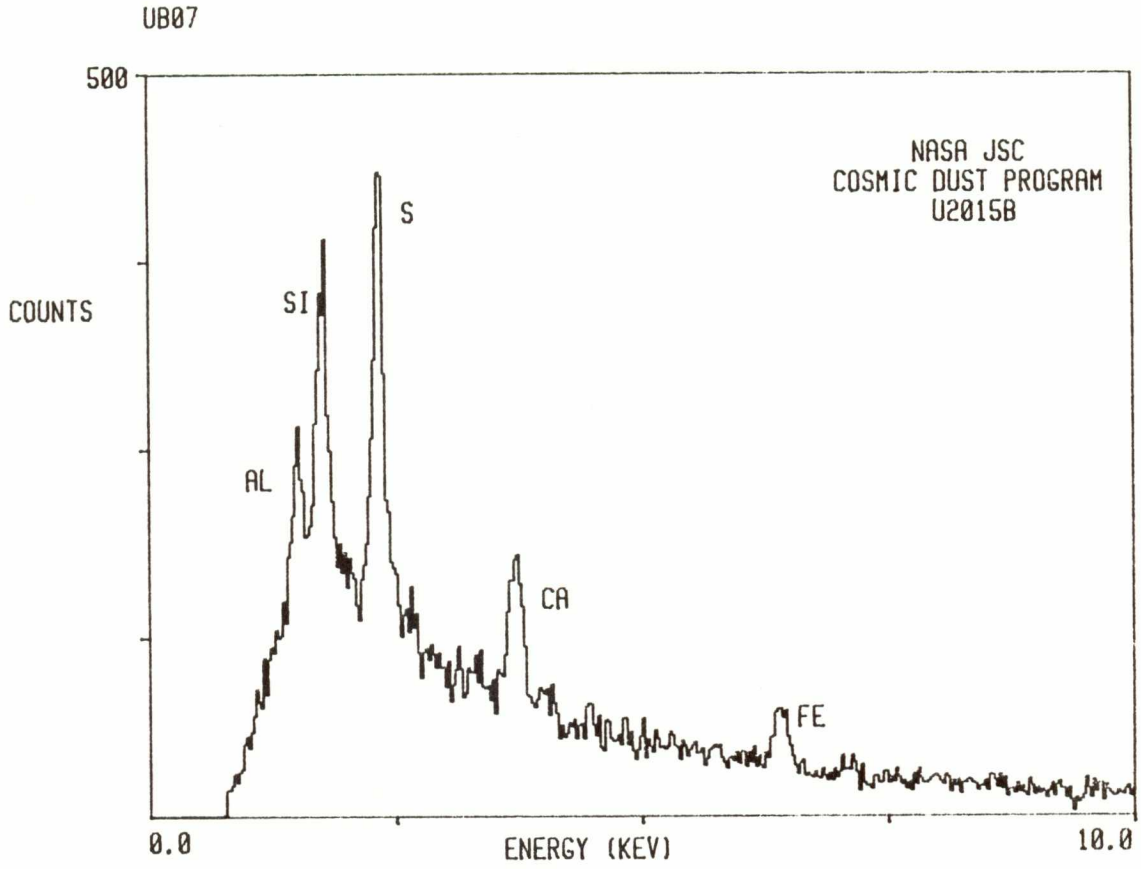


S-84-41366

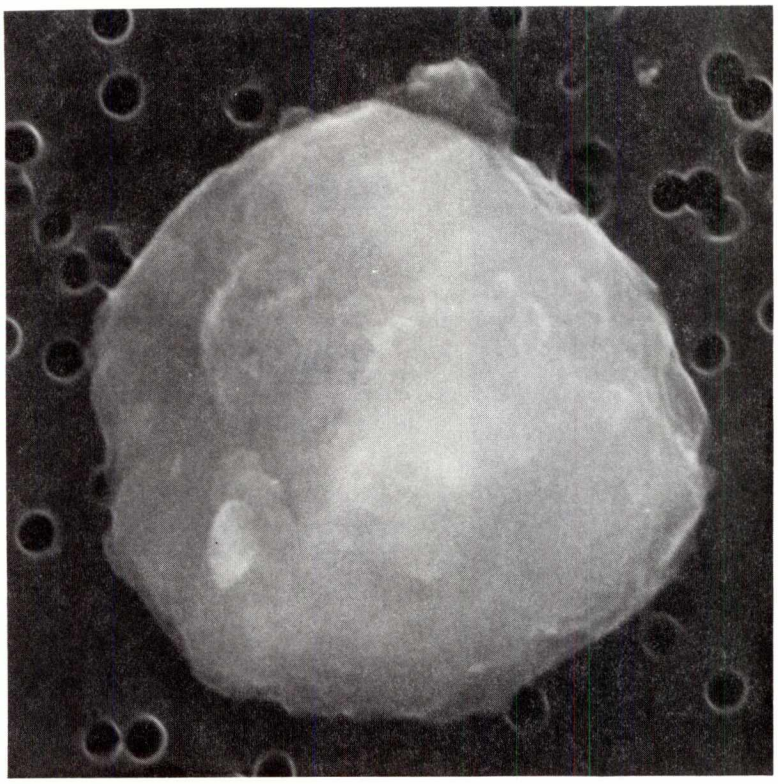
SIZE	SHAPE	TRANS.
6x7	I/E	O/TL

COLOR	LUSTER
Dk. brown-gray	SV

TYPE	COMMENTS
TCN?	Parent is ~150 μm



U2015B8

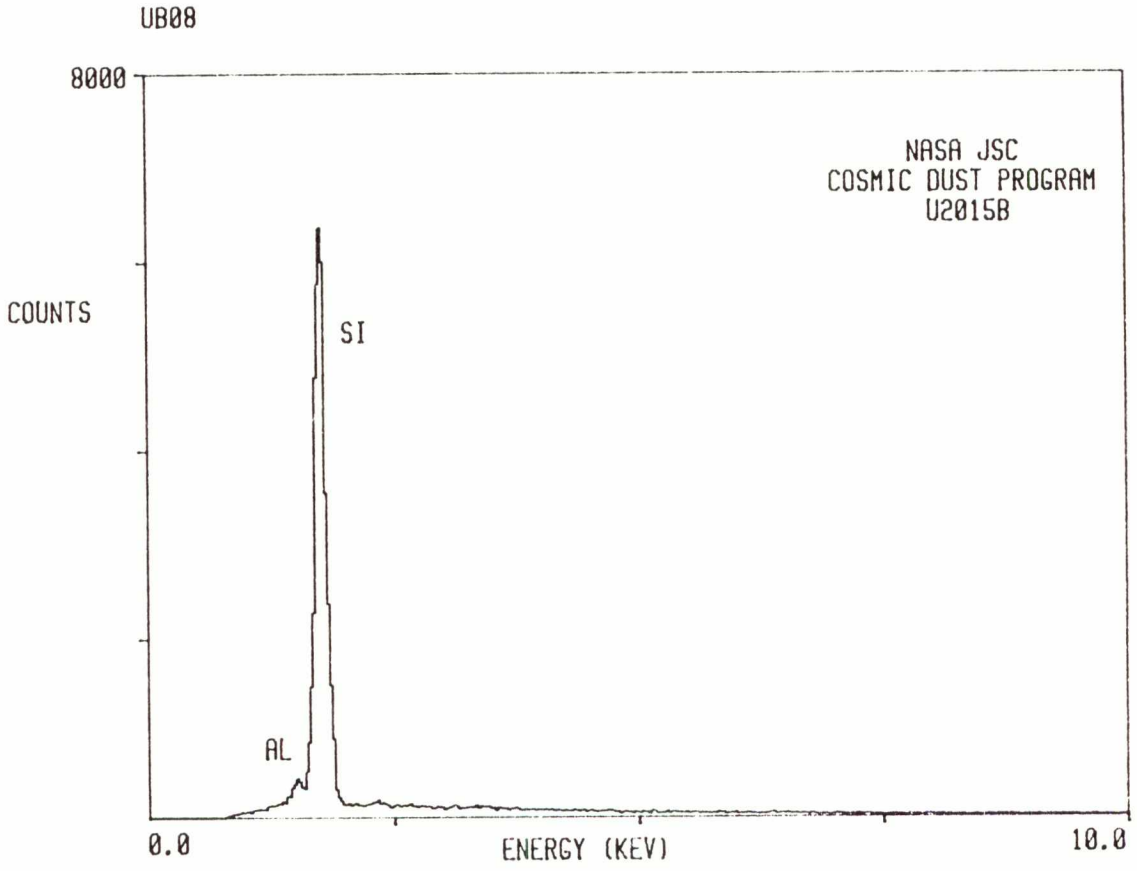


S-84-41367

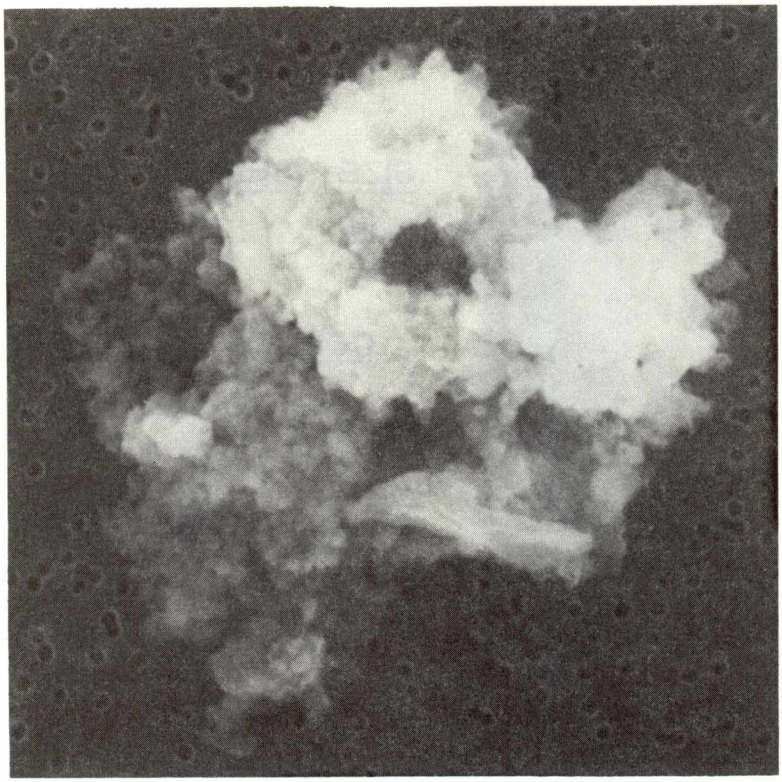
SIZE	SHAPE	TRANS.
6	E	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
TCN?	Same parent as for U2015B7



U2015B9

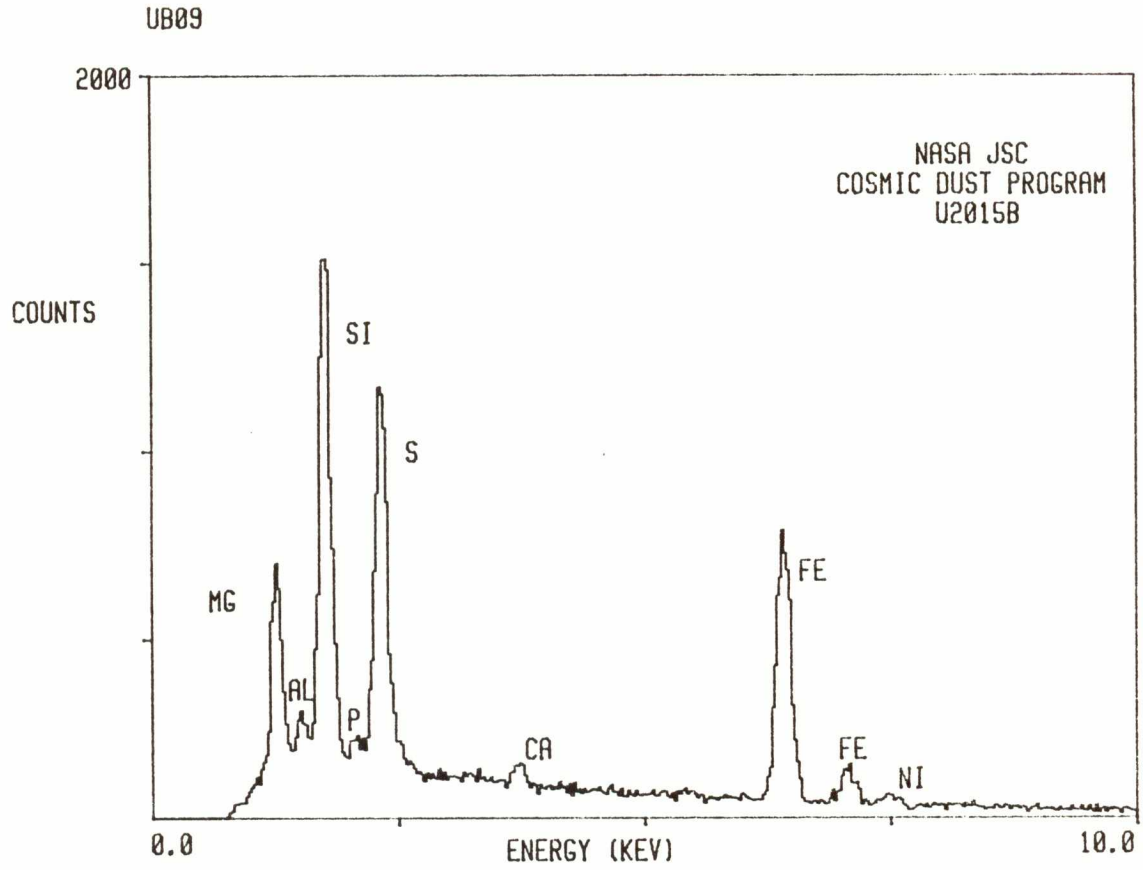


S-84-41368

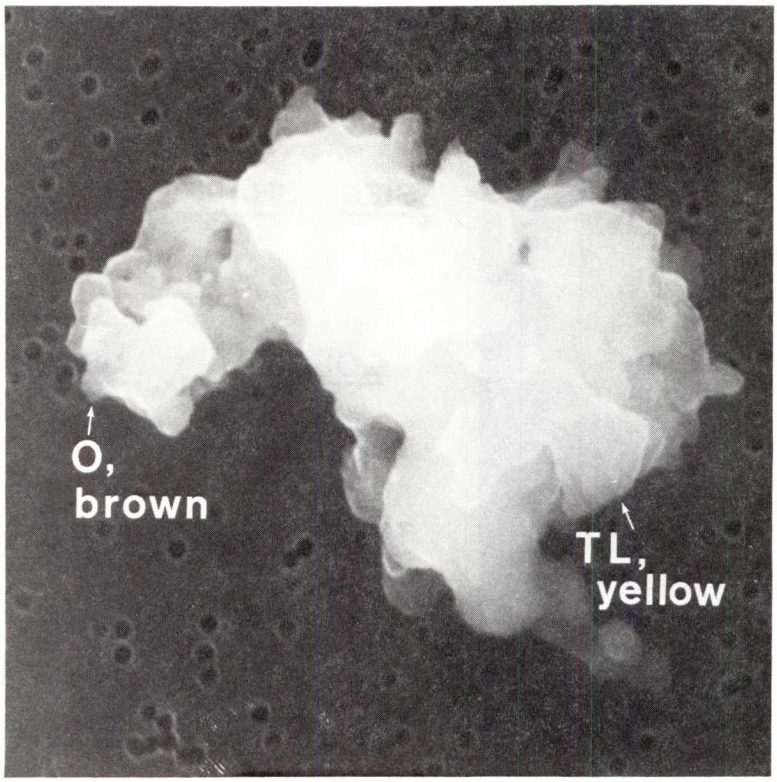
SIZE	SHAPE	TRANS.
16x17	I	O

COLOR	LUSTER
Dk. brown to black	D/SM

TYPE	COMMENTS
C	May be related to U2015*B



U2015B10

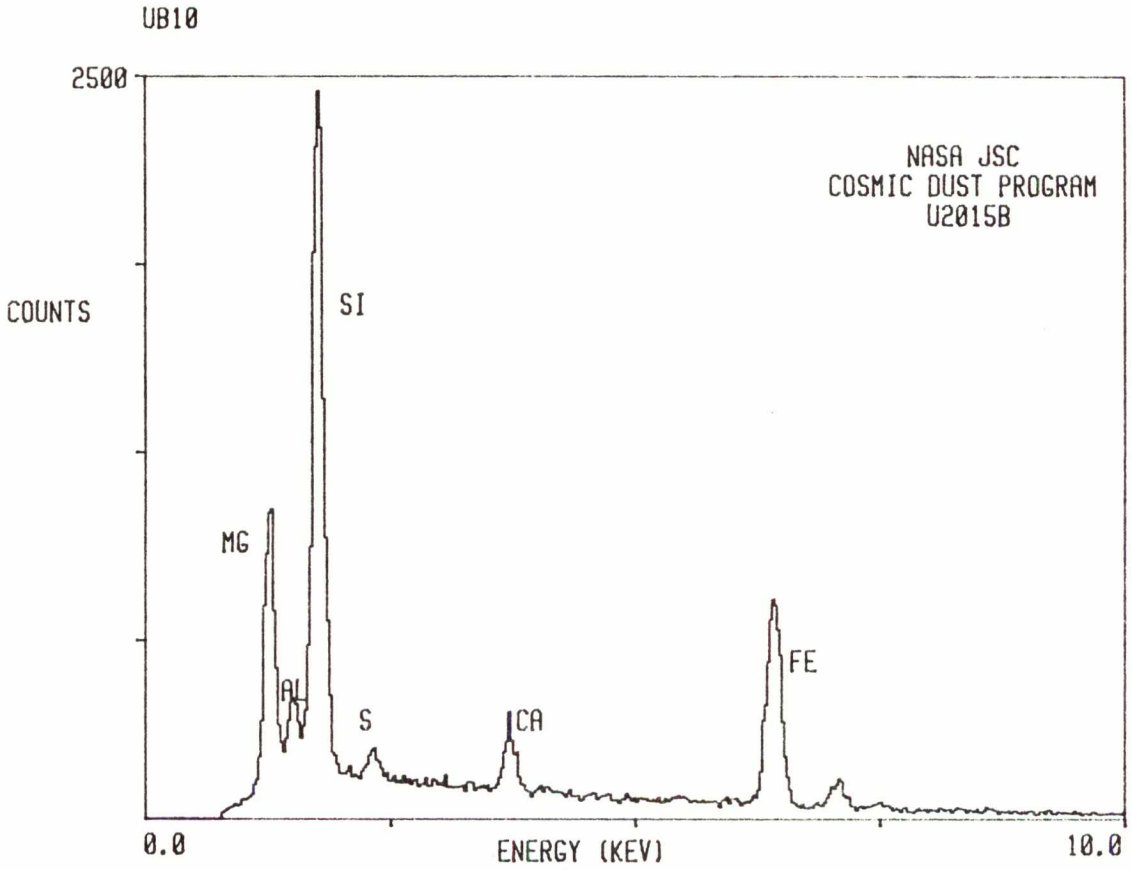


S-84-41369

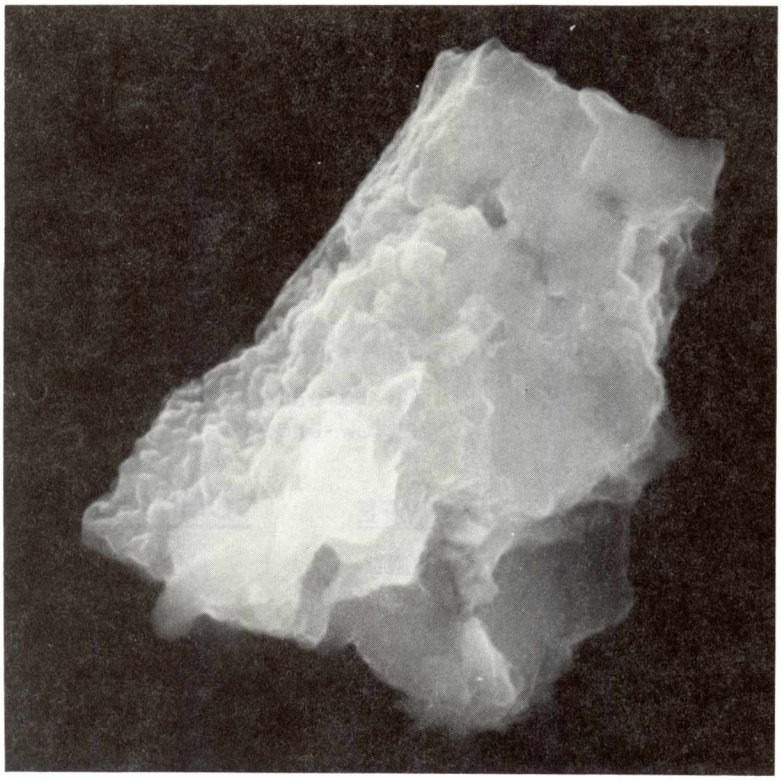
SIZE	SHAPE	TRANS.
9x13	I	O/TL

COLOR	LUSTER
Pale yellow to brown	SV/V

TYPE	COMMENTS
C	



U2015B11

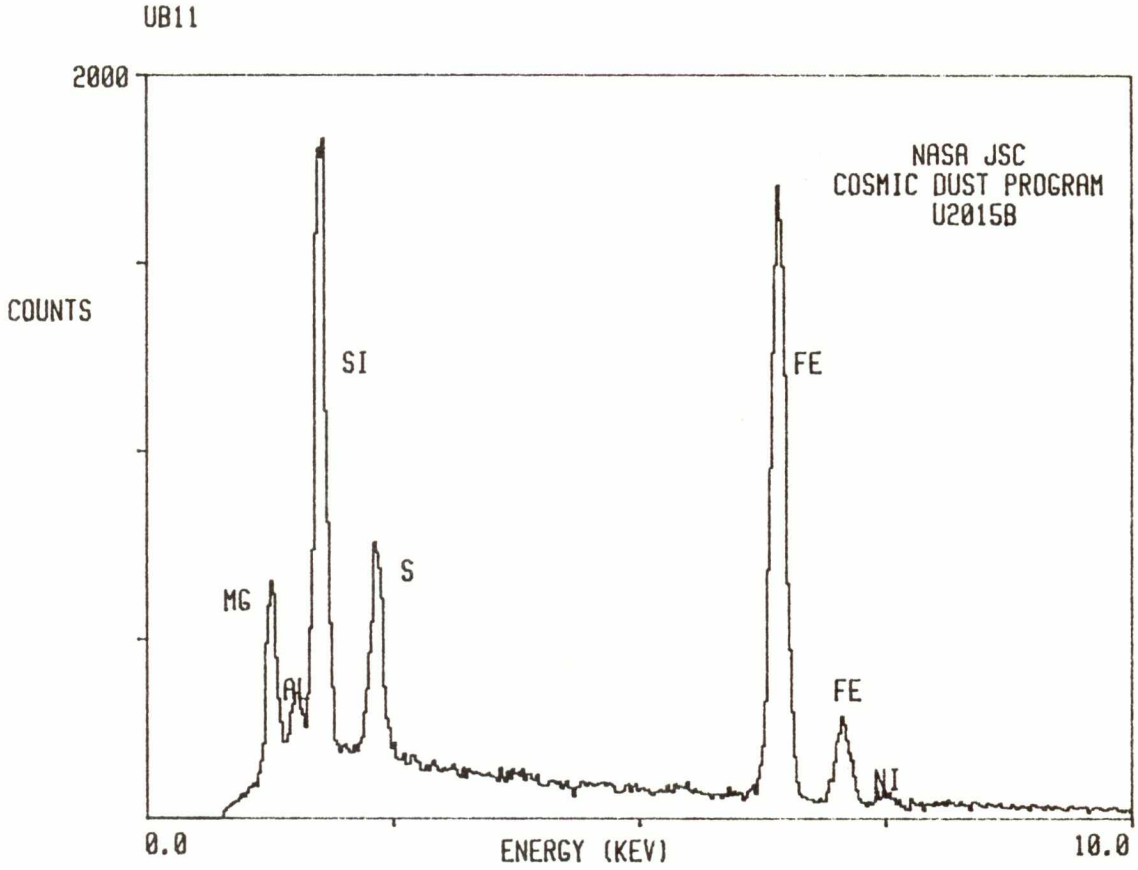


S-84-41371

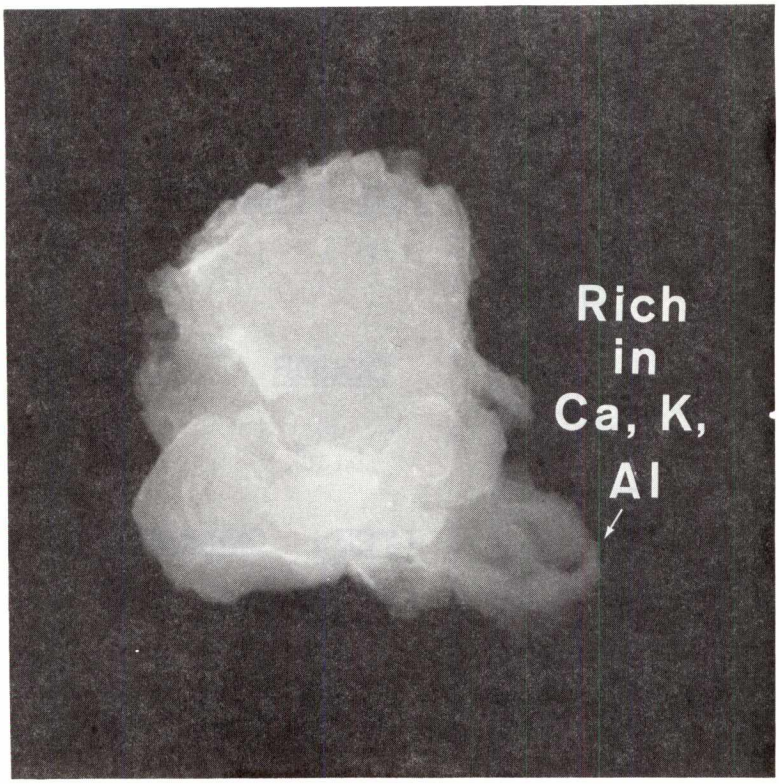
SIZE	SHAPE	TRANS.
11x15	I	0

COLOR	LUSTER
Dk. gray to black	SV/SM

TYPE	COMMENTS
C	



U2015B12

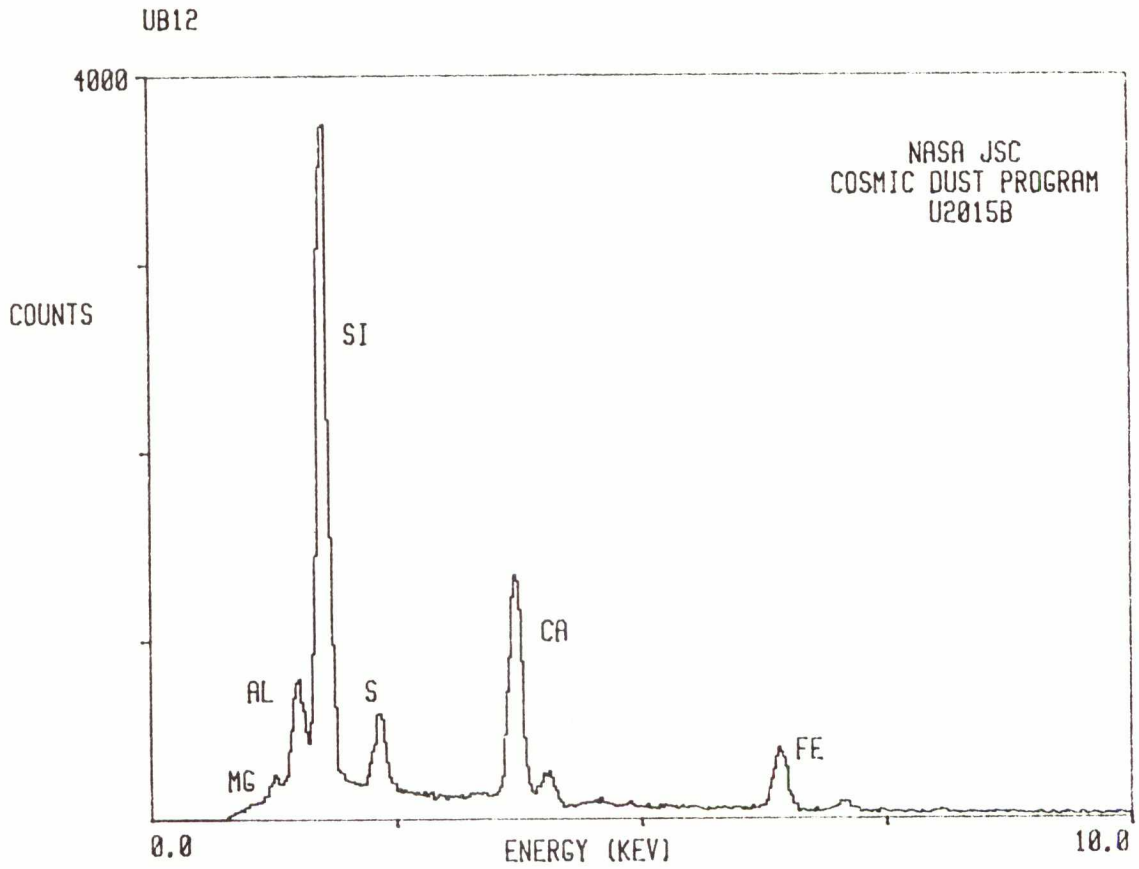


S-84-41372

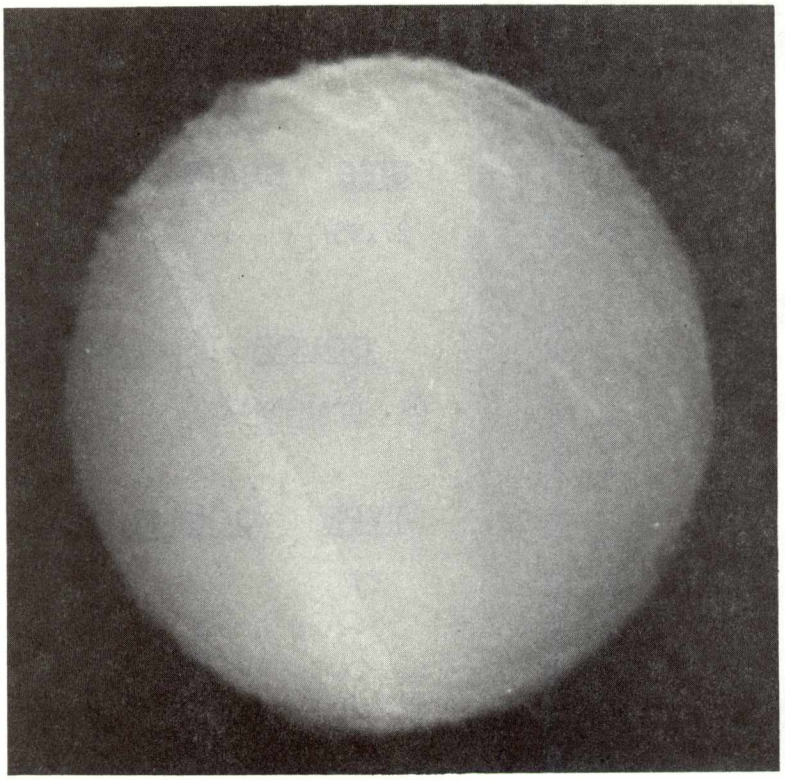
SIZE	SHAPE	TRANS.
18x21	I	TL

COLOR	LUSTER
CL to pale yellow-brown	V

TYPE	COMMENTS
TCN?	



U2015B13

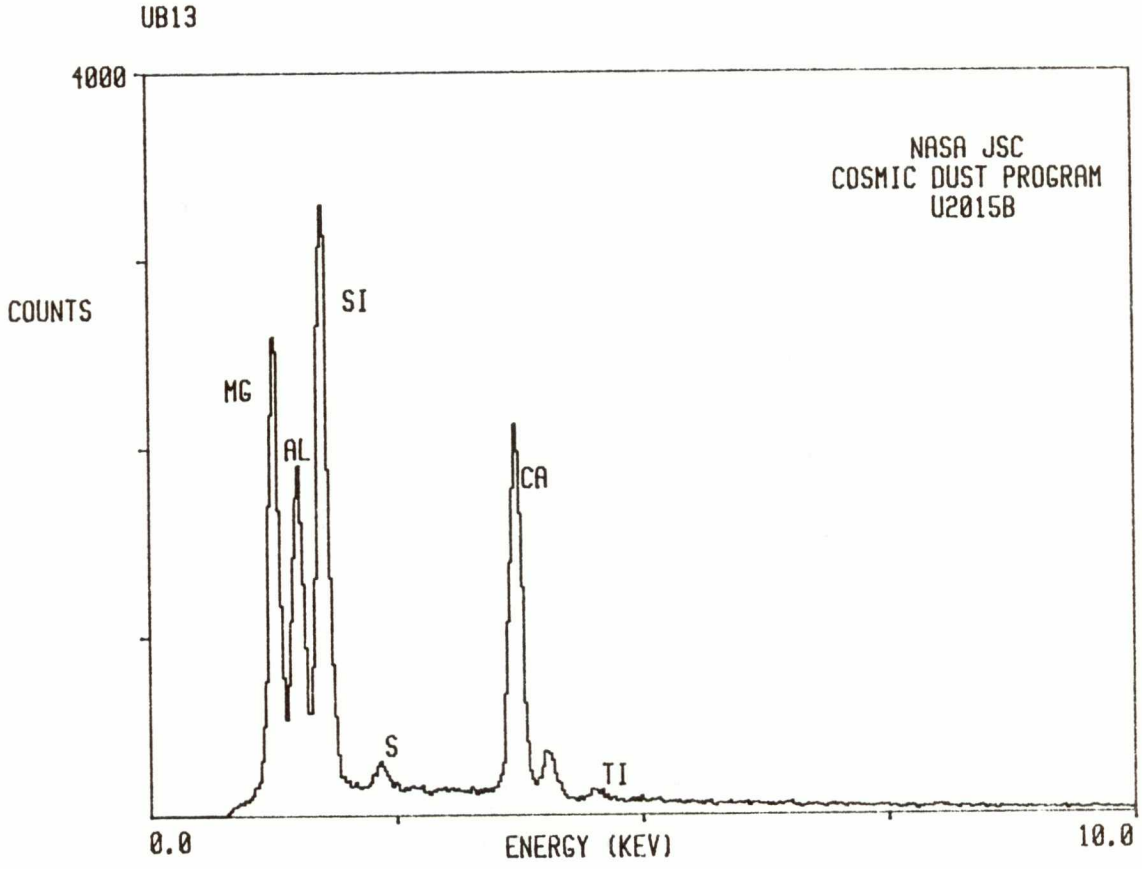


S-84-41373

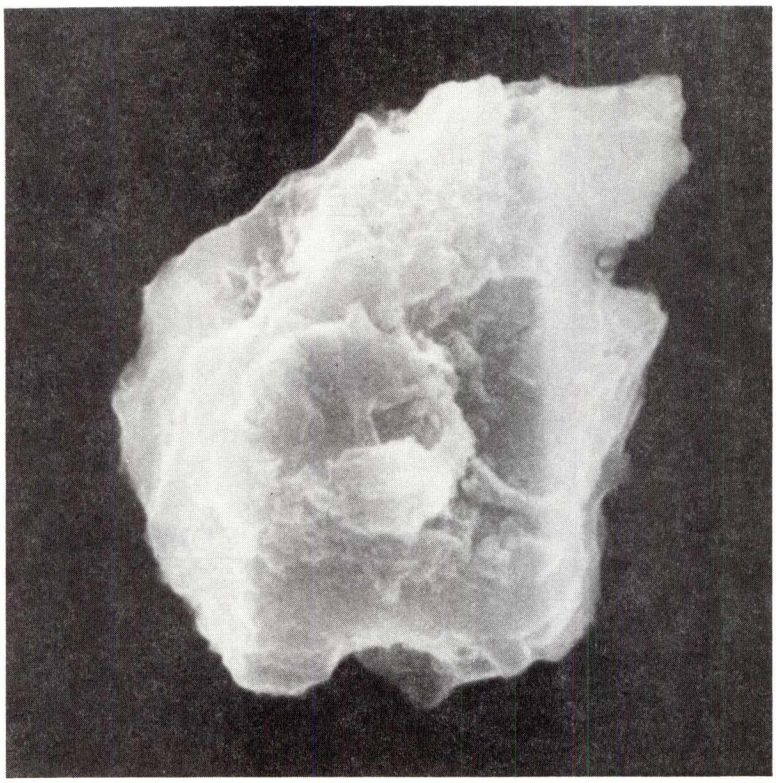
SIZE	SHAPE	TRANS.
11	S	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
C?	



U2015B14

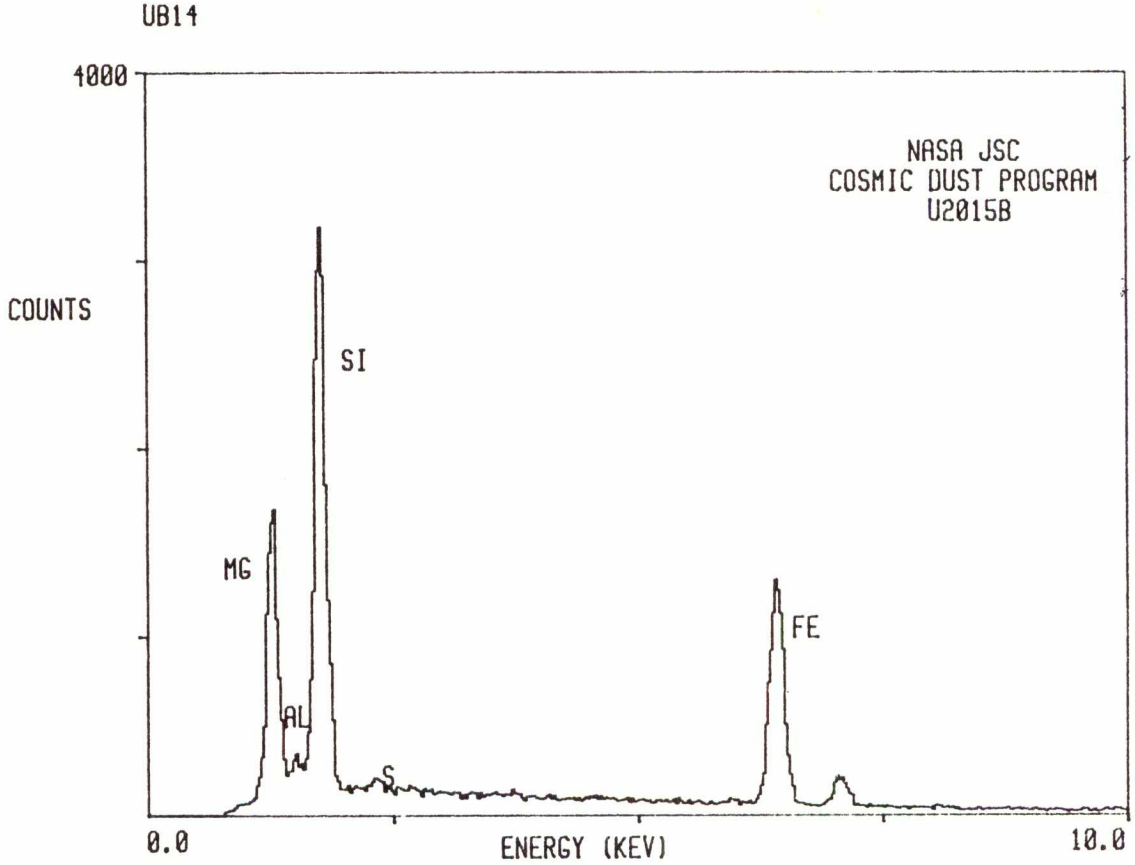


SIZE	SHAPE	TRANS.
27x35	I	O

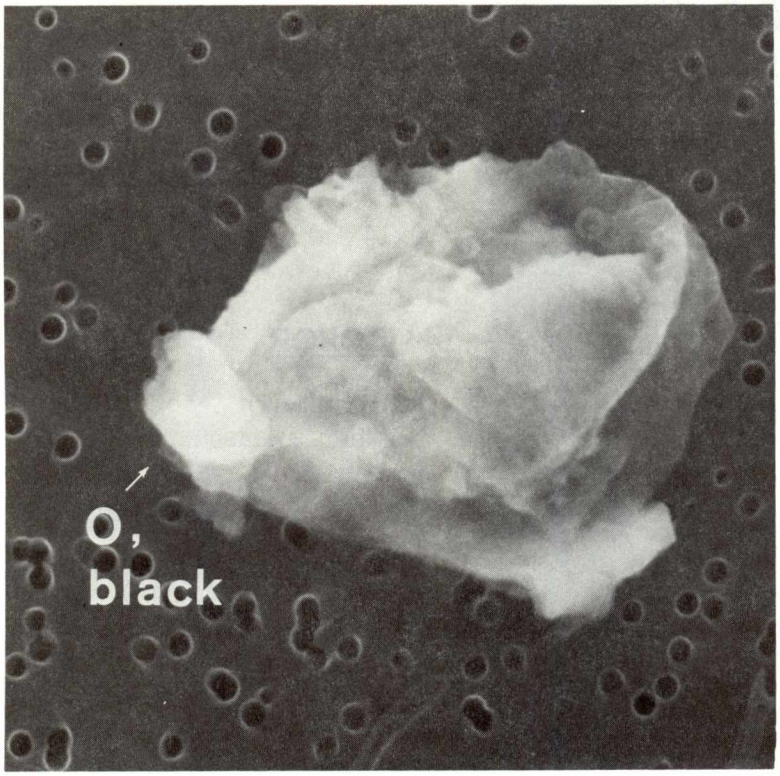
COLOR	LUSTER
Dk. gray-brown	SV

TYPE	COMMENTS
C?	

S-84-41374



U2015B15

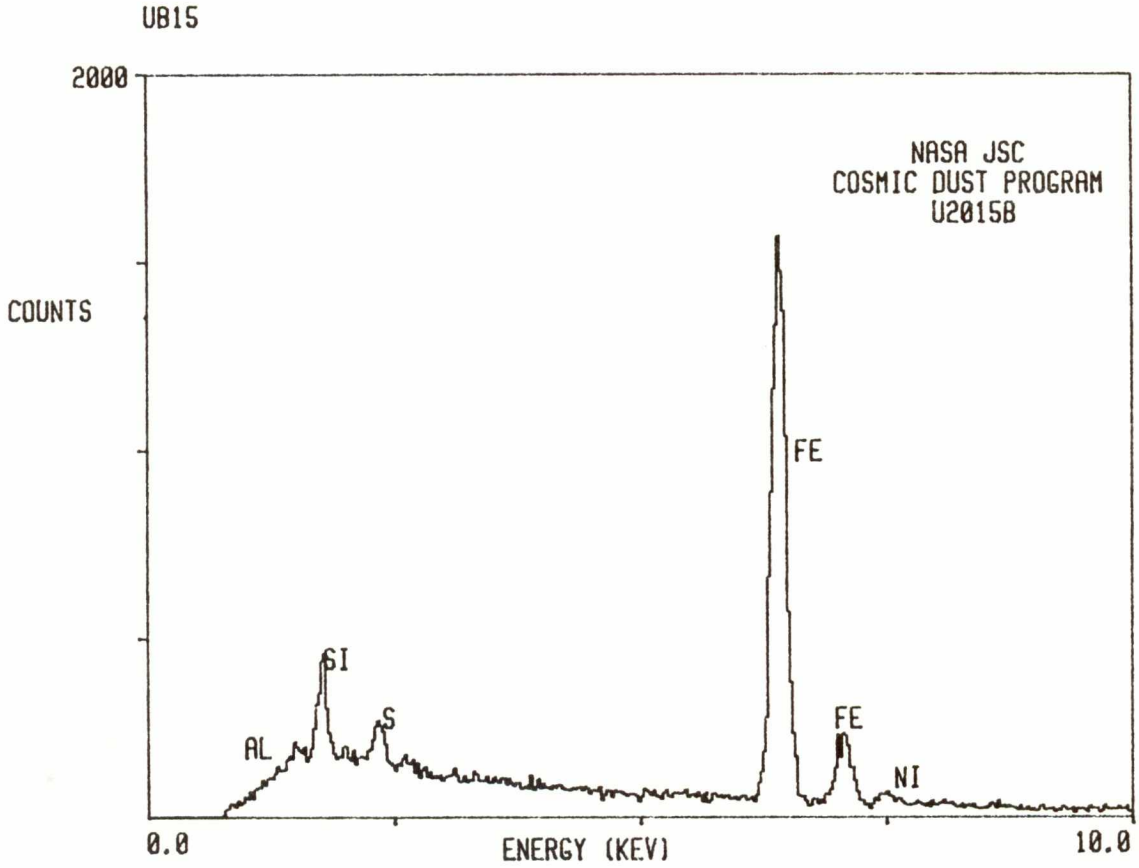


S-84-41375

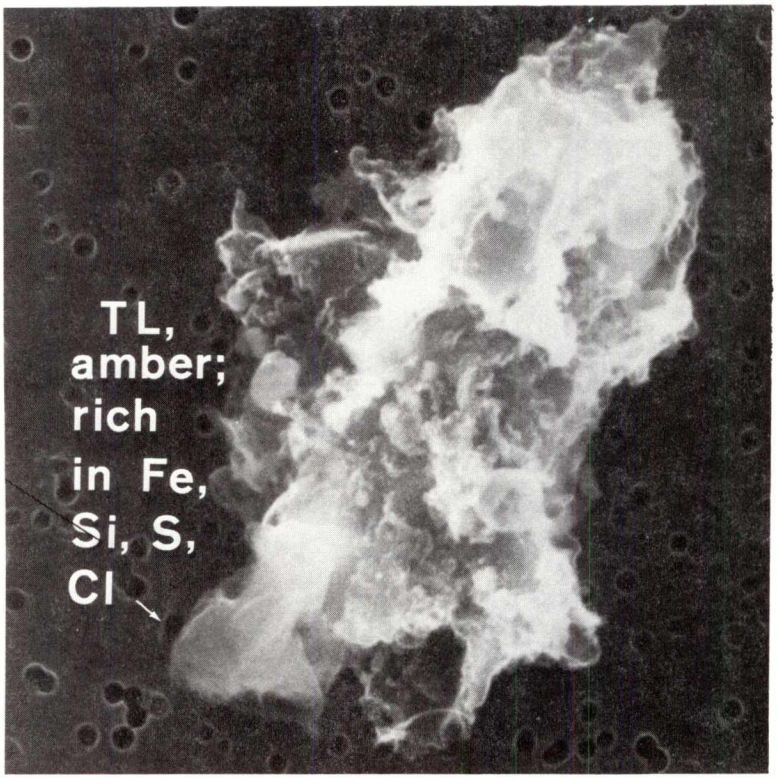
SIZE	SHAPE	TRANS.
7x9	I	TL

COLOR	LUSTER
Amber	SV/V

TYPE	COMMENTS
C?	



U2015B16

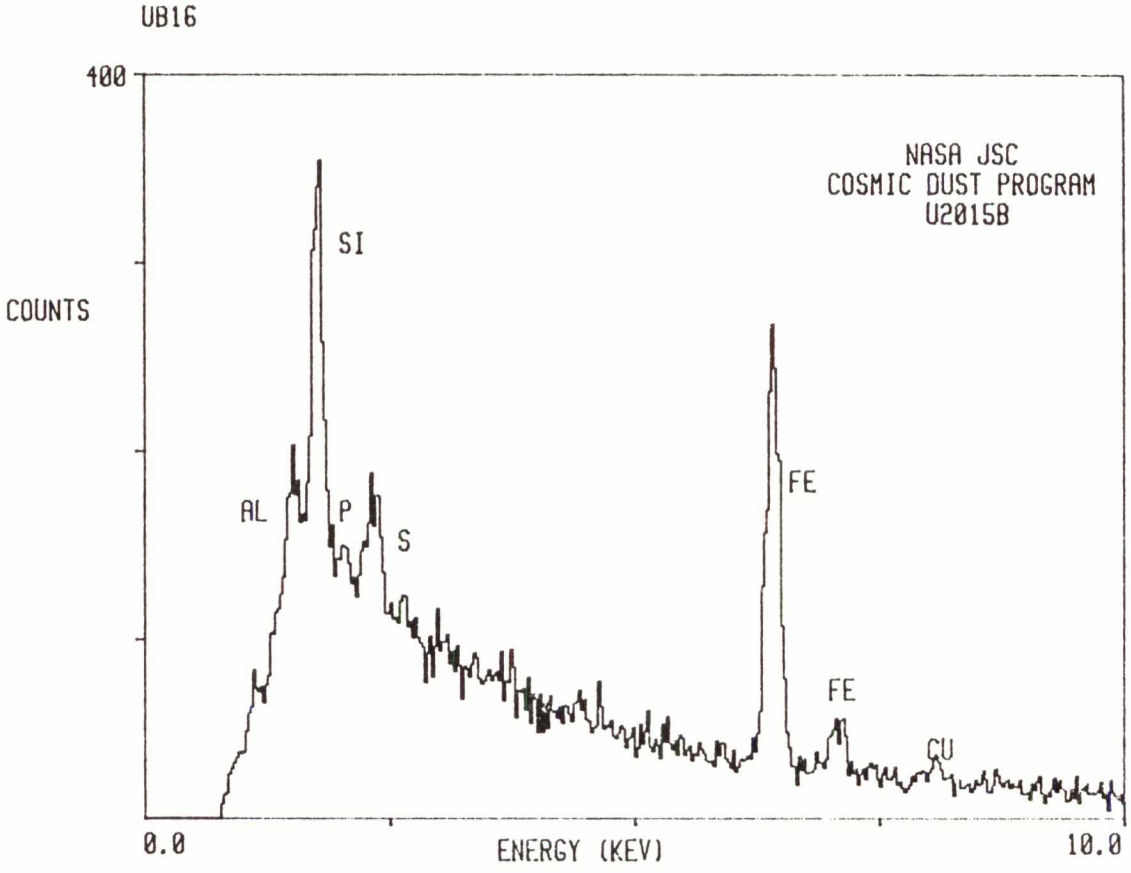


S-84-41376

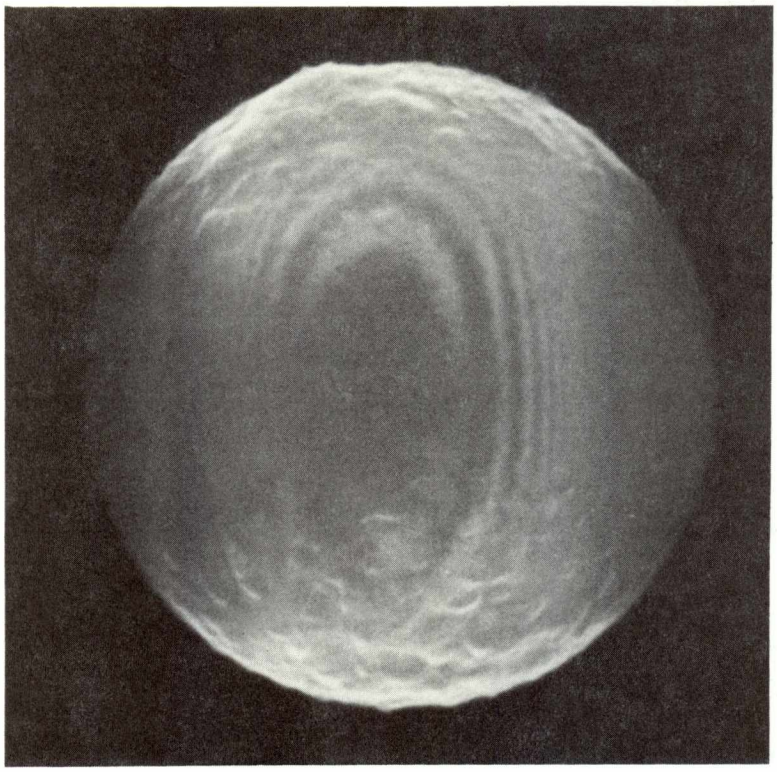
SIZE	SHAPE	TRANS.
9x14	I	TL/O

COLOR	LUSTER
Black with amber areas	SV/SM

TYPE	COMMENTS
?	Largest of several fragments



U2015B17

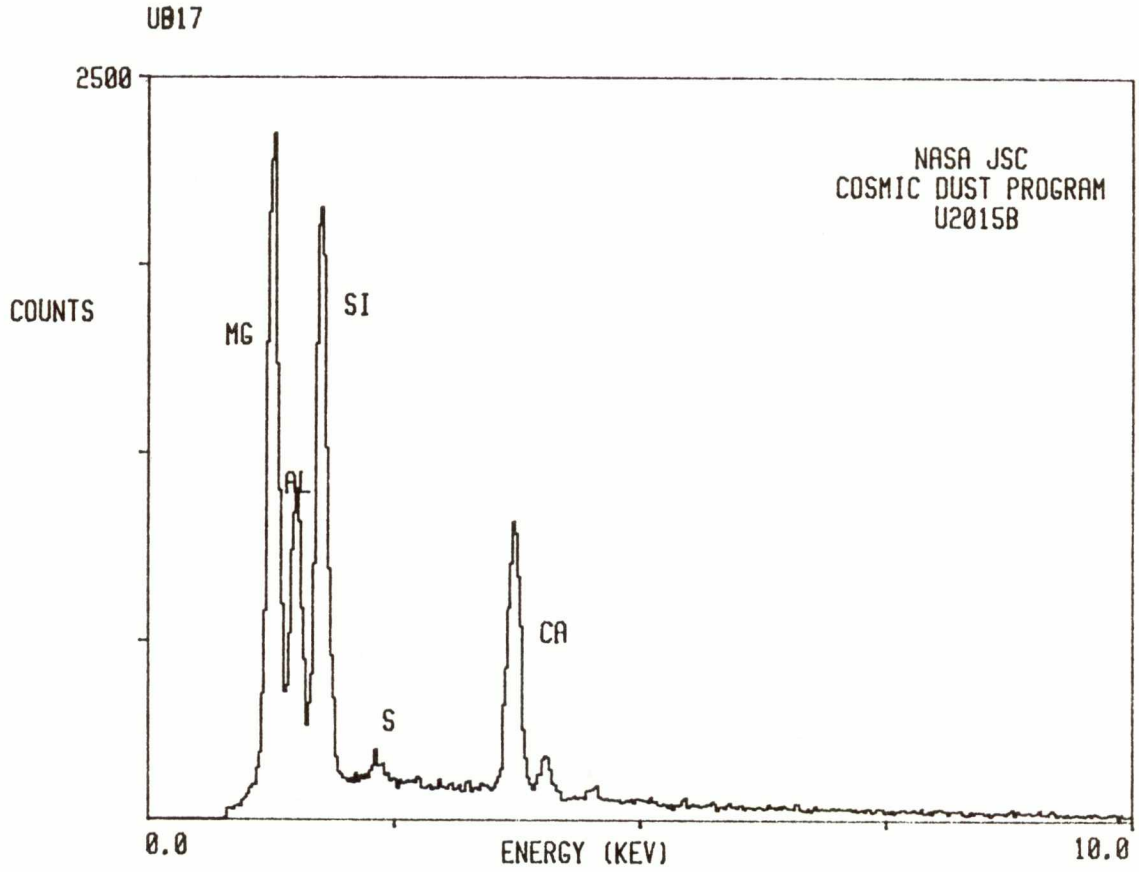


S-84-41377

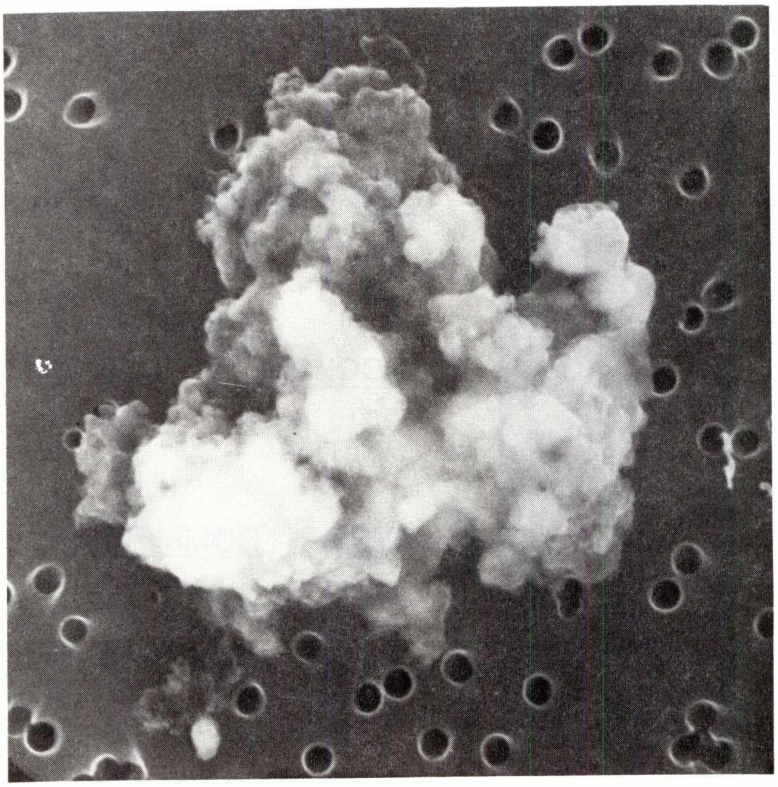
SIZE	SHAPE	TRANS.
13	S	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
C?	



U2015B18

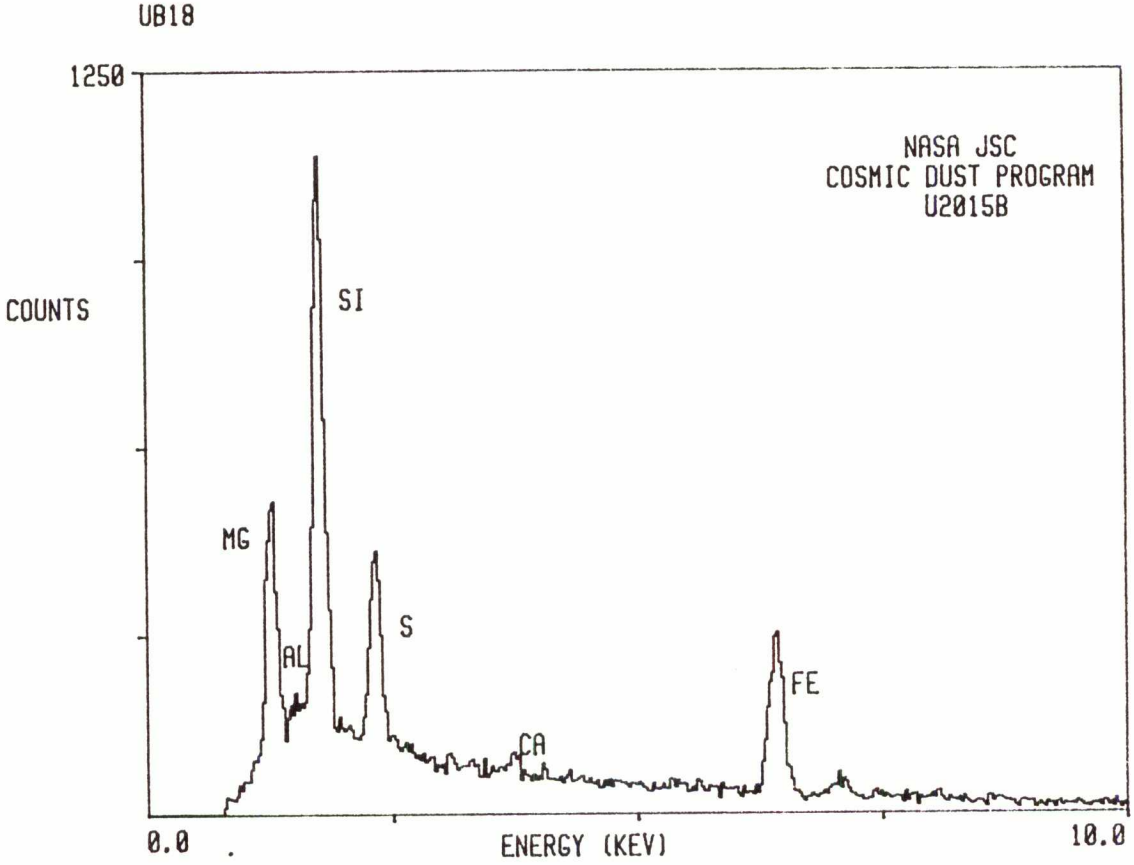


S-84-41378

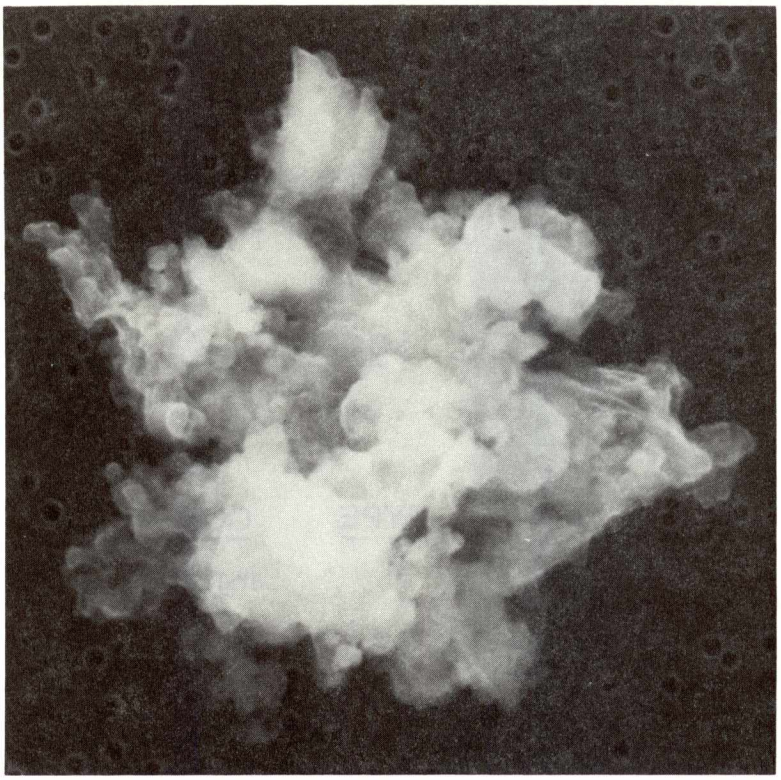
SIZE	SHAPE	TRANS.
7x8	I	O/TL

COLOR	LUSTER
Dk. gray	D/SM

TYPE	COMMENTS
C	Largest of several fragments



U2015B19

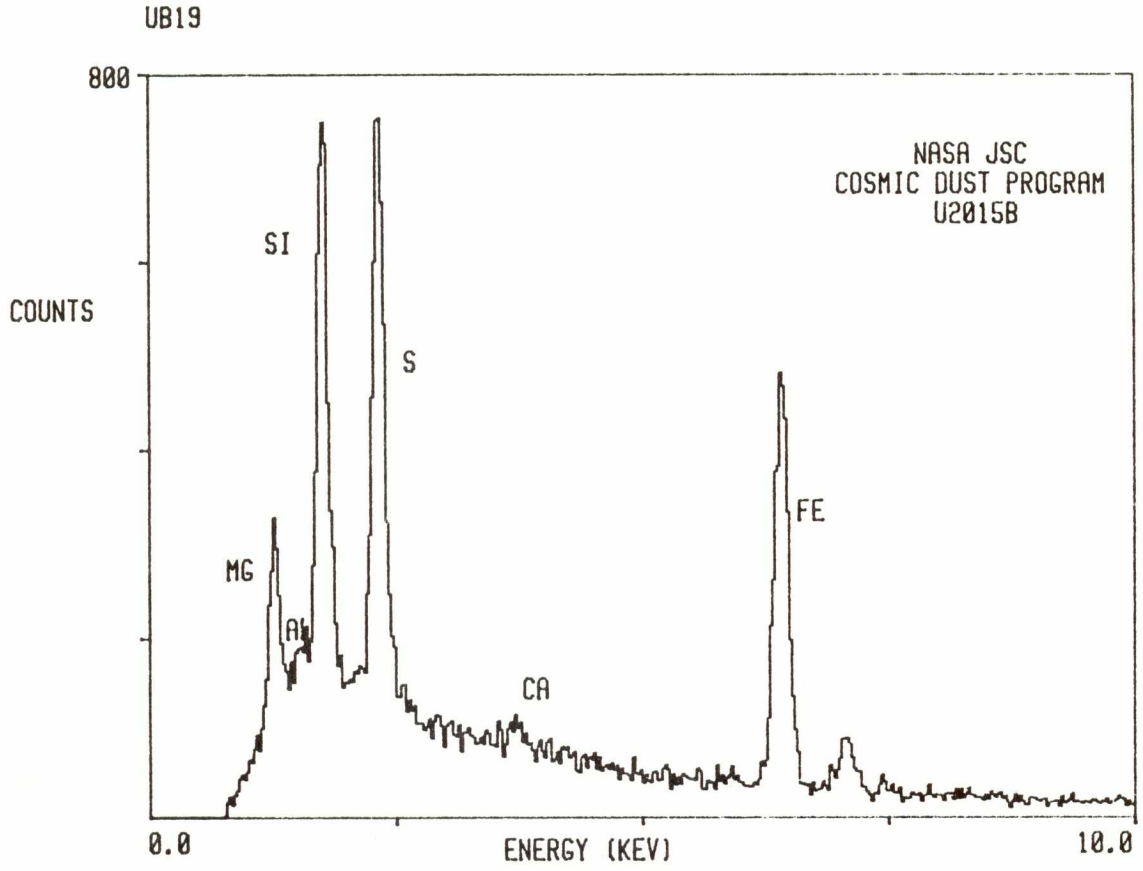


SIZE	SHAPE	TRANS.
12x13	I	0

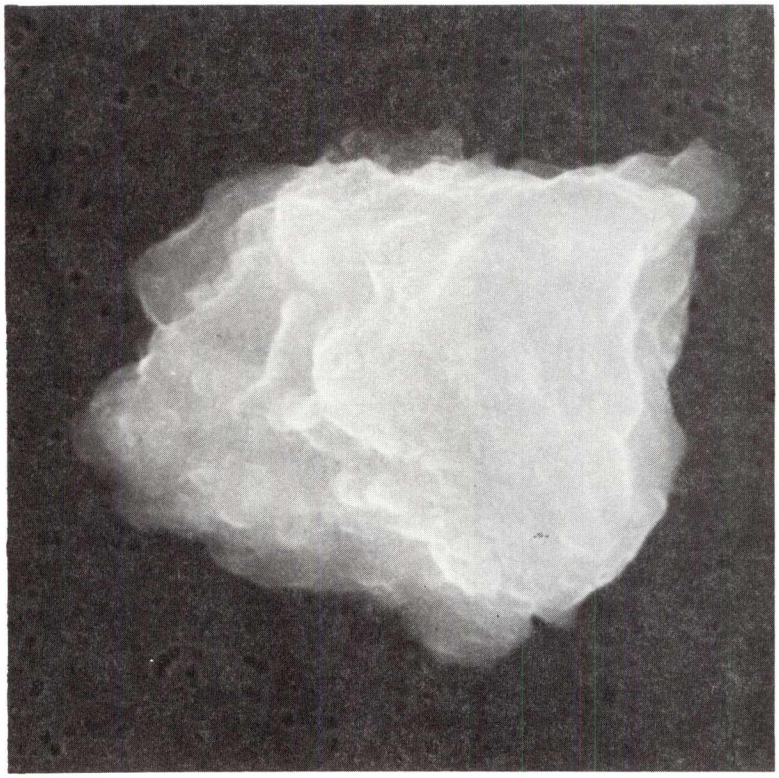
COLOR	LUSTER
Dk. gray to black	SV/SM

TYPE	COMMENTS
C	

S-84-41379



U2015B20

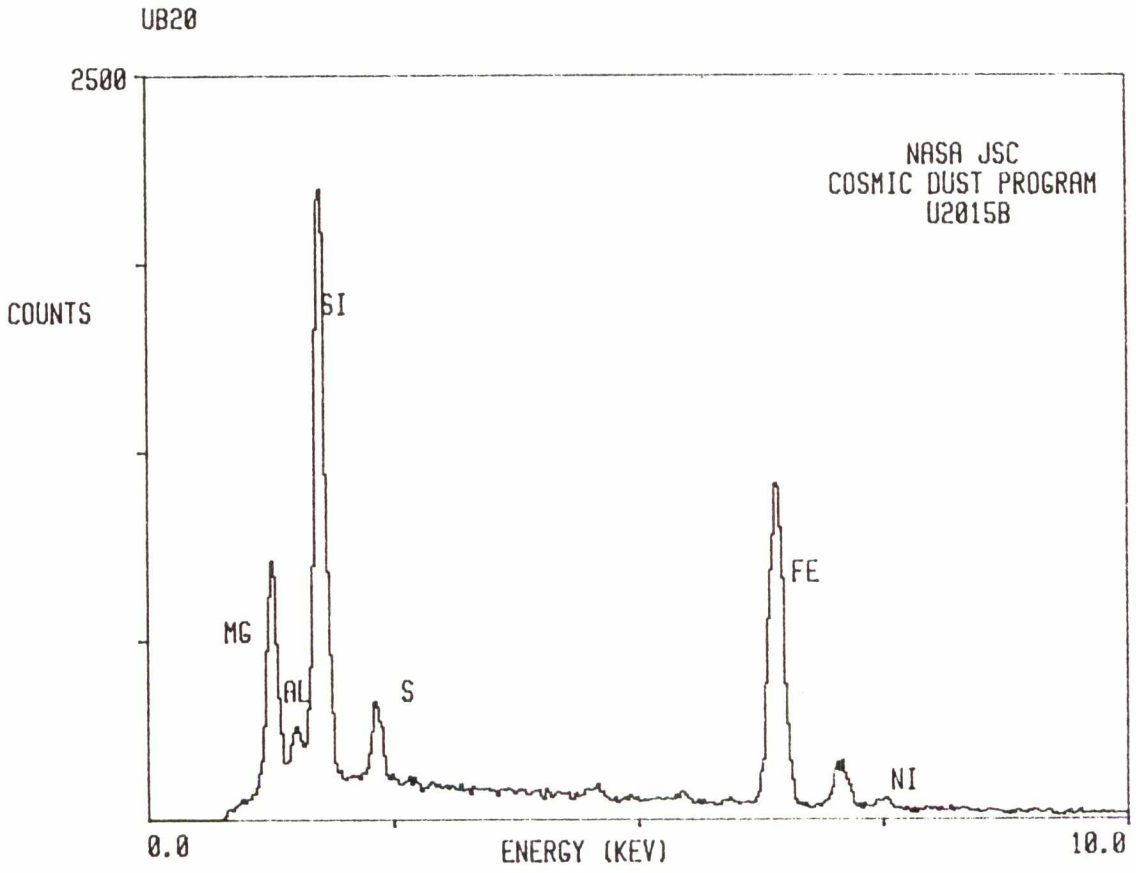


S-84-41380

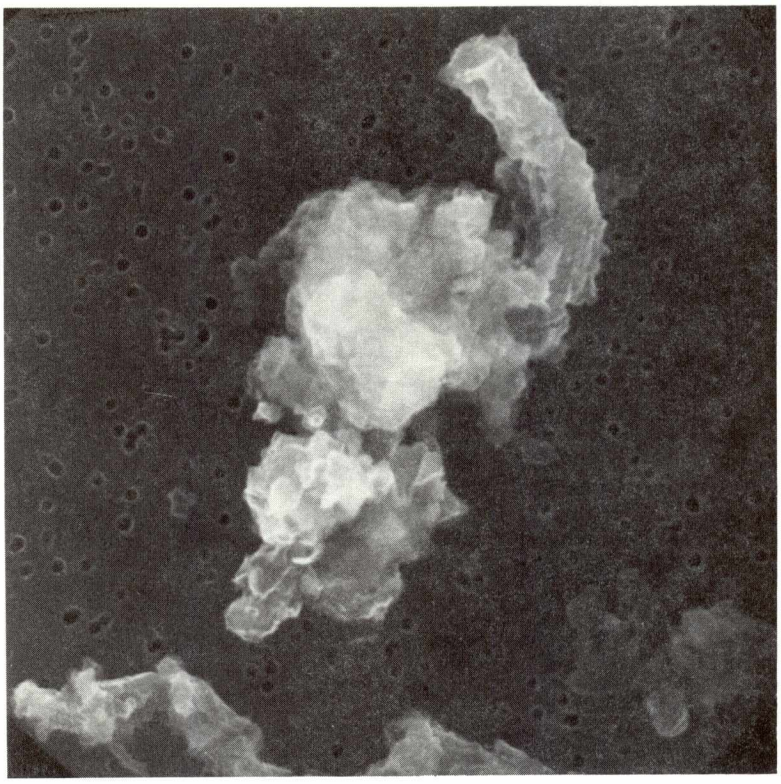
SIZE	SHAPE	TRANS.
12x16	I	0

COLOR	LUSTER
Black	SV/V

TYPE	COMMENTS
C	Largest of several fragments



U2015B21

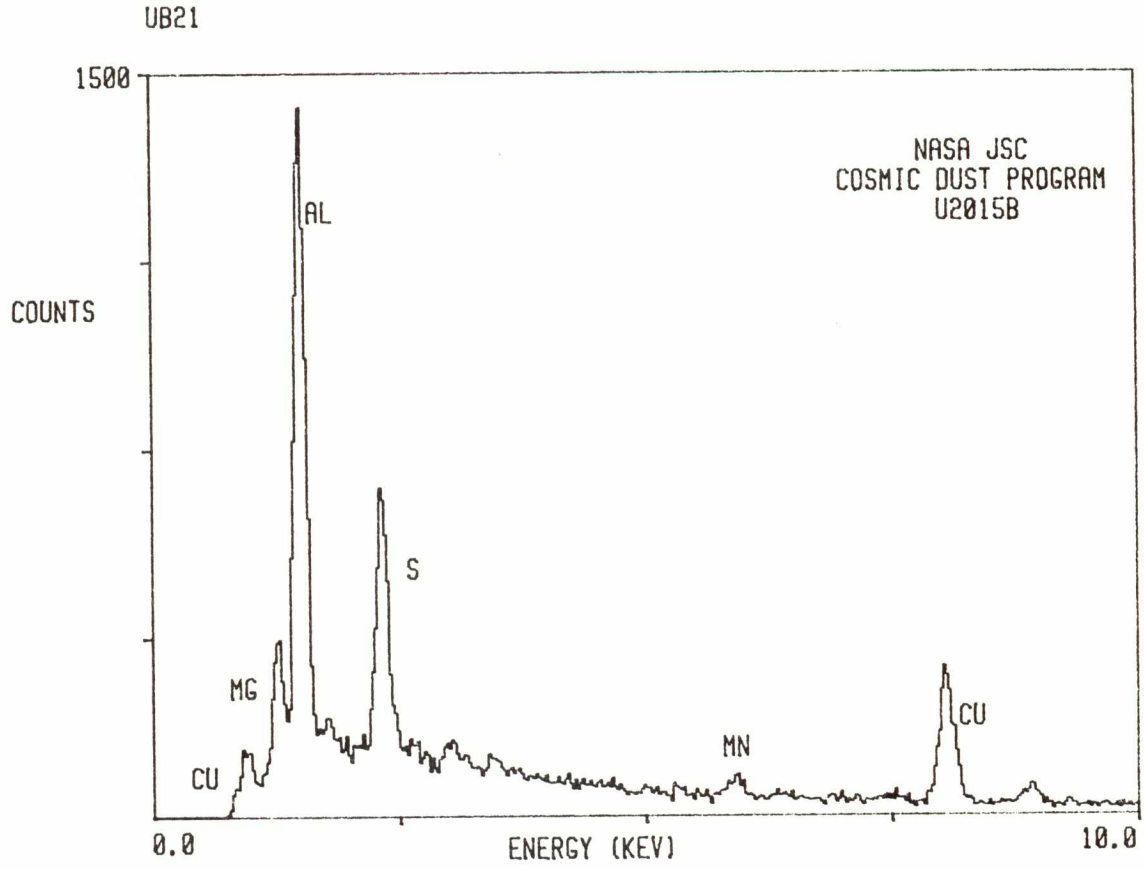


S-84-41381

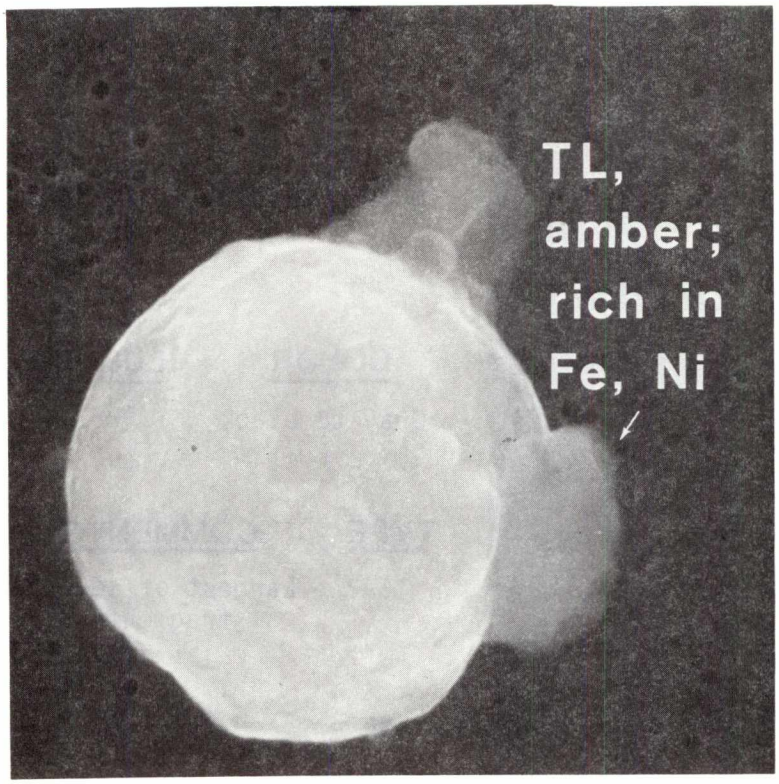
SIZE	SHAPE	TRANS.
9x18	I	O/TL

COLOR	LUSTER
Gray to black	SV

TYPE	COMMENTS
TCA?	Largest of several fragments



U2015B22

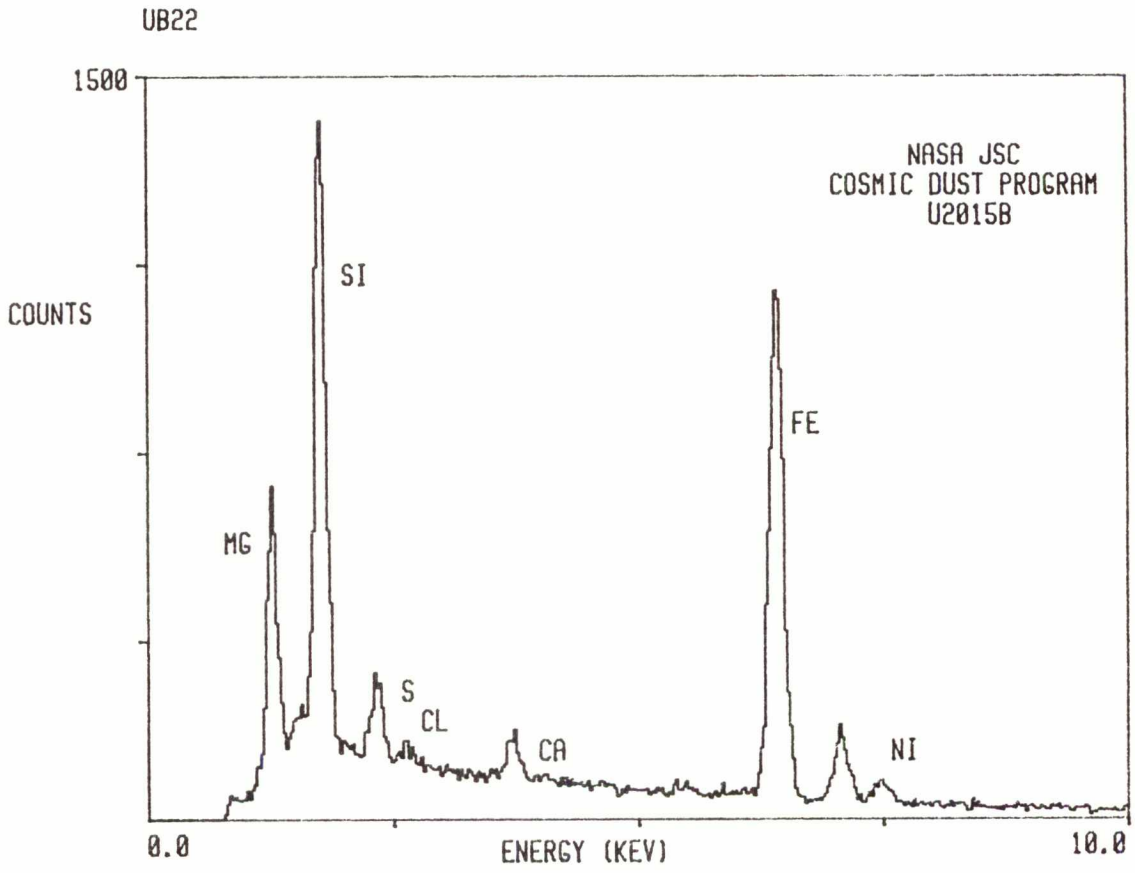


S-84-41382

SIZE	SHAPE	TRANS.
11x12	S/E	O/TL

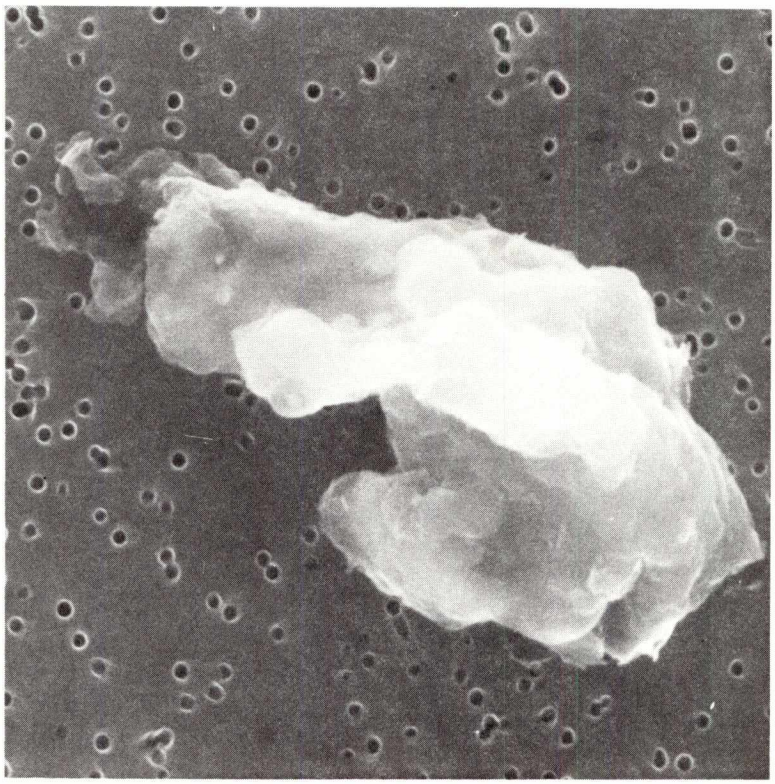
COLOR	LUSTER
Dk. gray to black with amber attachments	SV/SM

TYPE	COMMENTS
C?	



U2015C

U2015C1

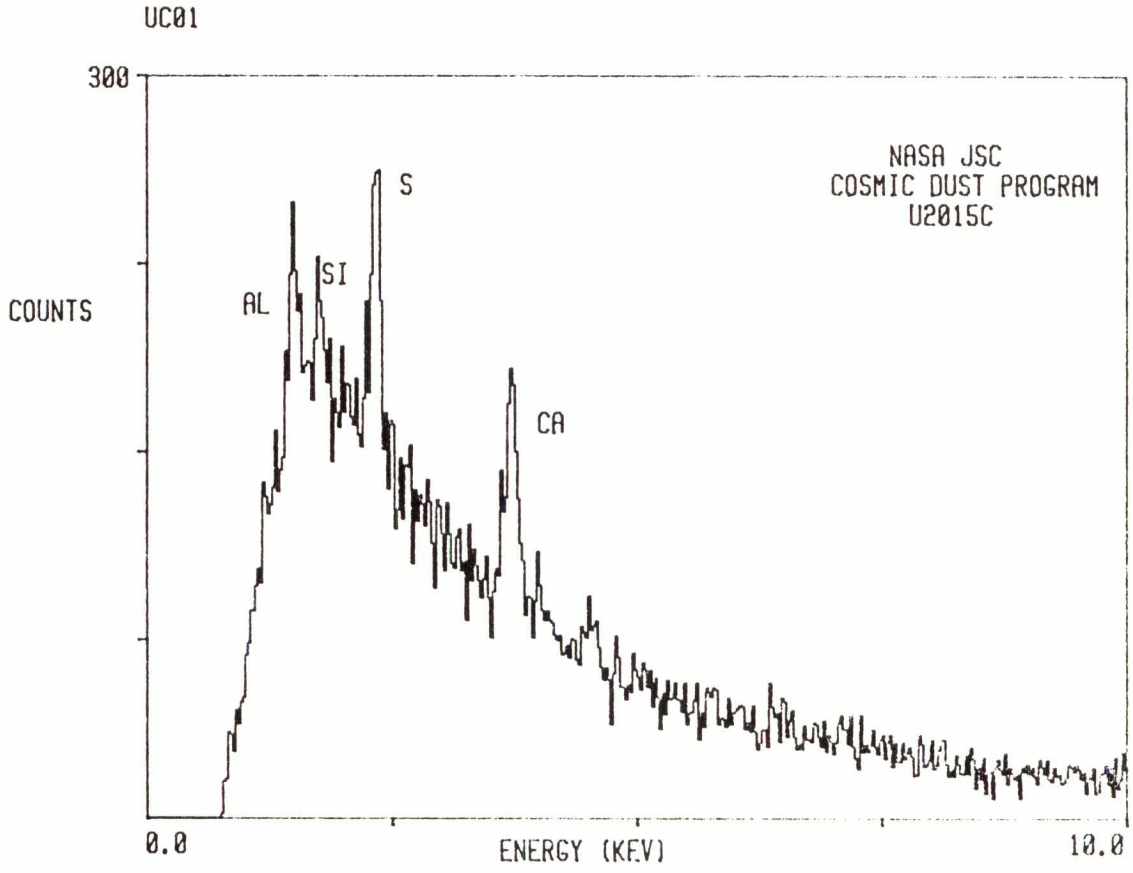


S-84-41406

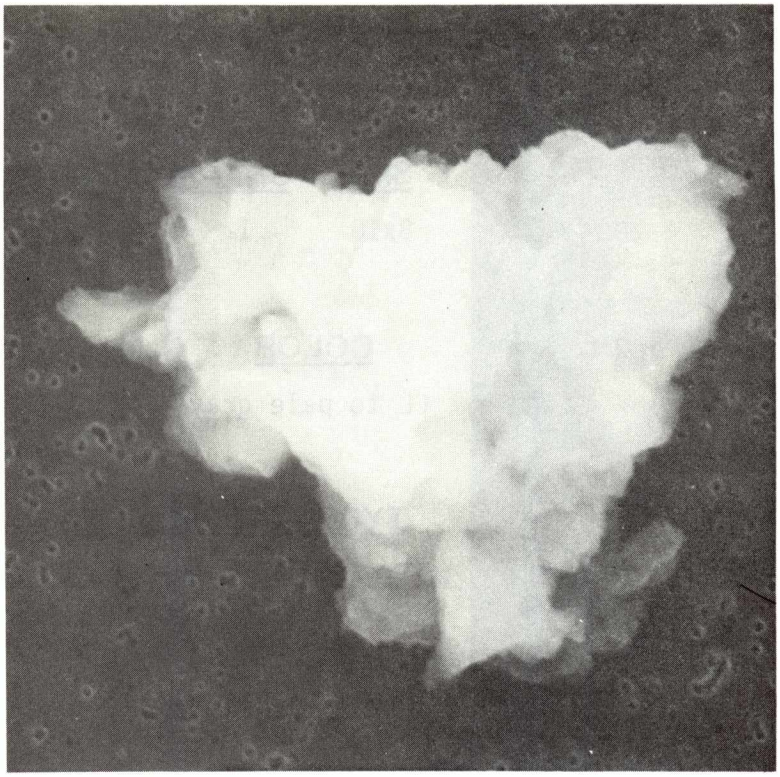
SIZE	SHAPE	TRANS.
9x19	I	O/TL

COLOR	LUSTER
Dk. brown-gray to black	SV/SM

TYPE	COMMENTS
?	



U2015C2

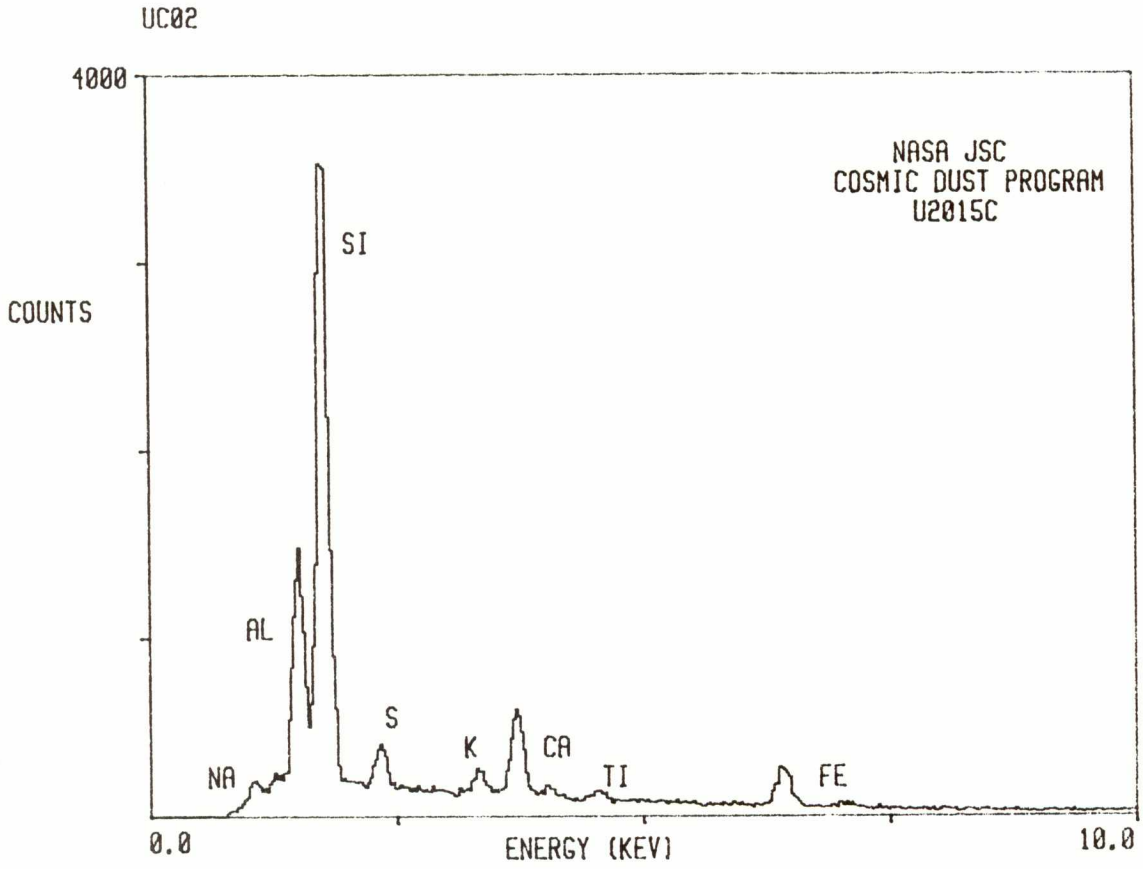


S-84-41407

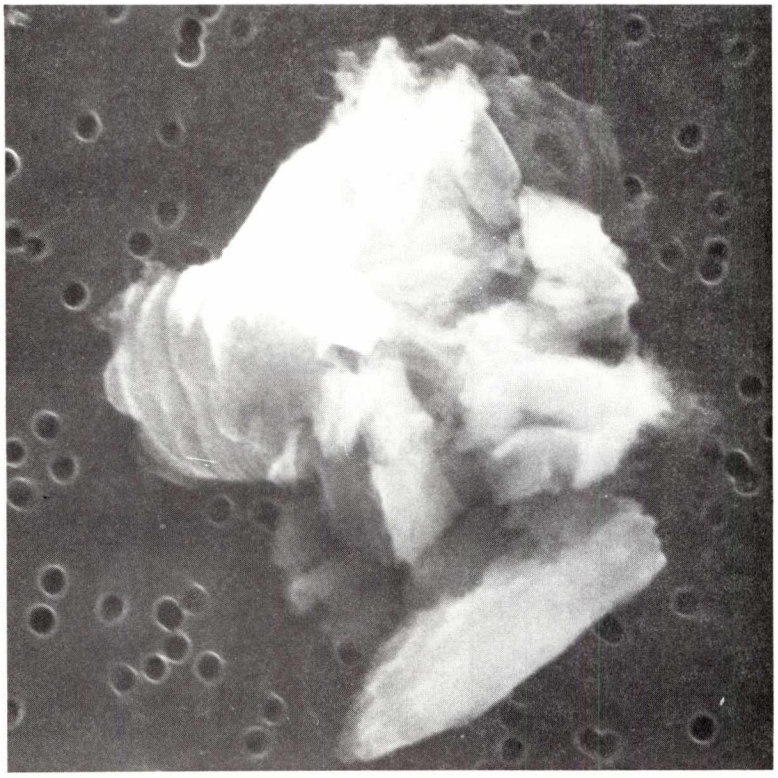
SIZE	SHAPE	TRANS.
20x20	E/I	TL

COLOR	LUSTER
CL to pale brown-yellow	SV/V

TYPE	COMMENTS
TCN	



U2015C3

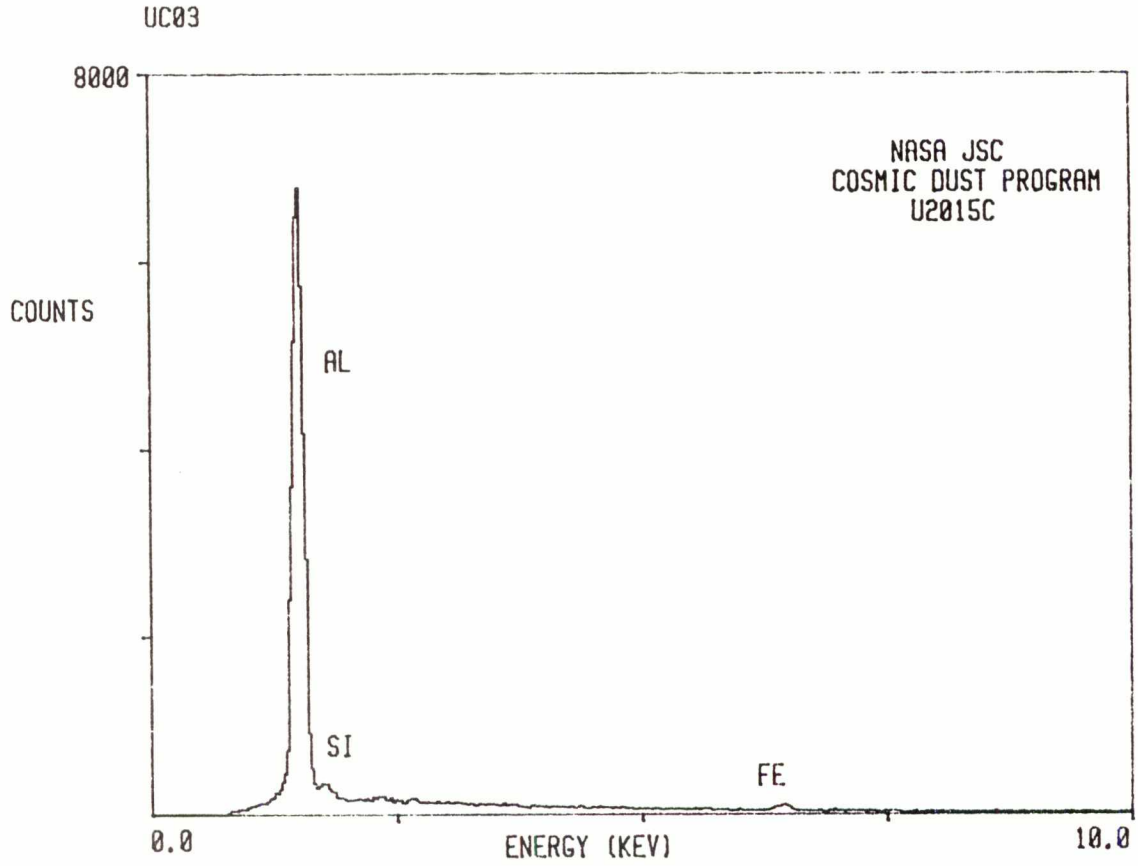


S-84-41408

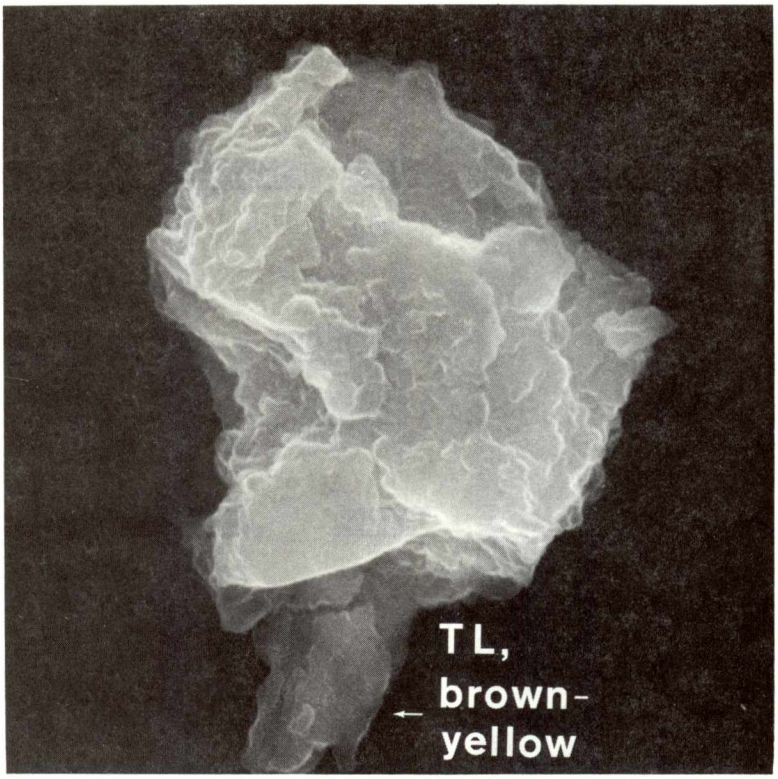
SIZE	SHAPE	TRANS.
8x10	I	TL/O

COLOR	LUSTER
CL to pale gray	SV/V

TYPE	COMMENTS
TCA?	Larger of two fragments



U2015C4

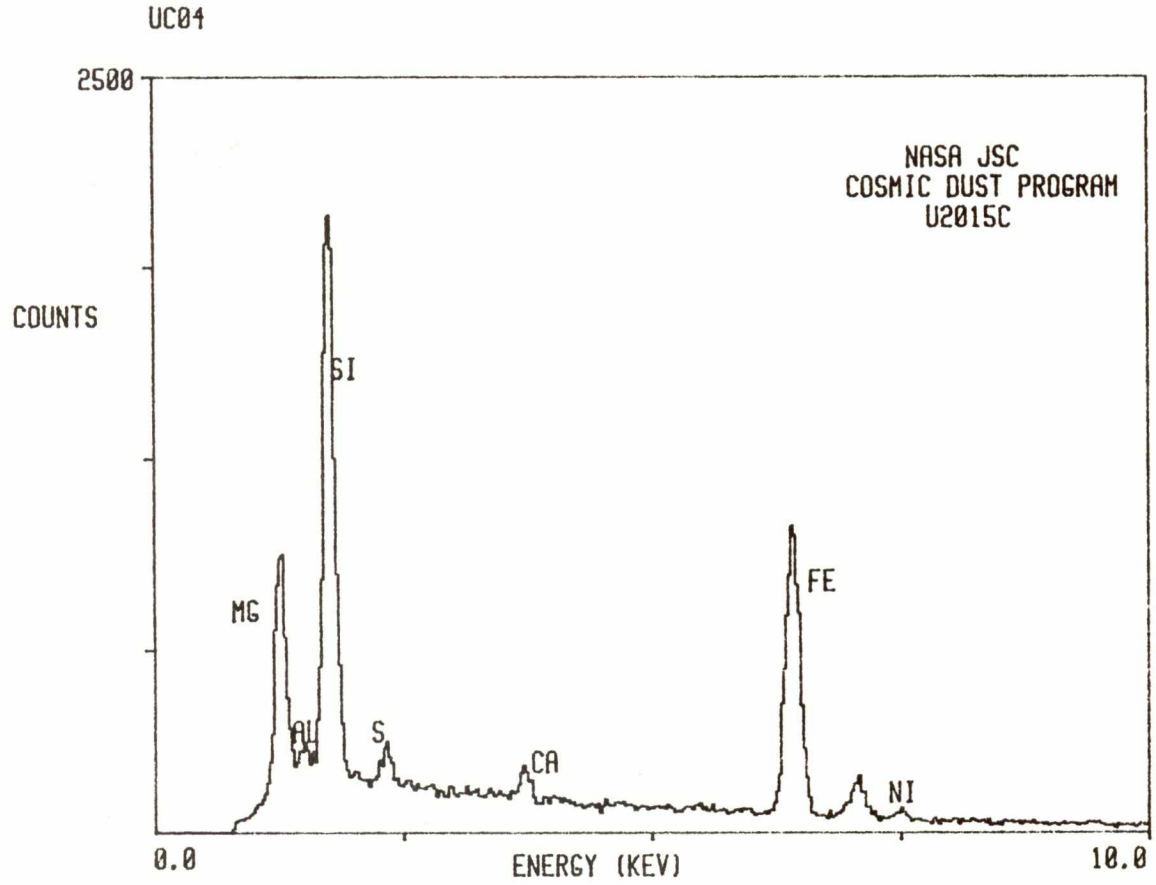


S-84-41411

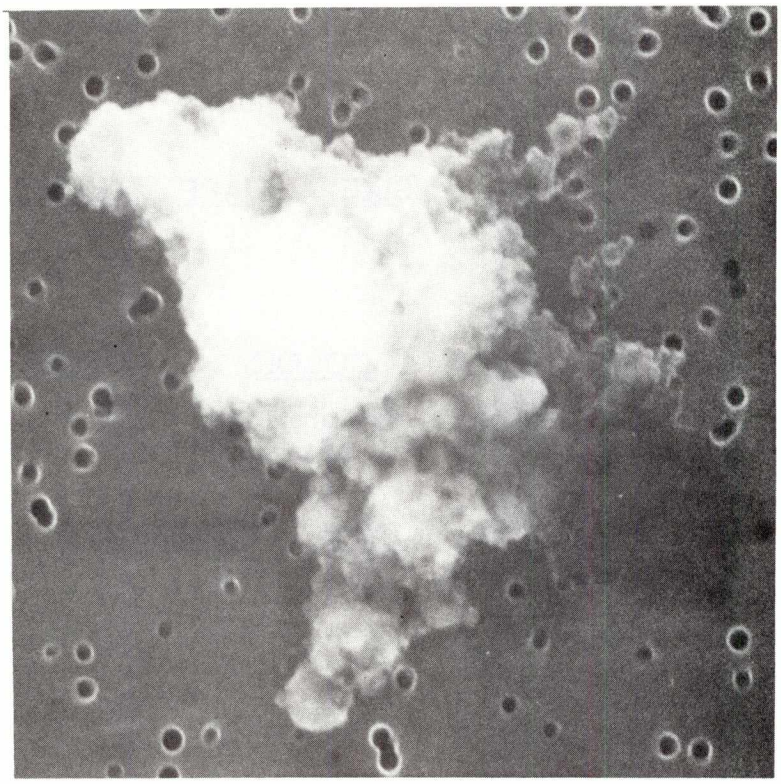
SIZE	SHAPE	TRANS.
16x21	I	O

COLOR	LUSTER
Dk. brown to black	D/SM

TYPE	COMMENTS
C?	



U2015C5

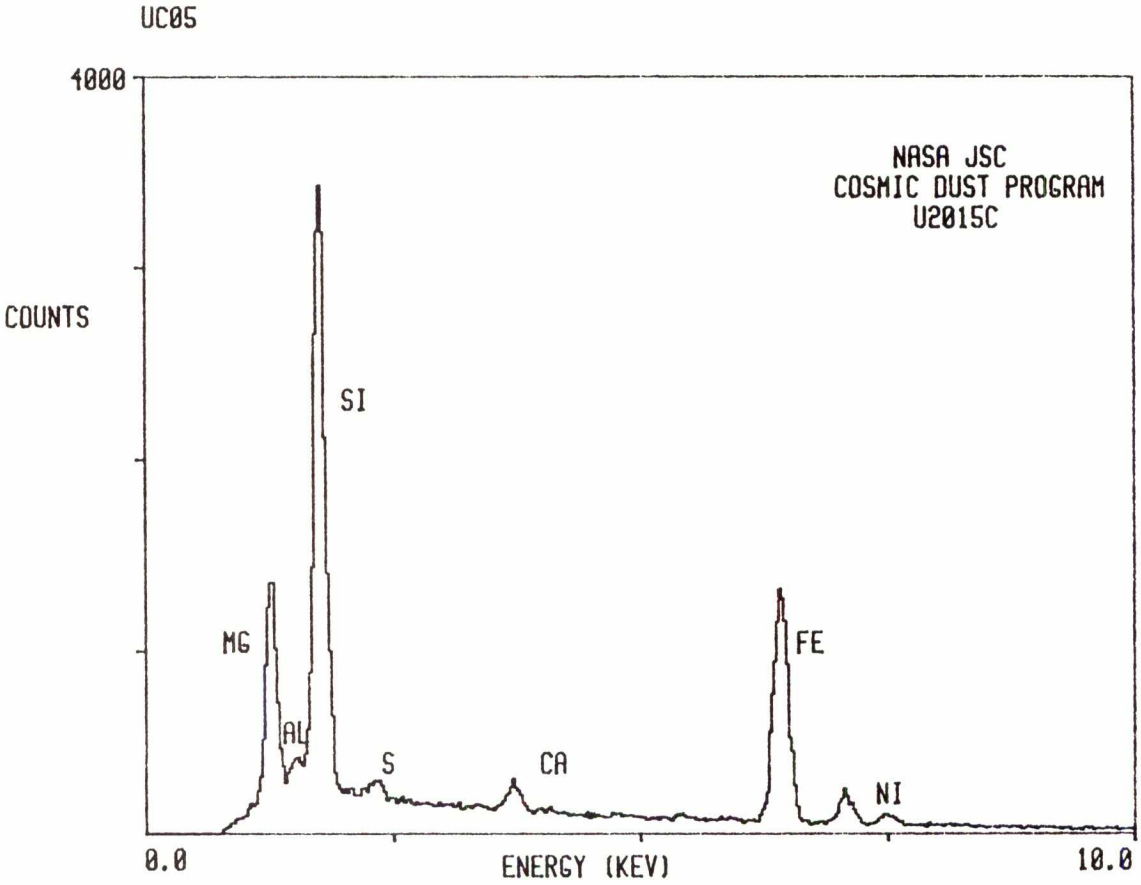


SIZE	SHAPE	TRANS.
9x11	I	0

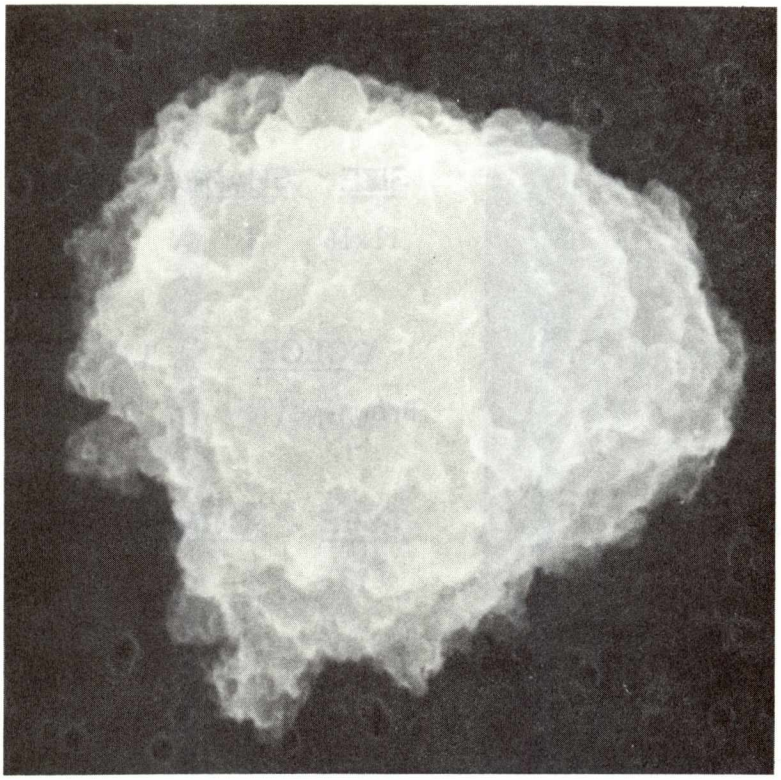
COLOR	LUSTER
Gray to red-brown	D/SM

TYPE	COMMENTS
C	Larger of two fragments

S-84-41412



U2015C6

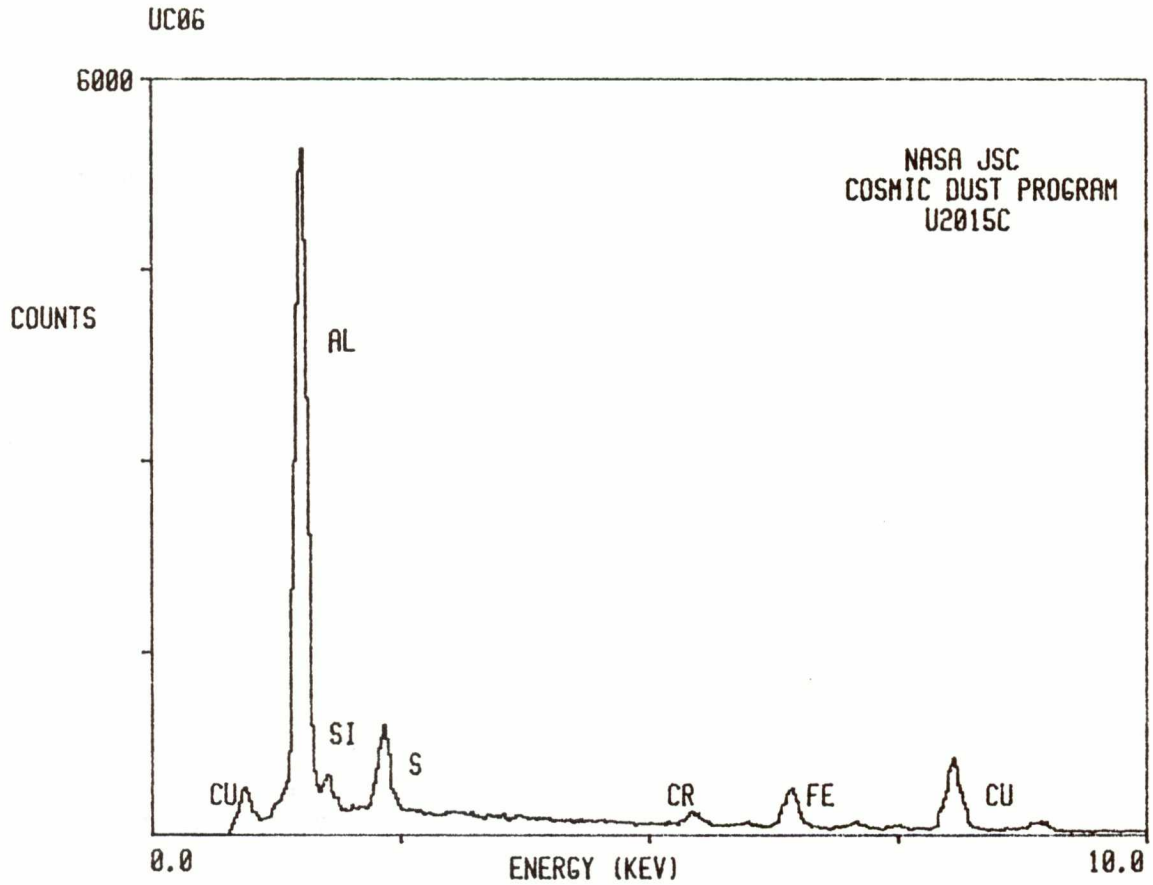


SIZE	SHAPE	TRANS.
10x10	E	0

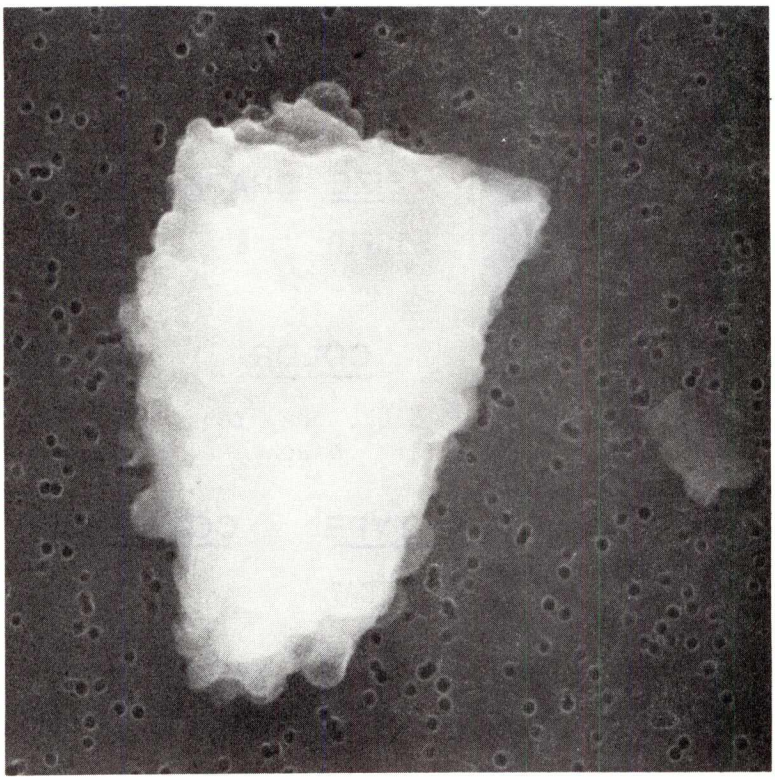
COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
TCA?	

S-84-41413



U2015C7

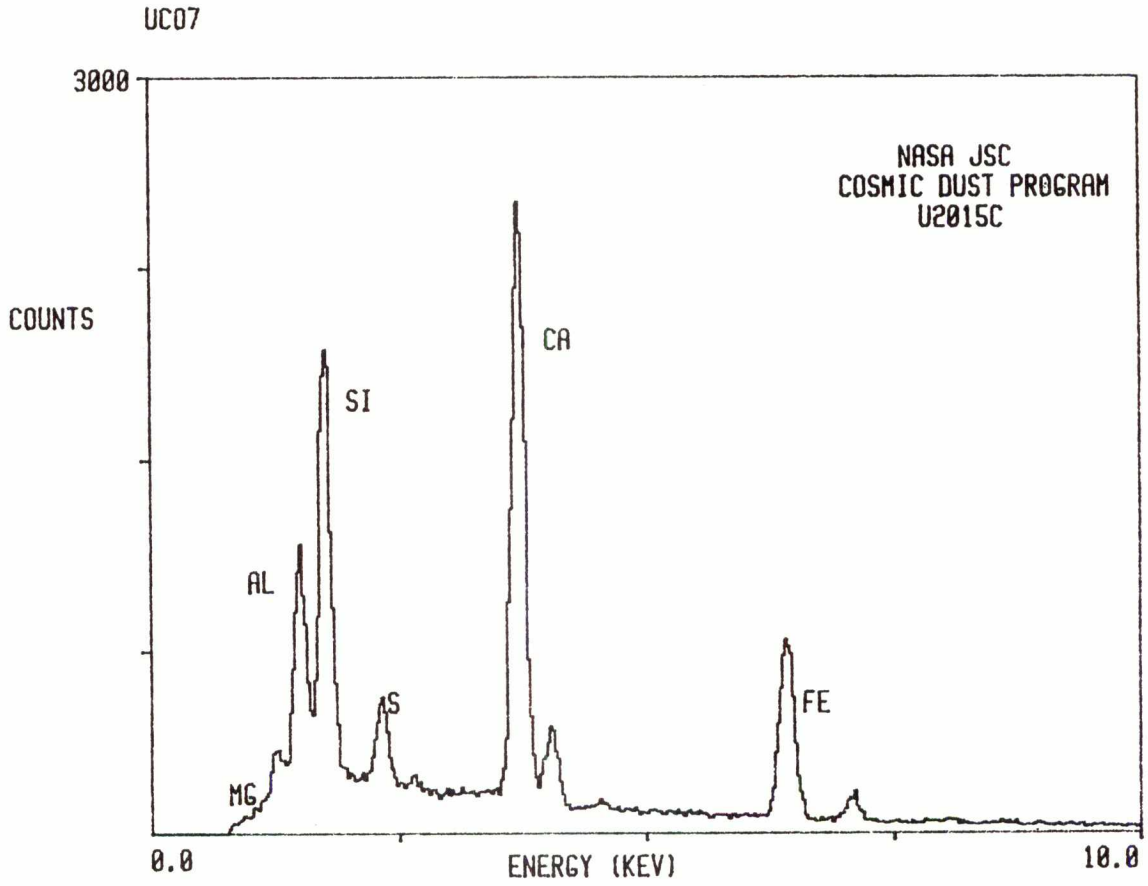


S-84-41414

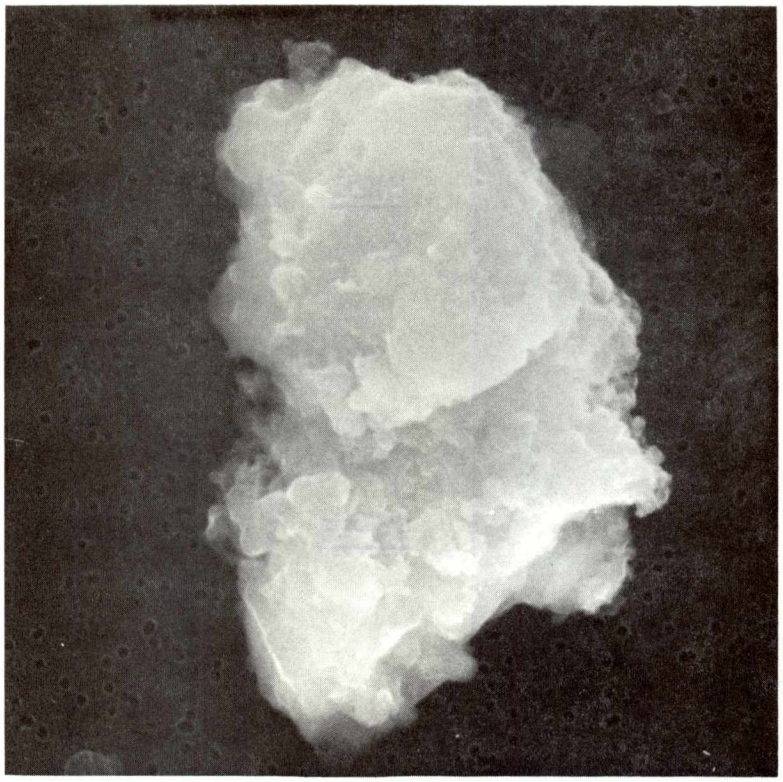
SIZE	SHAPE	TRANS.
11x16	I	TL

COLOR	LUSTER
Brown-yellow	SV

TYPE	COMMENTS
C??	



U2015C8

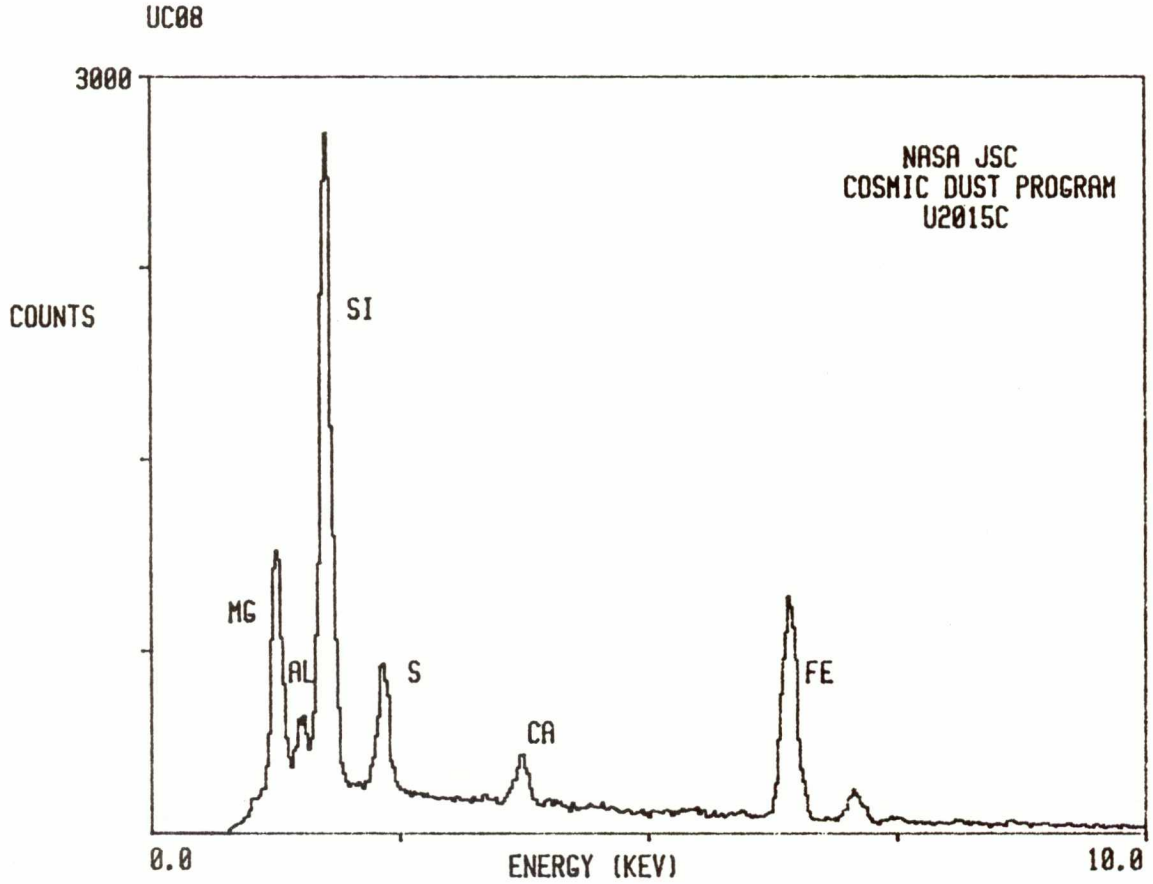


SIZE	SHAPE	TRANS.
13x21	I	O

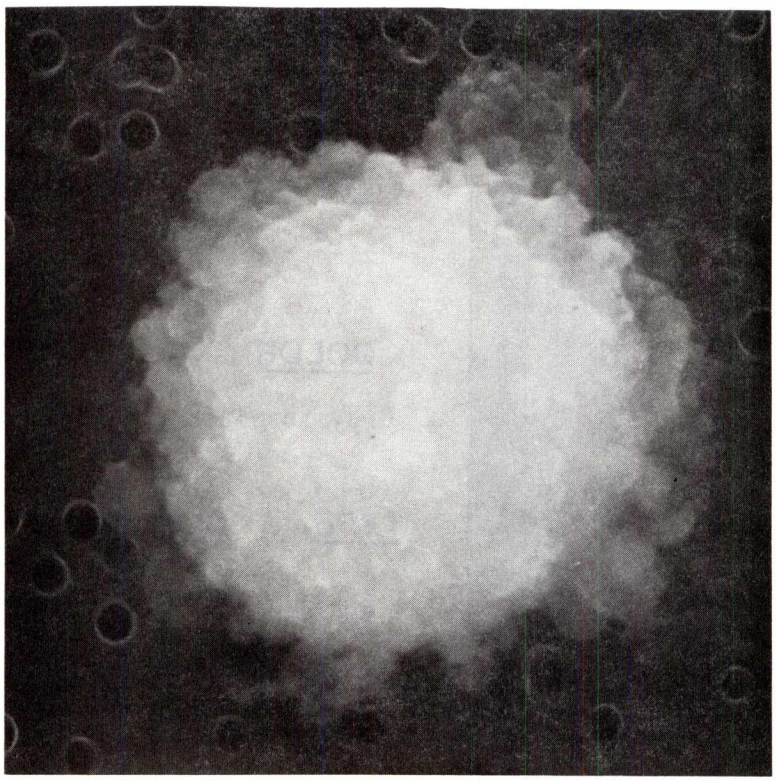
COLOR	LUSTER
Gray to black	D/SM

TYPE	COMMENTS
C	

S-84-41415



U2015C9

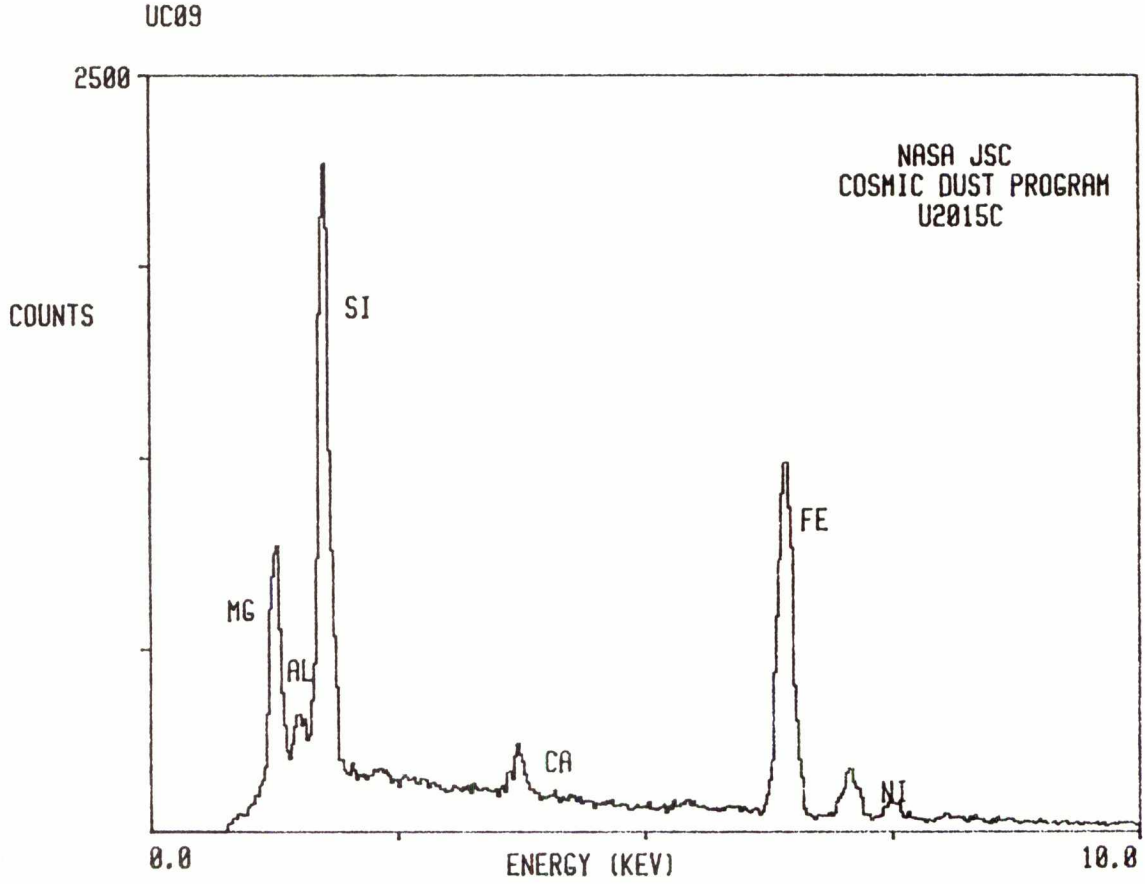


S-84-41416

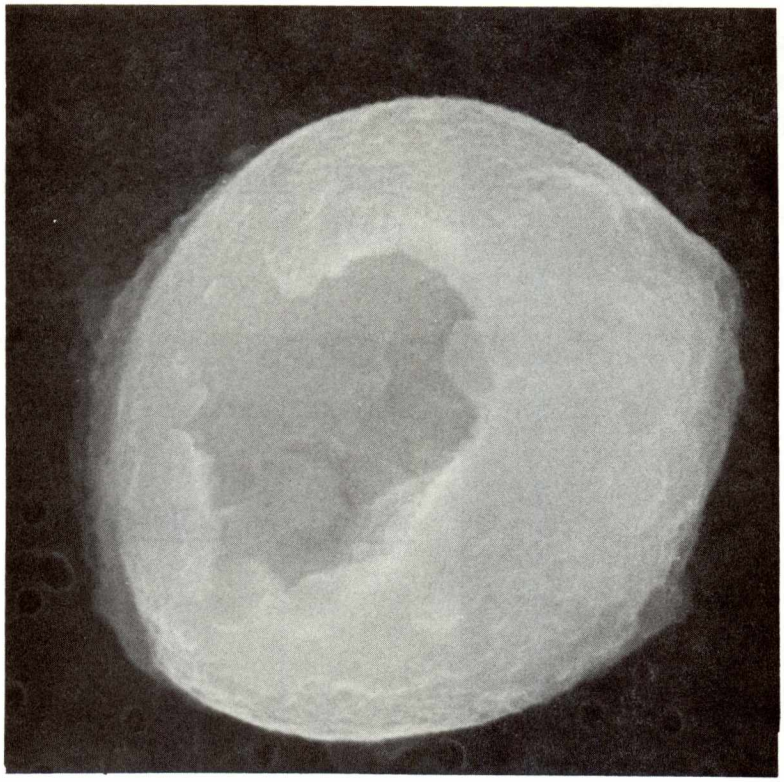
SIZE	SHAPE	TRANS.
6x7	E	O

COLOR	LUSTER
Brown-gray to black	D/SM

TYPE	COMMENTS
C	



U2015C10

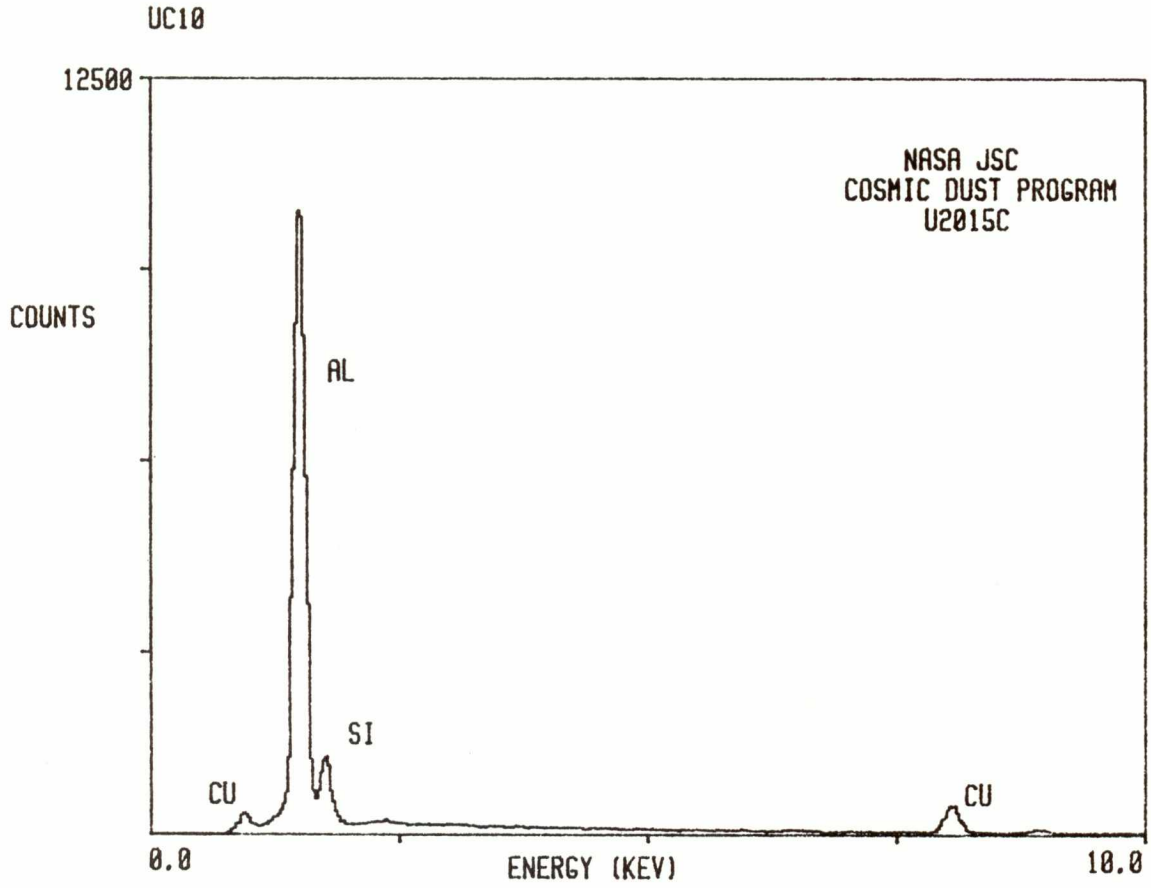


SIZE	SHAPE	TRANS.
10x11	I	0

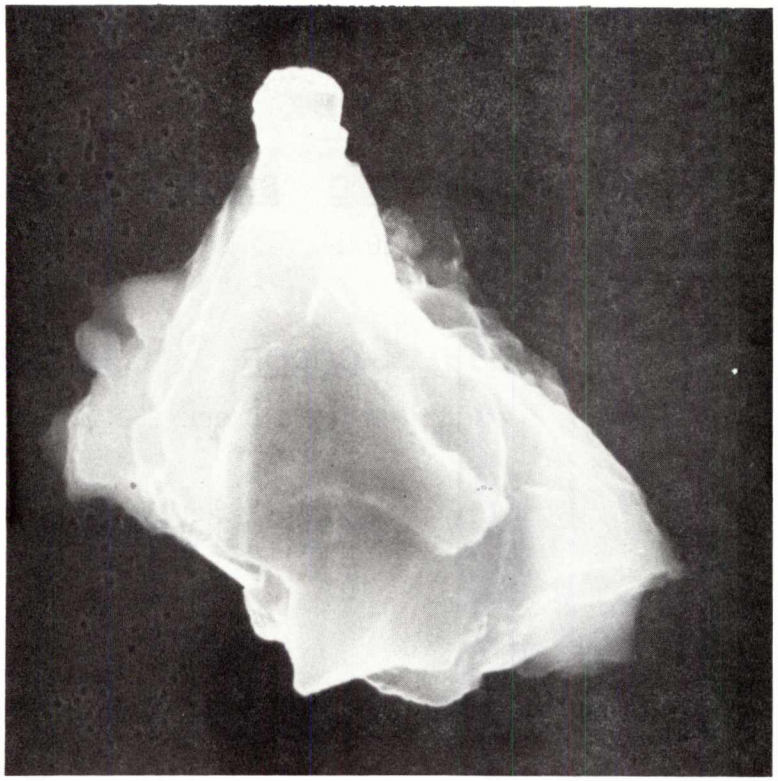
COLOR	LUSTER
Gray to black	M

TYPE	COMMENTS
TCA	

S-84-41417



U2015C11

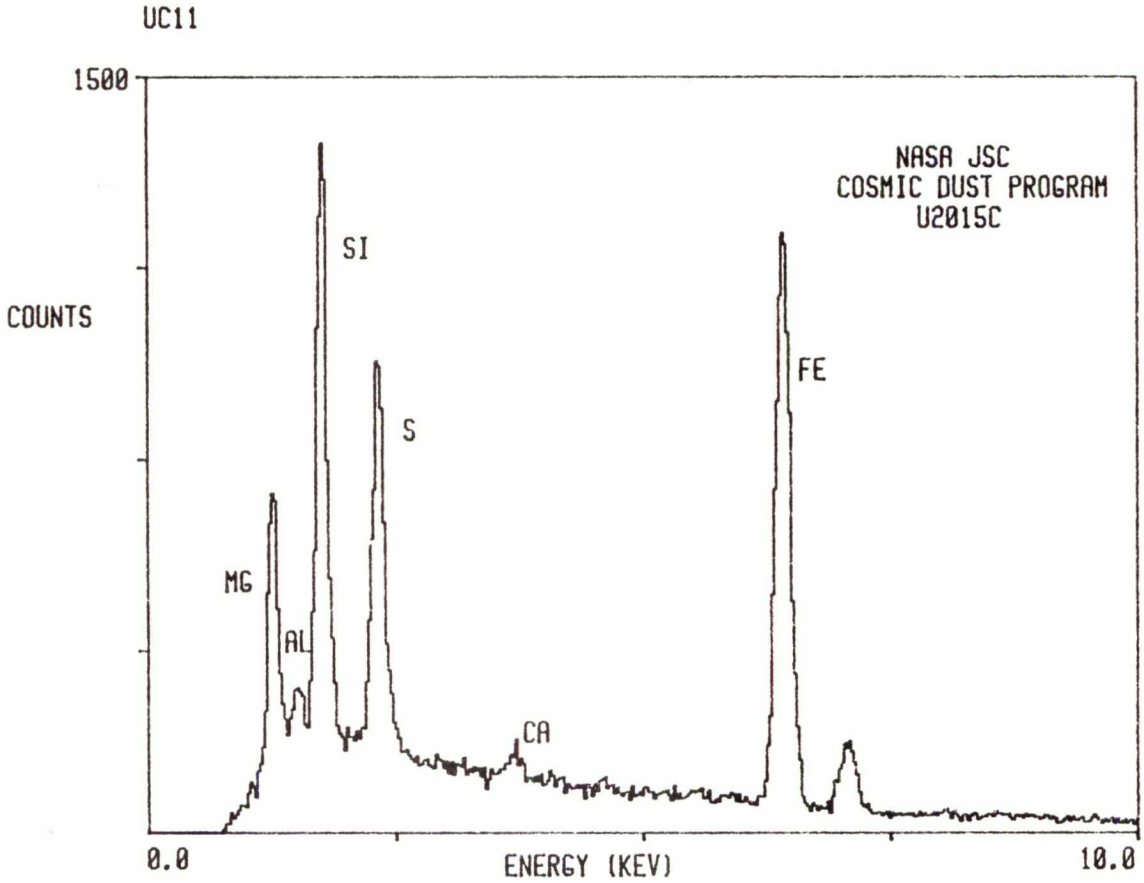


SIZE	SHAPE	TRANS.
14x21	I	0

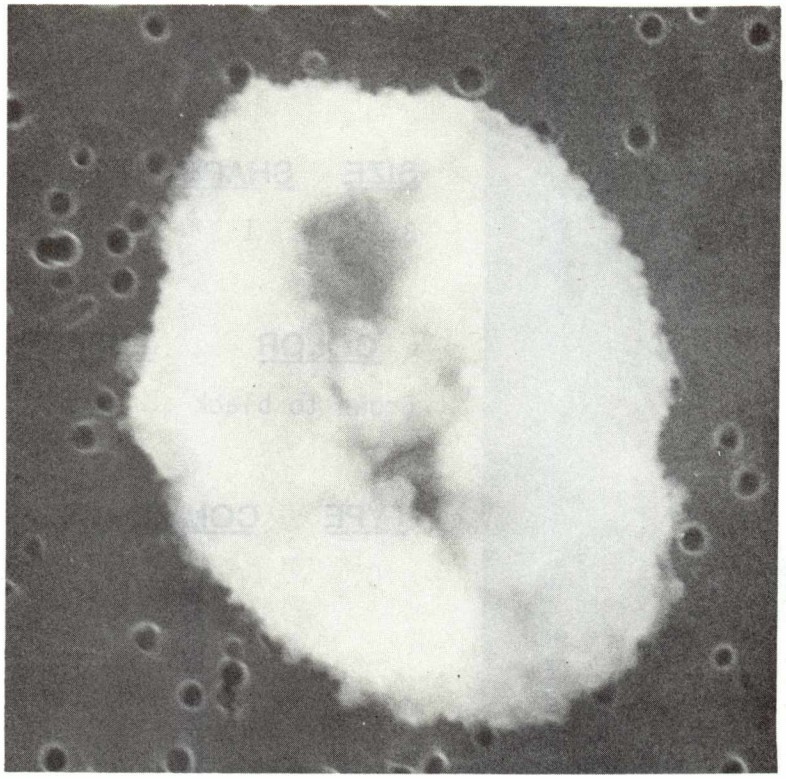
COLOR	LUSTER
Gray to black	SV/SM

TYPE	COMMENTS
C	

S-84-41418



U2015C12

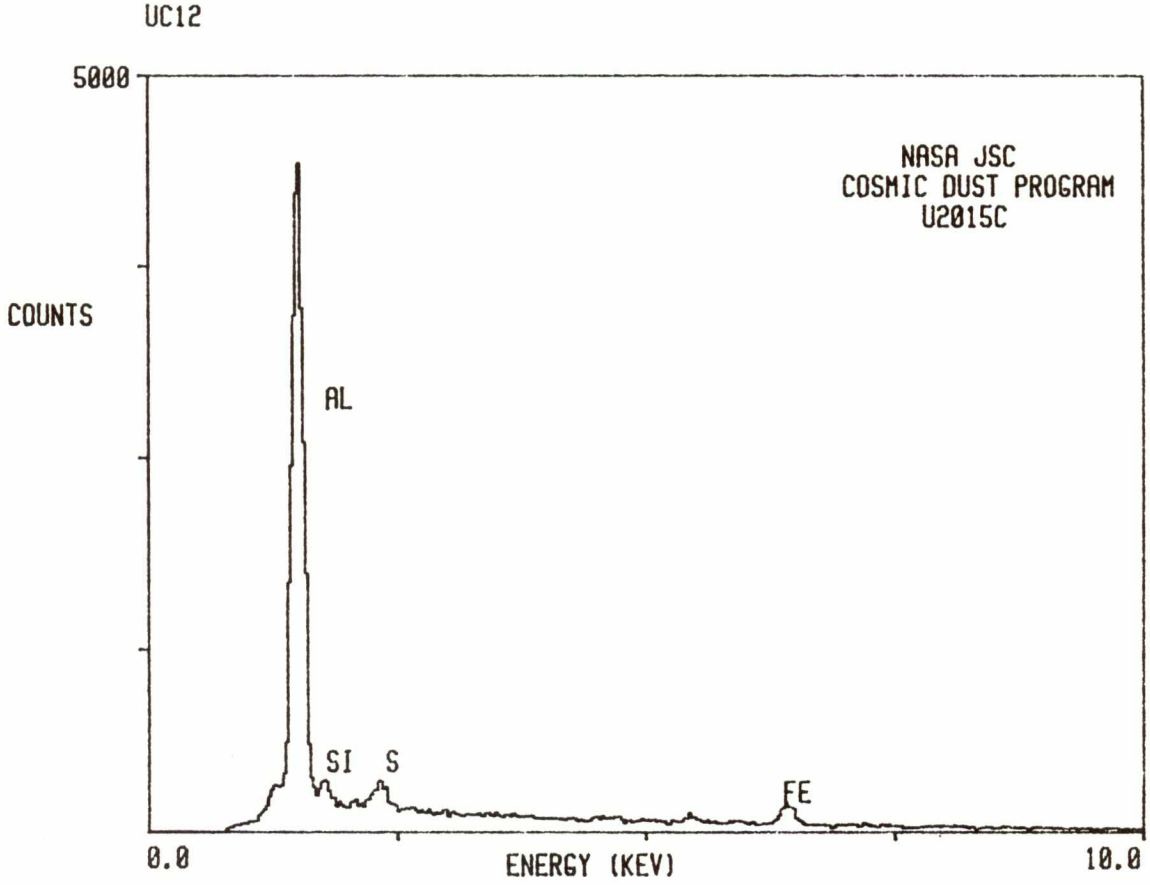


SIZE	SHAPE	TRANS.
7x9	I/E	0

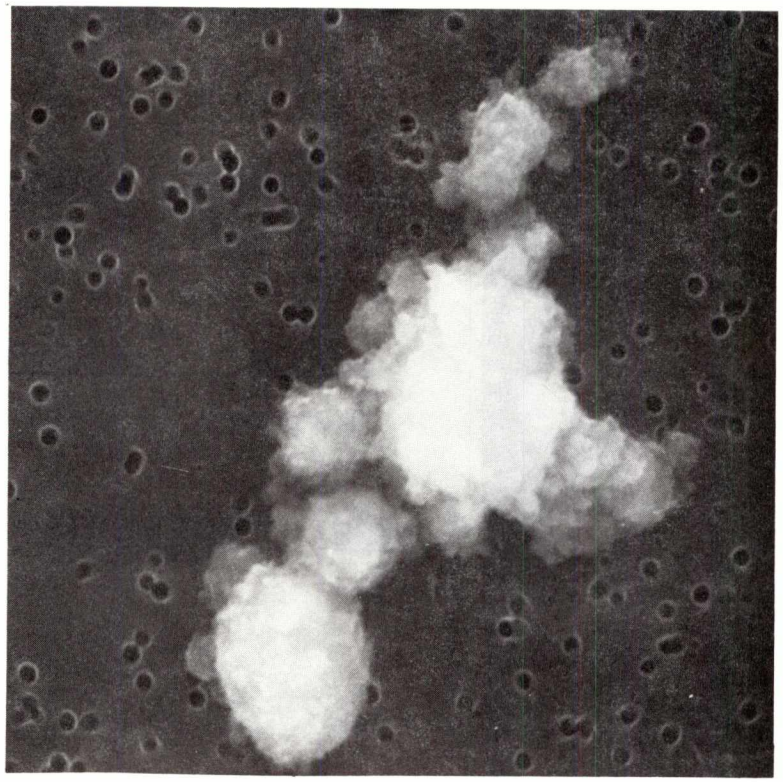
COLOR	LUSTER
Dk. gray	D/SM

TYPE	COMMENTS
?	

S-84-41419



U2015C13

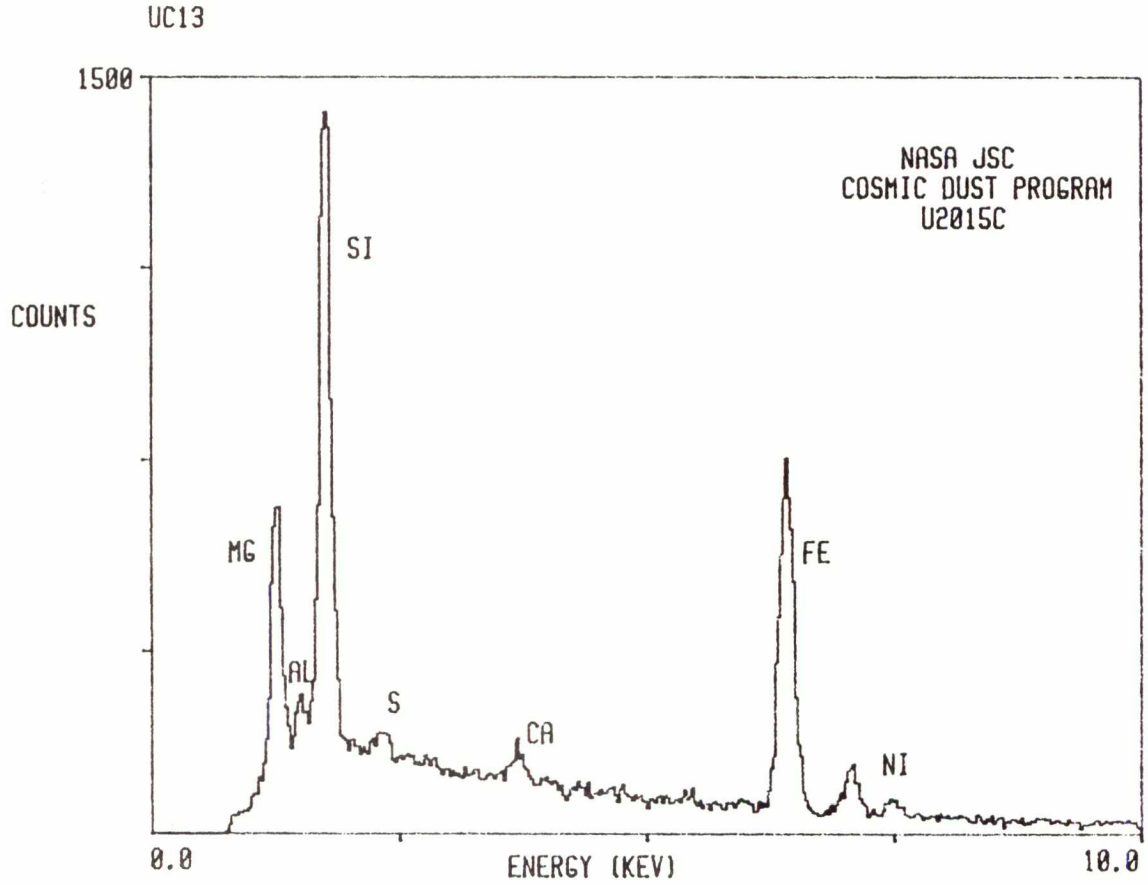


SIZE	SHAPE	TRANS.
8x15	I	O

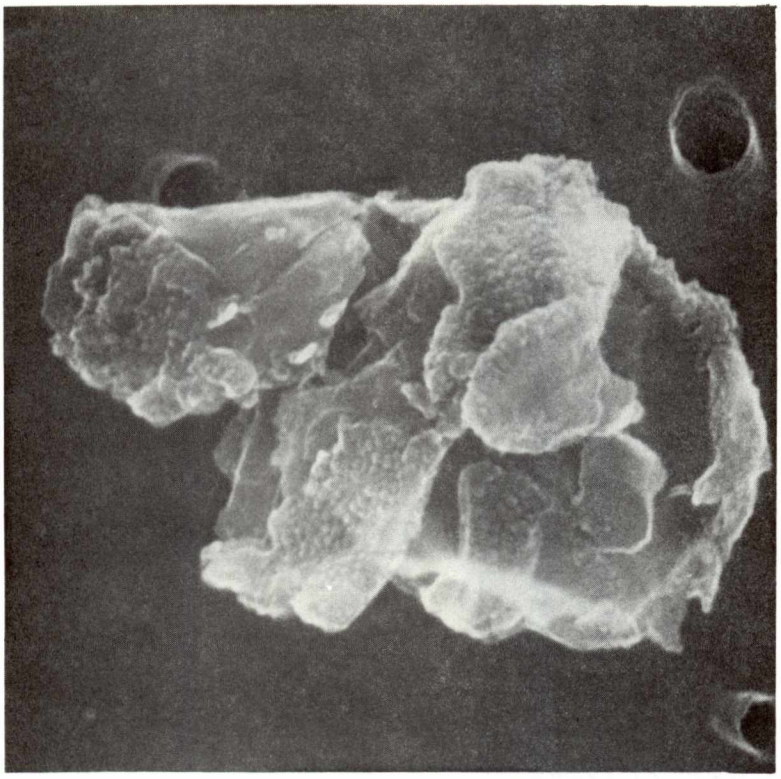
COLOR	LUSTER
Brown to black	D/SM

TYPE	COMMENTS
C	

S-84-41420



U2015C14

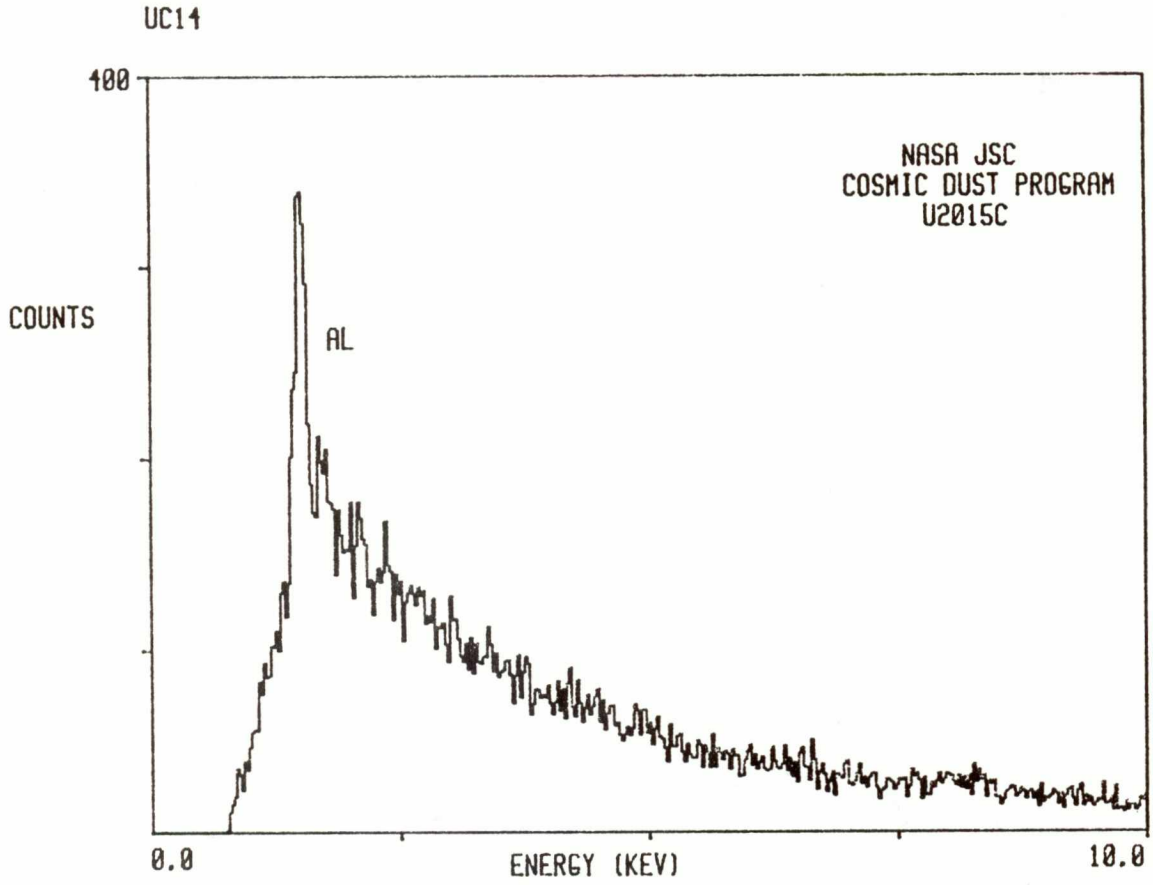


SIZE	SHAPE	TRANS.
4x6	E	T

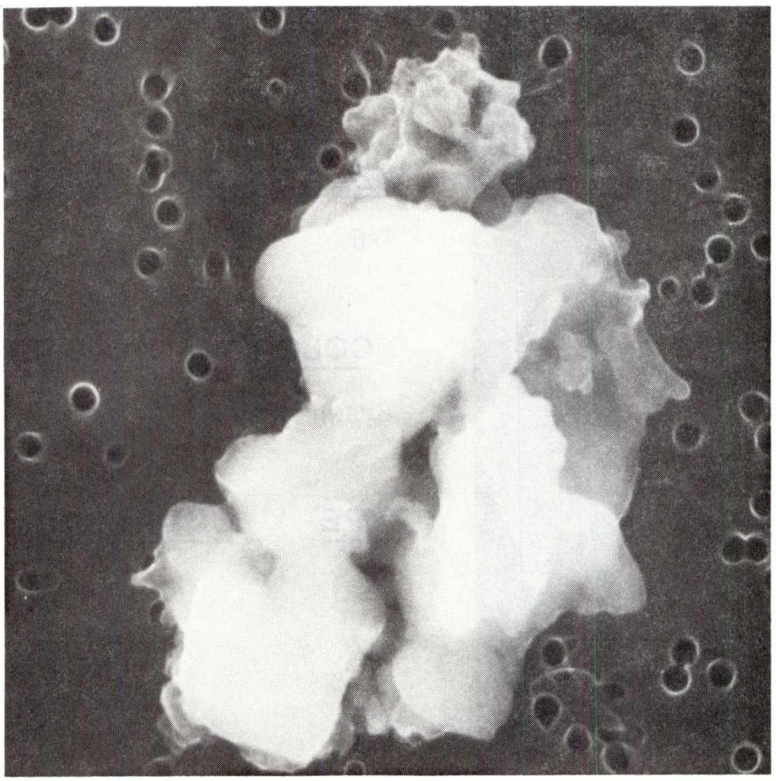
COLOR	LUSTER
Brown-gray	V

TYPE	COMMENTS
?	

S-84-41421



U2015C16

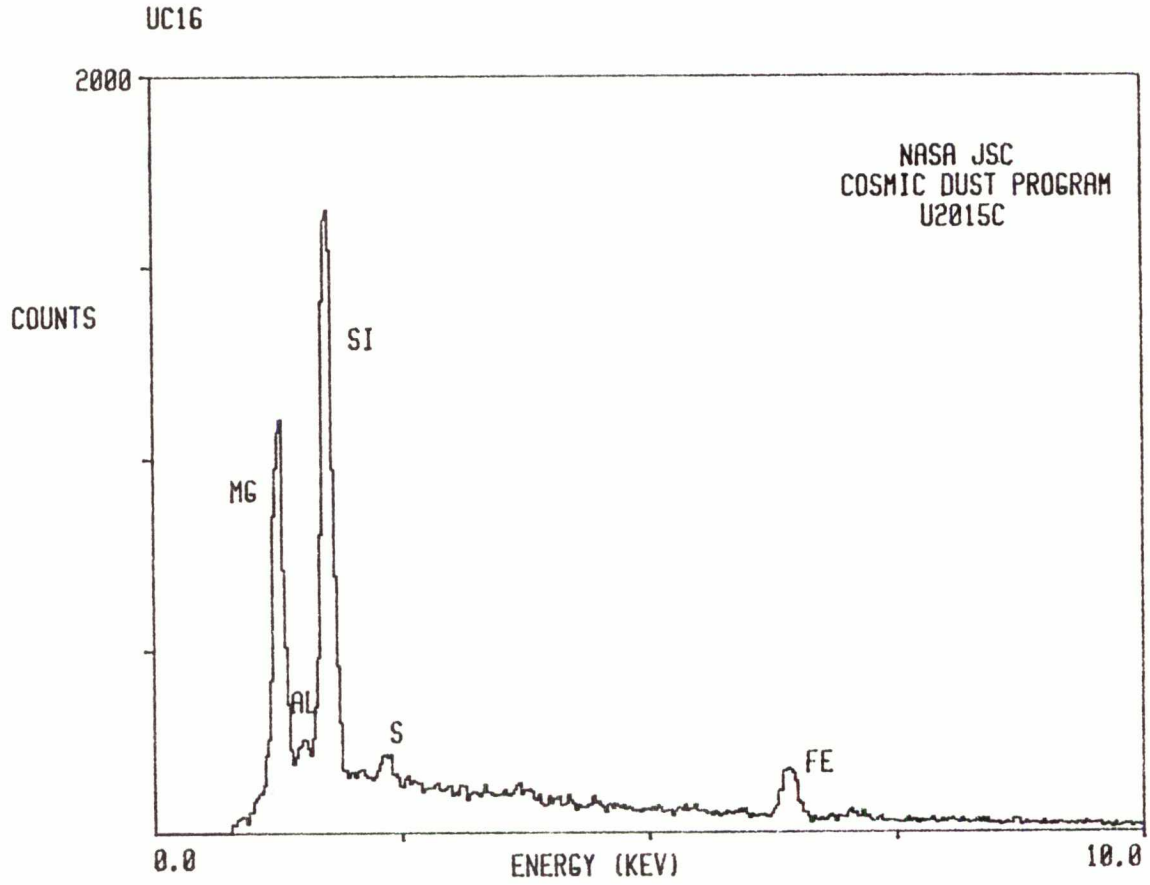


SIZE	SHAPE	TRANS.
7x10	I	TL

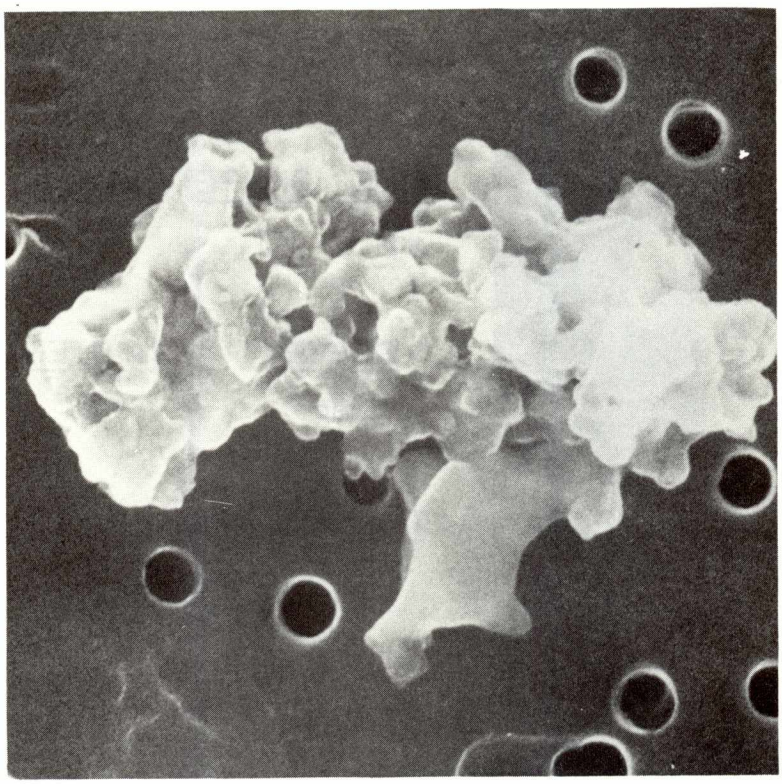
COLOR	LUSTER
Yellow-gray	SV

TYPE	COMMENTS
C?	

S-84-41423



U2015C17

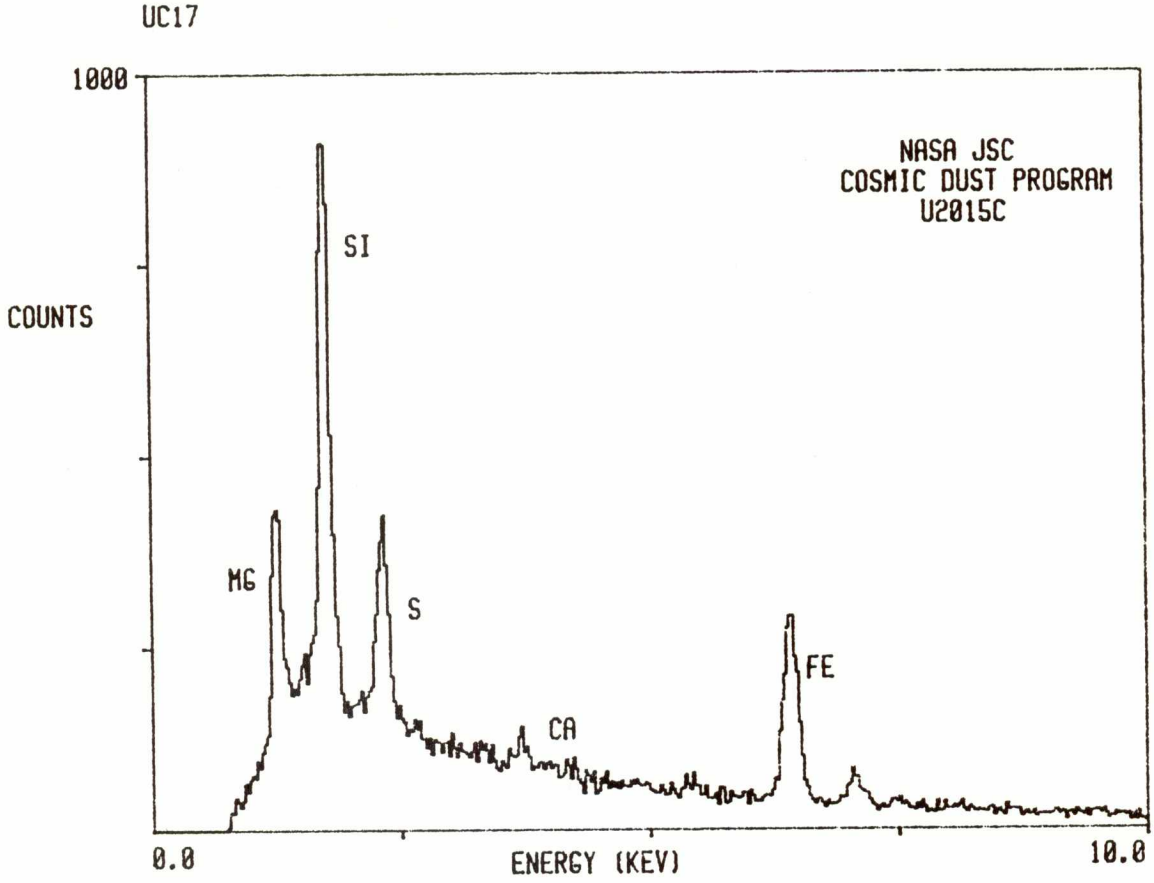


S-84-41424

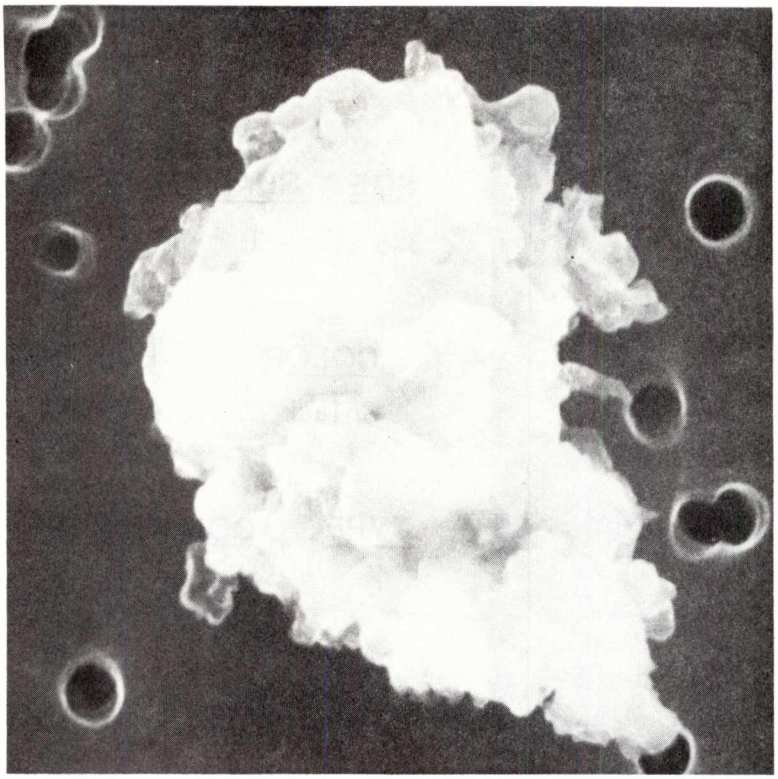
SIZE	SHAPE	TRANS.
3x5	I	O

COLOR	LUSTER
Black	D/SM

TYPE	COMMENTS
C	Related to U2015C16



U2015C18

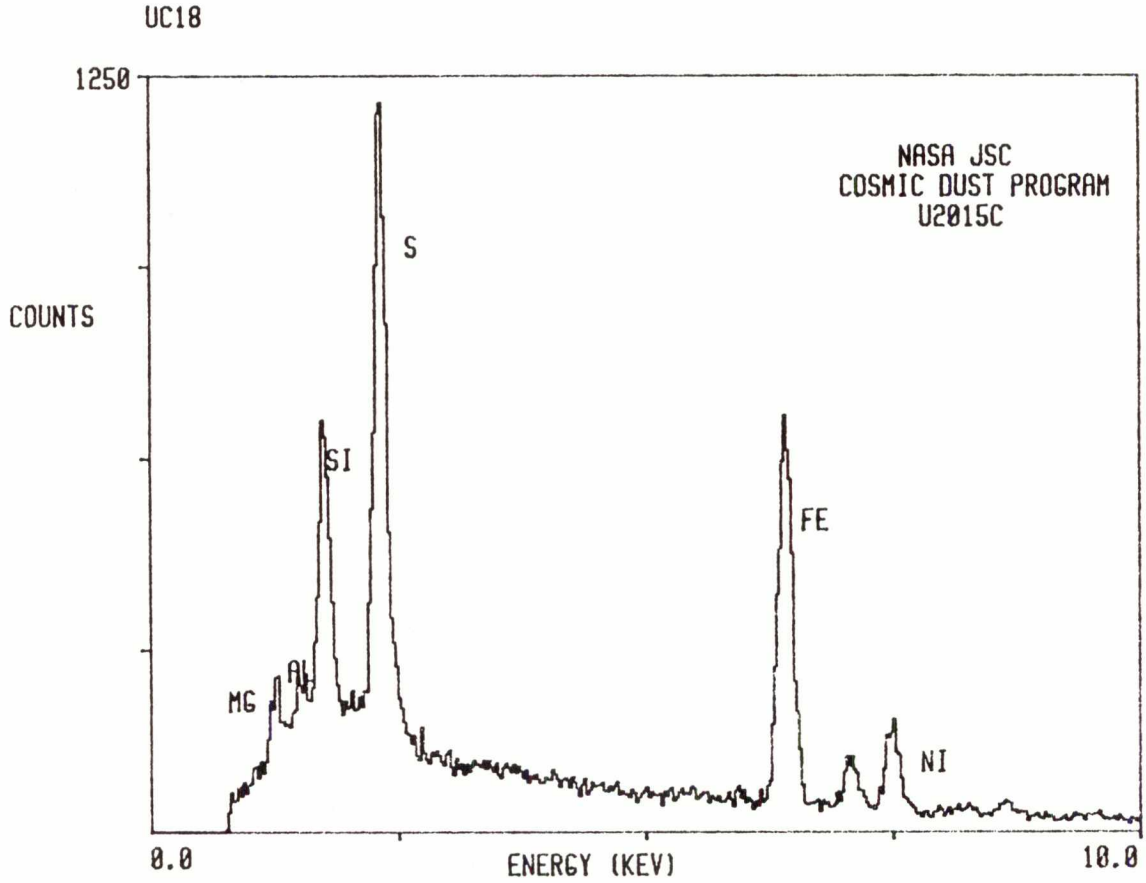


SIZE	SHAPE	TRANS.
3x5	I	0

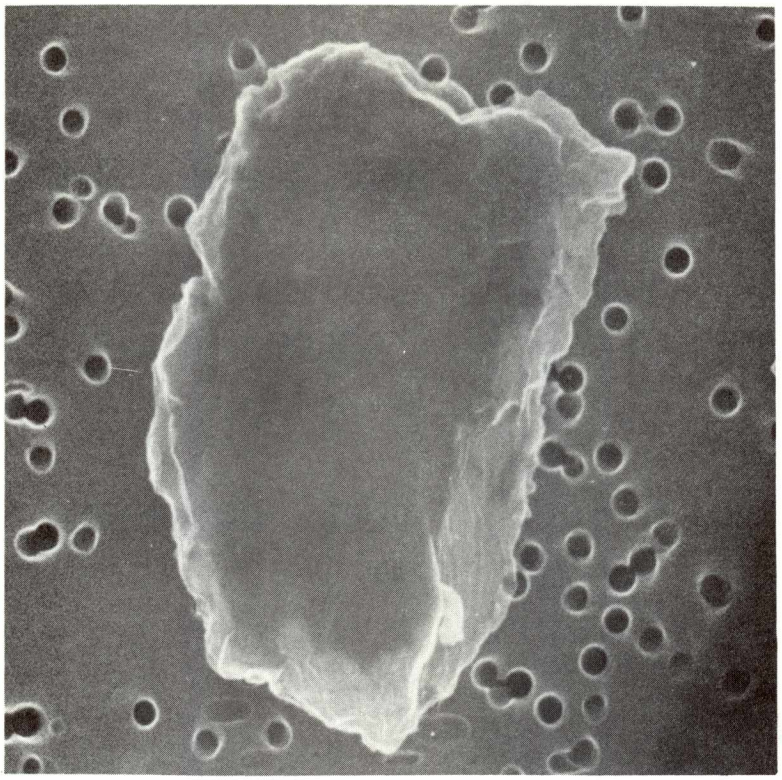
COLOR	LUSTER
Black	D/SM

TYPE	COMMENTS
C	Related to U2015C16

S-84-41425



U2015C19

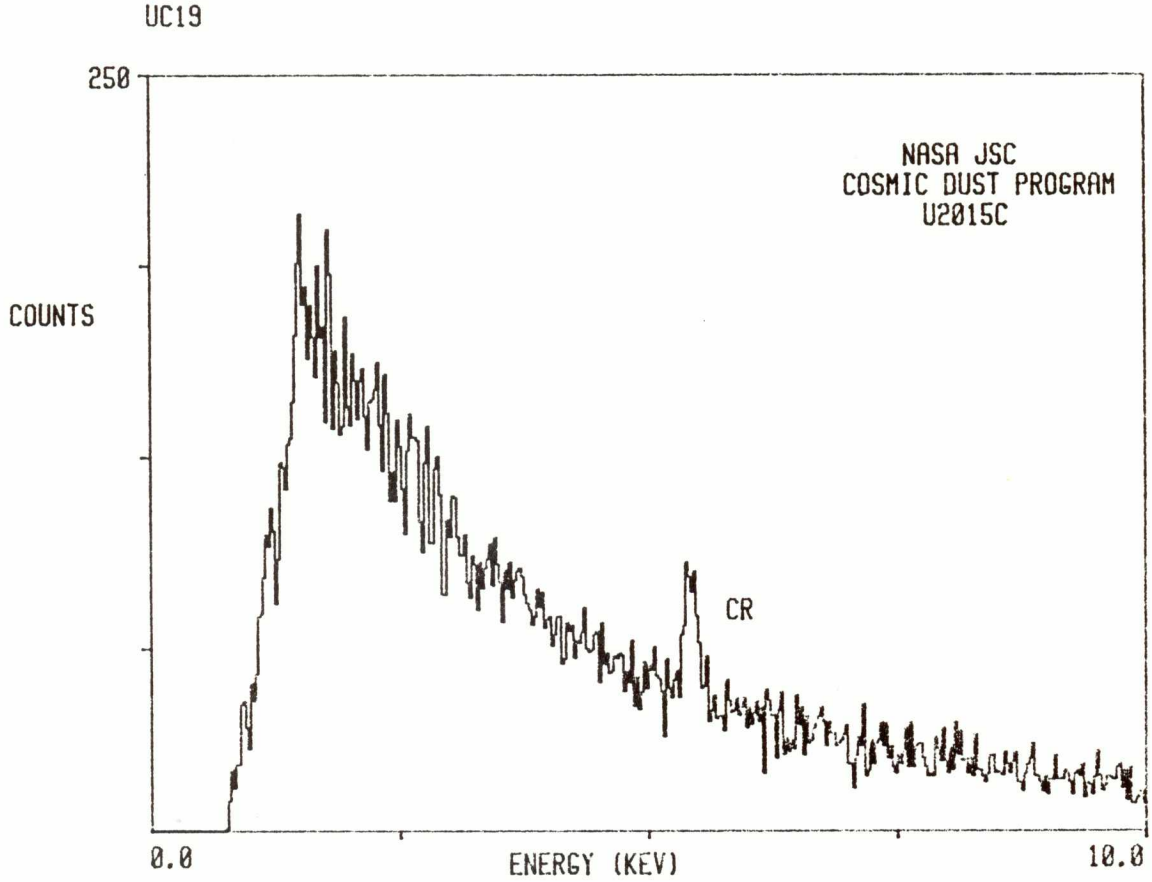


S-84-41426

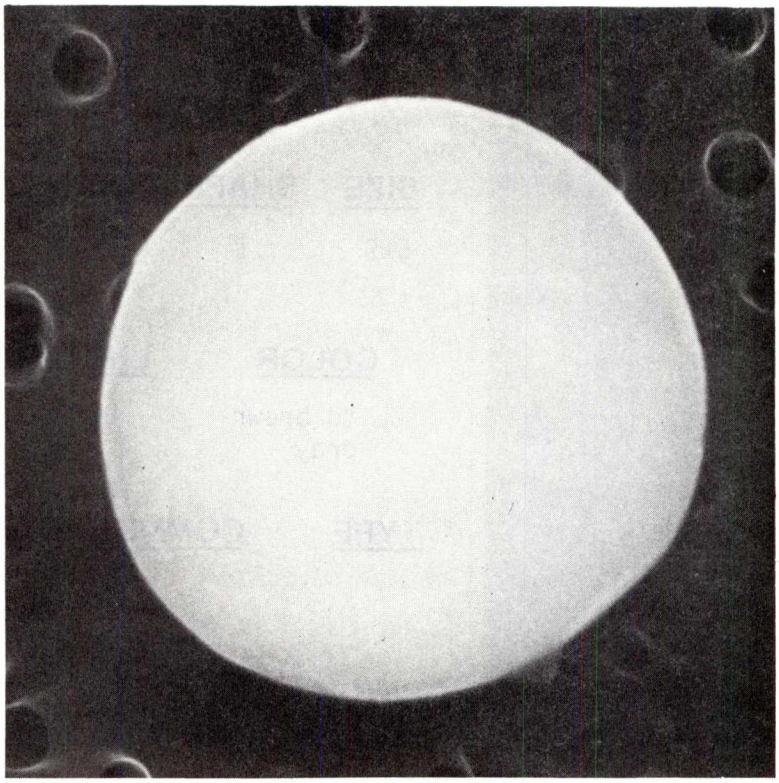
SIZE	SHAPE	TRANS.
5x9	I	T/TL

COLOR	LUSTER
CL to brown-gray	D/SV

TYPE	COMMENTS
?	



U2015C20

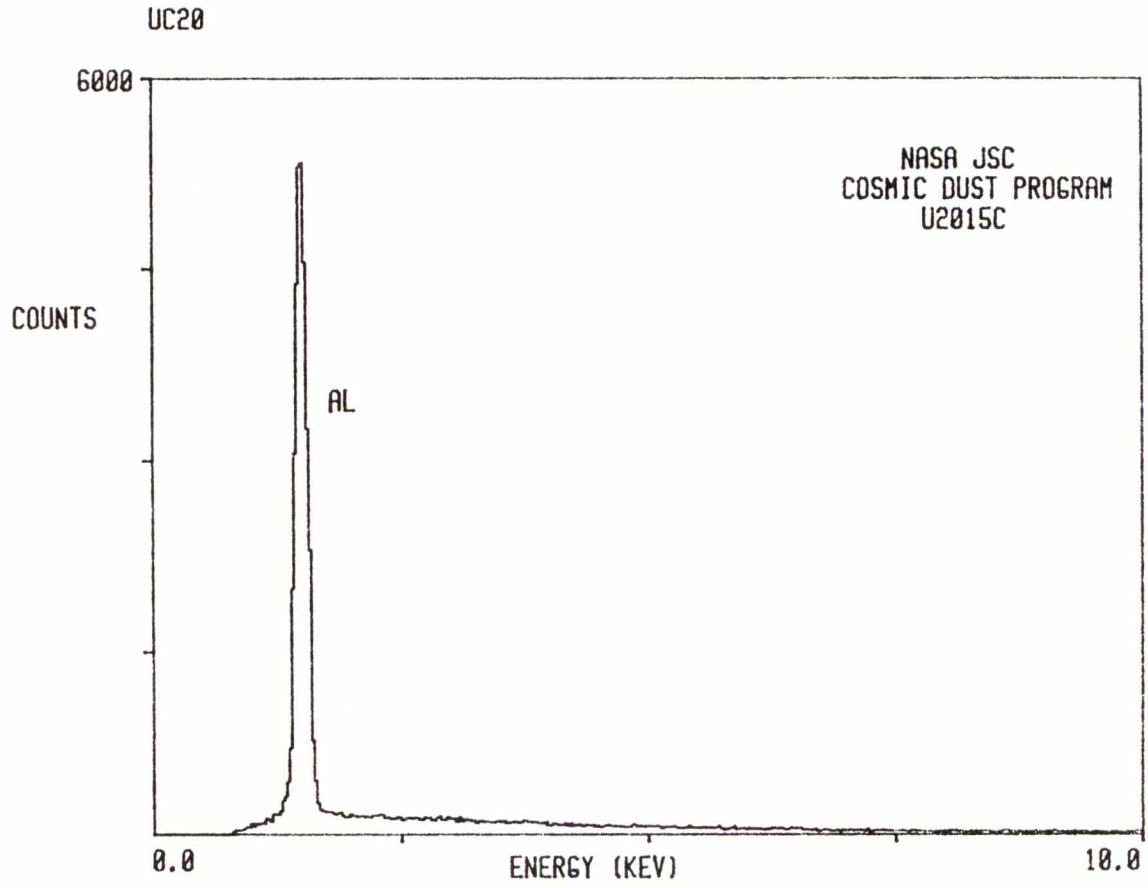


SIZE	SHAPE	TRANS.
4	S	T

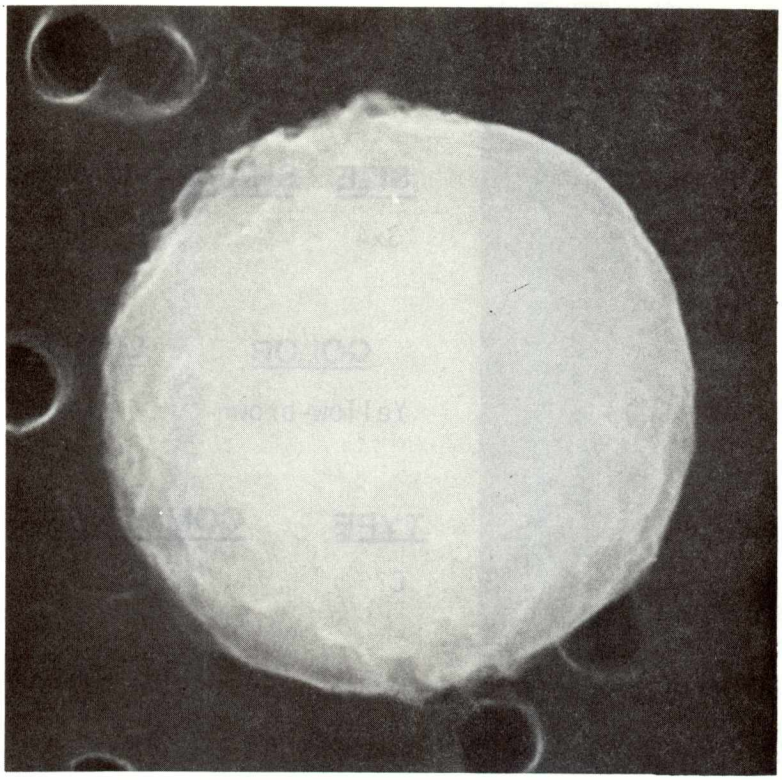
COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
AOS	

S-84-41427



U2015C21

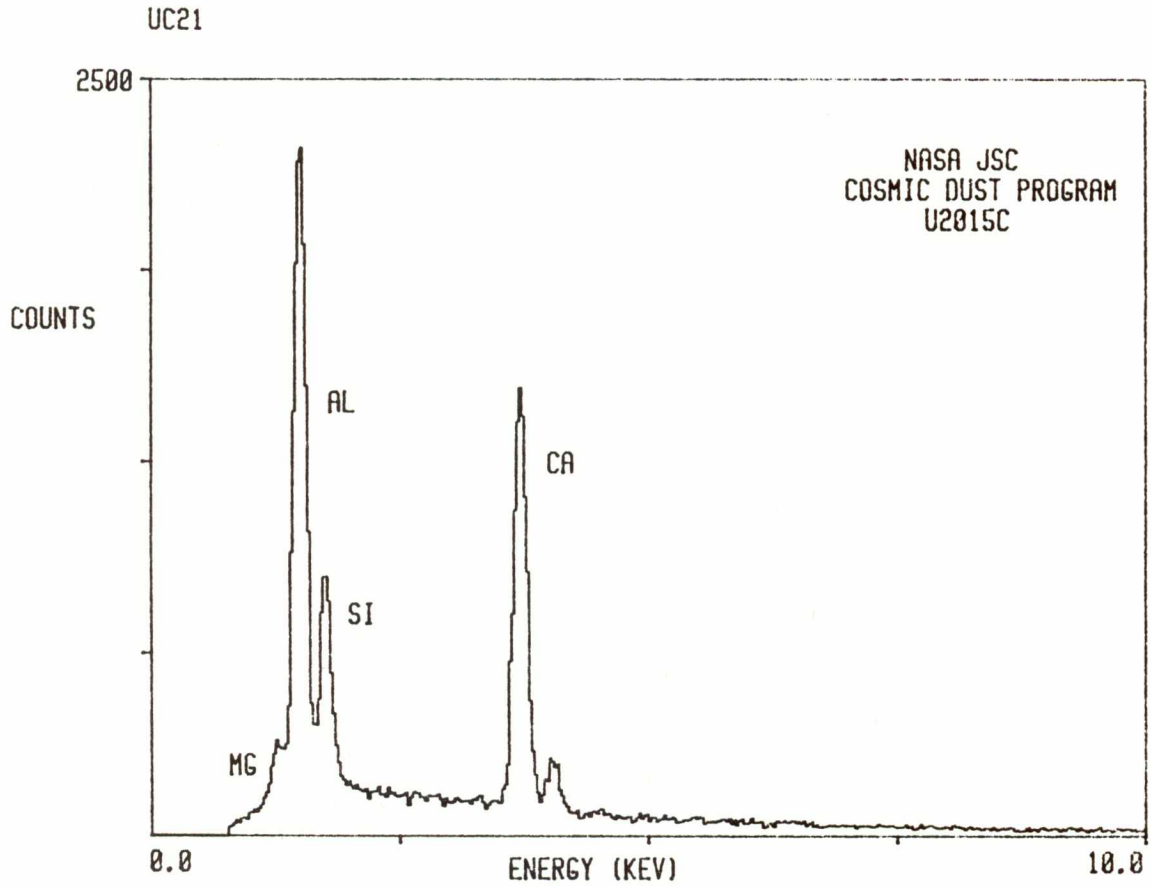


SIZE	SHAPE	TRANS.
3	S	T

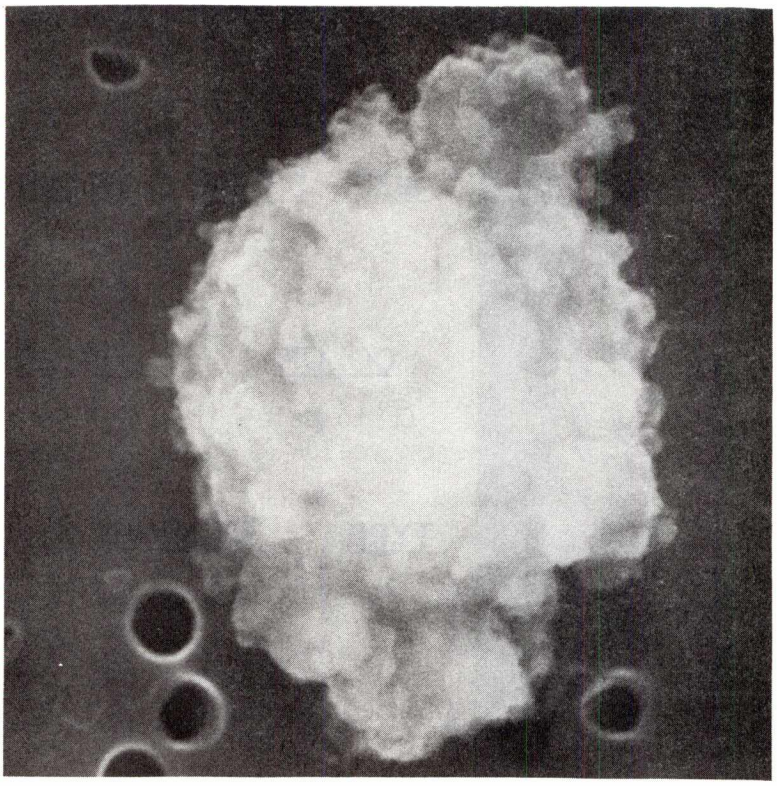
COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
?	

S-84-41428



U2015C22

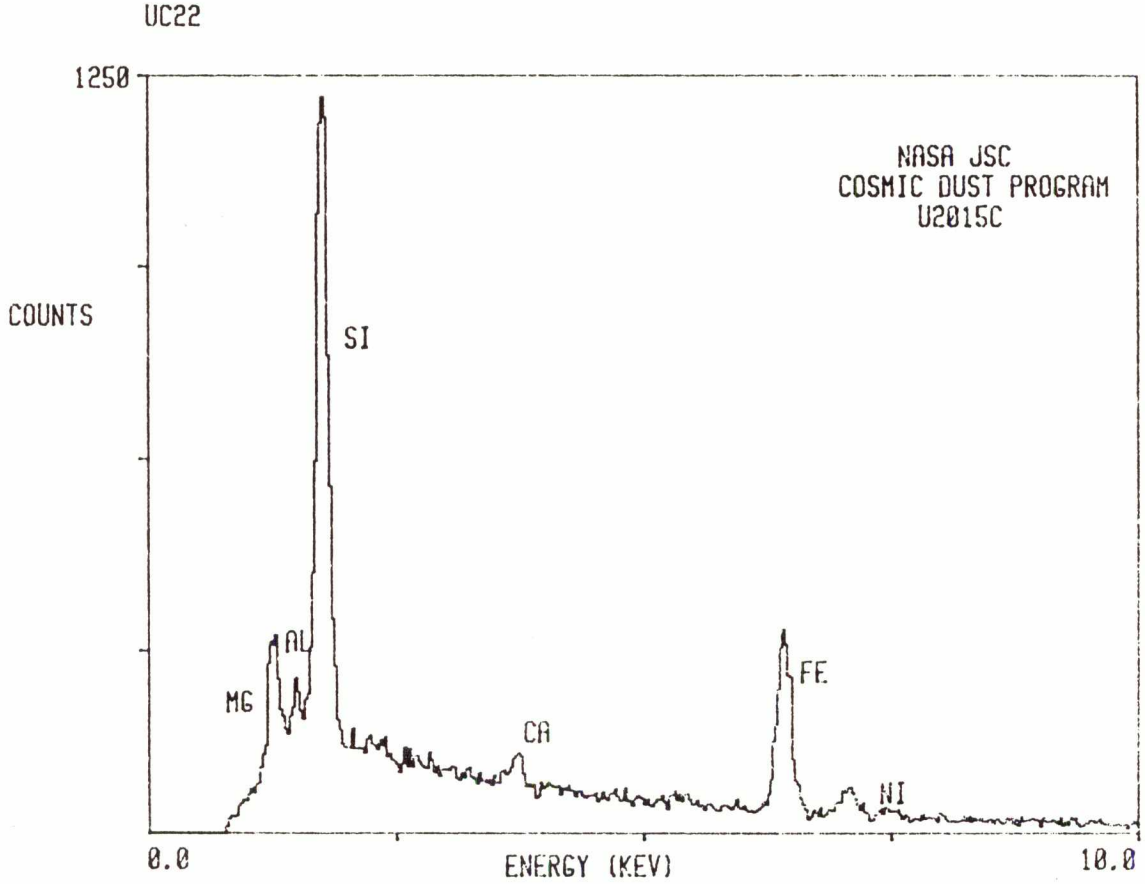


SIZE	SHAPE	TRANS.
3x4	I	TL

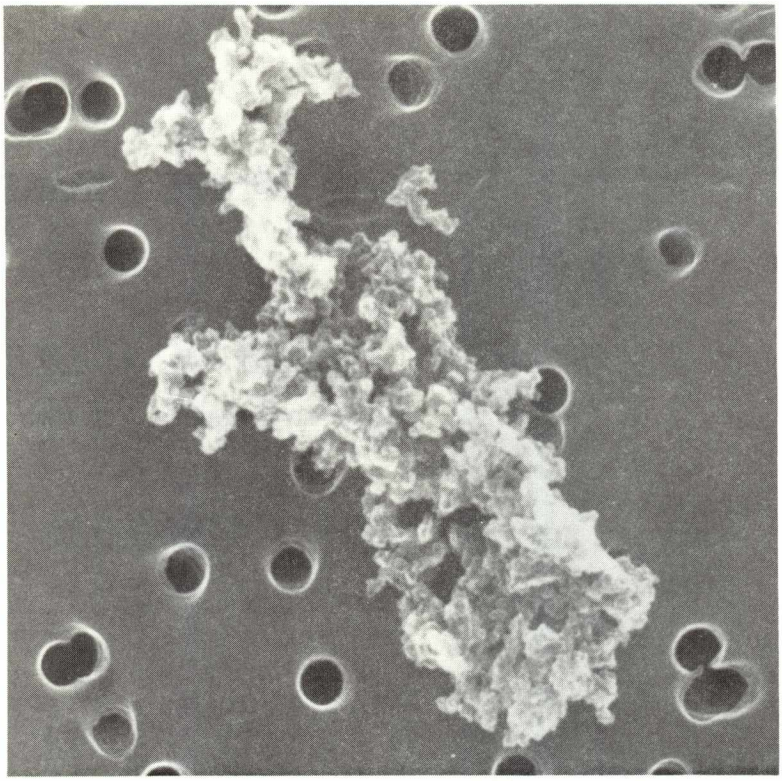
COLOR	LUSTER
Yellow-brown	D/SM

TYPE	COMMENTS
C?	

S-84-41429



U2015C23

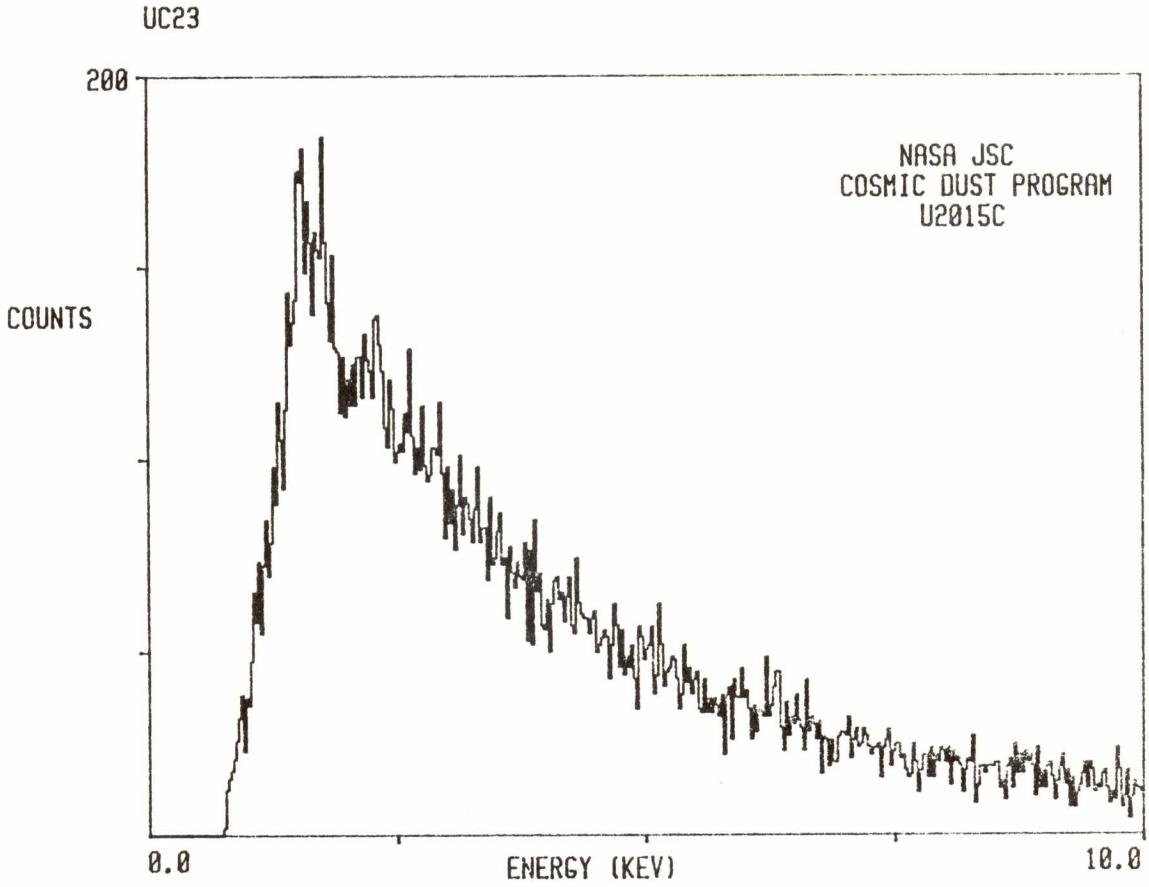


S-84-41430

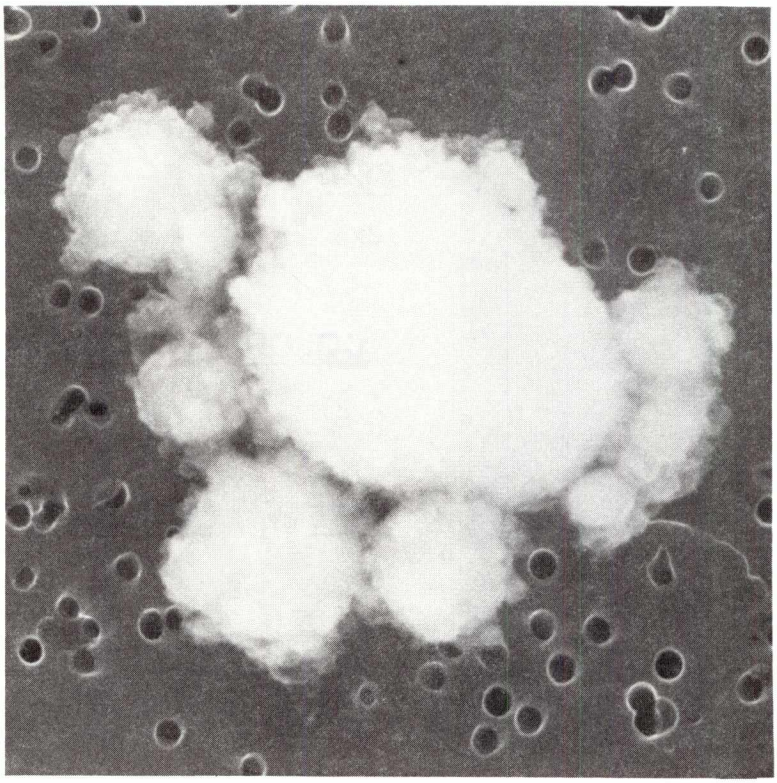
SIZE	SHAPE	TRANS.
3x6	I	0

COLOR	LUSTER
Black	SV/SM

TYPE	COMMENTS
?	



U2015C24

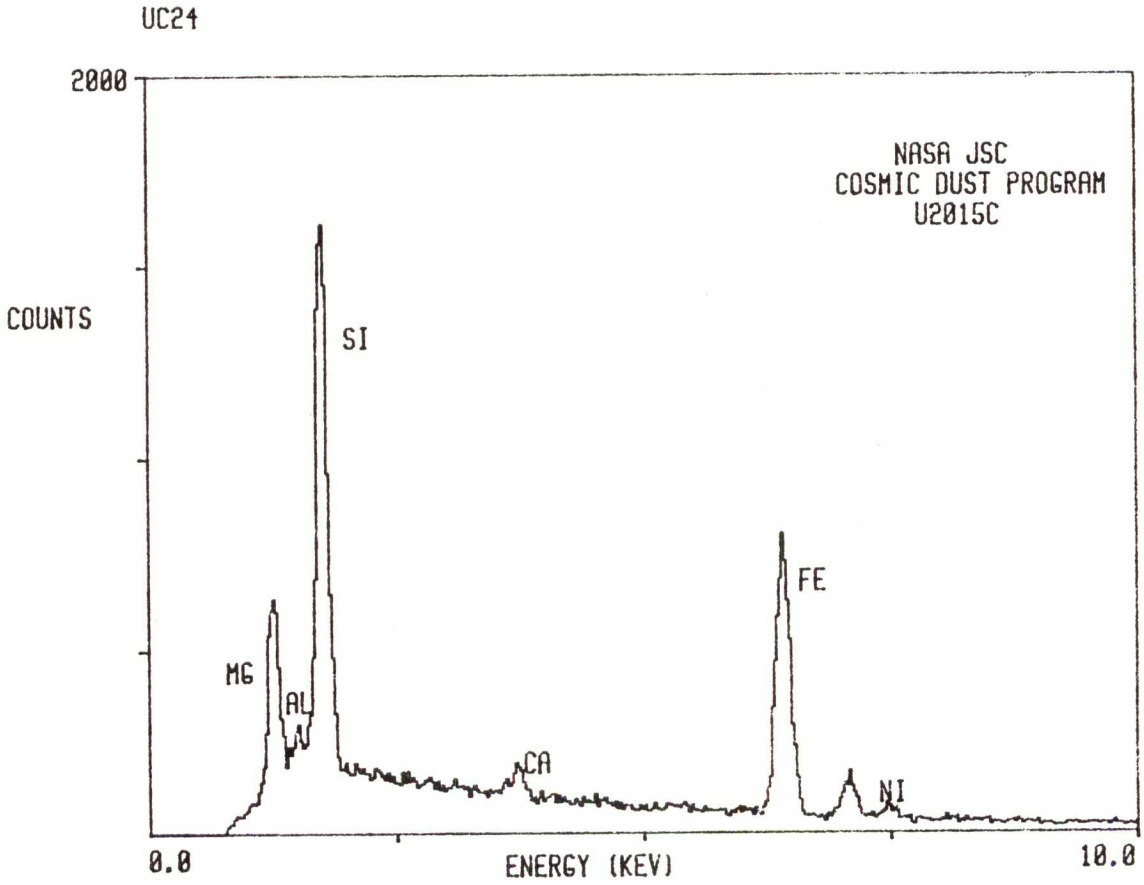


SIZE	SHAPE	TRANS.
8x10	I	0

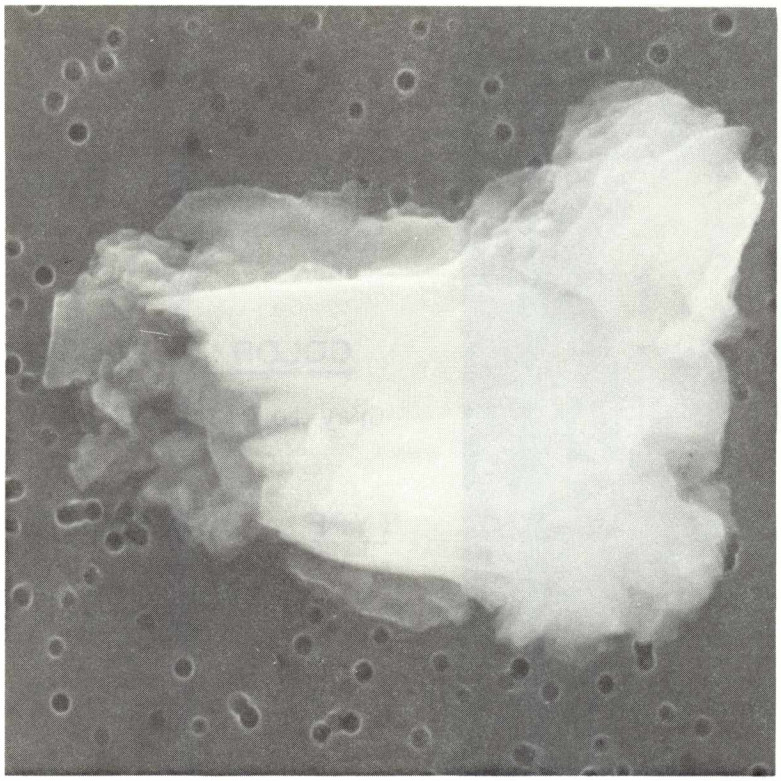
COLOR	LUSTER
Gray to black	SV/SM

TYPE	COMMENTS
C	

S-84-41431



U2015C25

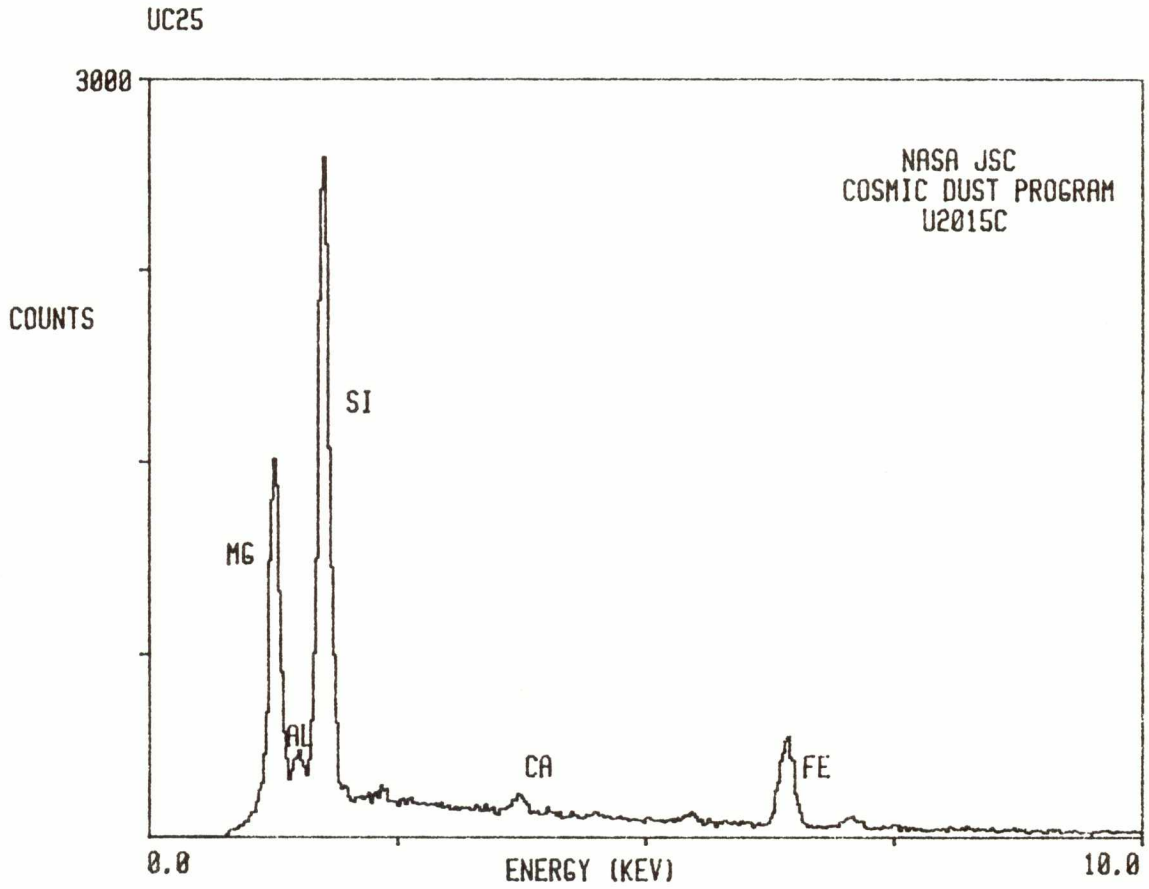


SIZE	SHAPE	TRANS.
10x13	I	TL

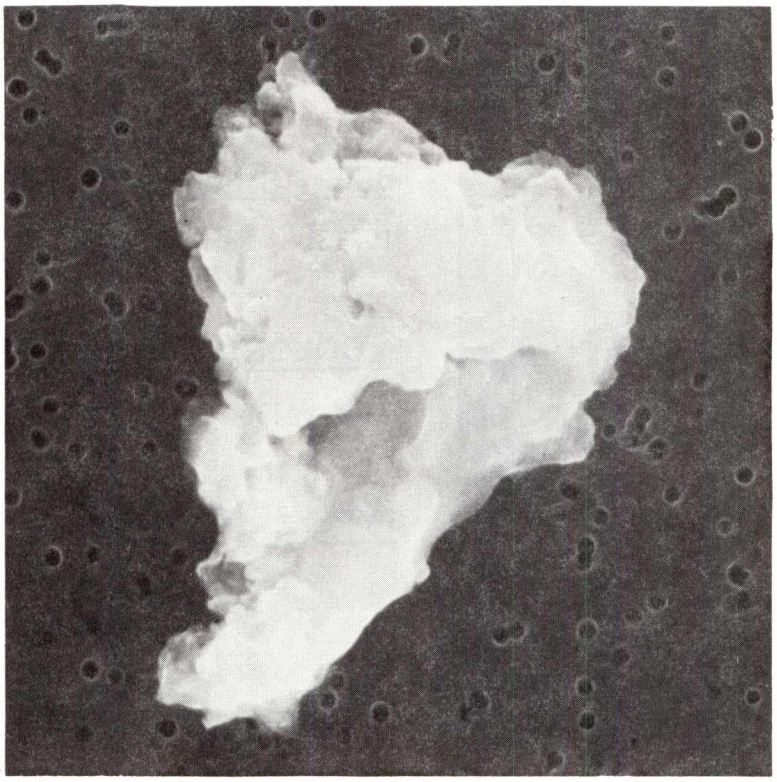
COLOR	LUSTER
Brown-yellow	SV/V

TYPE	COMMENTS
C	Parent is ~30 μm size

S-84-41432



U2015C26

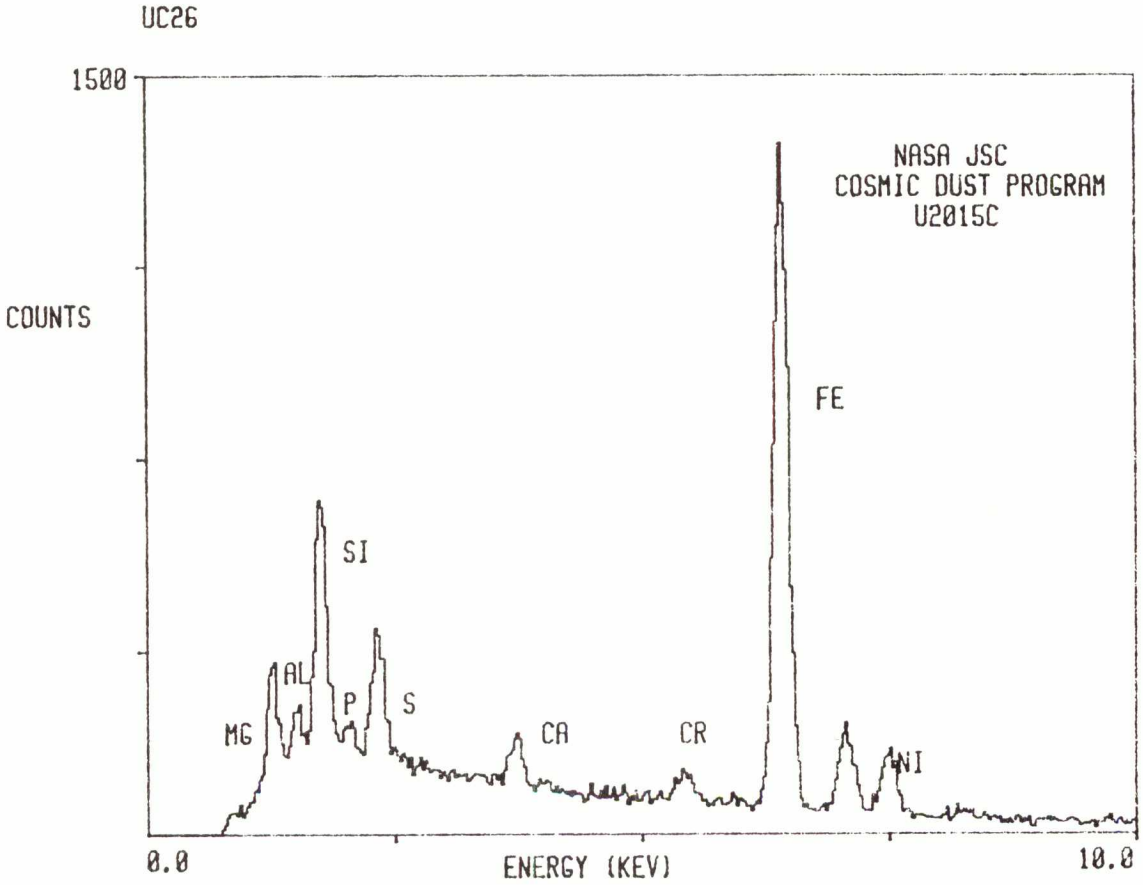


S-84-41433

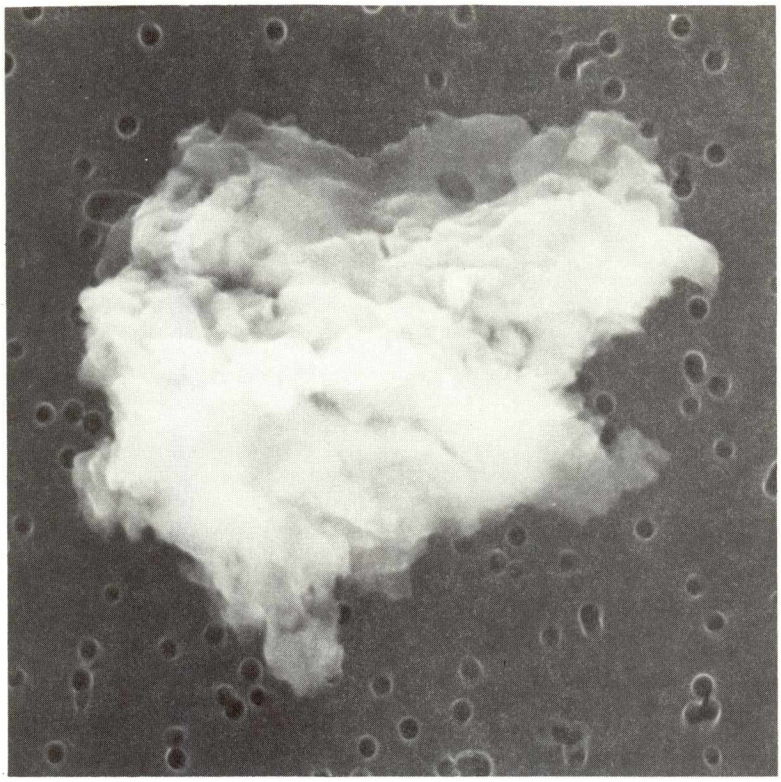
SIZE	SHAPE	TRANS.
10x13	I	0

COLOR	LUSTER
Gray to black	SV/M

TYPE	COMMENTS
C?	Same parent as for U2015C25



U2015C27

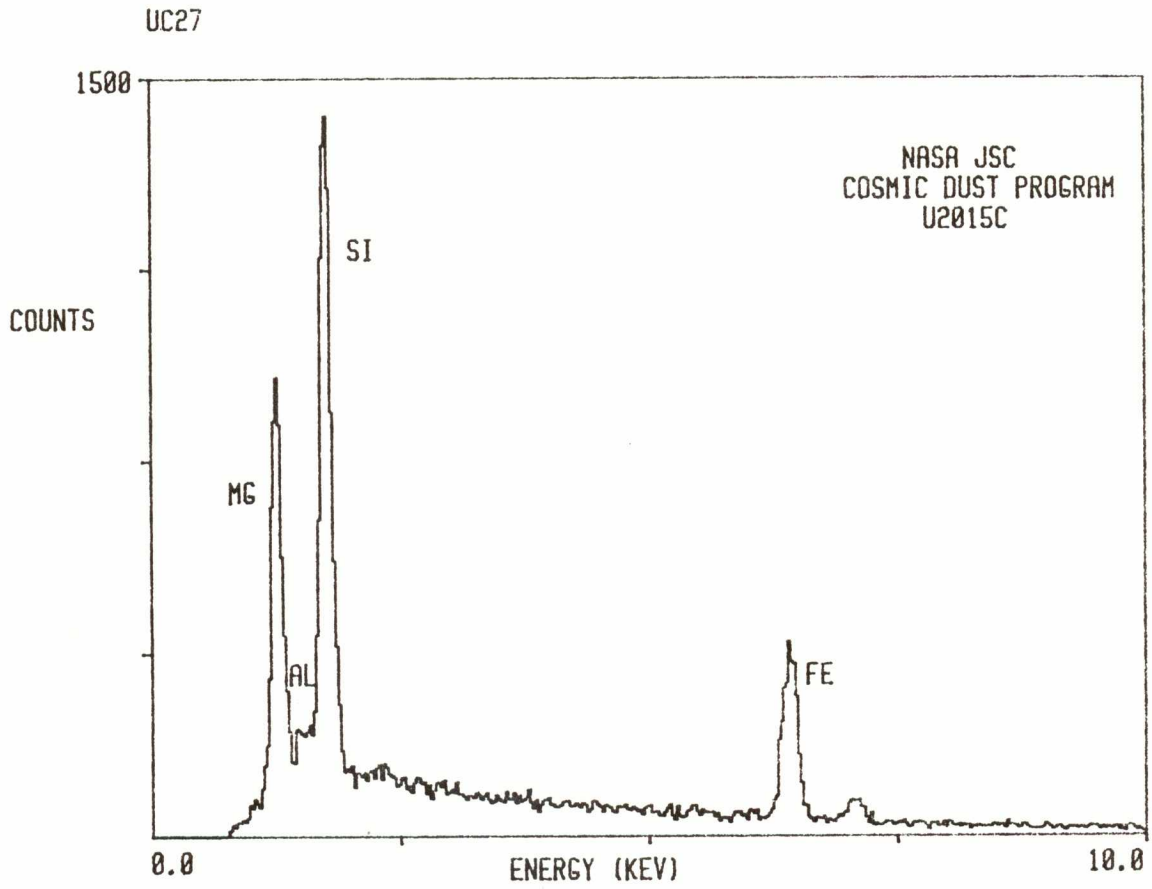


S-84-41434

SIZE	SHAPE	TRANS.
10x11	I/E	TL/O

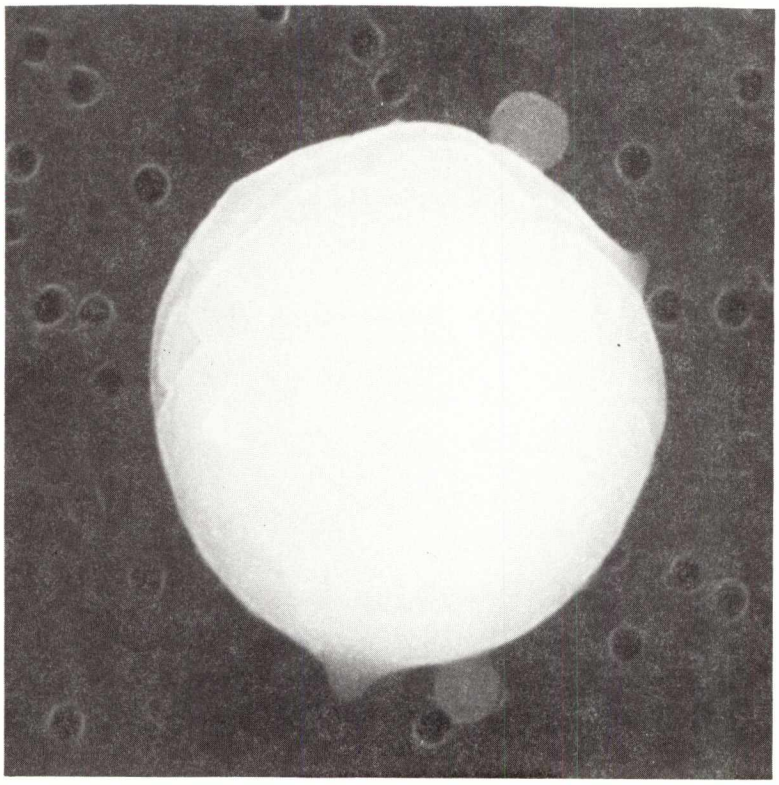
COLOR	LUSTER
Red-gray	SV

TYPE	COMMENTS
C	Same parent as for U2015C25



U2015D

U2015D1

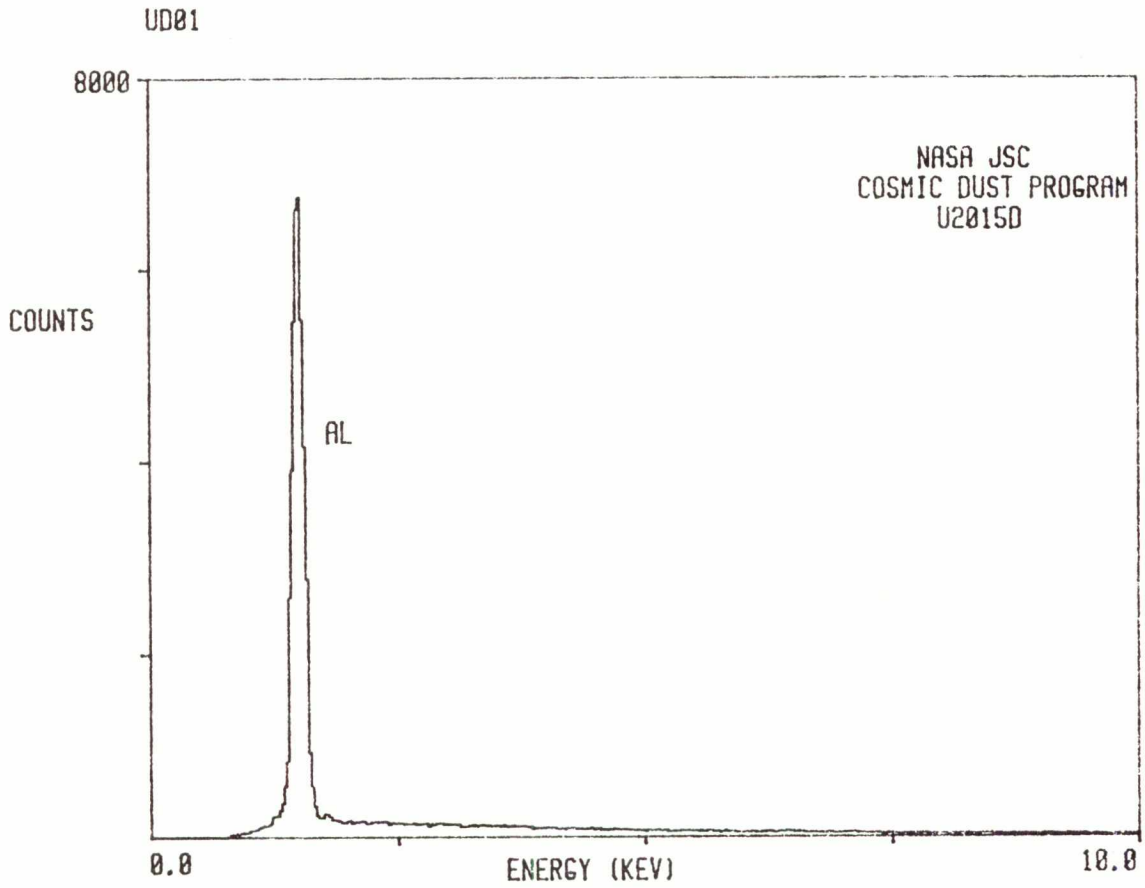


SIZE	SHAPE	TRANS.
5	S	T

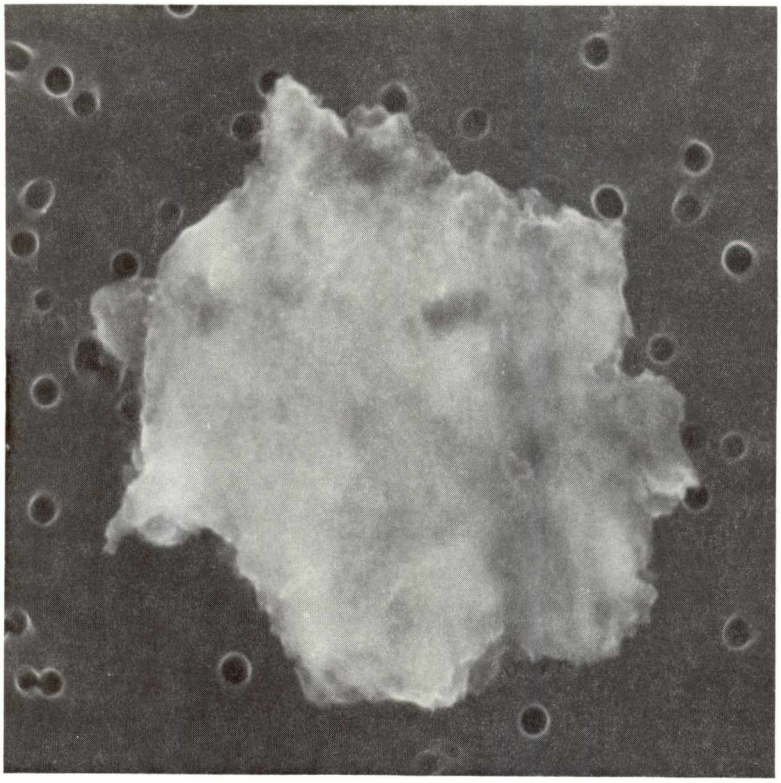
COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
AOS	

S-84-41326



U2015D2

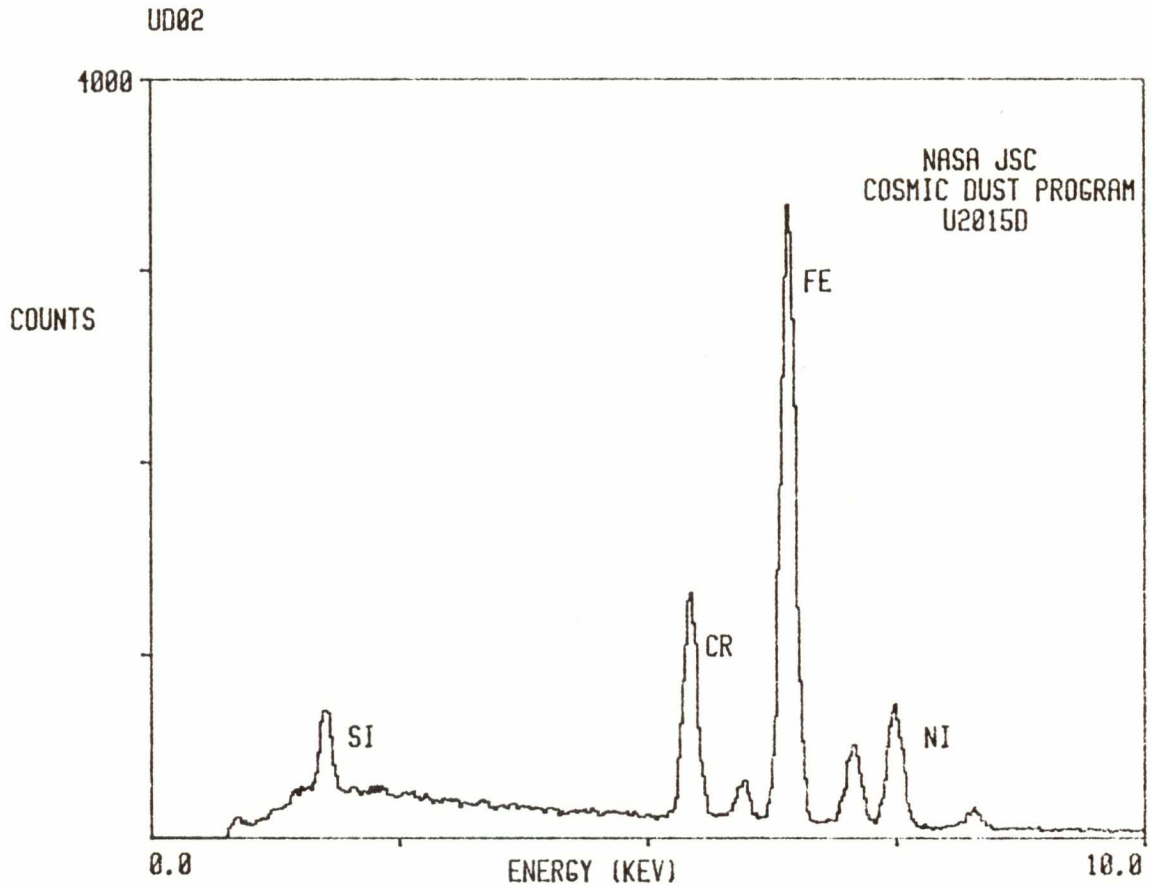


S-84-41329

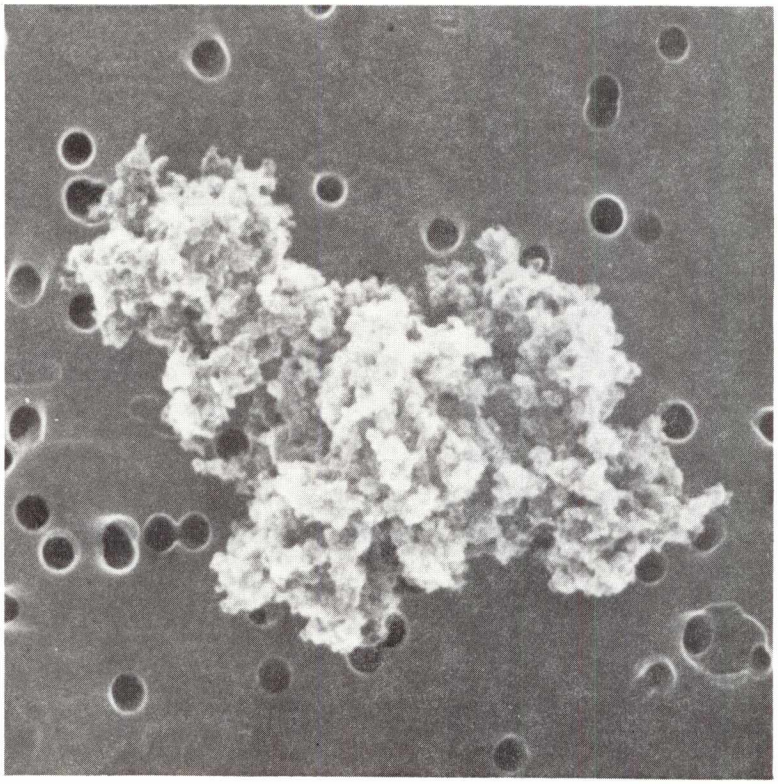
SIZE	SHAPE	TRANS.
5x7	E	0

COLOR	LUSTER
Brown to black	SM

TYPE	COMMENTS
TCA?	



U2015D3

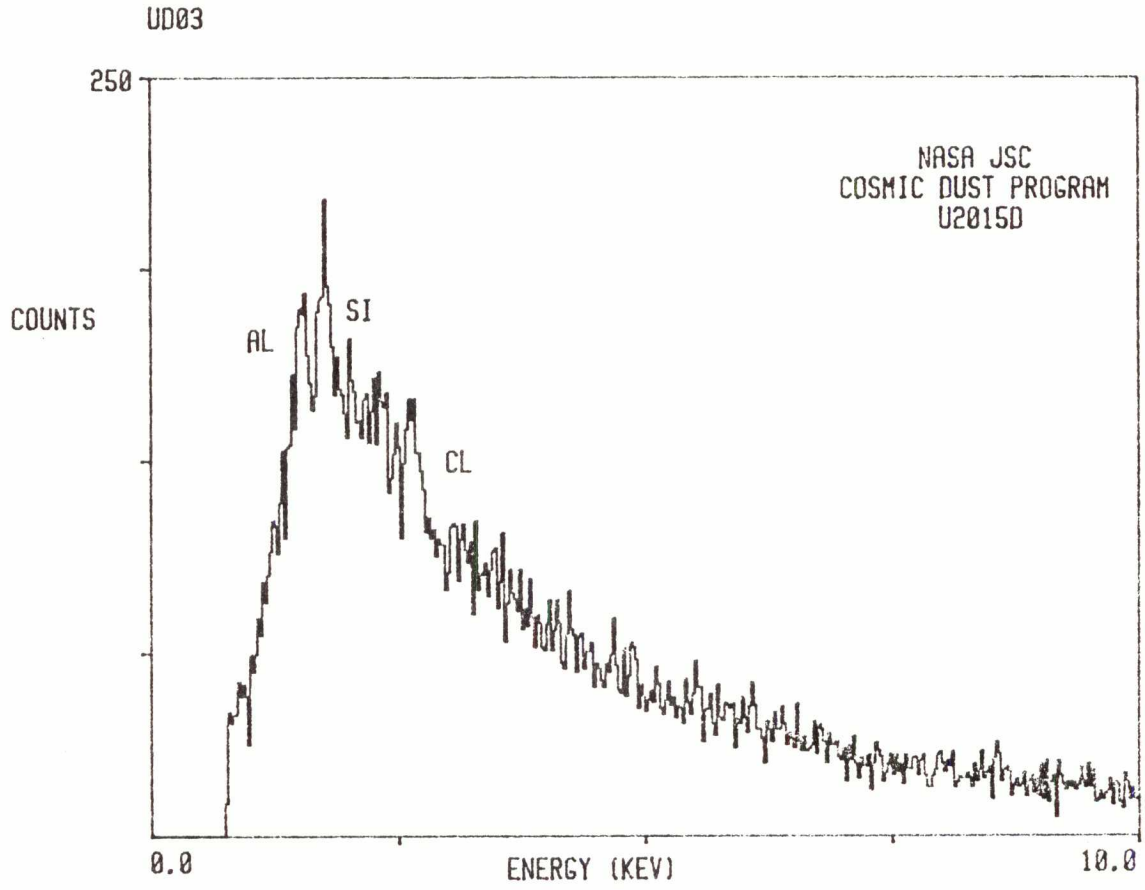


SIZE	SHAPE	TRANS.
4x6	I	O

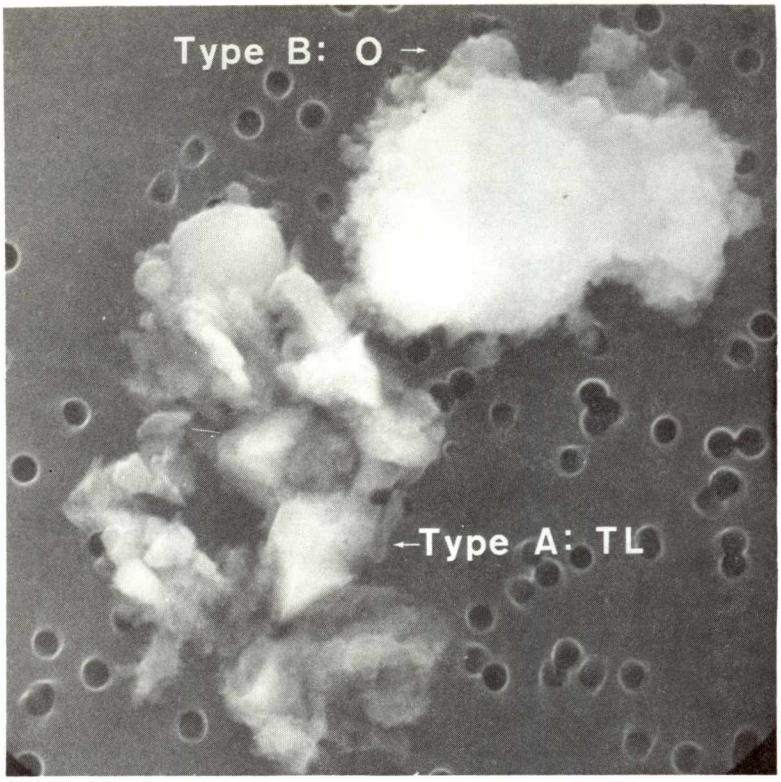
COLOR	LUSTER
Gray to black	D

TYPE	COMMENTS
TCA?	

S-84-41330



U2015D4

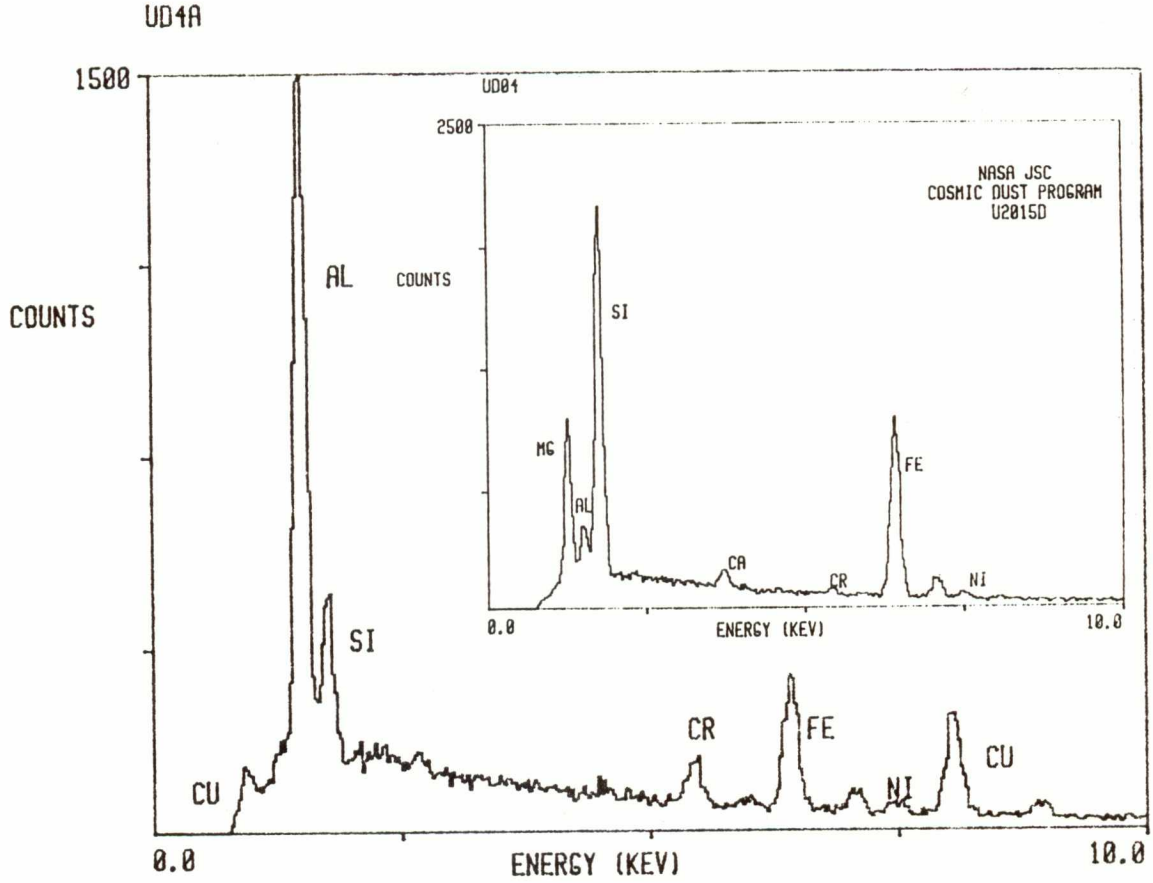


S-84-41334

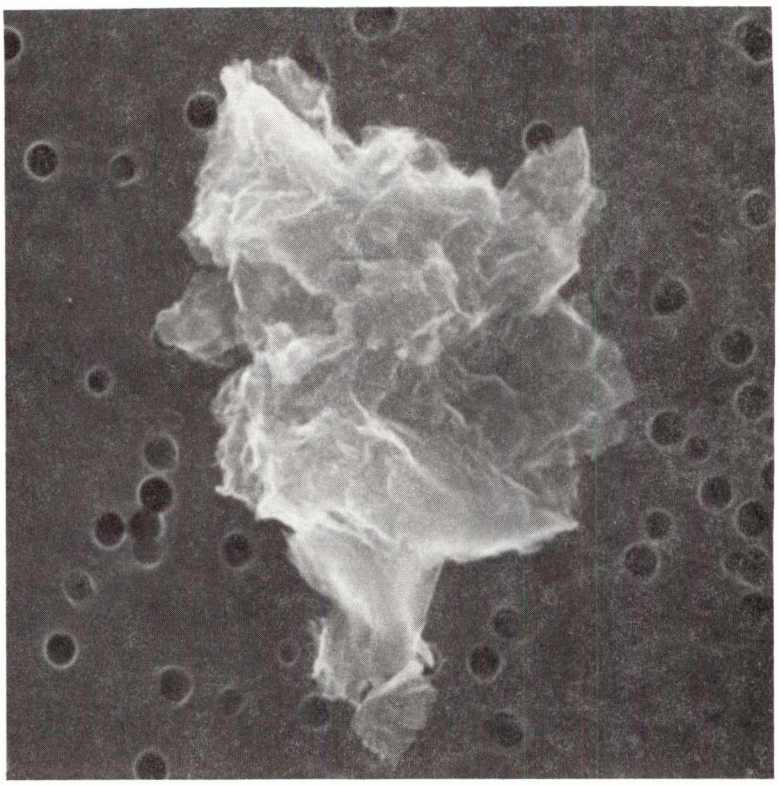
SIZE	SHAPE	TRANS.
5x8 (largest fragment)	I	TL/O

COLOR	LUSTER
Gray to red-brown	D/SV

TYPE	COMMENTS
C/TCA?	Several fragments of two basic types (A and B)



U2015D5

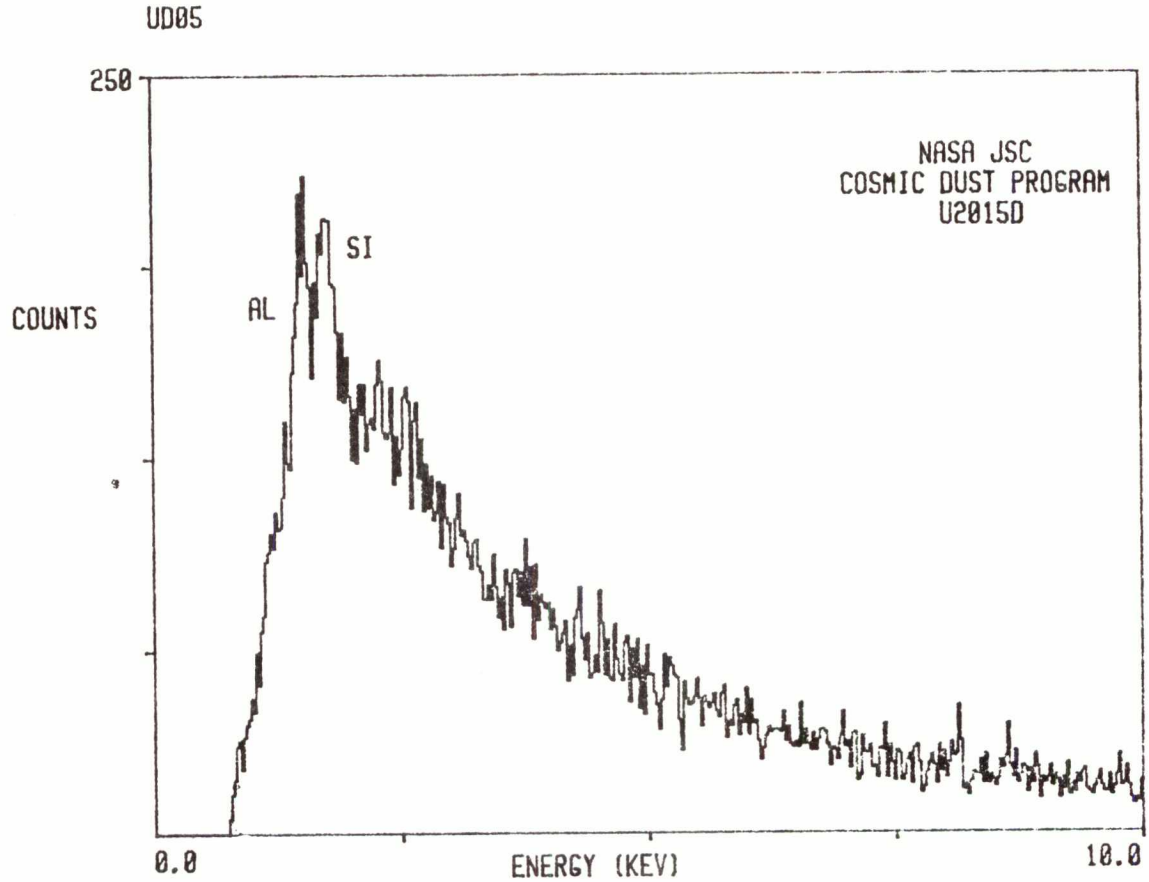


SIZE	SHAPE	TRANS.
5x8	I	O

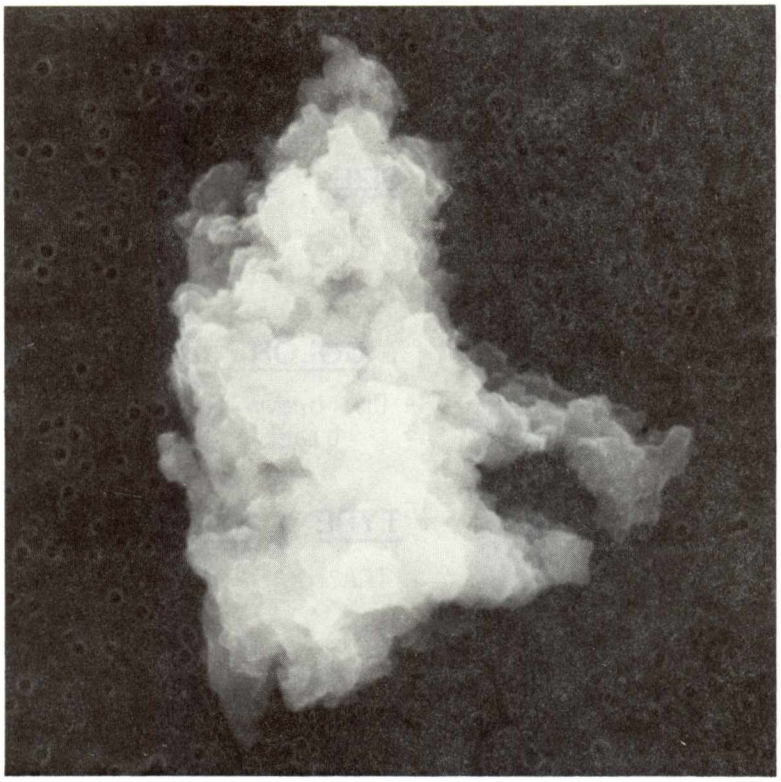
COLOR	LUSTER
Black	D/SM

TYPE	COMMENTS
?	

S-84-41337



U2015D6

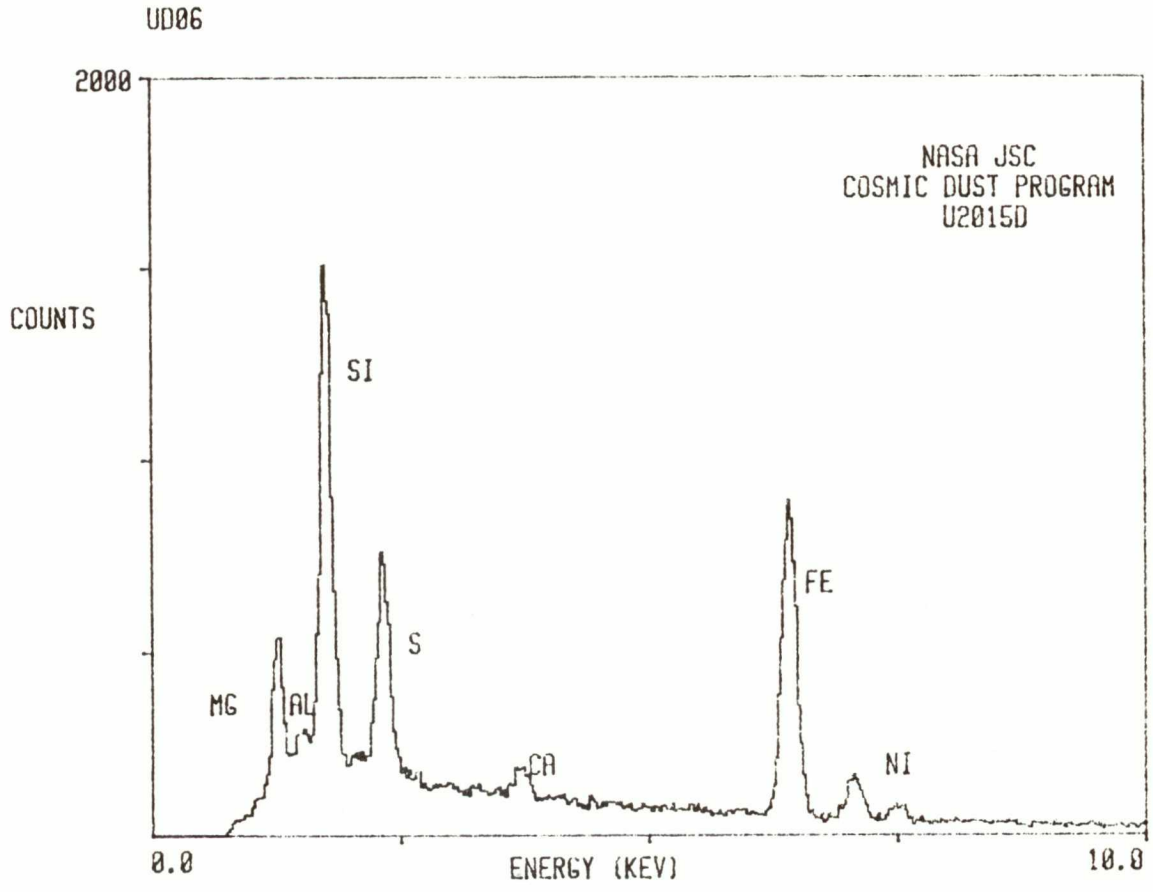


S-84-41338

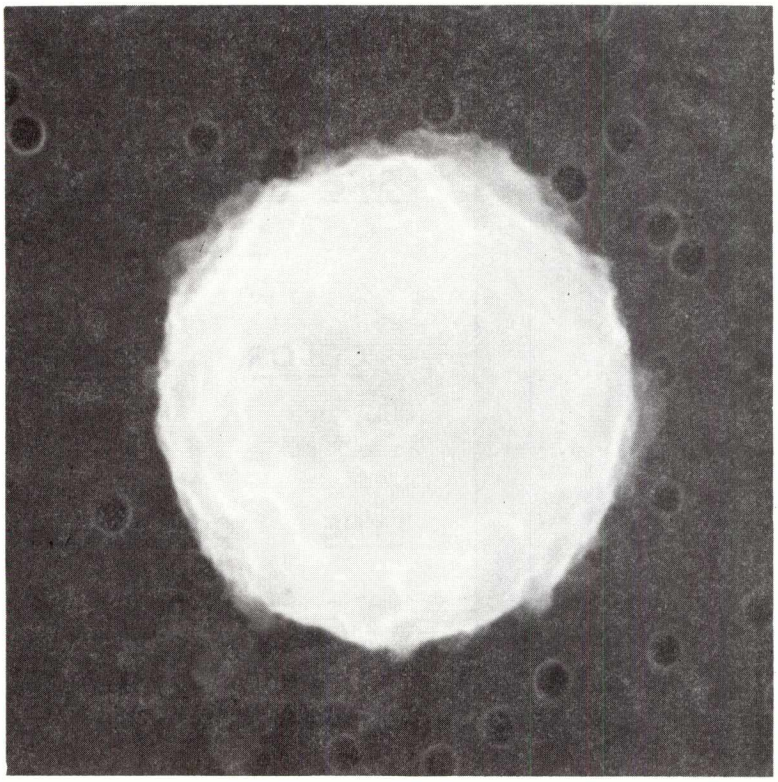
SIZE	SHAPE	TRANS.
14x18	I	O

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C	



U2015D7

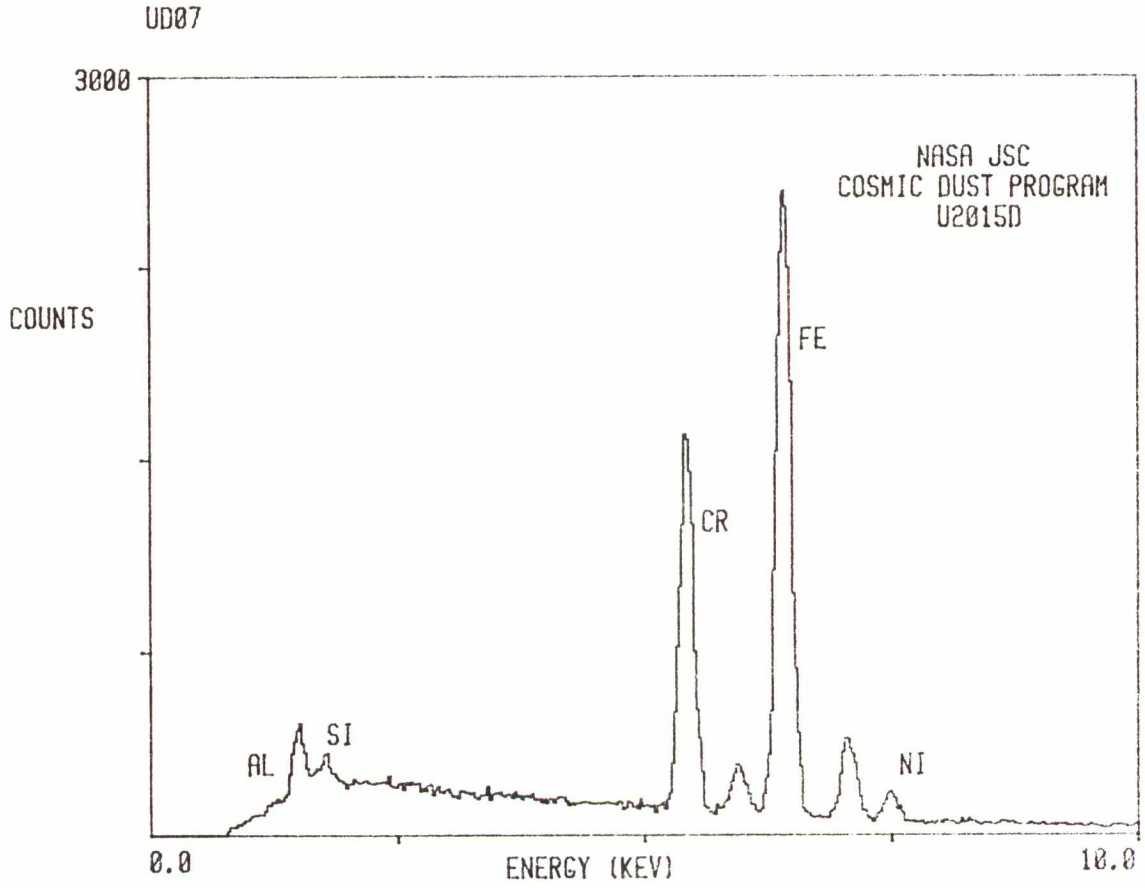


S-84-41339

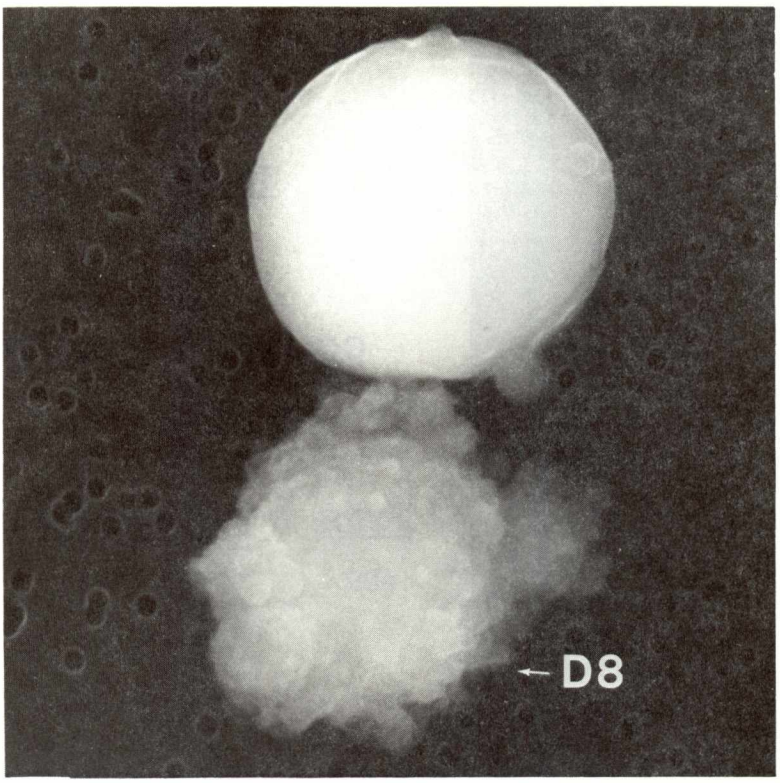
SIZE	SHAPE	TRANS.
5	S	0

COLOR	LUSTER
Dk. brown to black	SM

TYPE	COMMENTS
TCA?	



U2015D8

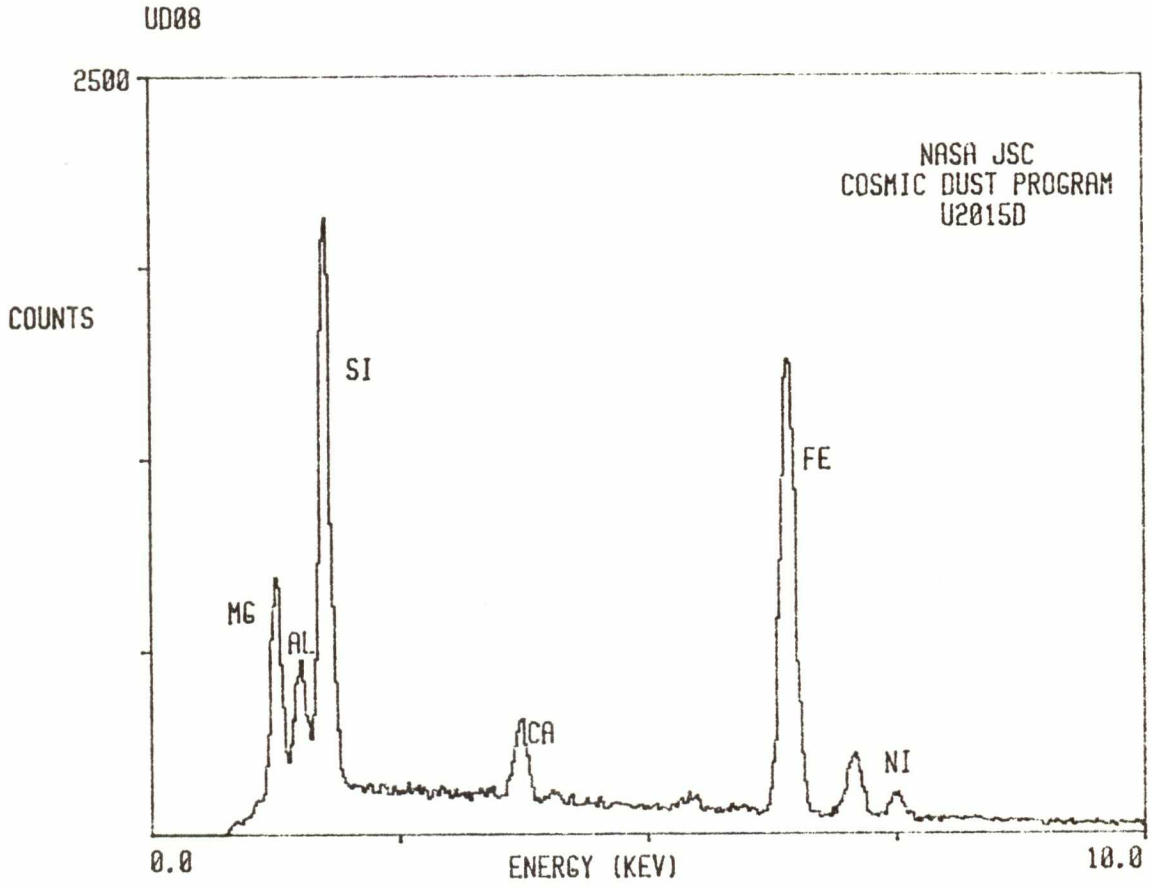


S-84-41340

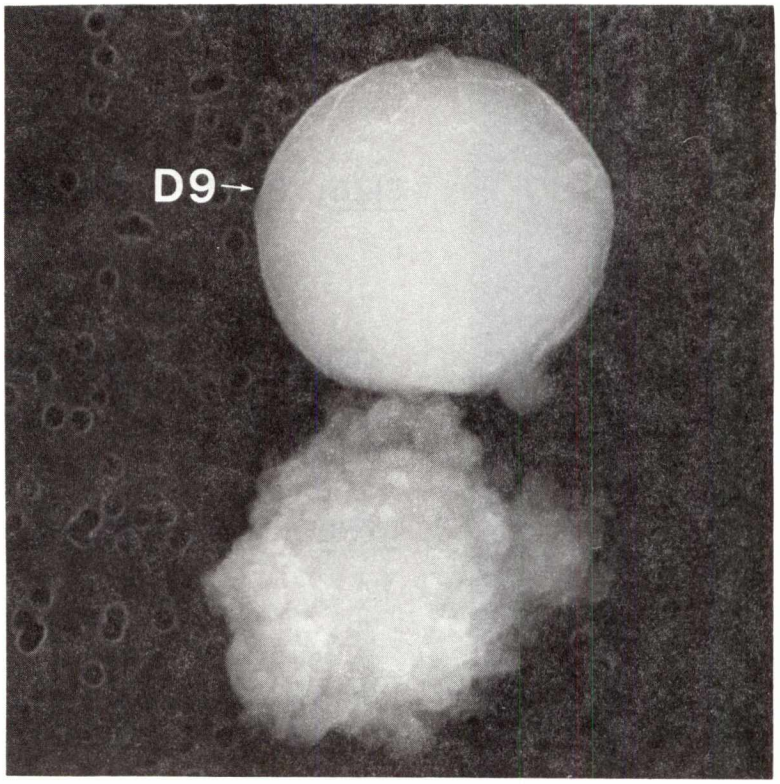
SIZE	SHAPE	TRANS.
6x7	I	O

COLOR	LUSTER
Red-brown to black	D/SV

TYPE	COMMENTS
C	



U2015D9

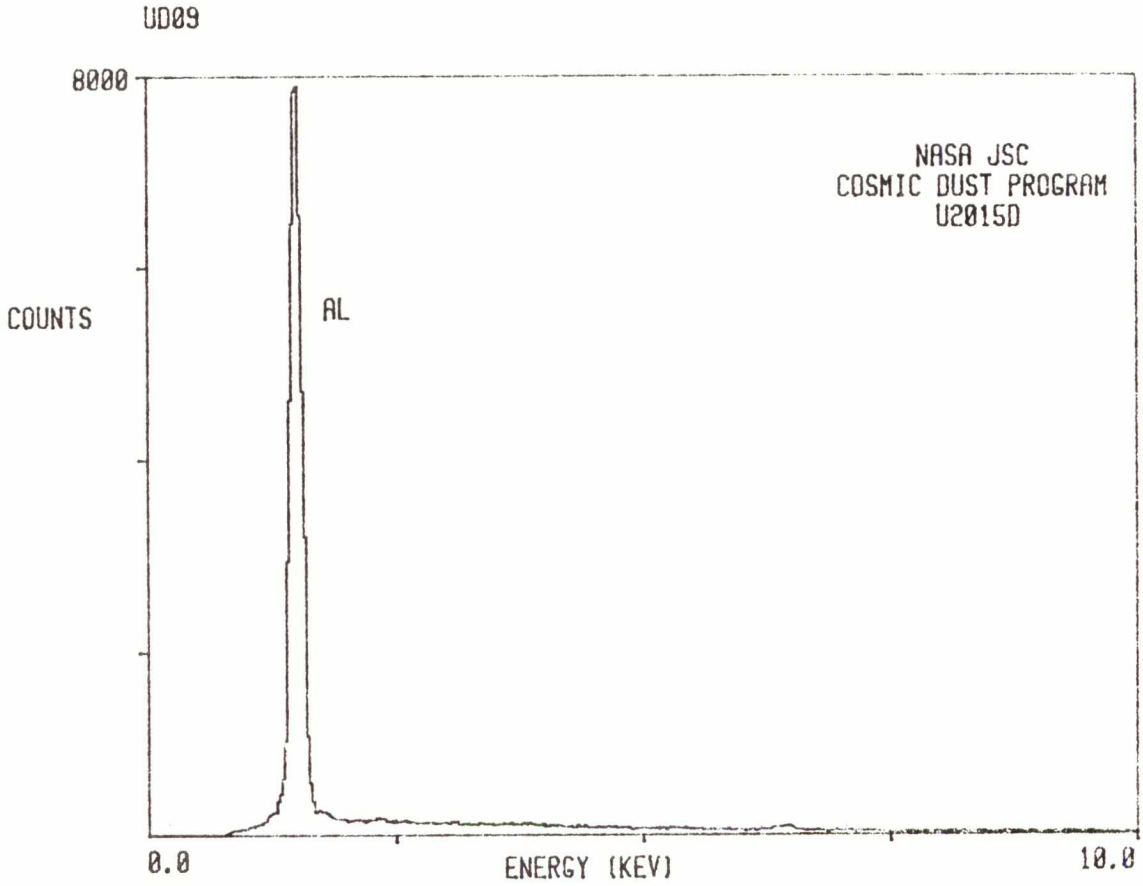


SIZE	SHAPE	TRANS.
6	S	T

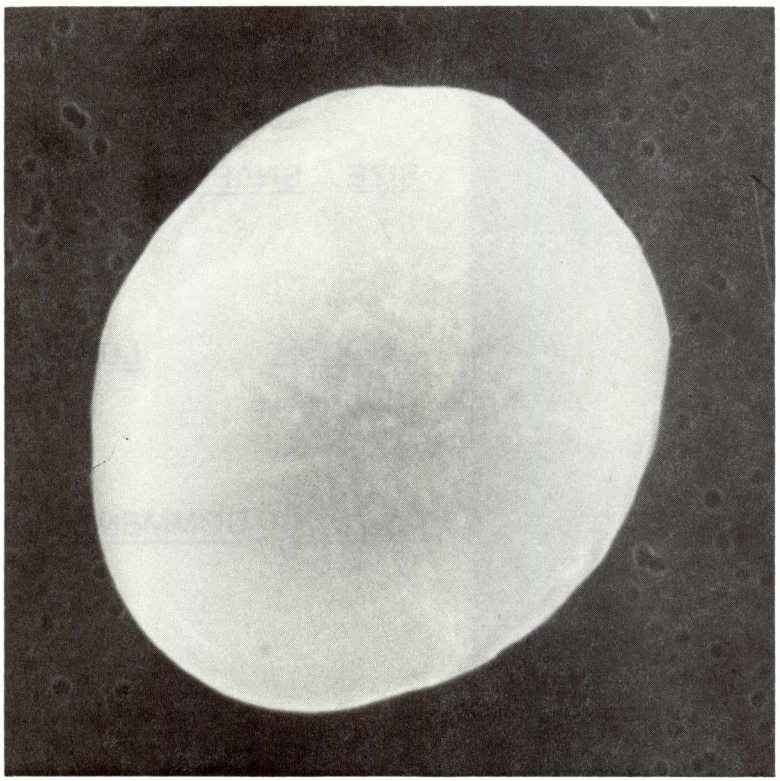
COLOR	LUSTER
Pale yellow-gray	V

TYPE	COMMENTS
AOS	

S-84-41340



U2015D10

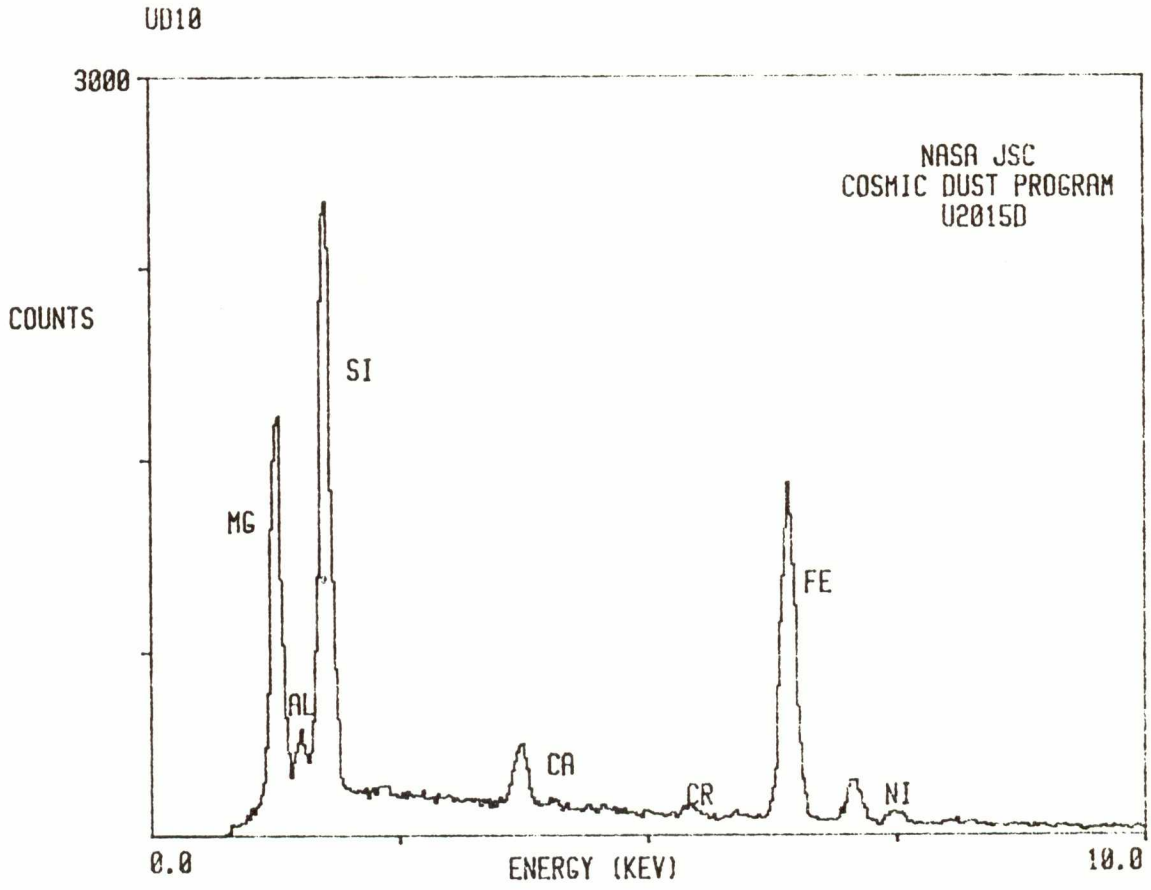


S-84-41341

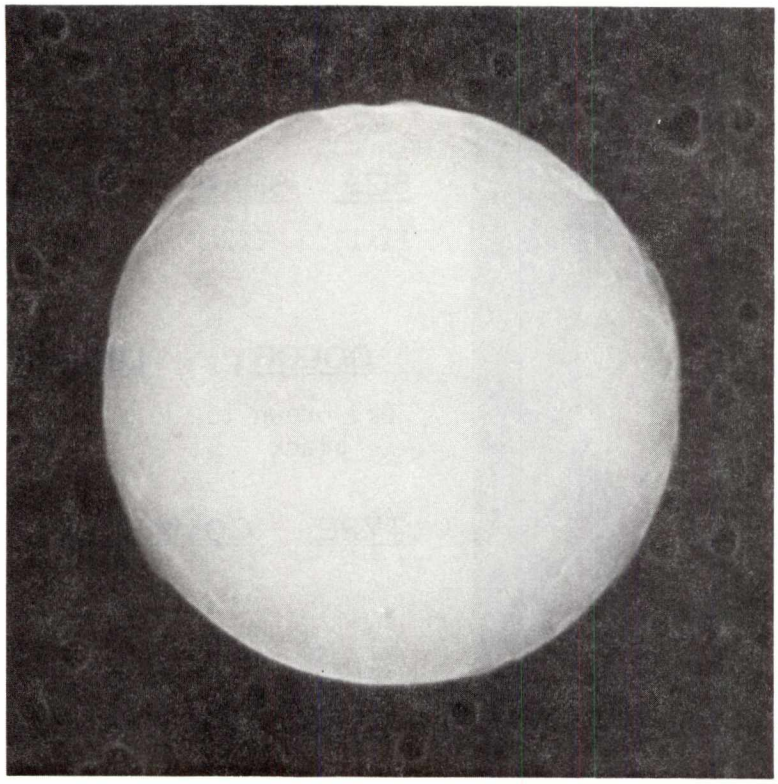
SIZE	SHAPE	TRANS.
11x13	E/S	O

COLOR	LUSTER
Dk. brown to black	SM

TYPE	COMMENTS
C	



U2015D11

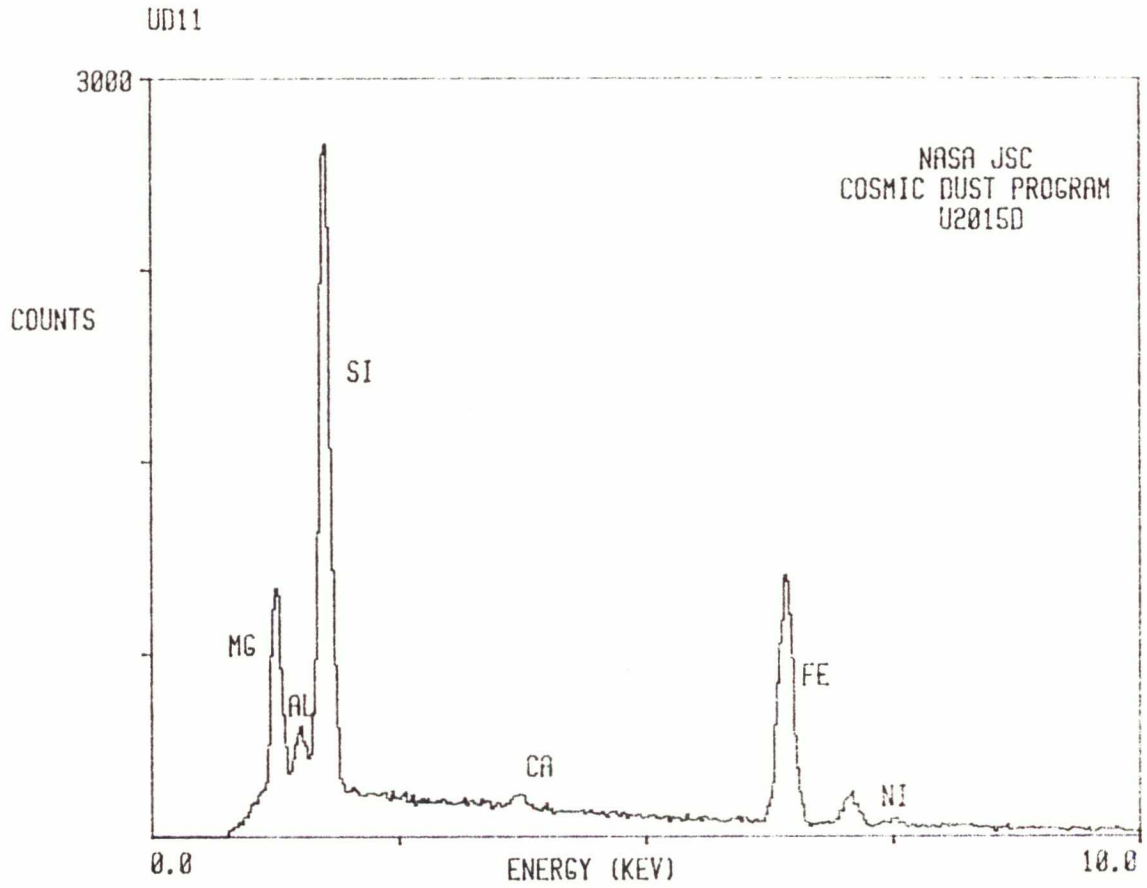


SIZE	SHAPE	TRANS.
7	S	0

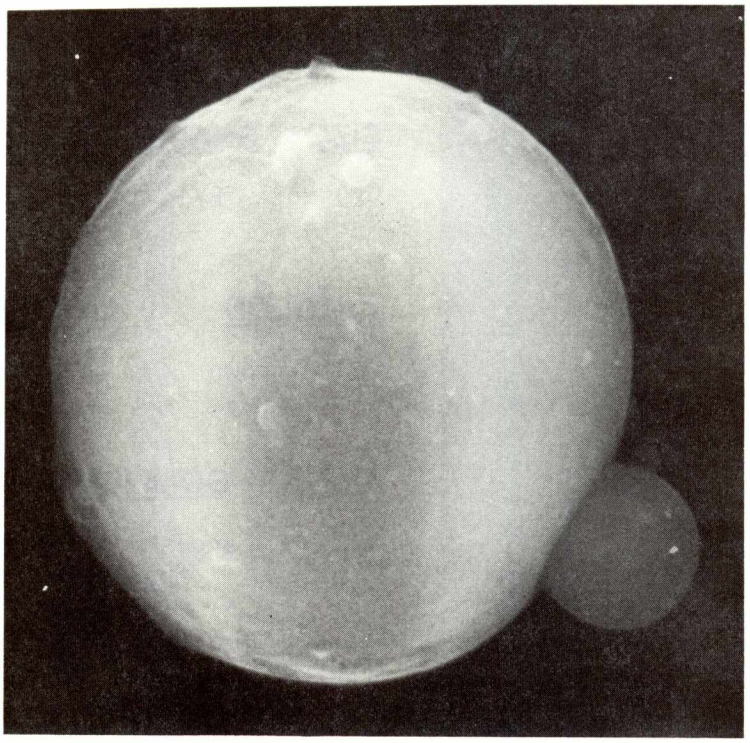
COLOR	LUSTER
Dk. brown	SM

TYPE	COMMENTS
C	

S-84-41342



U2015D12

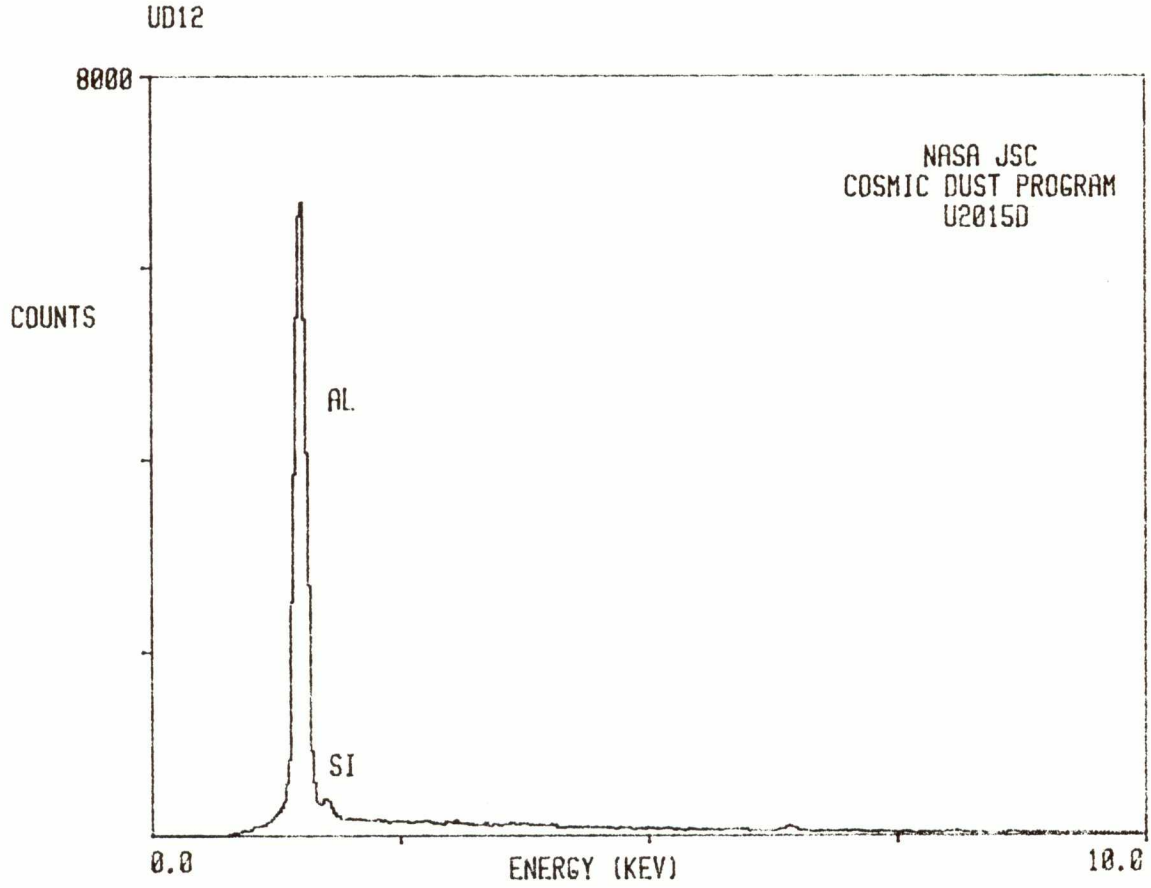


S-84-41343

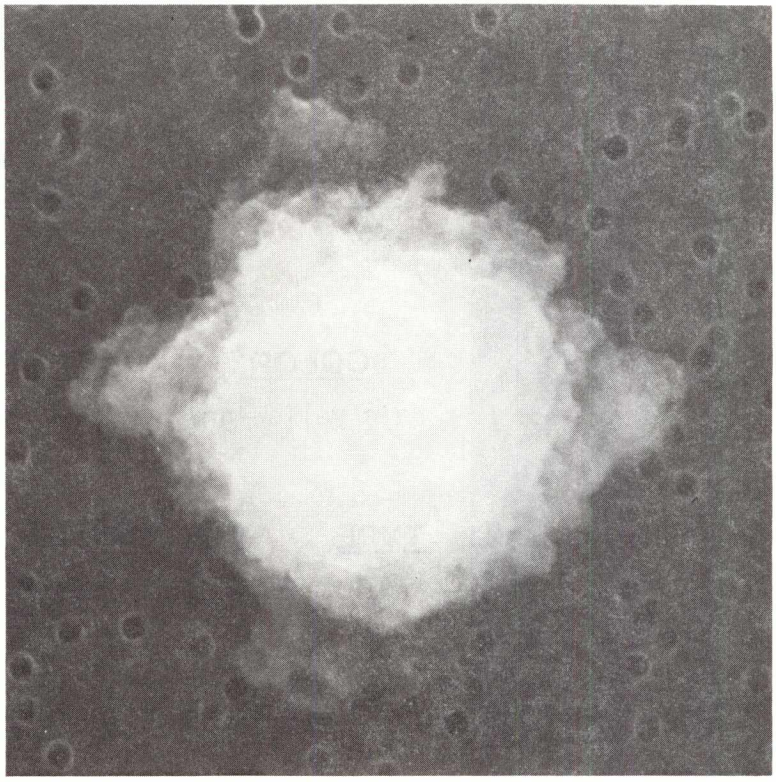
SIZE	SHAPE	TRANS.
5x6	S/E	TL

COLOR	LUSTER
Pale yellow-gray	V

TYPE	COMMENTS
AOS	Compound spherule



U2015D13

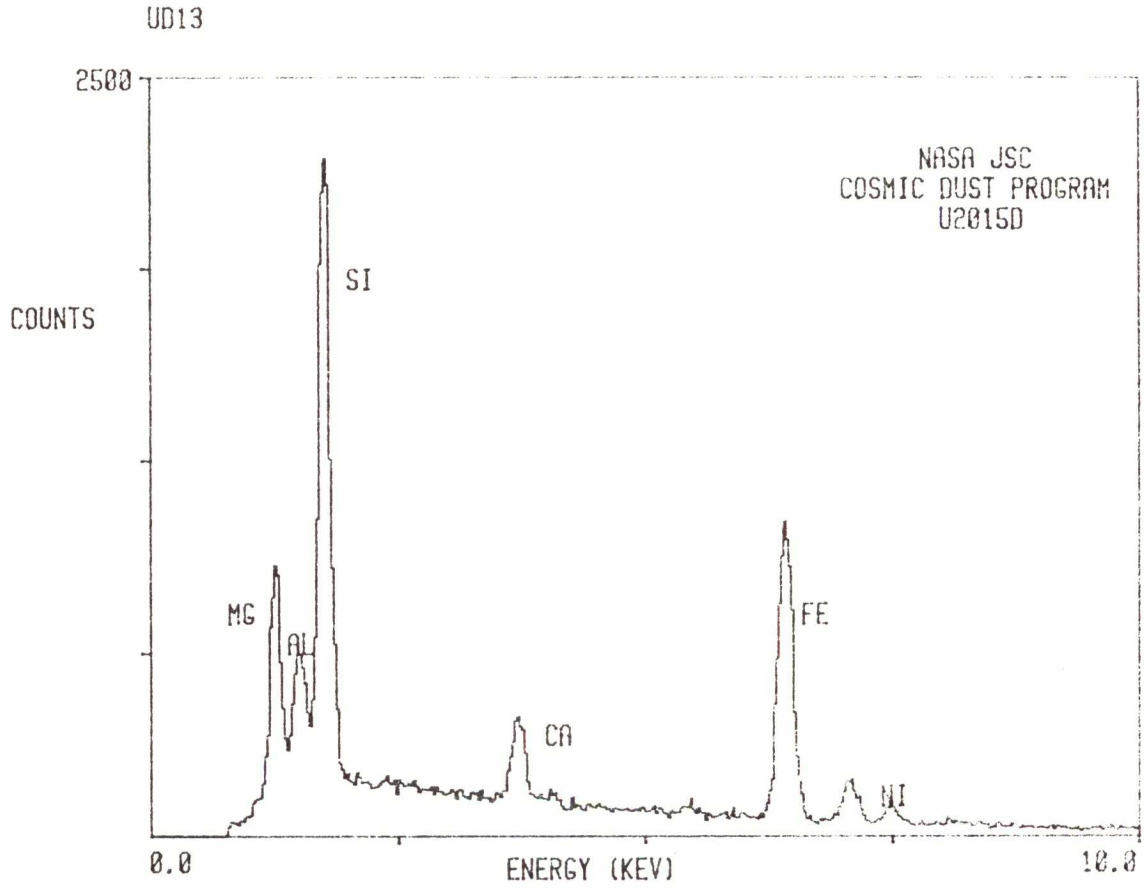


S-84-41344

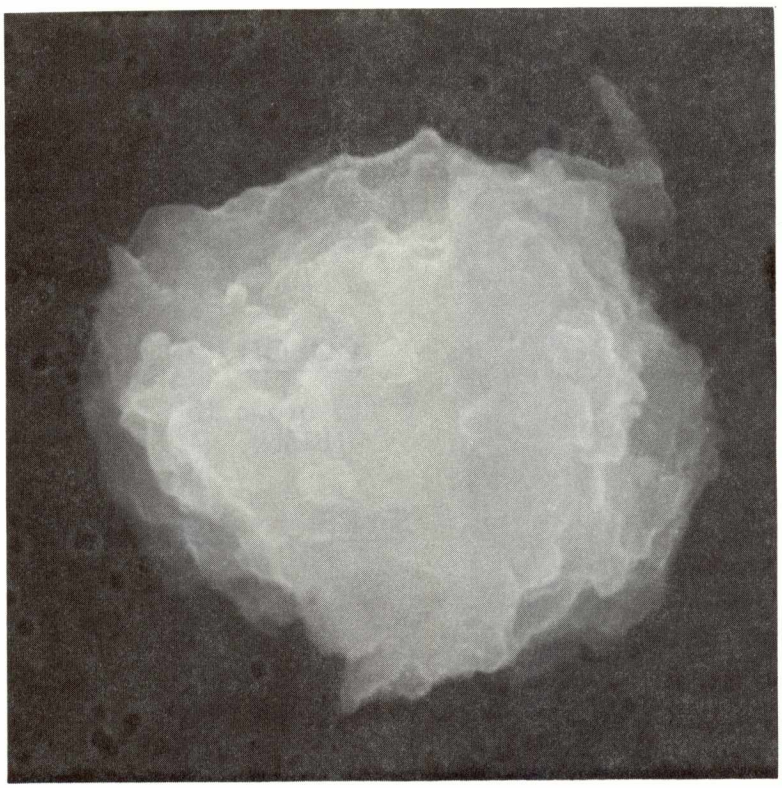
SIZE	SHAPE	TRANS.
9x9	E/I	O

COLOR	LUSTER
Red-brown to gray	D

TYPE	COMMENTS
C	Largest of several fragments



U2015D14

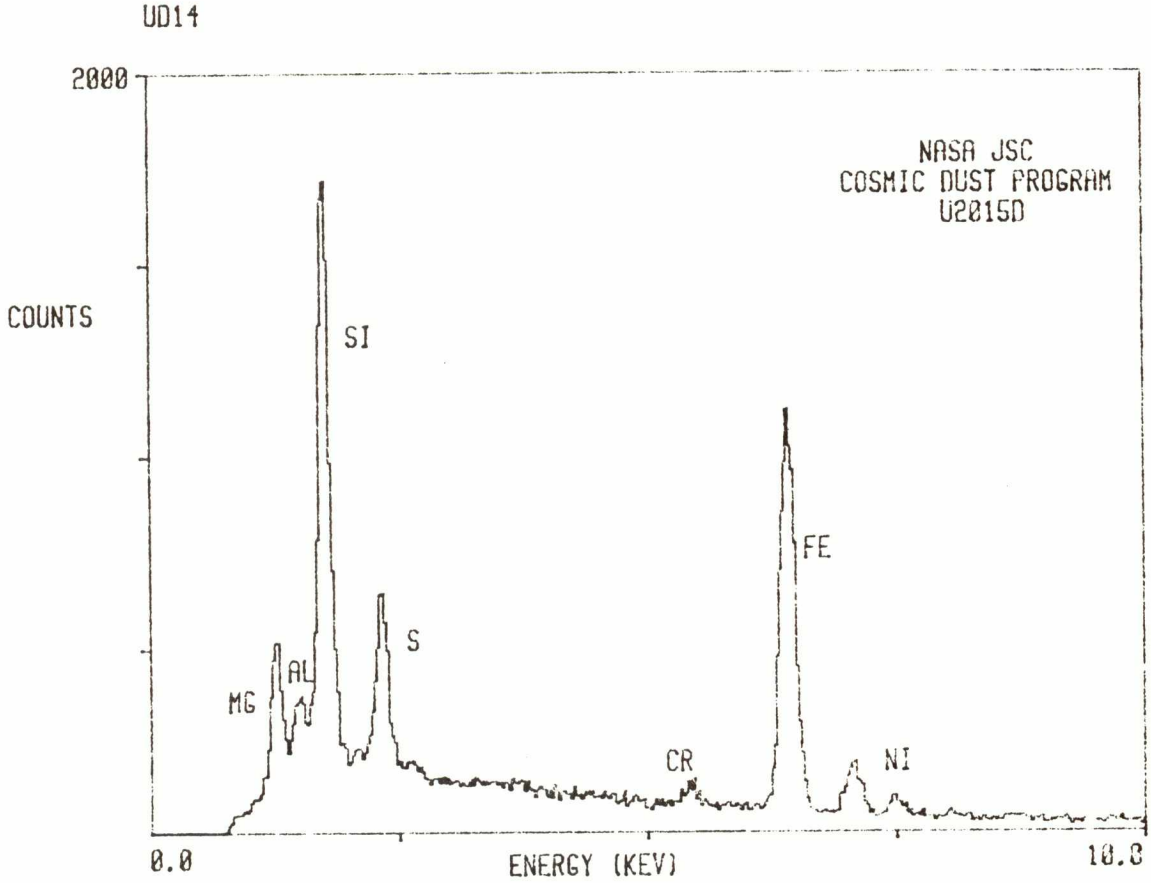


SIZE	SHAPE	TRANS.
11x11	E/I	O

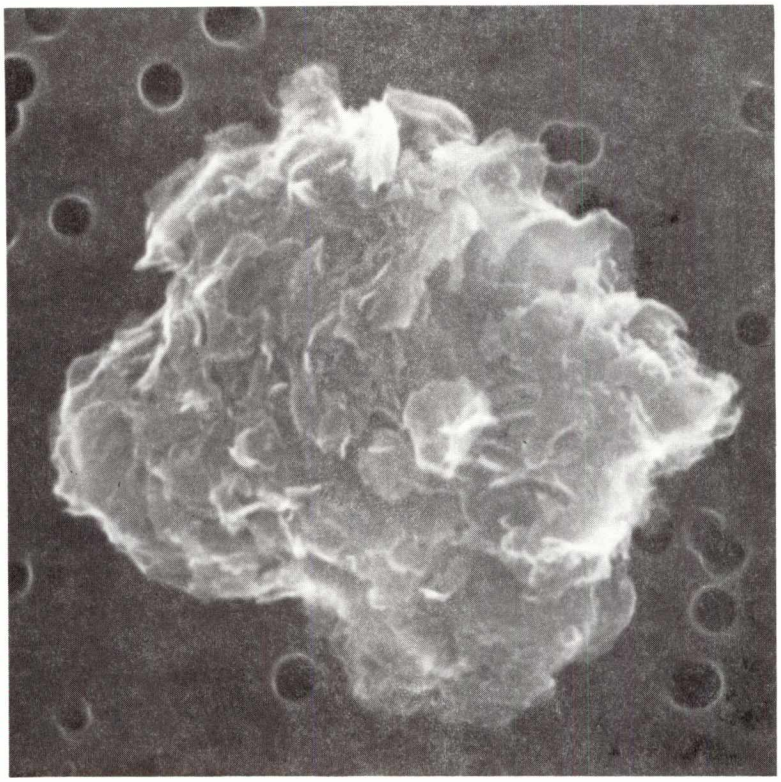
COLOR	LUSTER
Dk. brown to black	D/SM

TYPE	COMMENTS
C	

S-84-41345



U2015D15

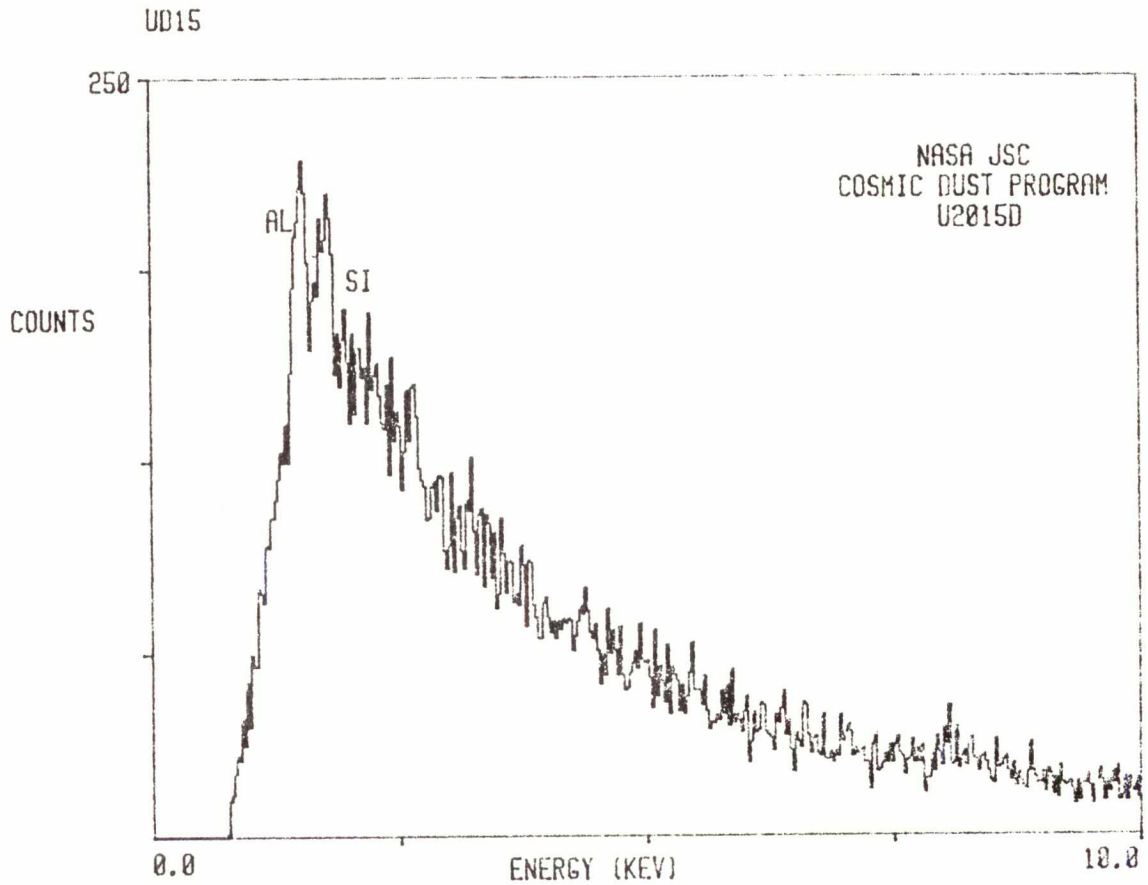


SIZE	SHAPE	TRANS.
5x5	E/I	0

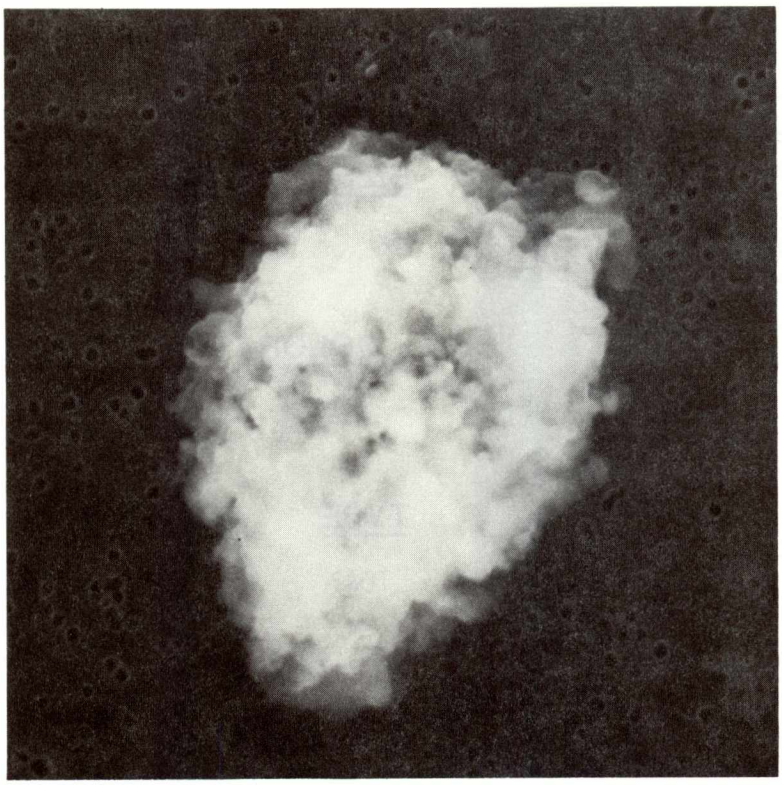
COLOR	LUSTER
Dk. brown to black	SM

TYPE	COMMENTS
TCA?	

S-84-41346



U2015D16

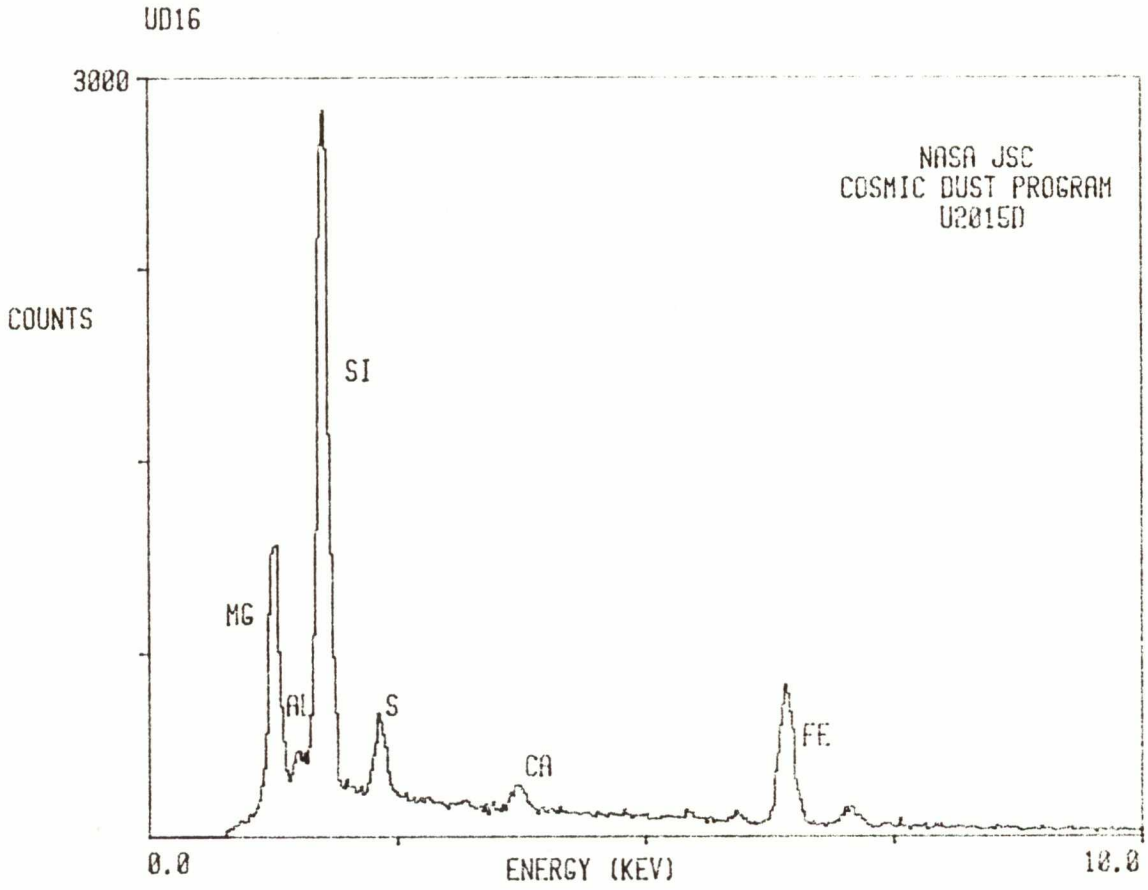


S-84-41347

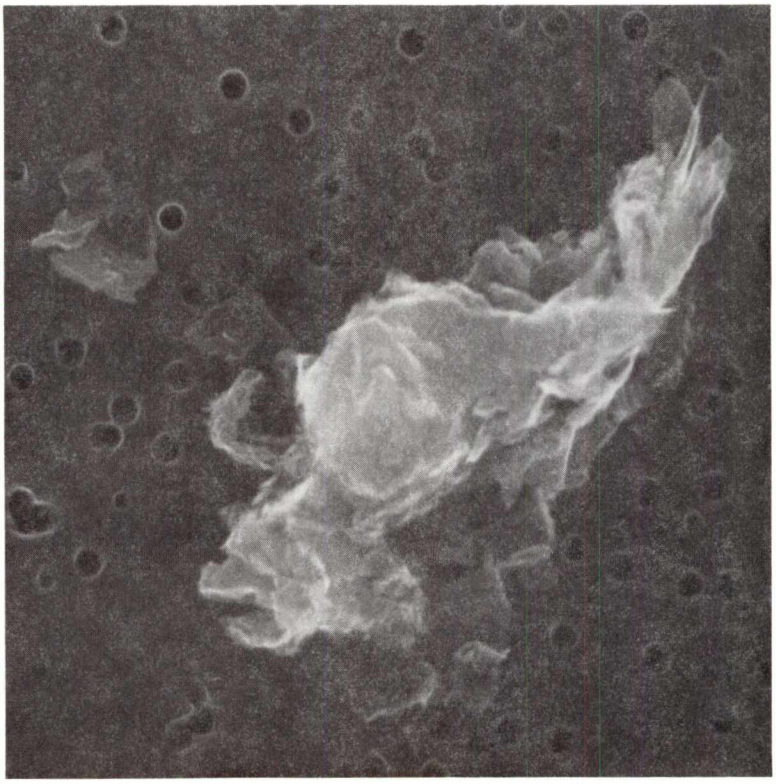
SIZE	SHAPE	TRANS.
11x15	I	O

COLOR	LUSTER
Dk. gray-brown	D/SV

TYPE	COMMENTS
C	



U2015D17

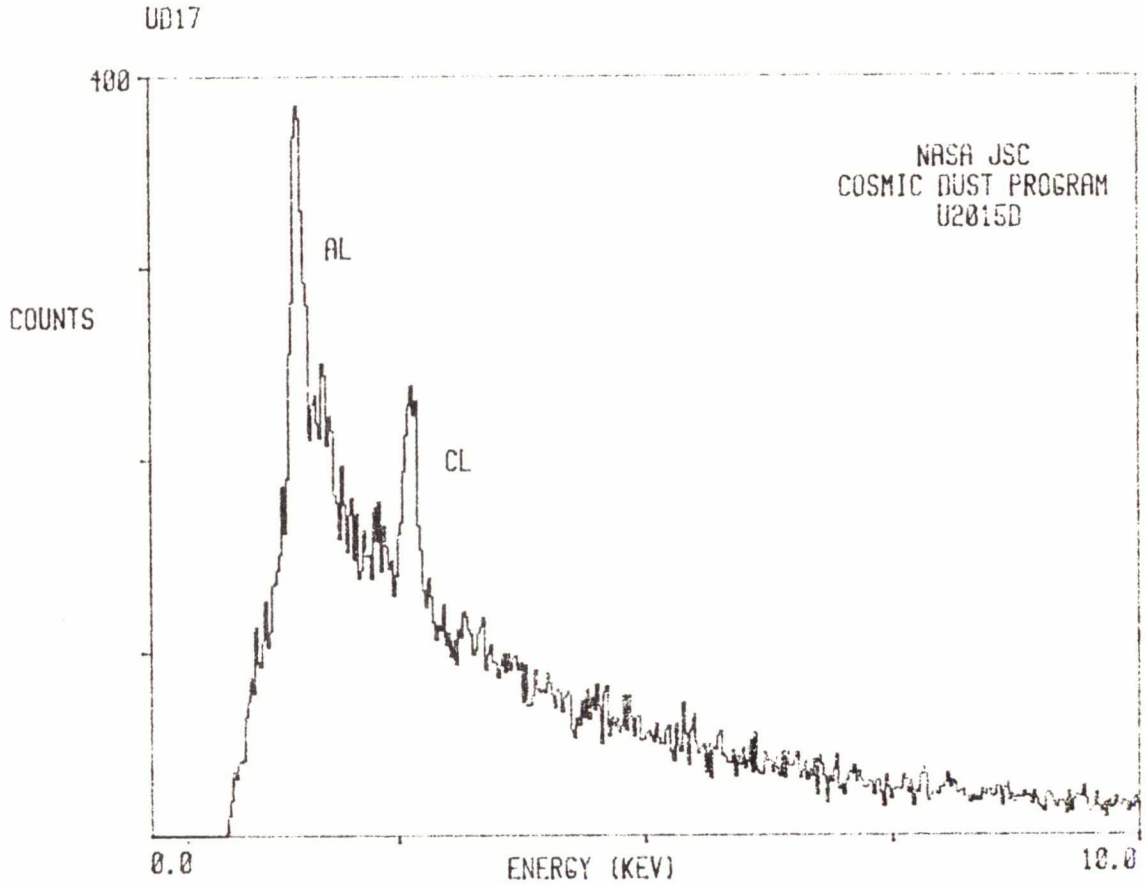


SIZE	SHAPE	TRANS.
6x9	I	O

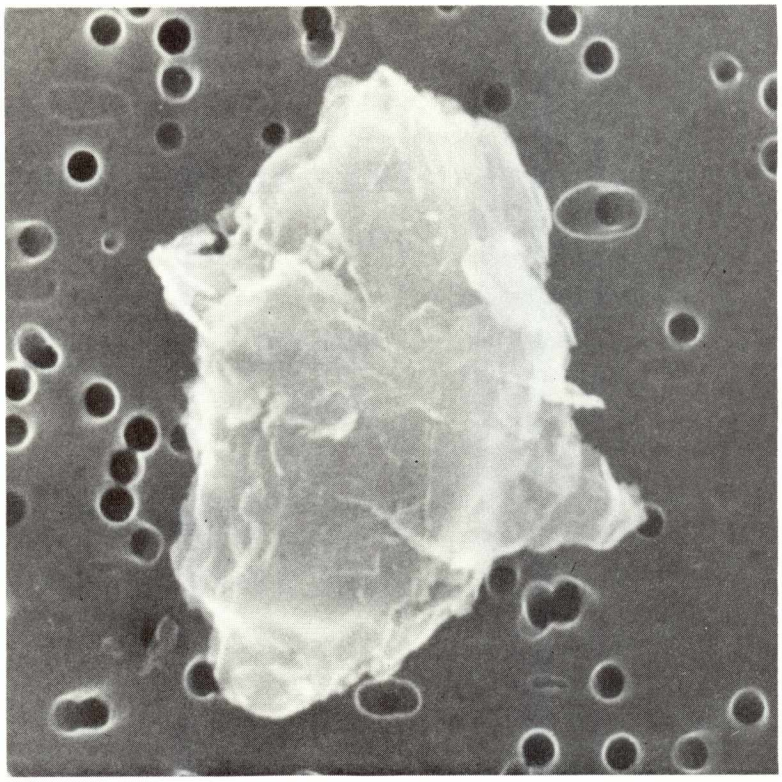
COLOR	LUSTER
Black	SM

TYPE	COMMENTS
TCA?	Associated with U2015D16

S-84-41348



U2015D18

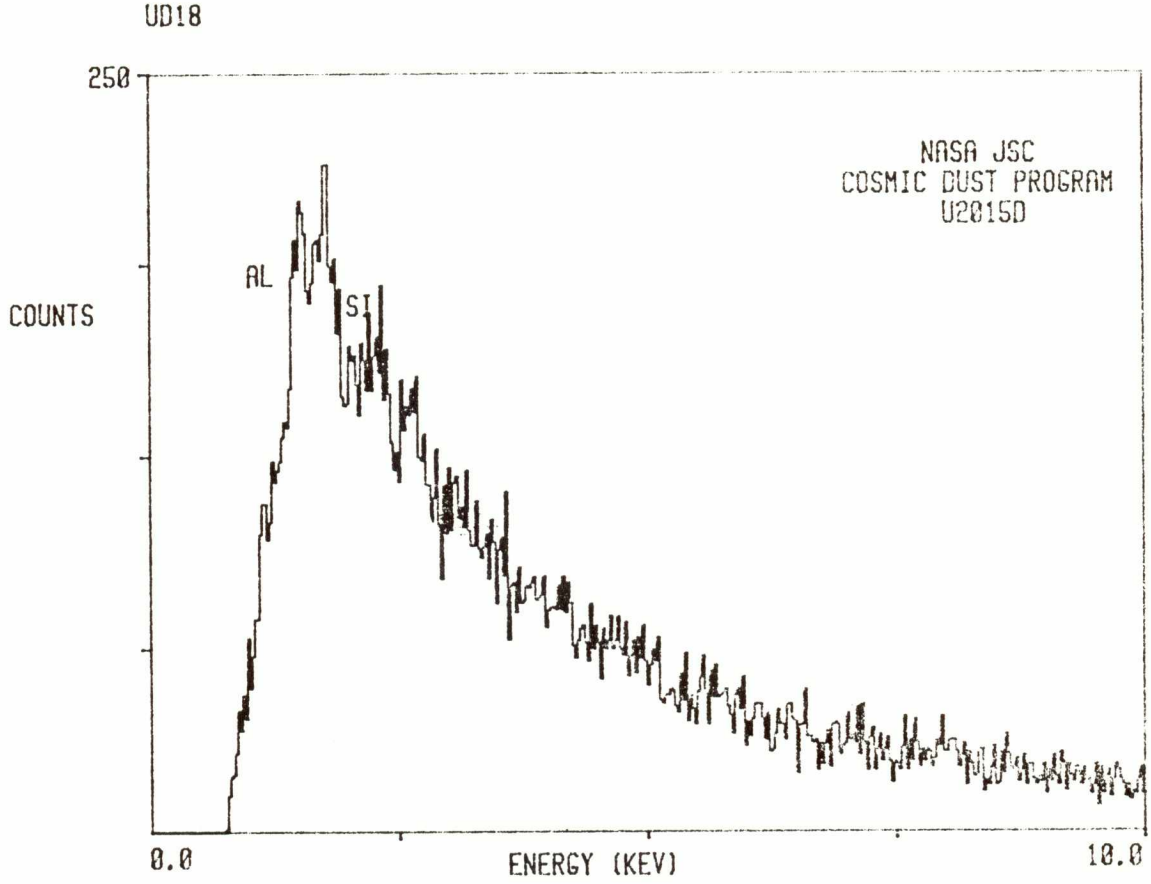


S-84-41349

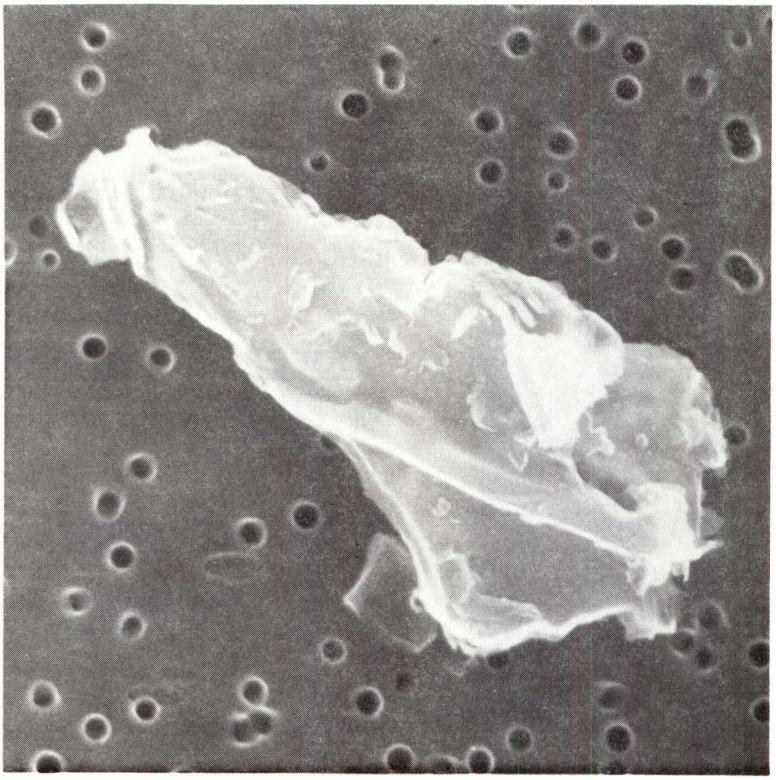
SIZE	SHAPE	TRANS.
5x7	E/I	O

COLOR	LUSTER
Dk. gray to black	M

TYPE	COMMENTS
TCA?	Associated with U2015D16



U2015D19

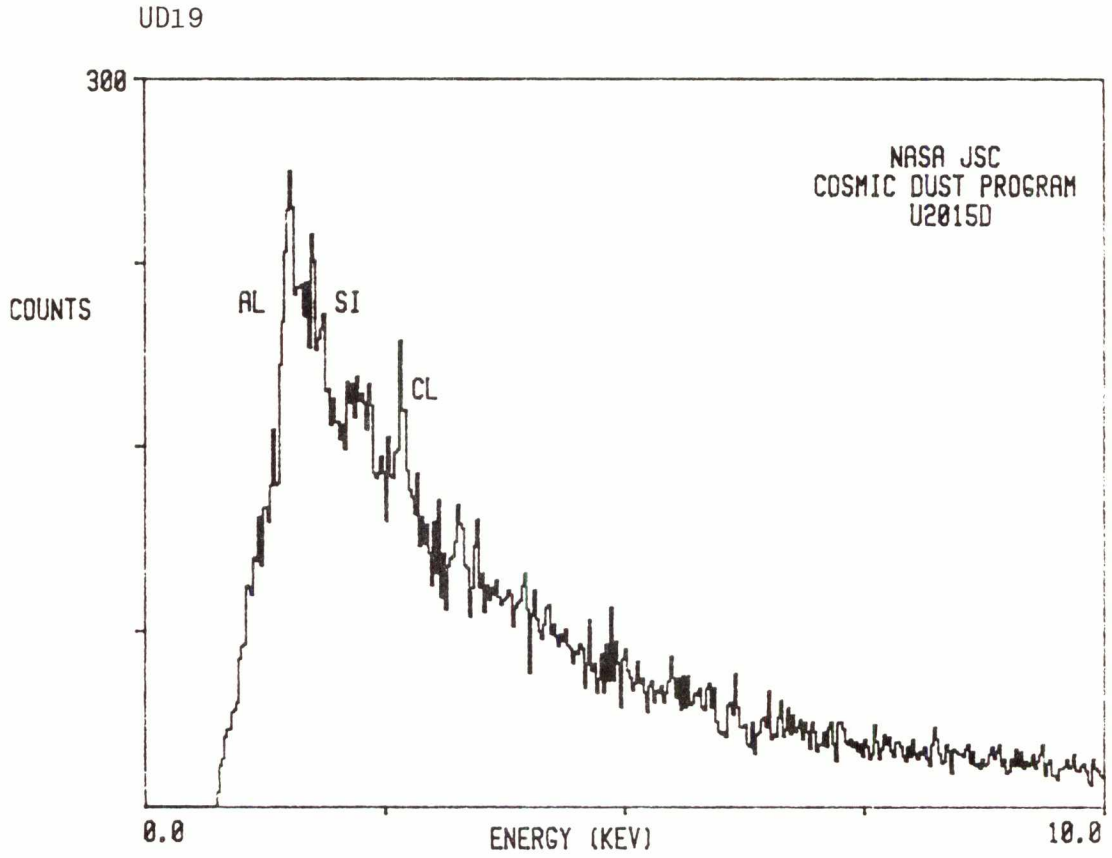


S-84-42622

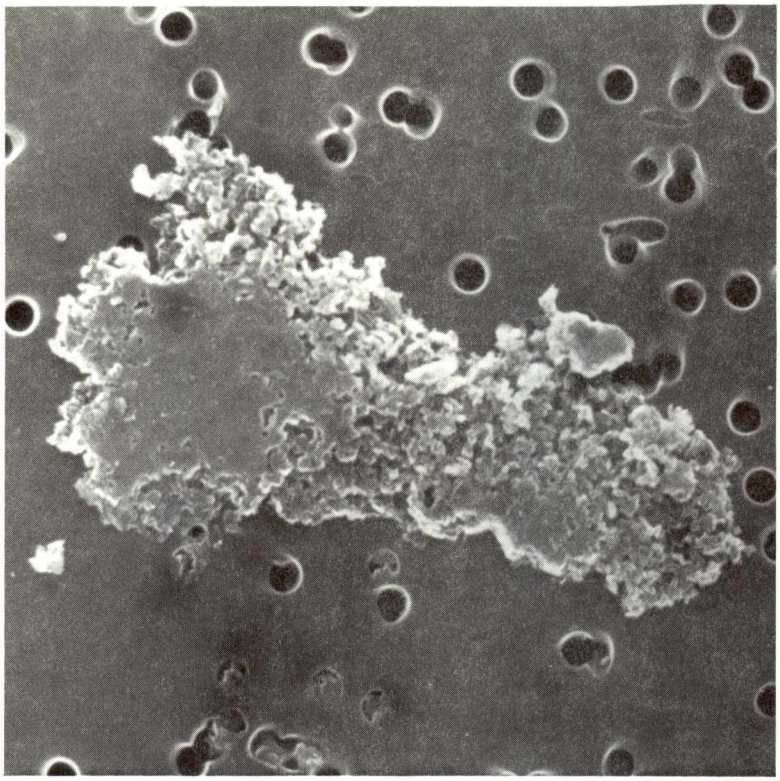
SIZE	SHAPE	TRANS.
5x10	I	0

COLOR	LUSTER
Black	M

TYPE	COMMENTS
TCA?	Associated with U2015D16



U2015D20

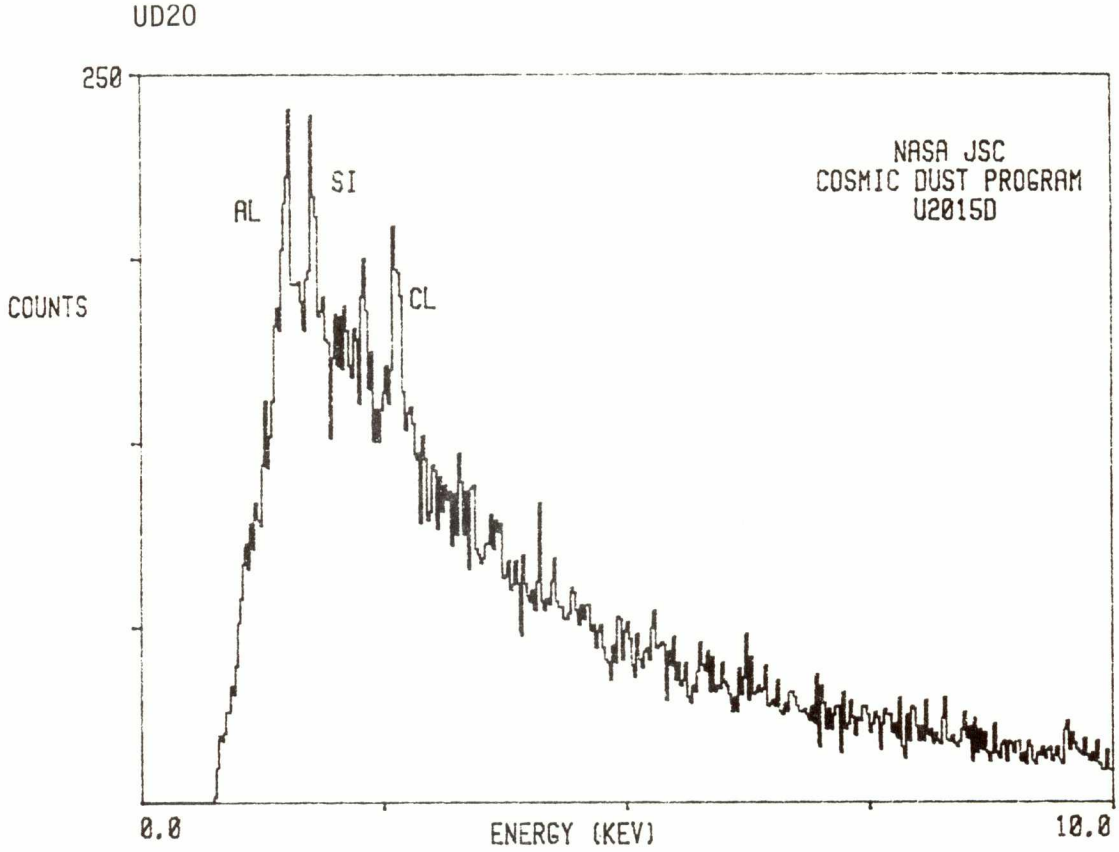


S-84-42623

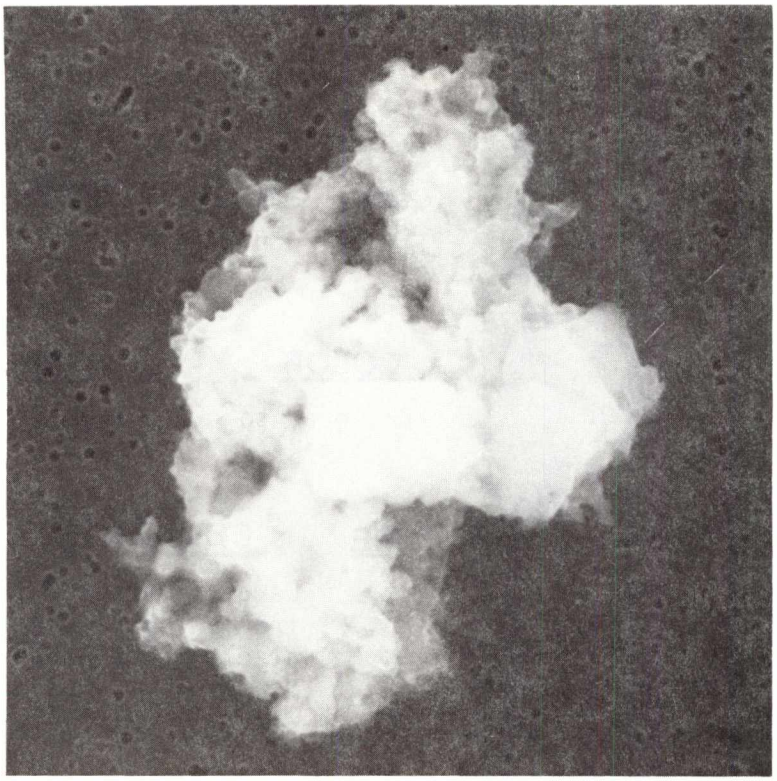
SIZE	SHAPE	TRANS.
4x8	I	0

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
TCA?	Largest of several fragments; associated with U2015D26



U2015D21

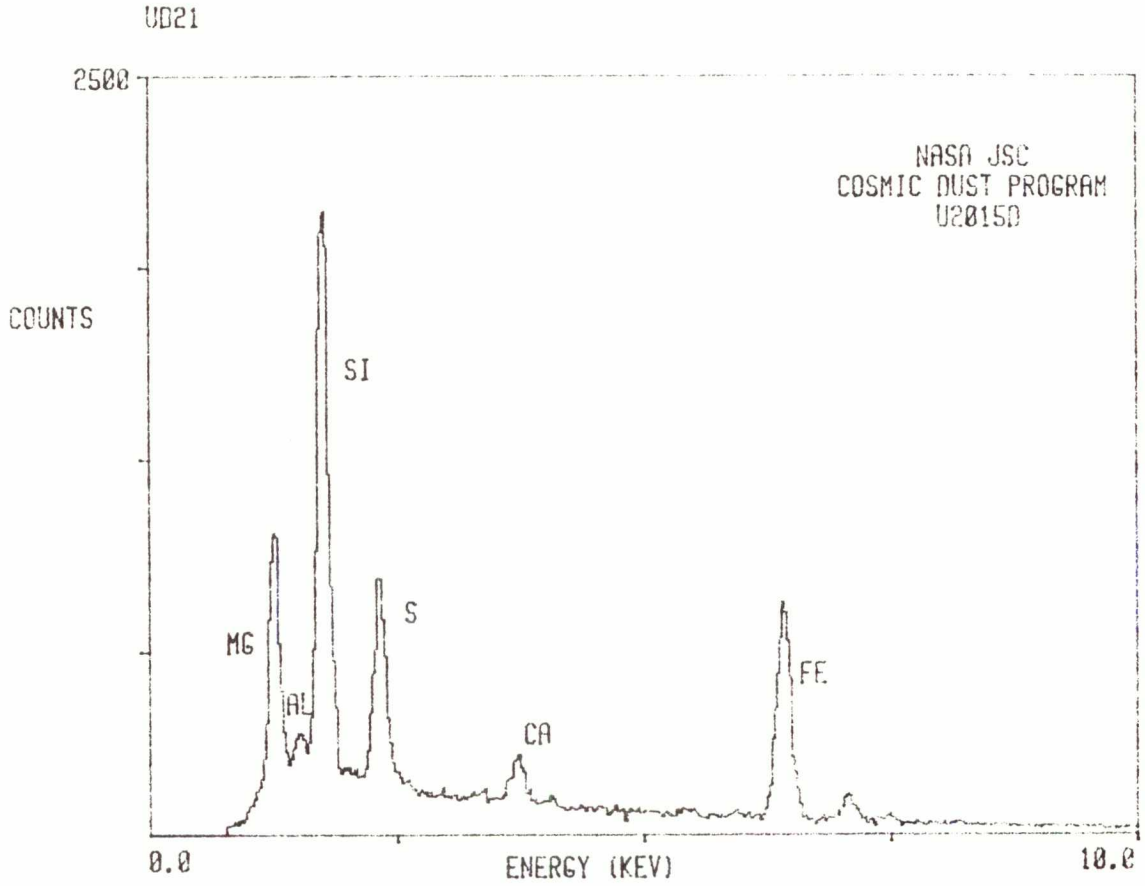


S-84-41352

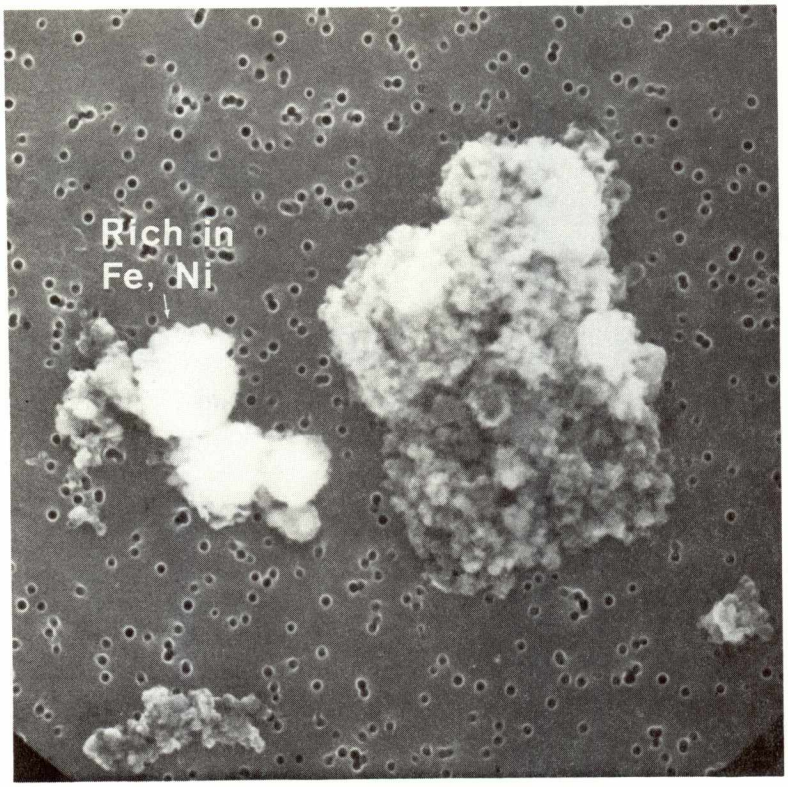
SIZE	SHAPE	TRANS.
14x20	I	0

COLOR	LUSTER
Dk. gray to black	SV/SM

TYPE	COMMENTS
C	Larger of two fragments



U2015D22

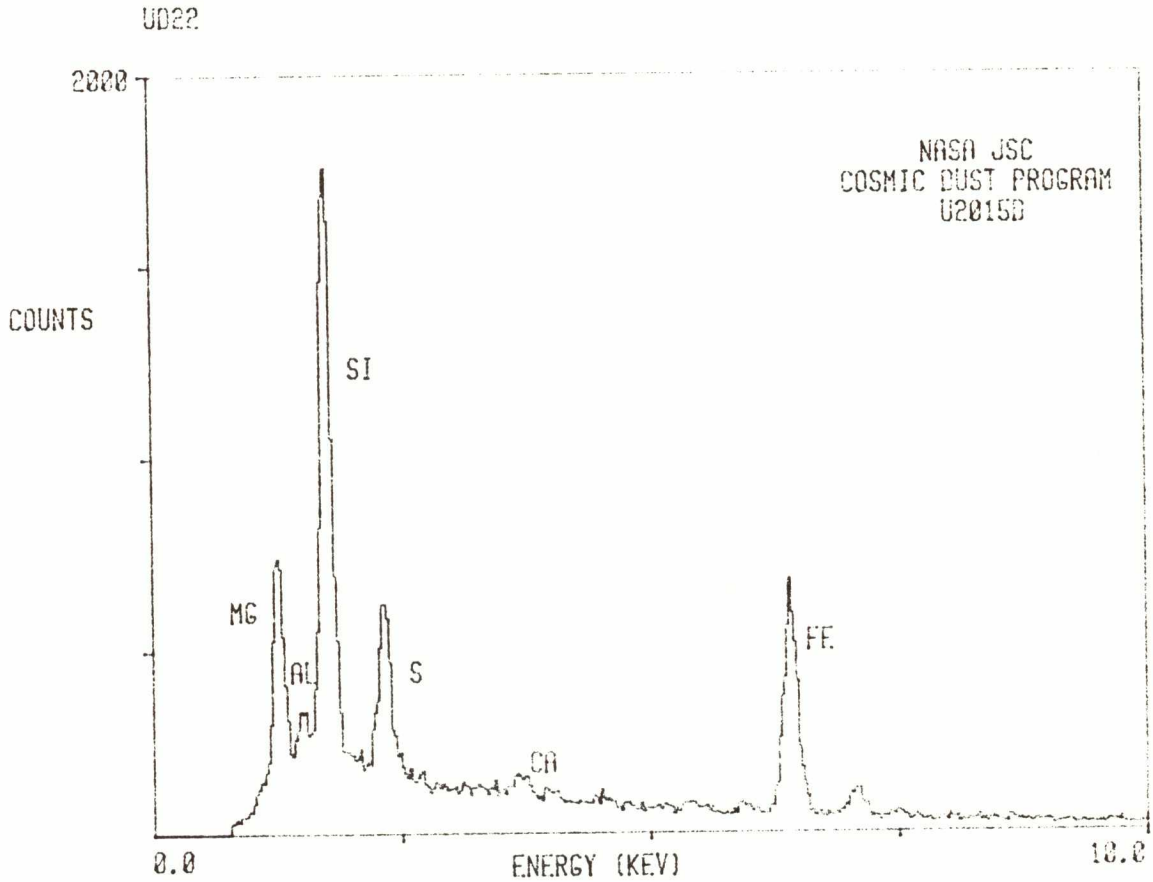


S-84-41354

SIZE	SHAPE	TRANS.
10x15	I	0

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C	Largest of several fragments



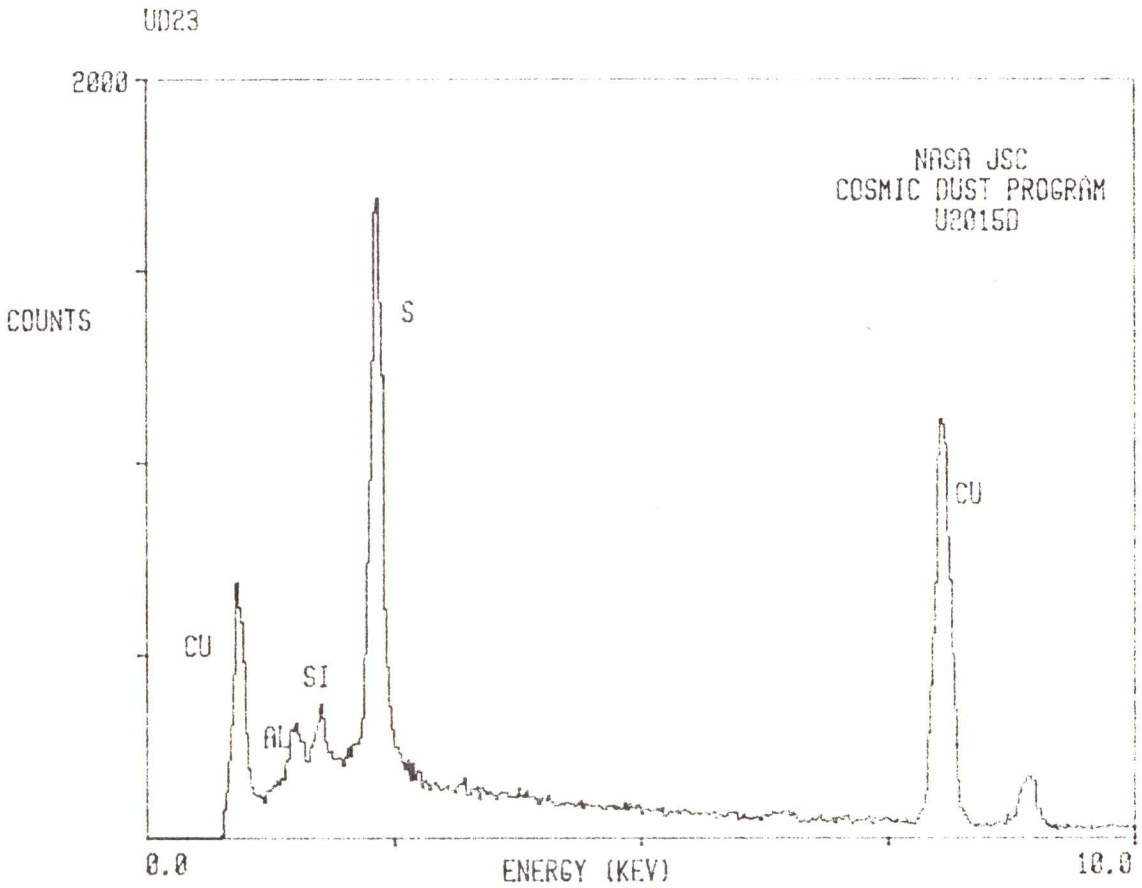
U2015D23

SIZE	SHAPE	TRANS.
11x18	I	O/TL

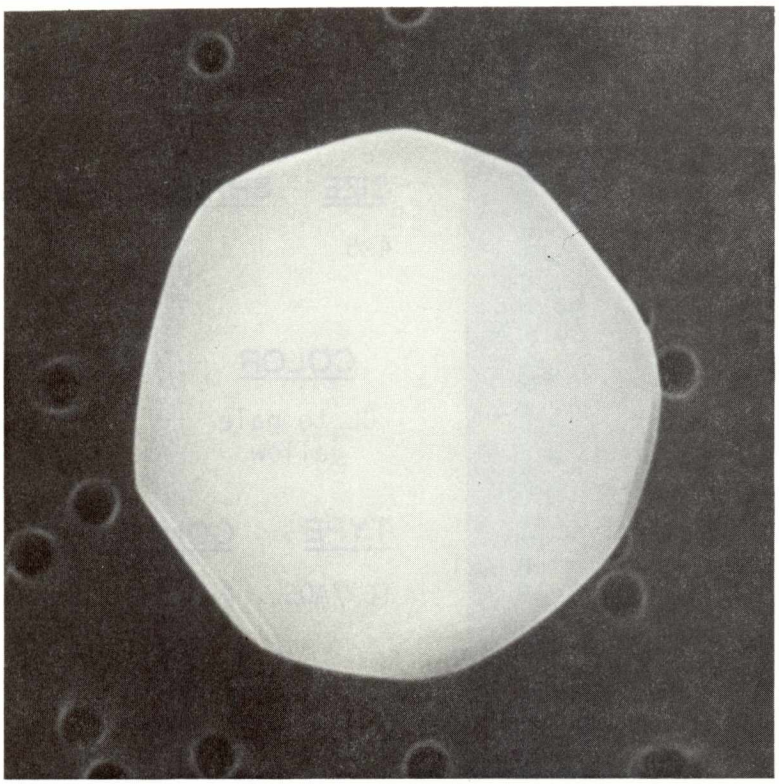
COLOR	LUSTER
Dk. gray-brown	D/SV

TYPE	COMMENTS
TCA?	Largest of several fragments, all with arborescent to rosette morphologies

S-84-41355



U2015D24

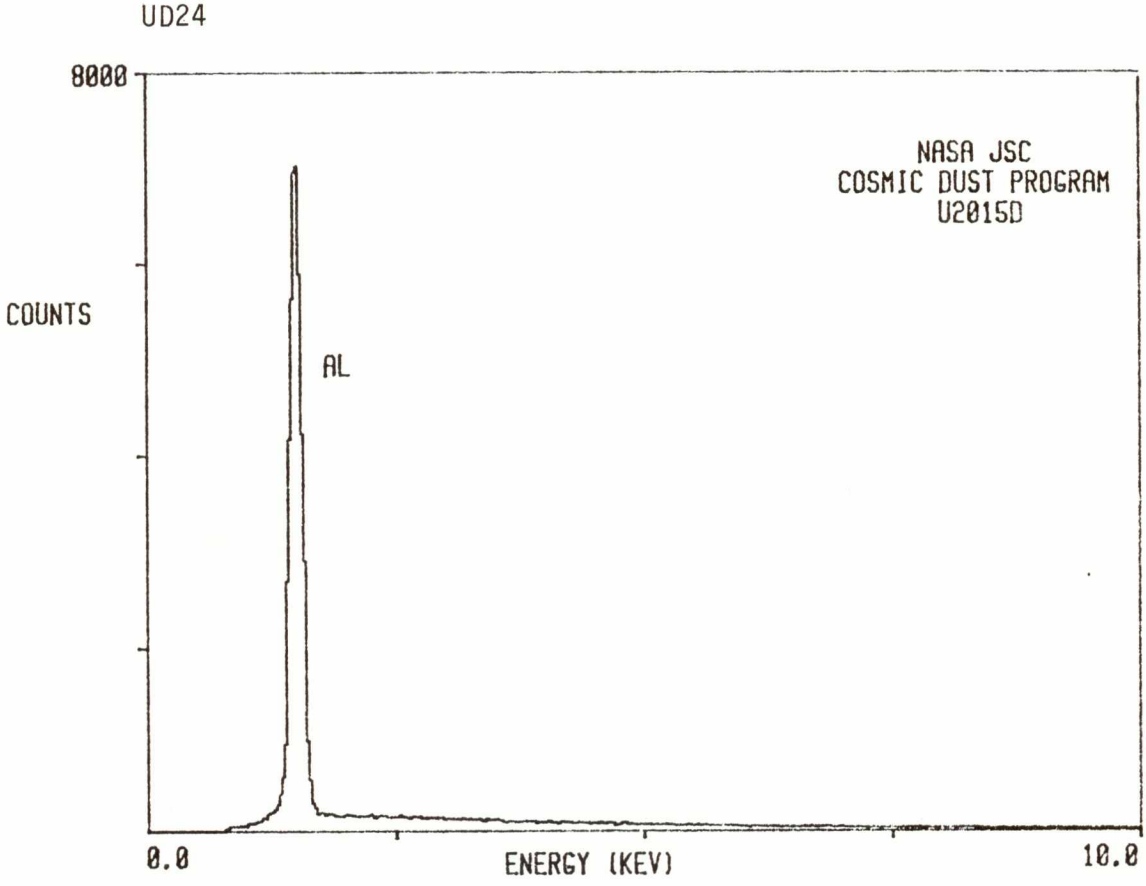


S-84-41327

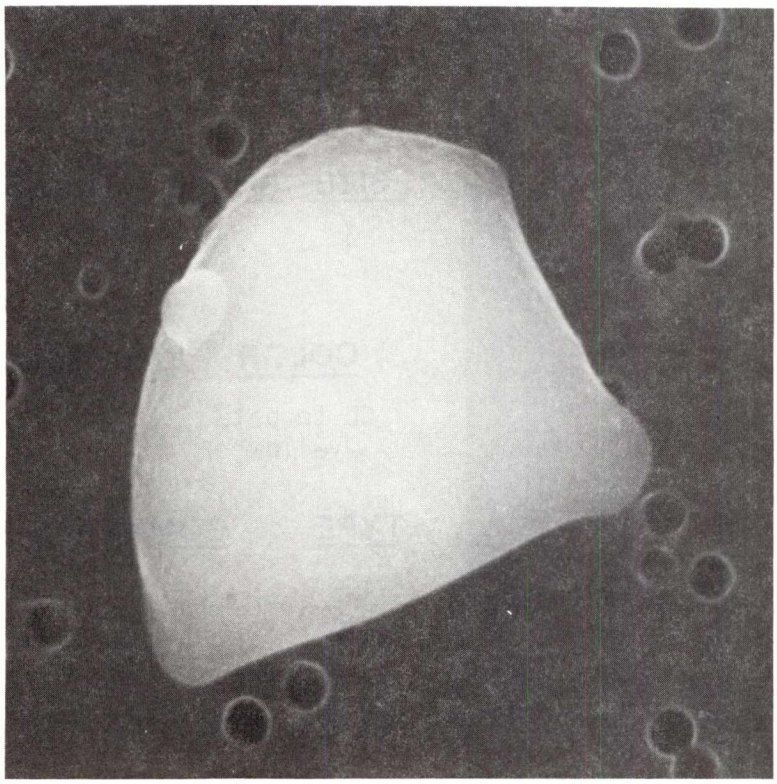
SIZE	SHAPE	TRANS.
4	S	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
AOS	



U2015D25

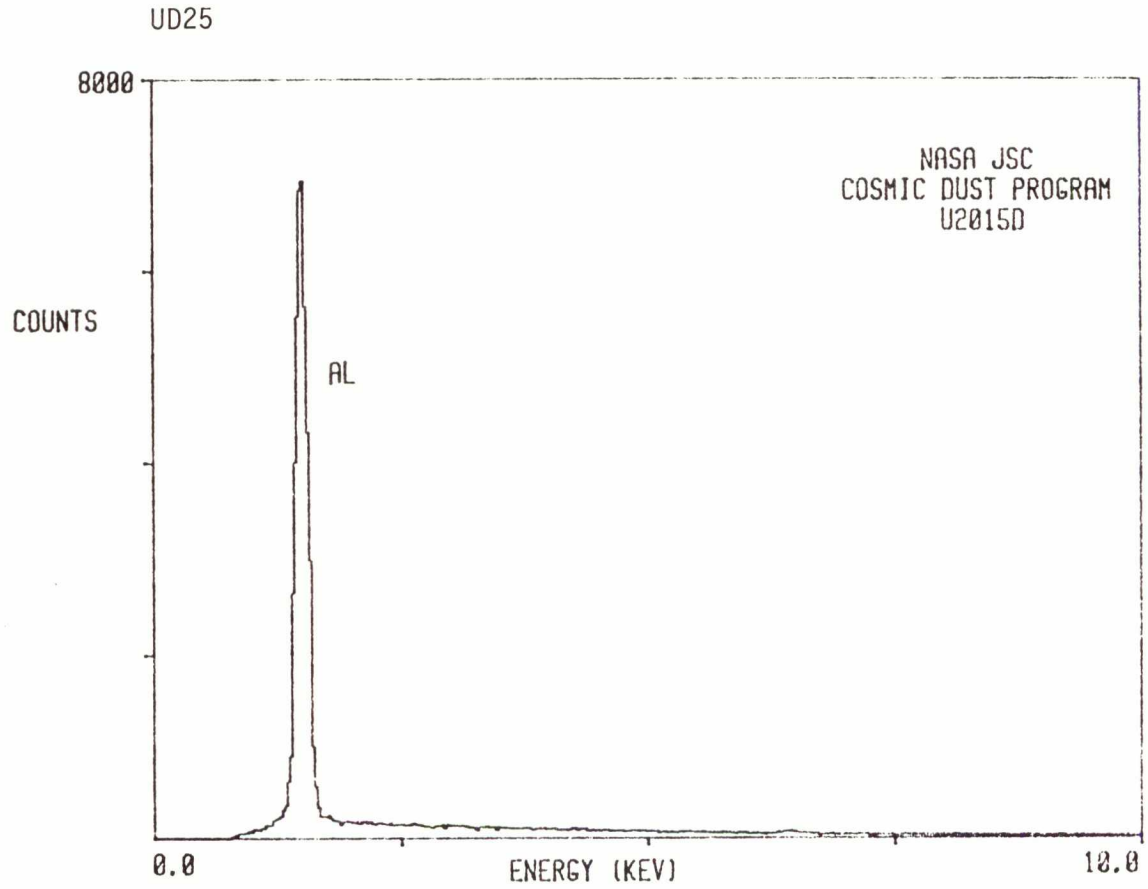


S-84-41328

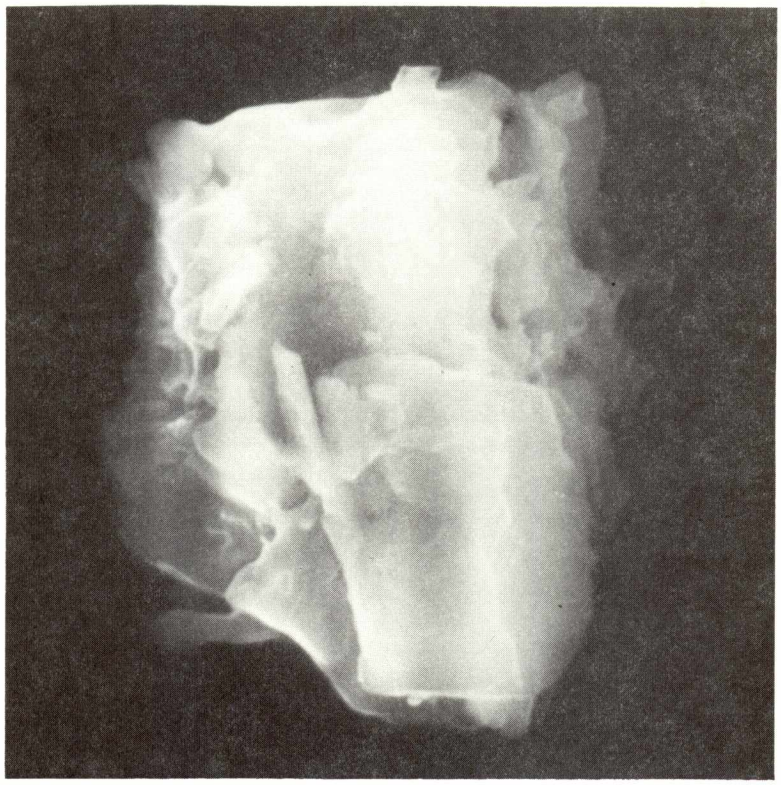
SIZE	SHAPE	TRANS.
4x5	I	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
TCA/AOS	Probably an AOS fragment



U2015D26

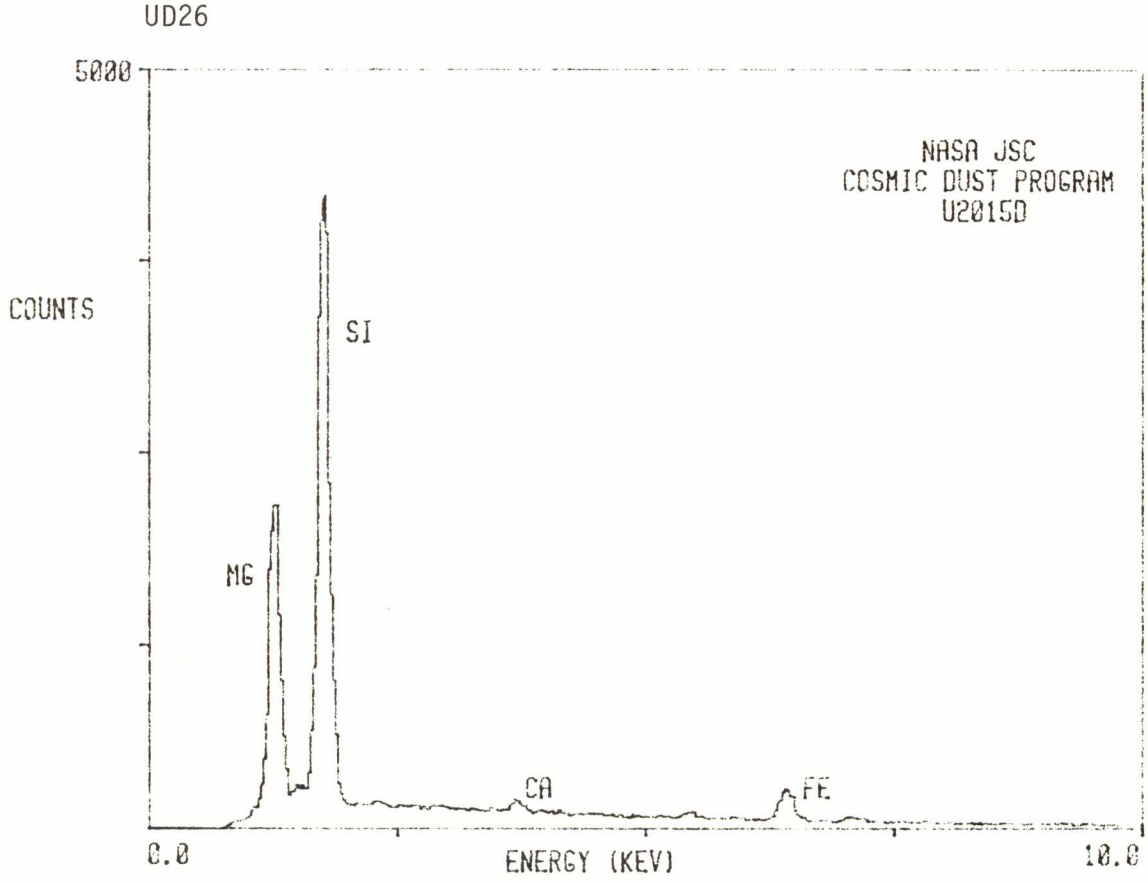


S-84-41351

SIZE	SHAPE	TRANS.
23x28	I	TL

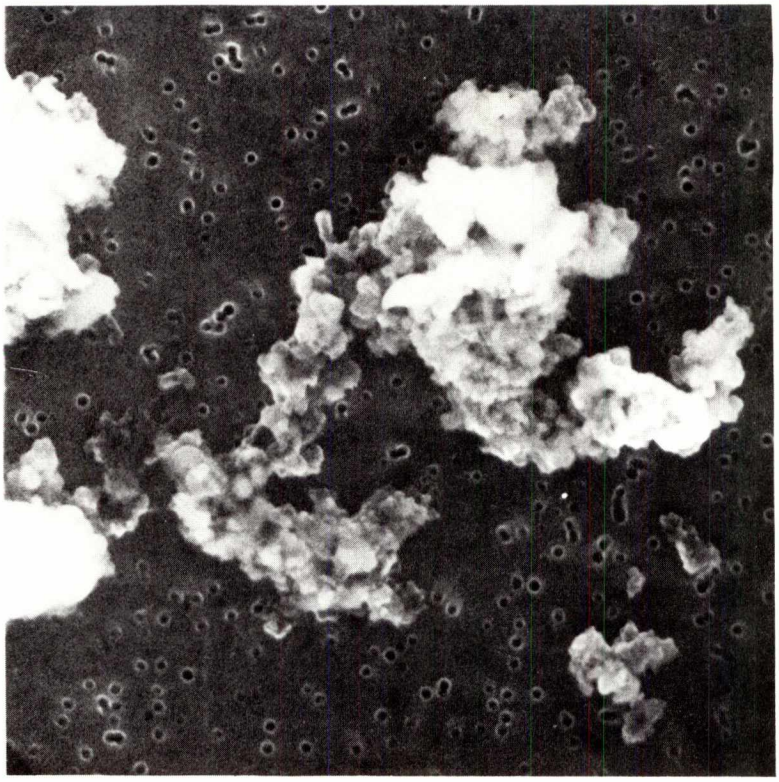
COLOR	LUSTER
CL to pale yellow	SV/V

TYPE	COMMENTS
C?	



U2015E

U2015E3

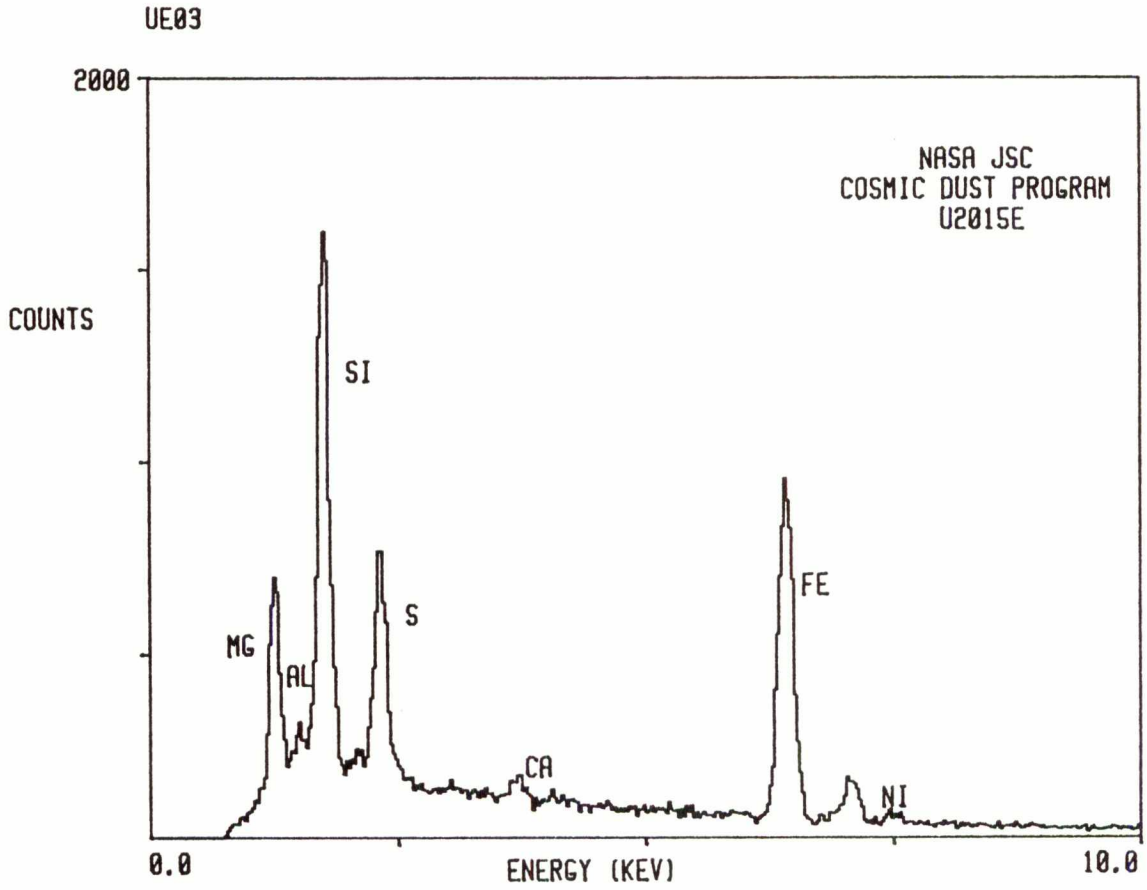


S-84-41383

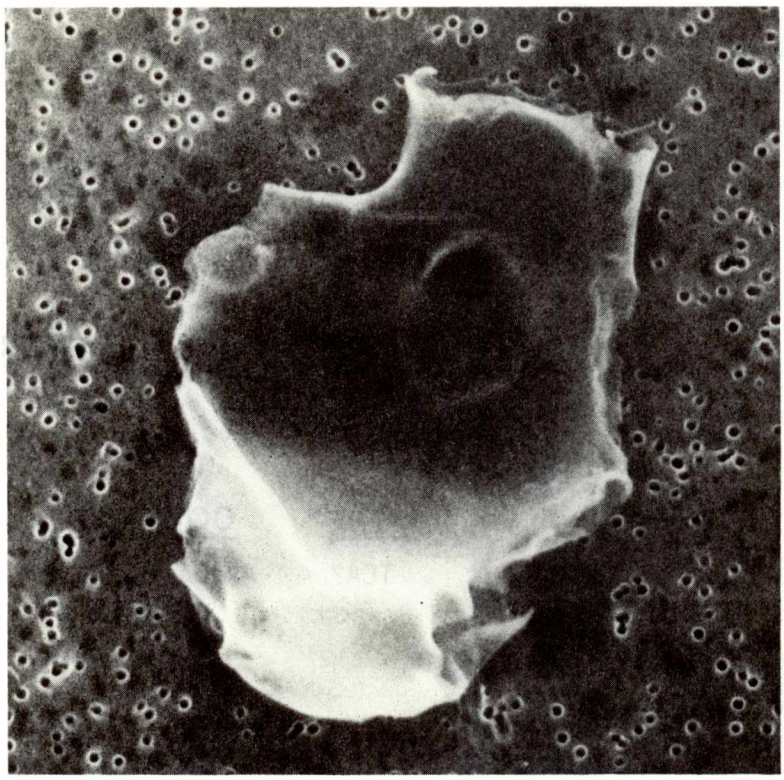
SIZE	SHAPE	TRANS.
10x14	I	O/TL

COLOR	LUSTER
Brown-gray to black	SV/SM

TYPE	COMMENTS
C	Largest of several fragments



U2015E4

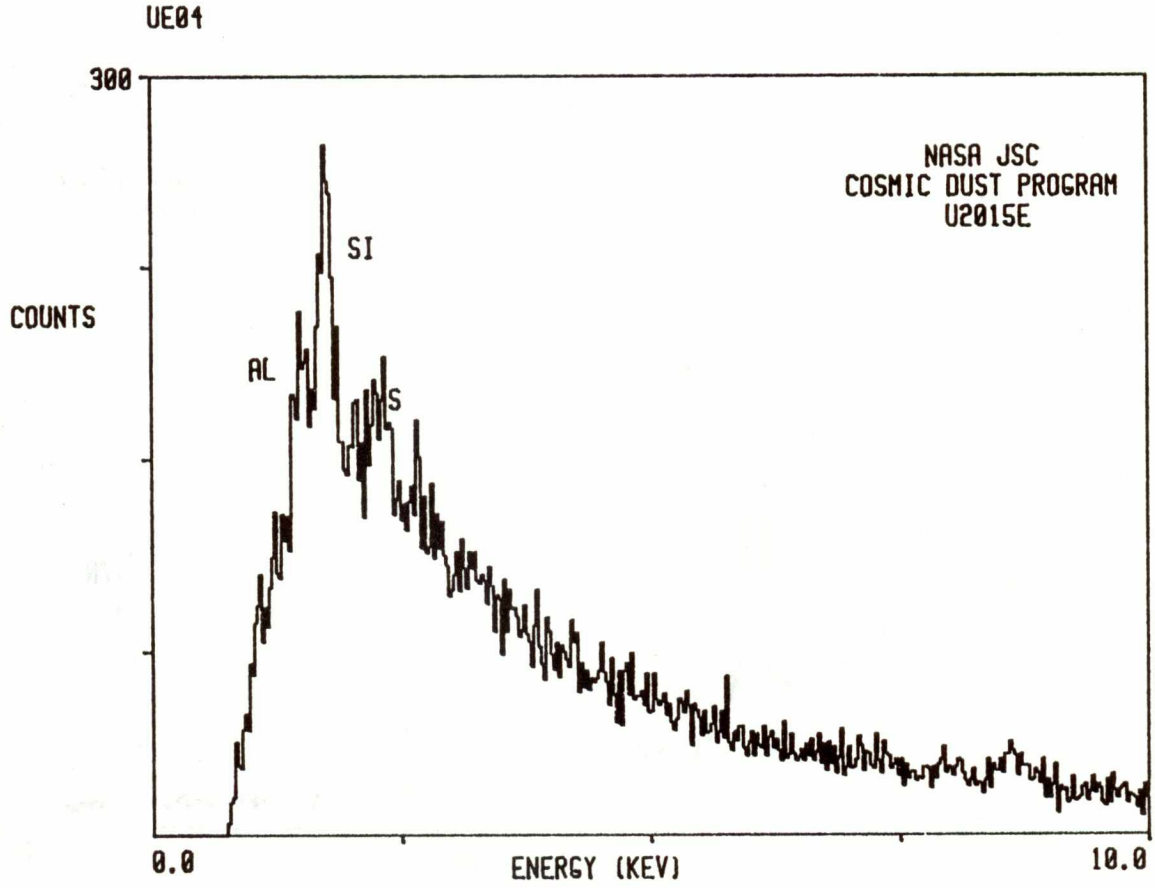


S-84-41386

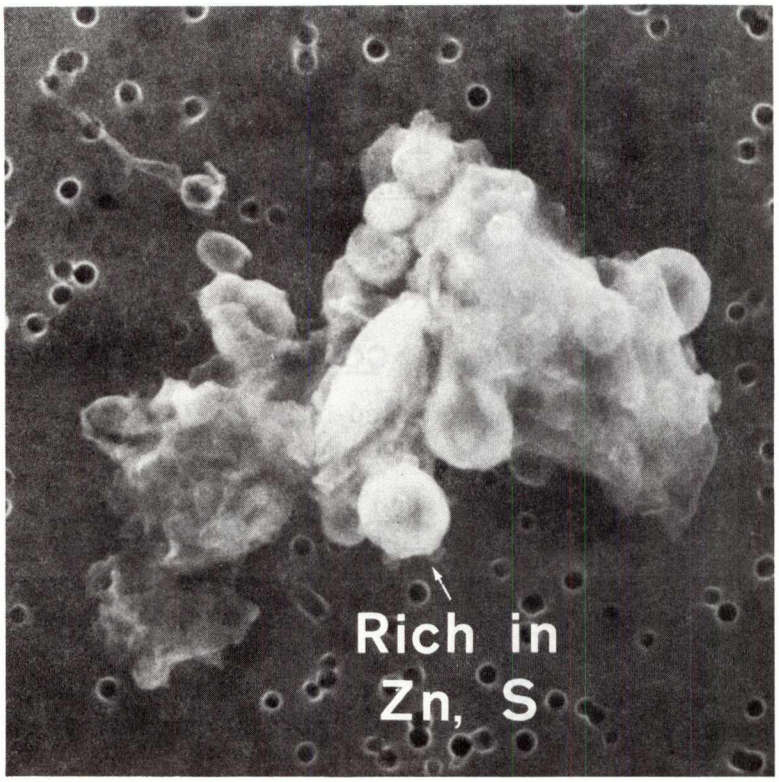
SIZE	SHAPE	TRANS.
15x20	I	T/TL

COLOR	LUSTER
Red-brown	V

TYPE	COMMENTS
?	Largest of several fragments; associated with U2015E5



U2015E5

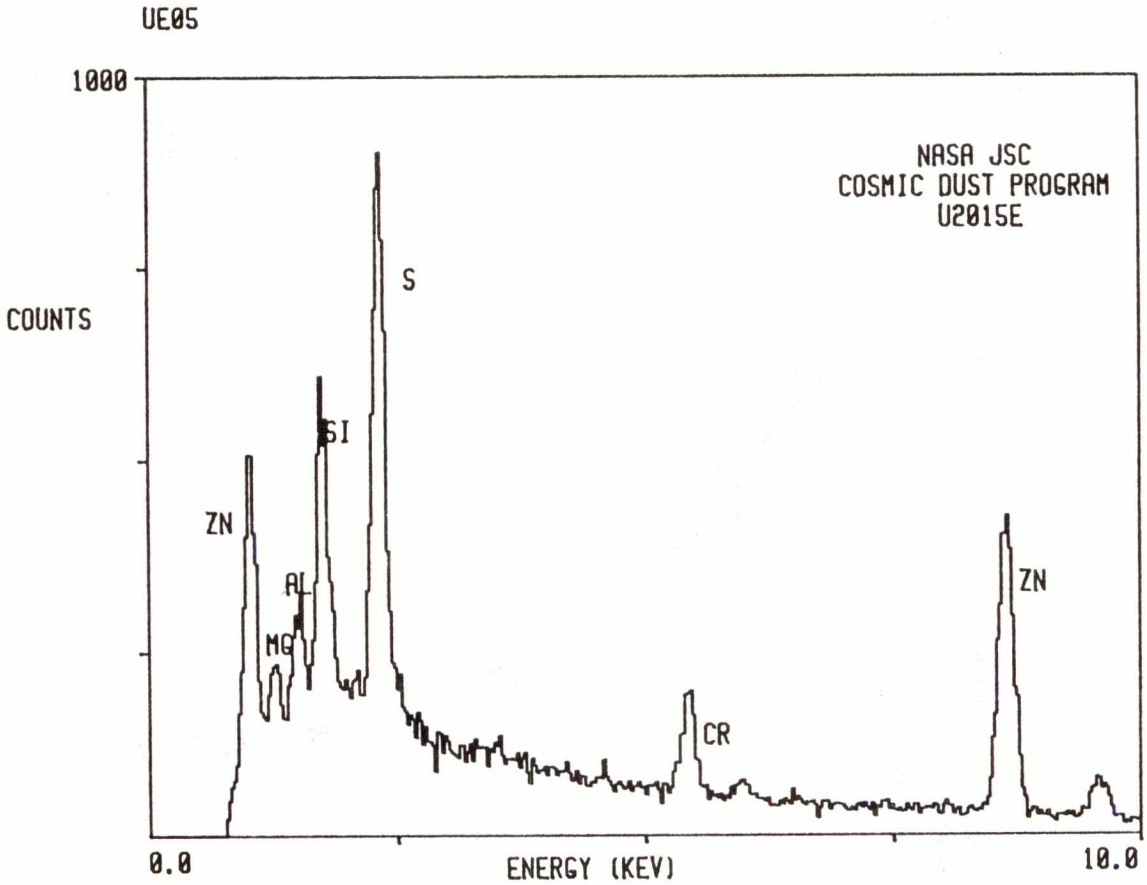


S-84-41387

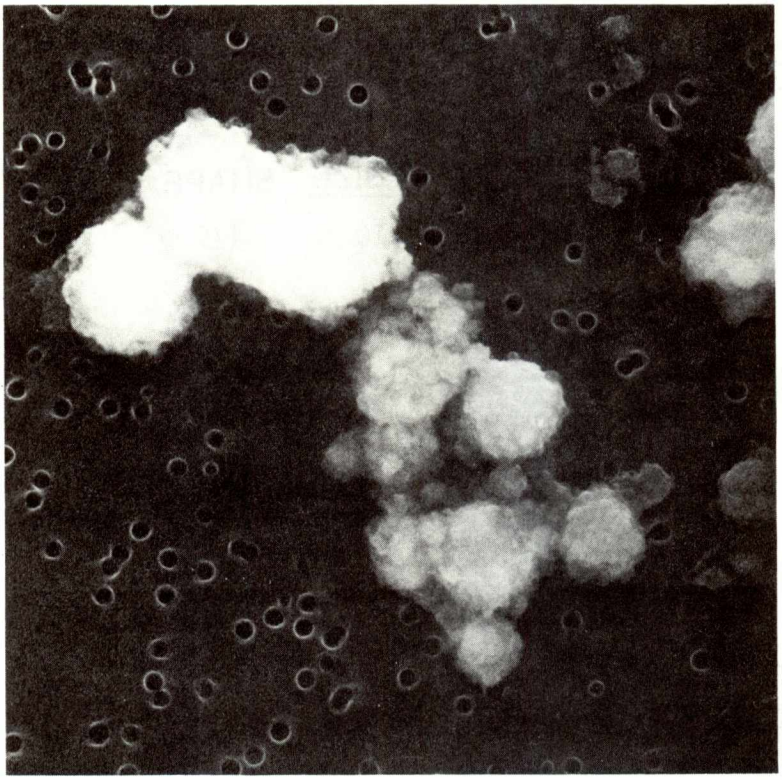
SIZE	SHAPE	TRANS.
9x13	I	T

COLOR	LUSTER
CL to pale yellow-gray	SV

TYPE	COMMENTS
TCA?	Associated with U2015E4



U2015E6

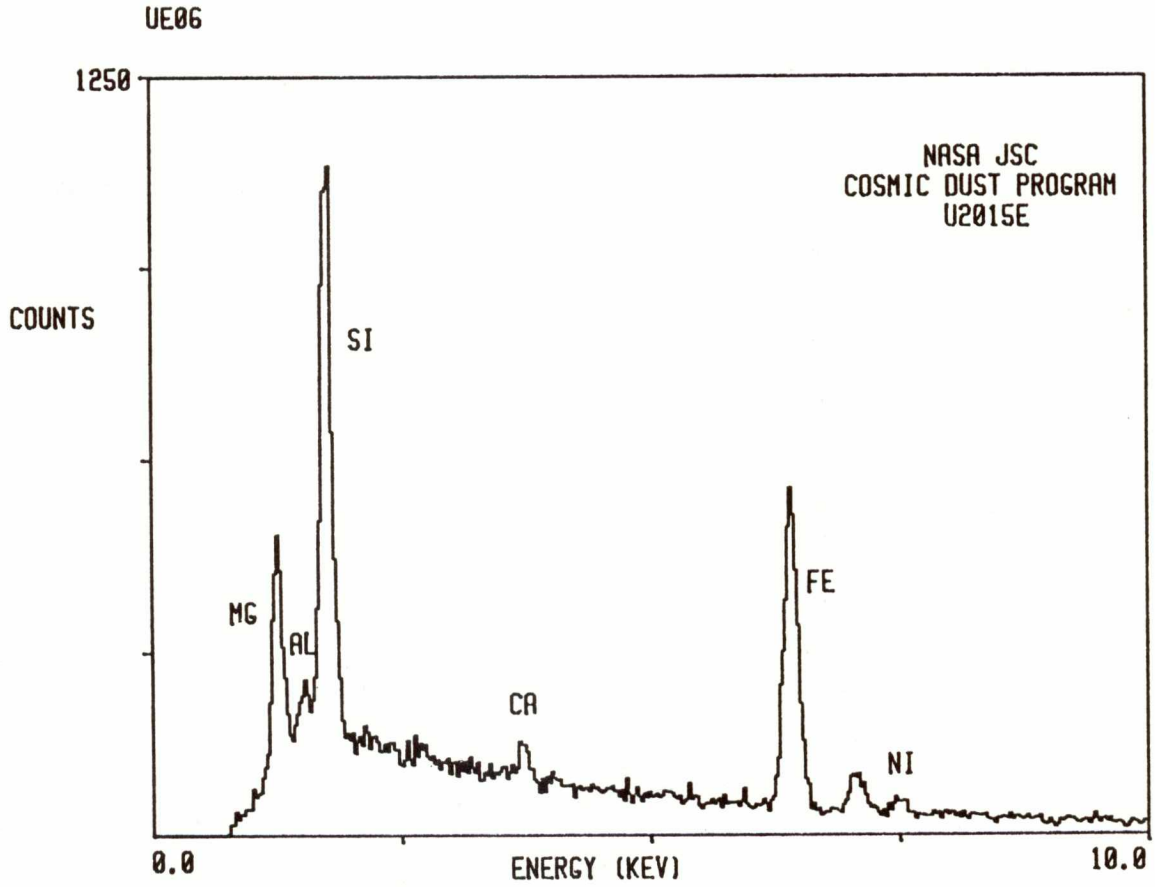


SIZE	SHAPE	TRANS.
≤5 each fragment)	I	O/TL

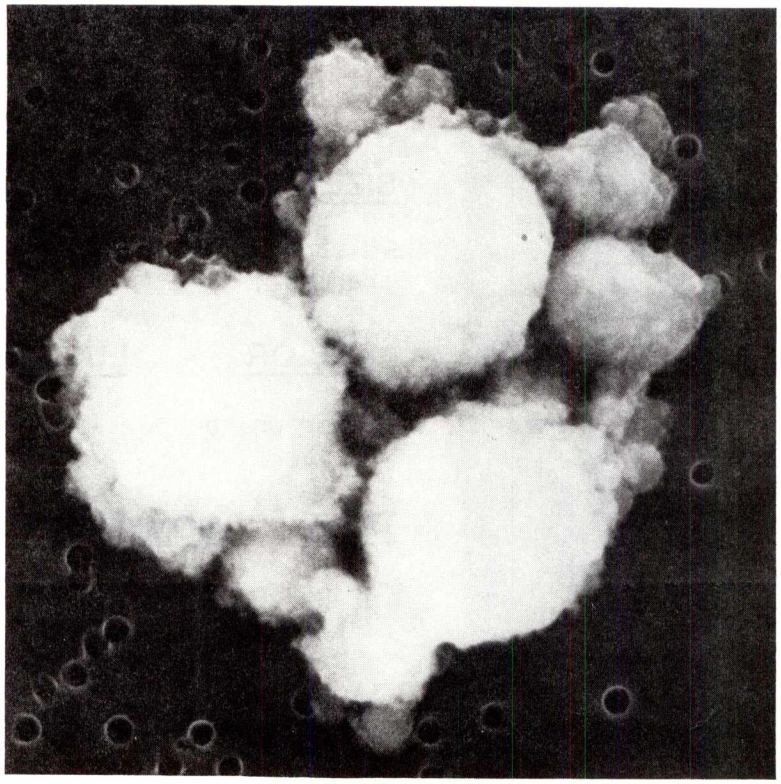
COLOR	LUSTER
Red-brown to black	D/SM

TYPE	COMMENTS
C	Several fragments

S-84-41389



U2015E7

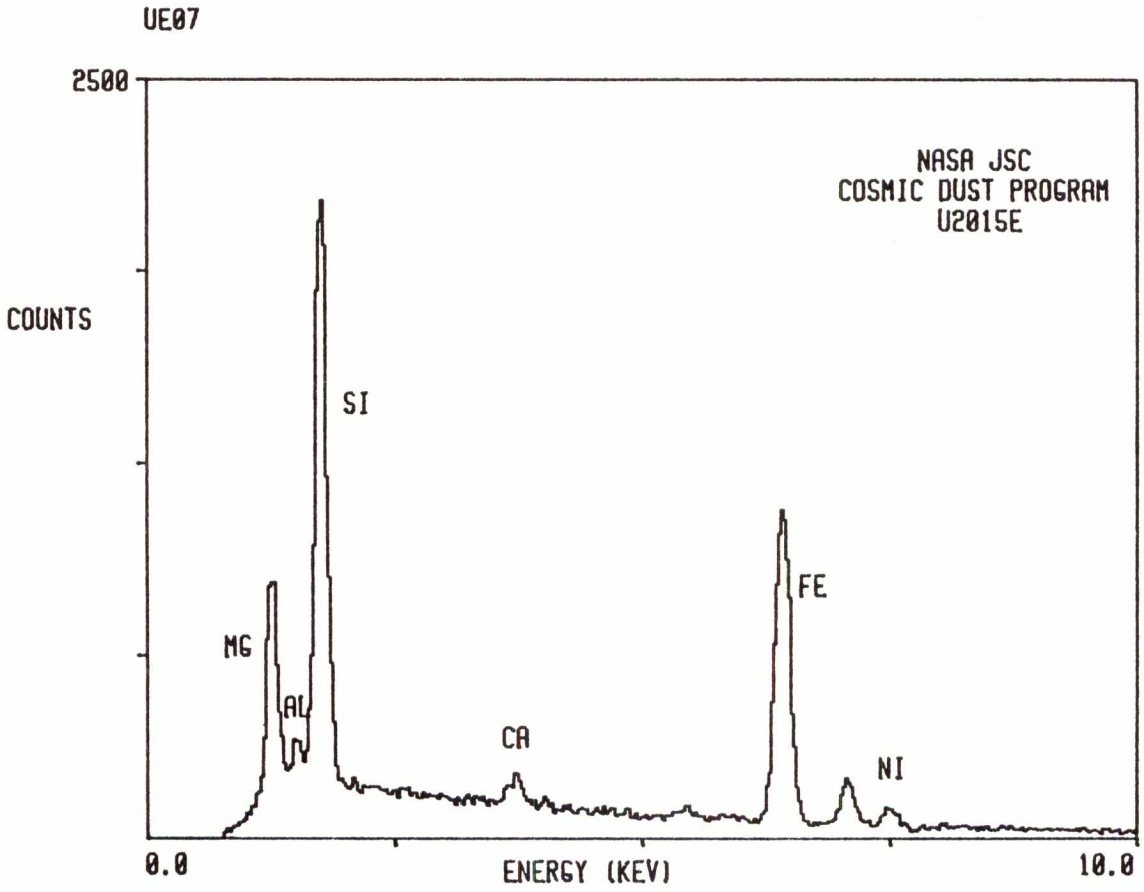


SIZE	SHAPE	TRANS.
10x10	I/E	O/TL

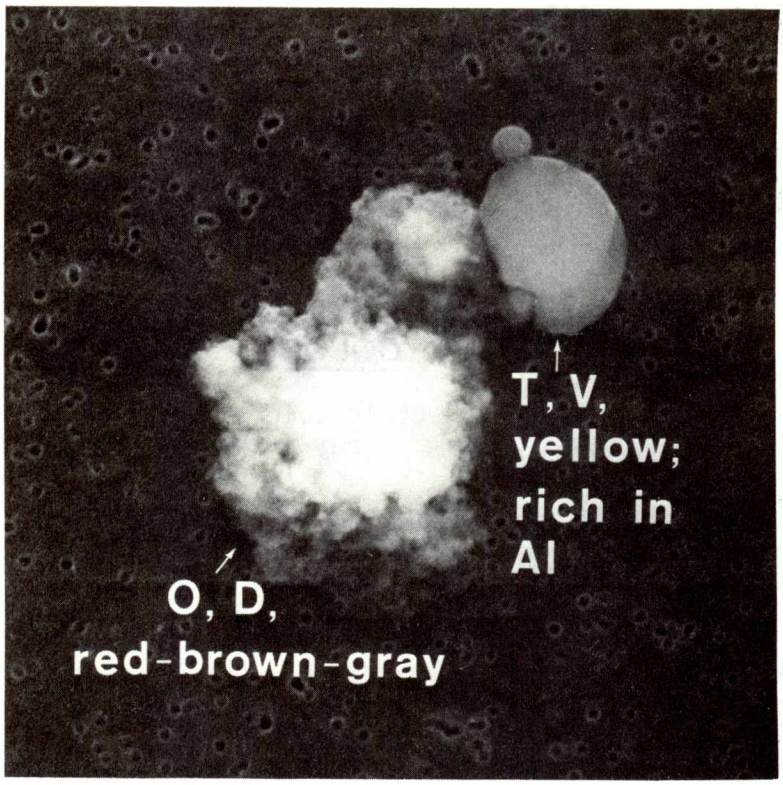
COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C	

S-84-41390



U2015E8

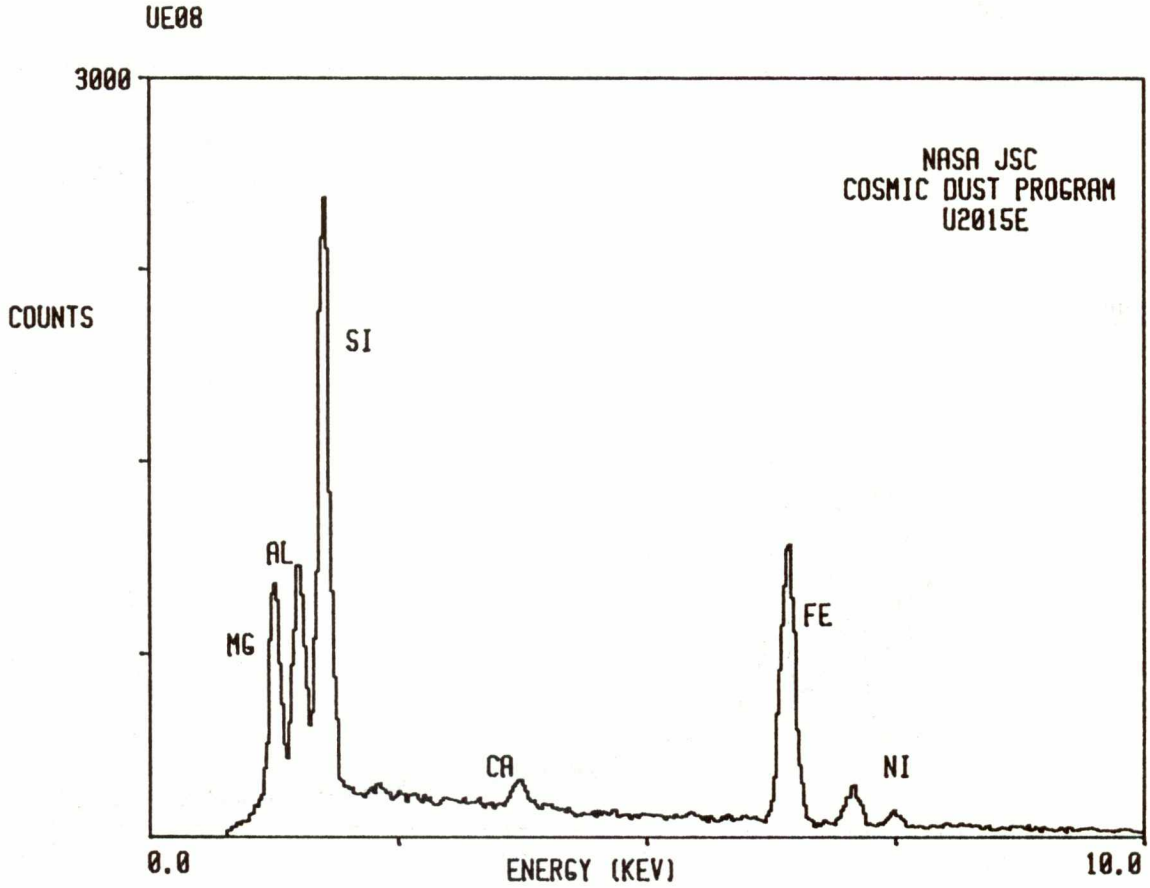


S-84-41391

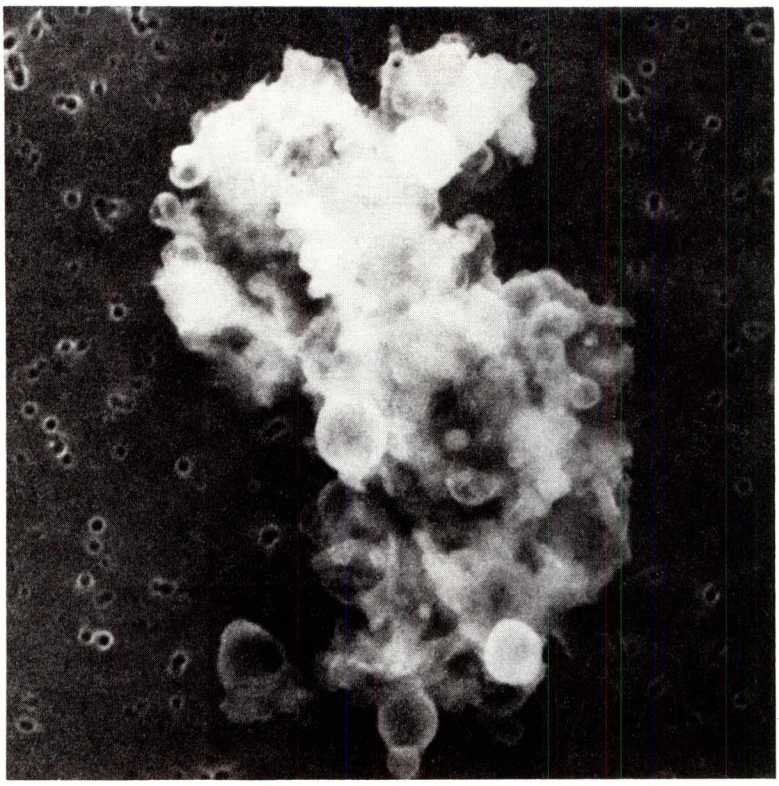
SIZE	SHAPE	TRANS.
8x12	I	O/T

COLOR	LUSTER
Red-brown-gray to pale yellow	D/V

TYPE	COMMENTS
C	



U2015E9

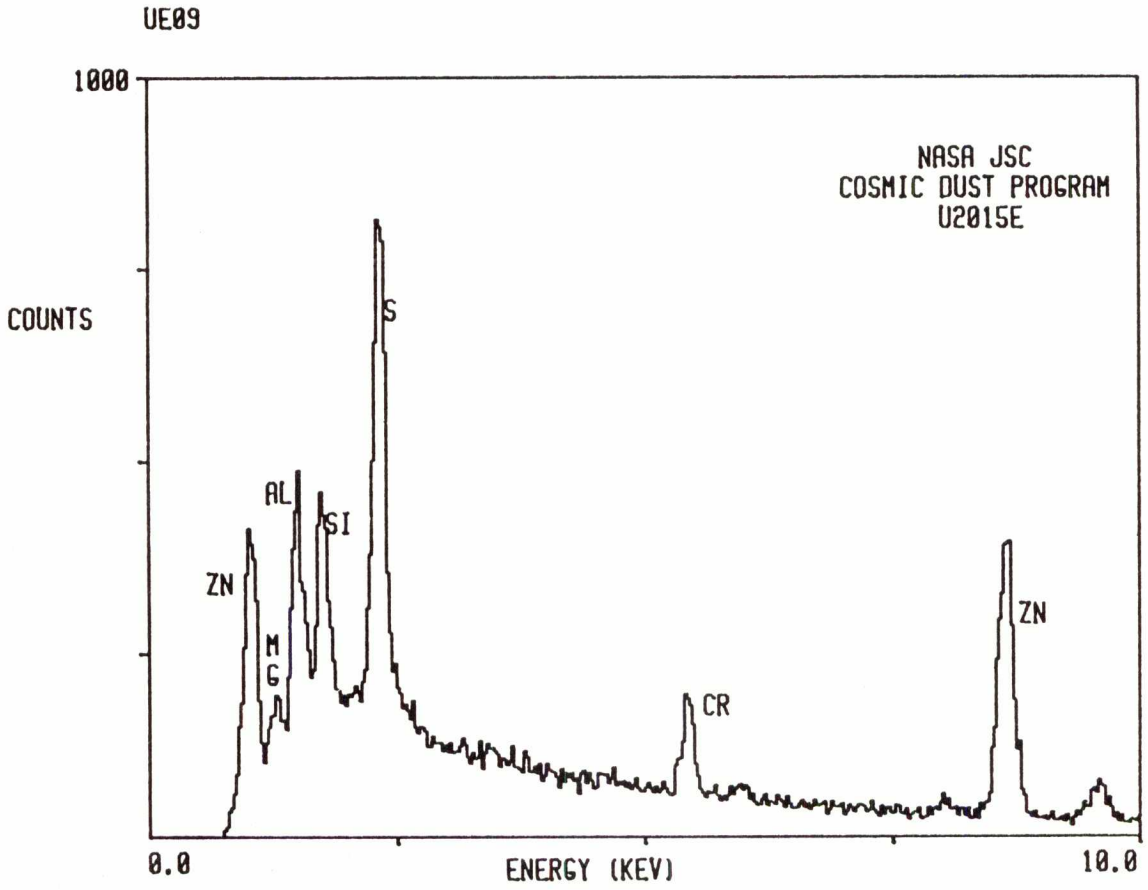


SIZE	SHAPE	TRANS.
12x20	I	TL

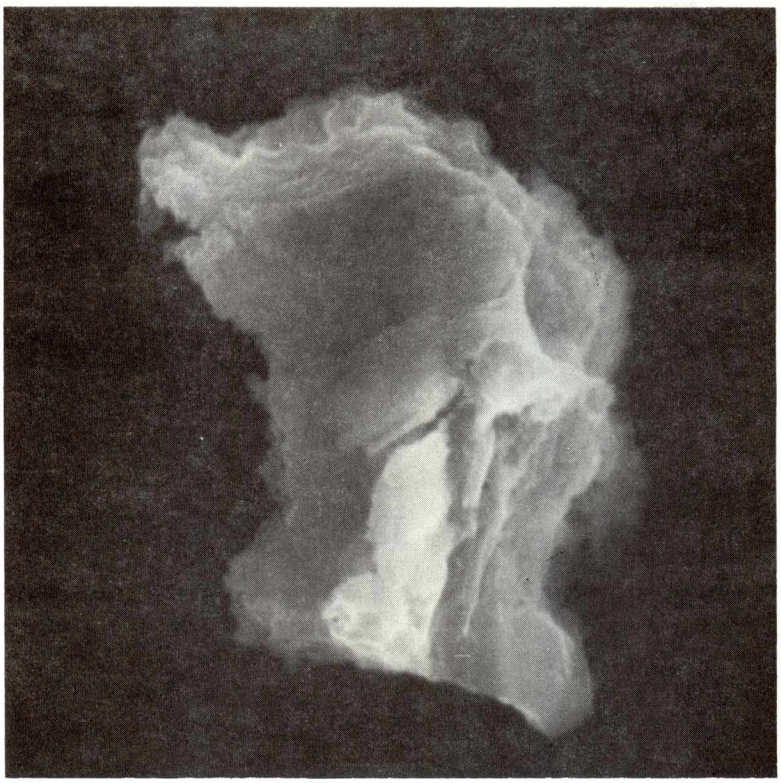
COLOR	LUSTER
CL to pale gray	SV

TYPE	COMMENTS
TCA	

S-84-41392



U2015E10

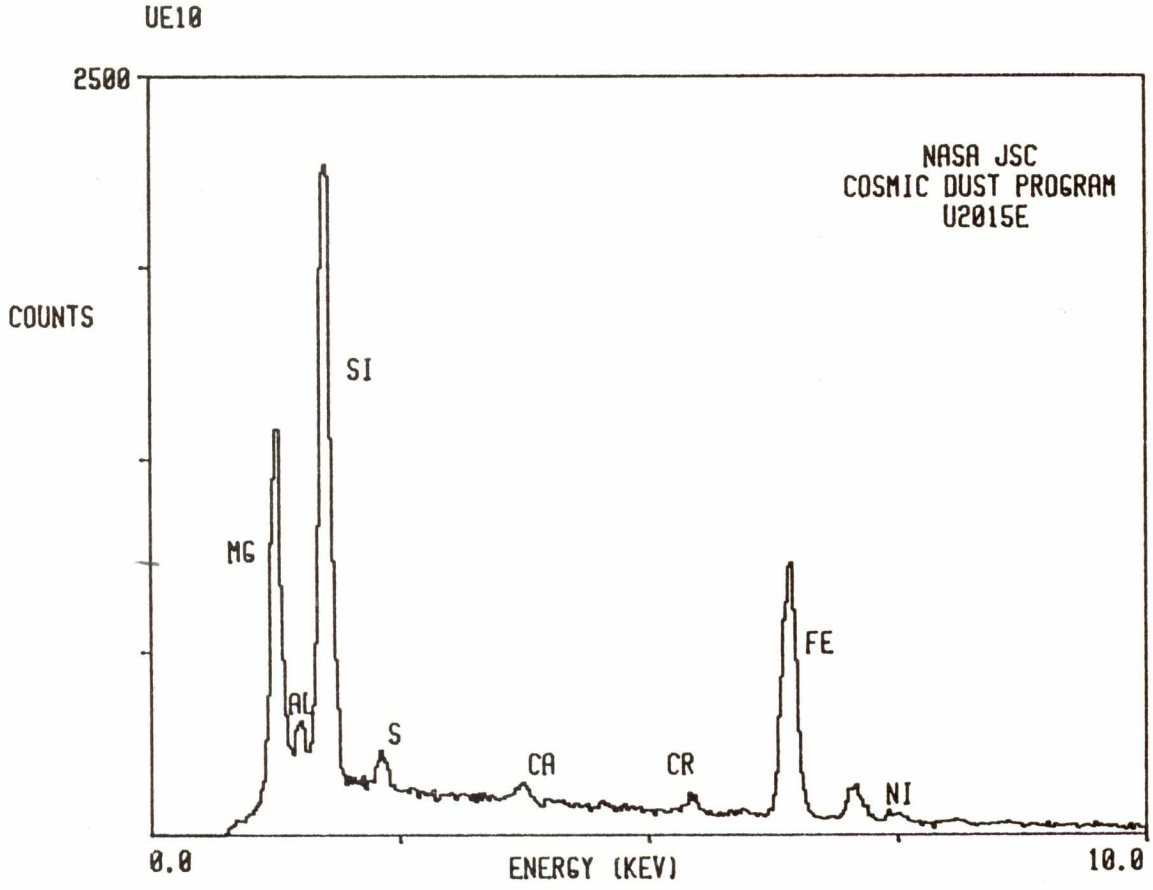


S-84-41393

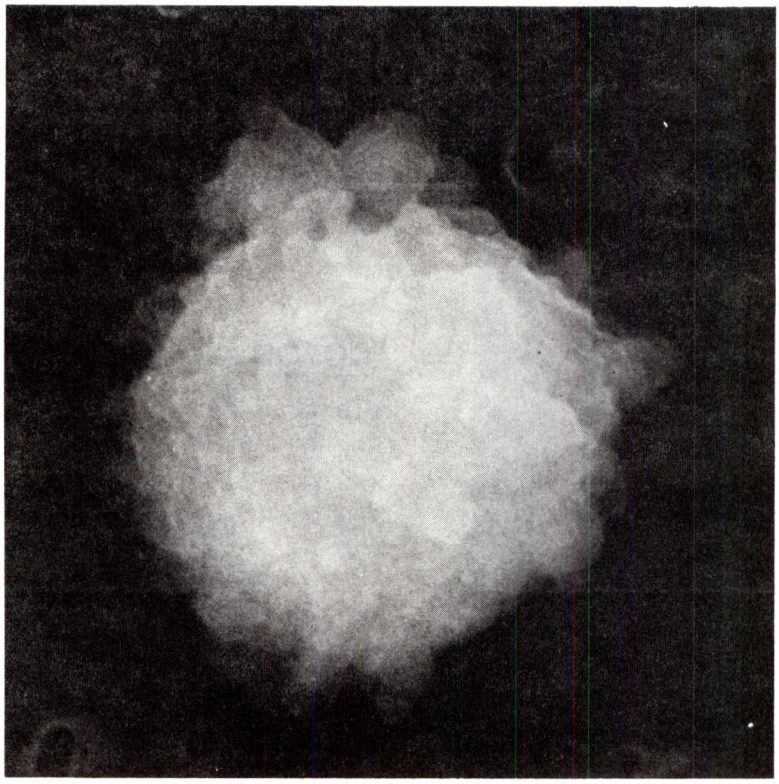
SIZE	SHAPE	TRANS.
30x45	I	0

COLOR	LUSTER
Pale gray to dk. brown	SV

TYPE	COMMENTS
C	Bright area in image is also optically light-colored



U2015E11

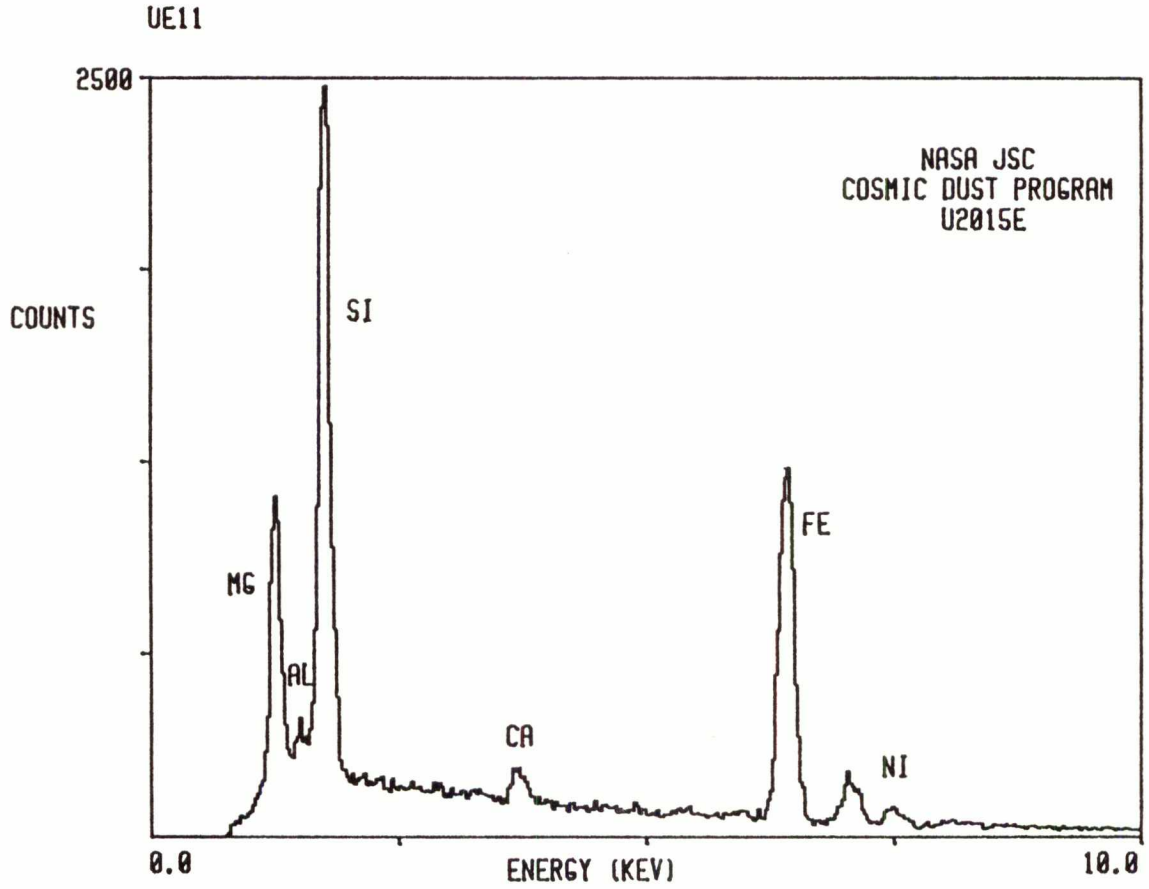


SIZE	SHAPE	TRANS.
5x6	I	0

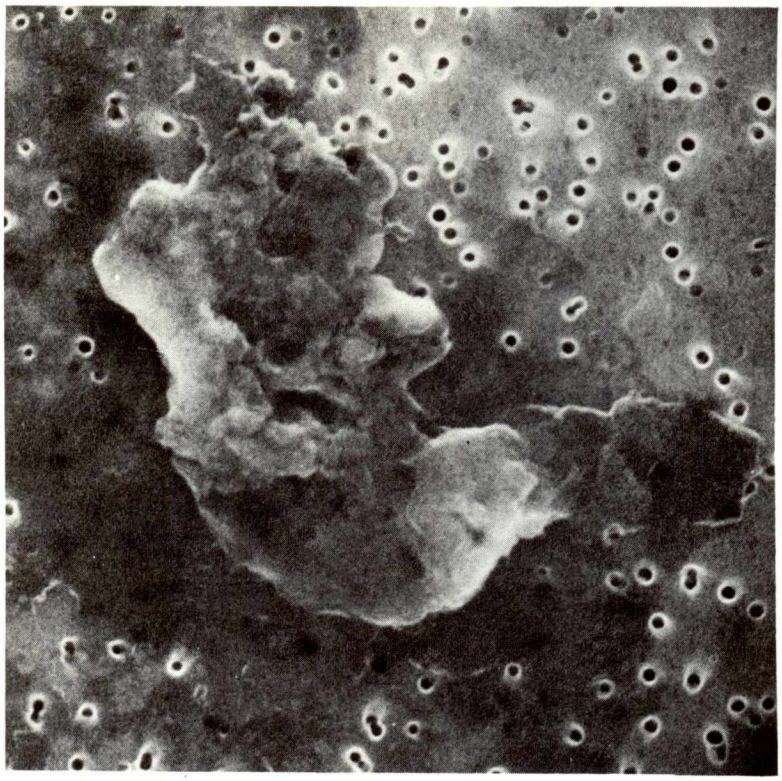
COLOR	LUSTER
Red-brown to black	D/SM

TYPE	COMMENTS
C	Largest of three fragments

S-84-41394



U2015E12

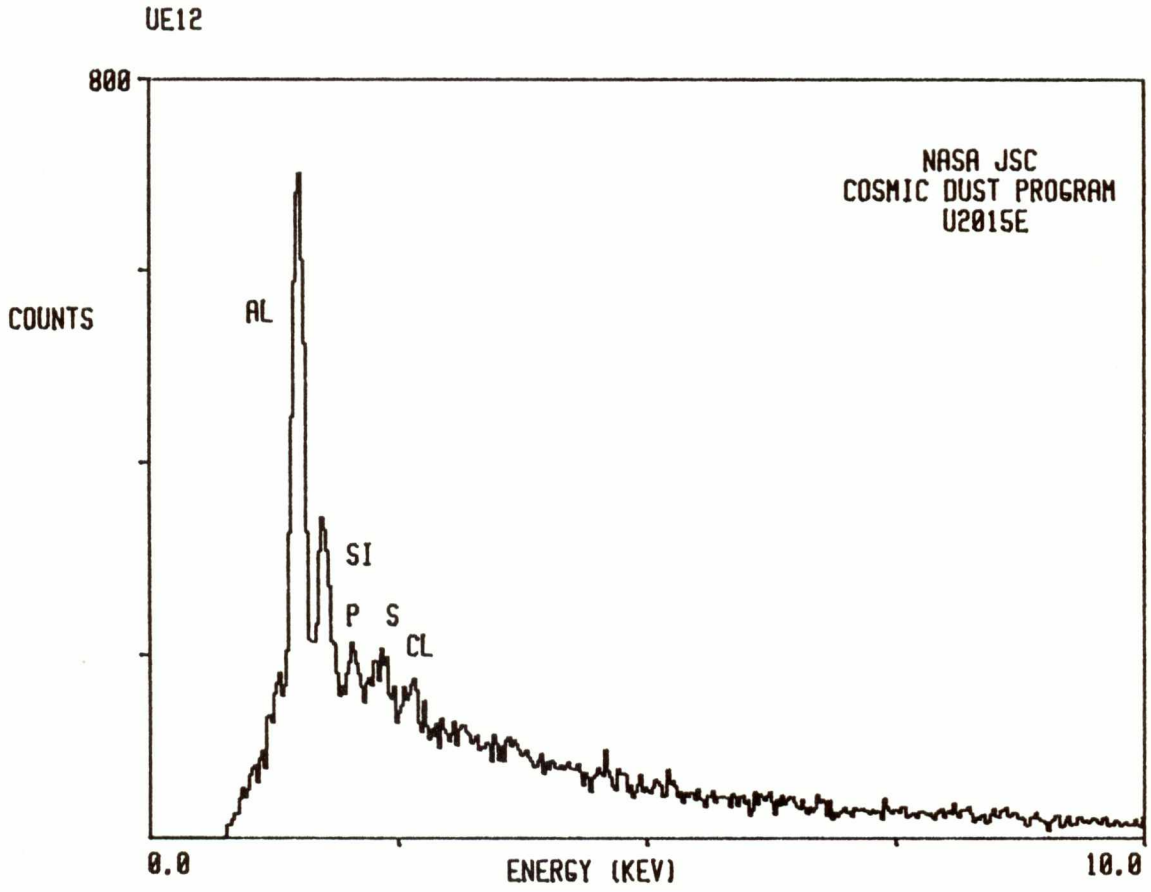


SIZE	SHAPE	TRANS.
5x12	I	T

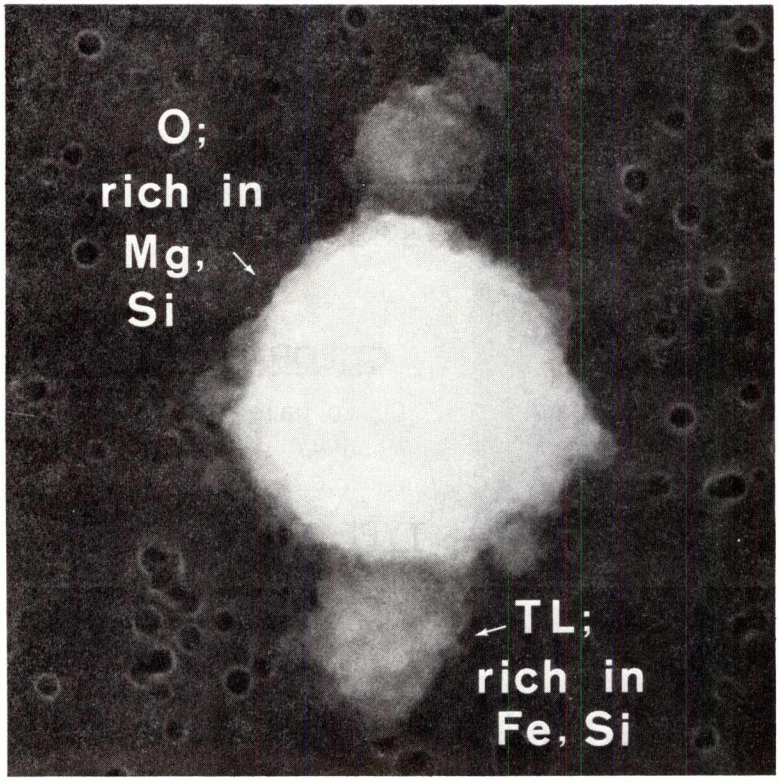
COLOR	LUSTER
CL to pale gray	SV

TYPE	COMMENTS
?	May be an evaporation residue from a liquid droplet

S-84-41397



U2015E13

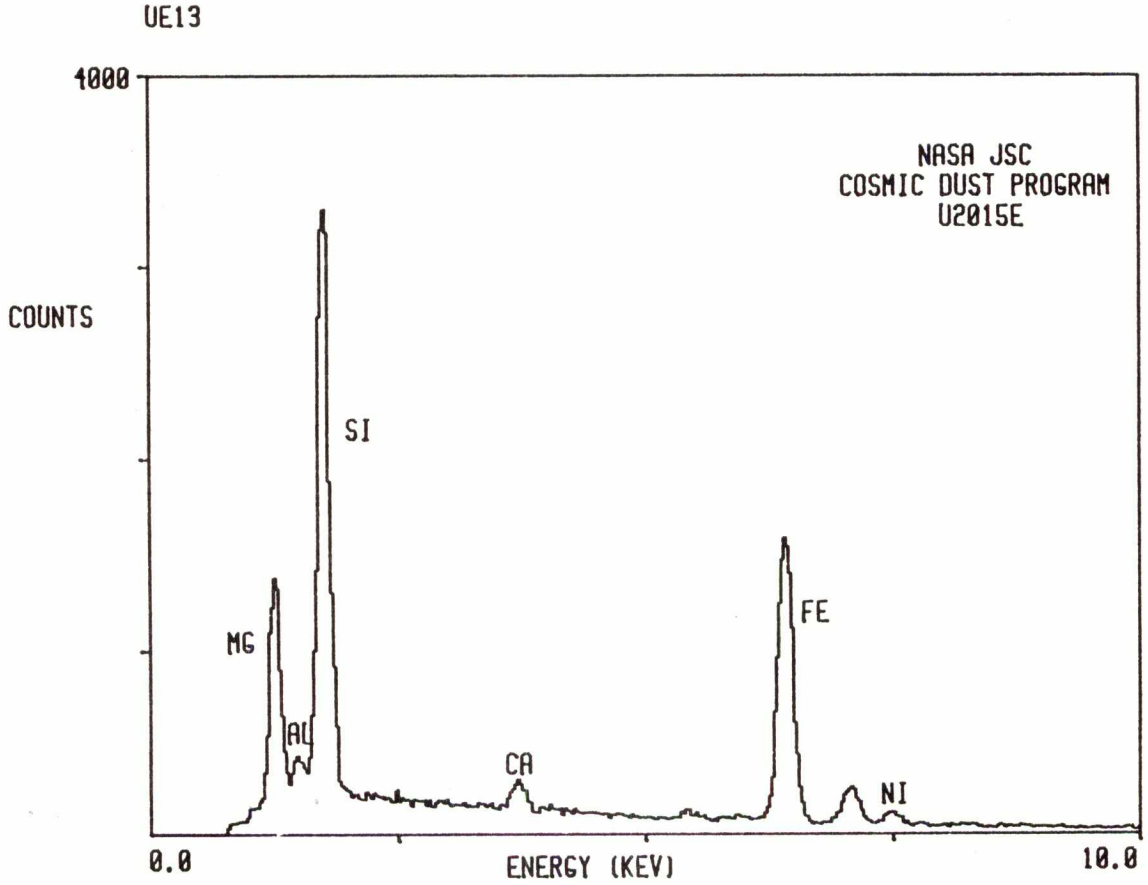


S-84-41398

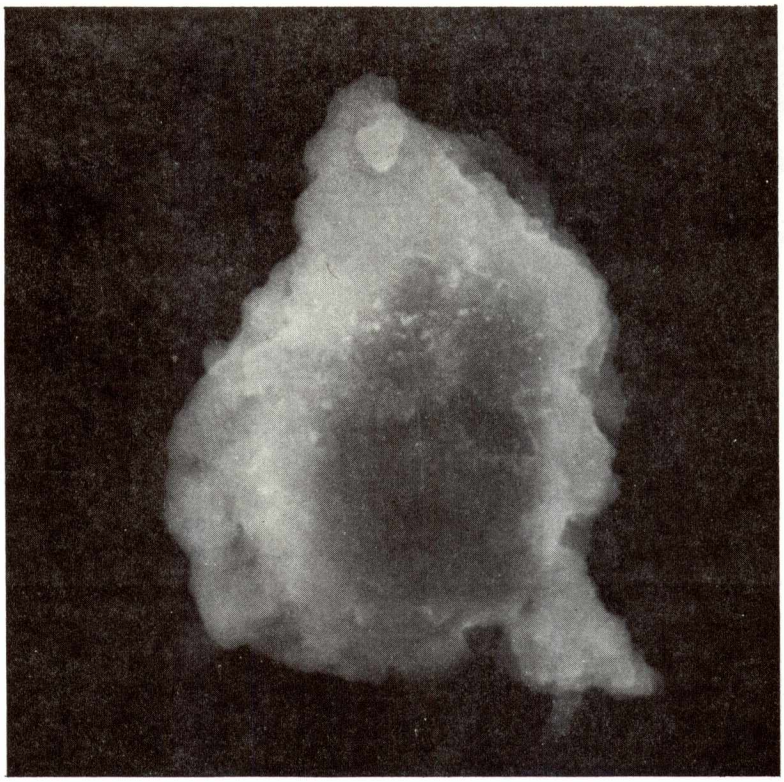
SIZE	SHAPE	TRANS.
6x10	I	O/TL

COLOR	LUSTER
Gray to black	SM

TYPE	COMMENTS
C	



U2015E14

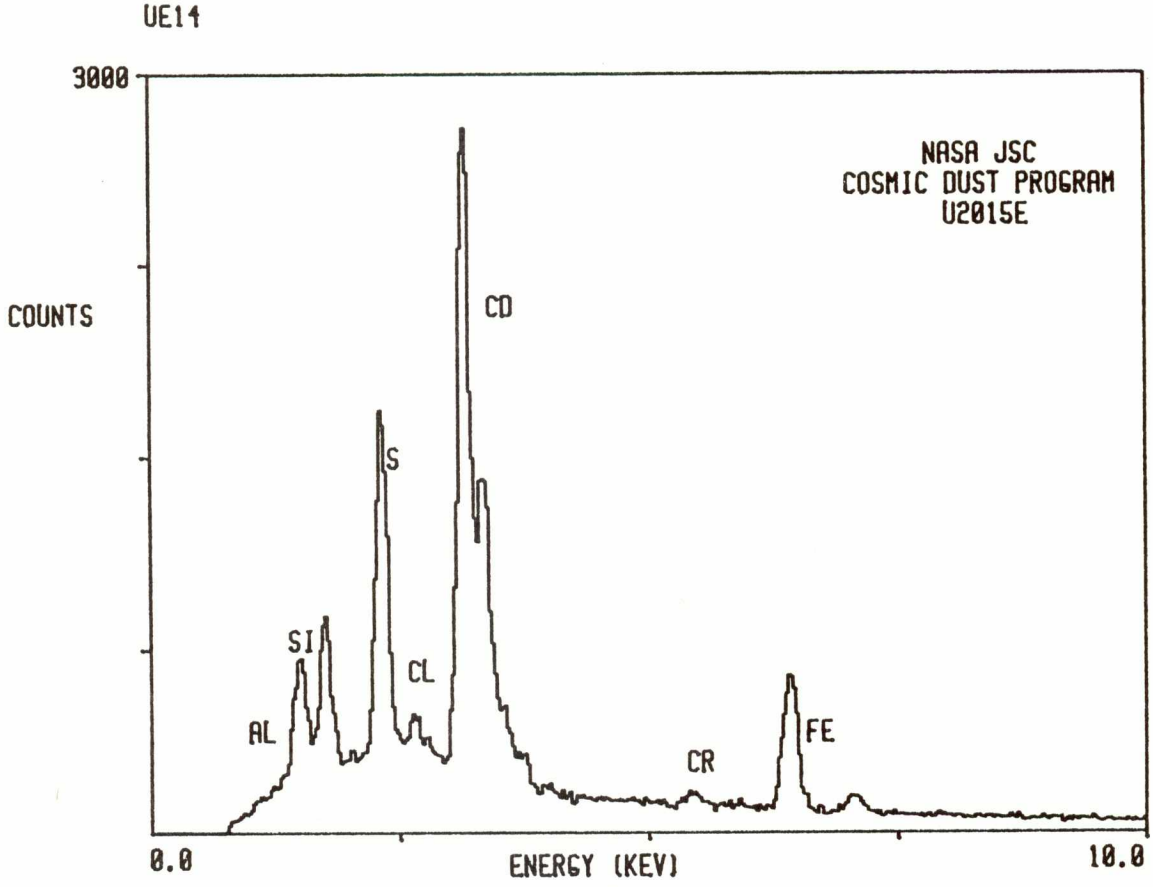


SIZE	SHAPE	TRANS.
48x63	I	O/TL

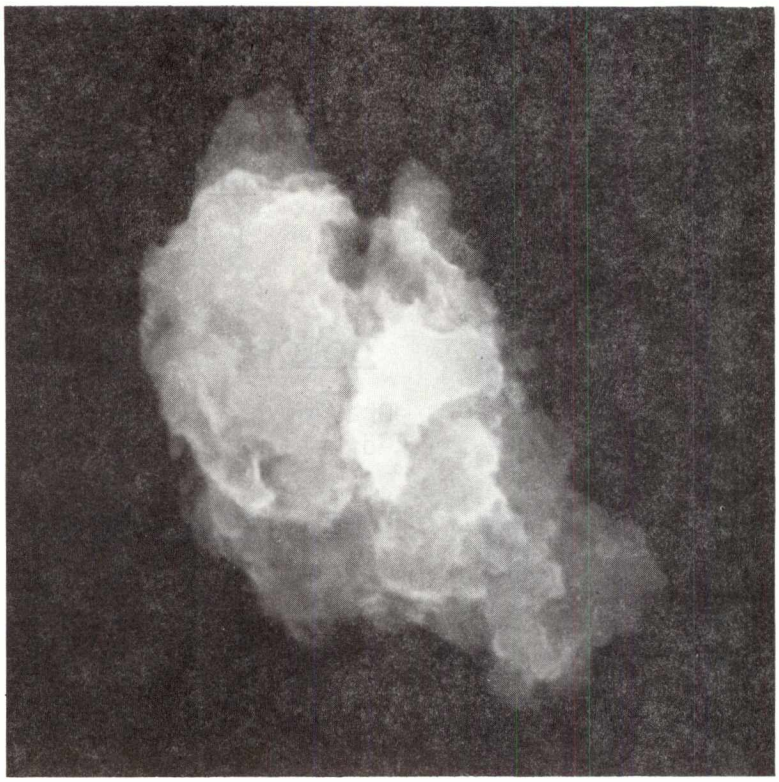
COLOR	LUSTER
Gray with red "stains"	D/SV

TYPE	COMMENTS
TCA	

S-84-41399



U2015E15

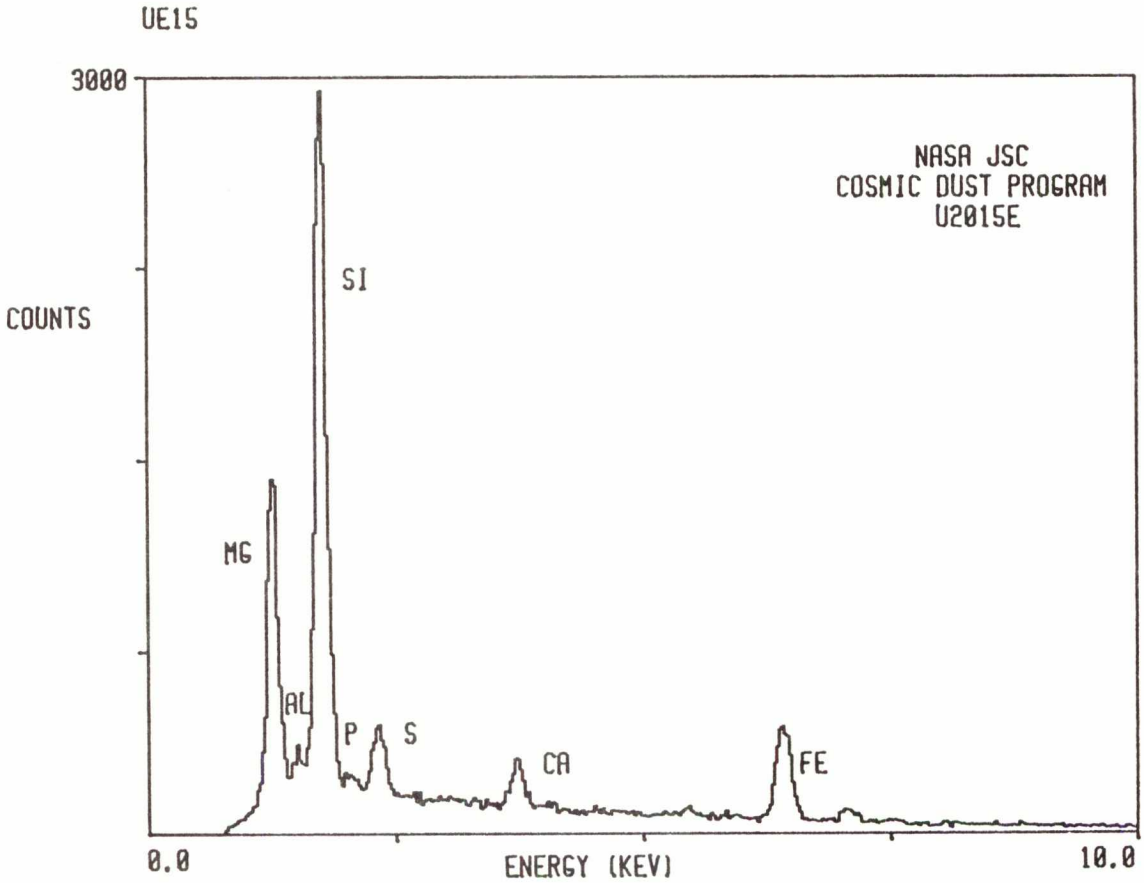


SIZE	SHAPE	TRANS.
11x20	I	O

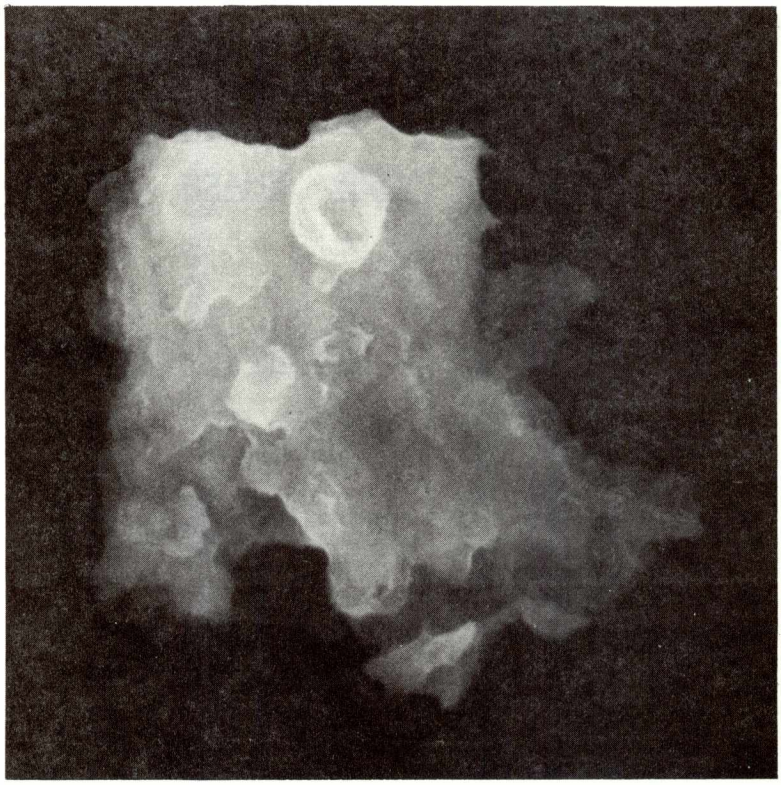
COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C?	

S-84-41400



U2015E16

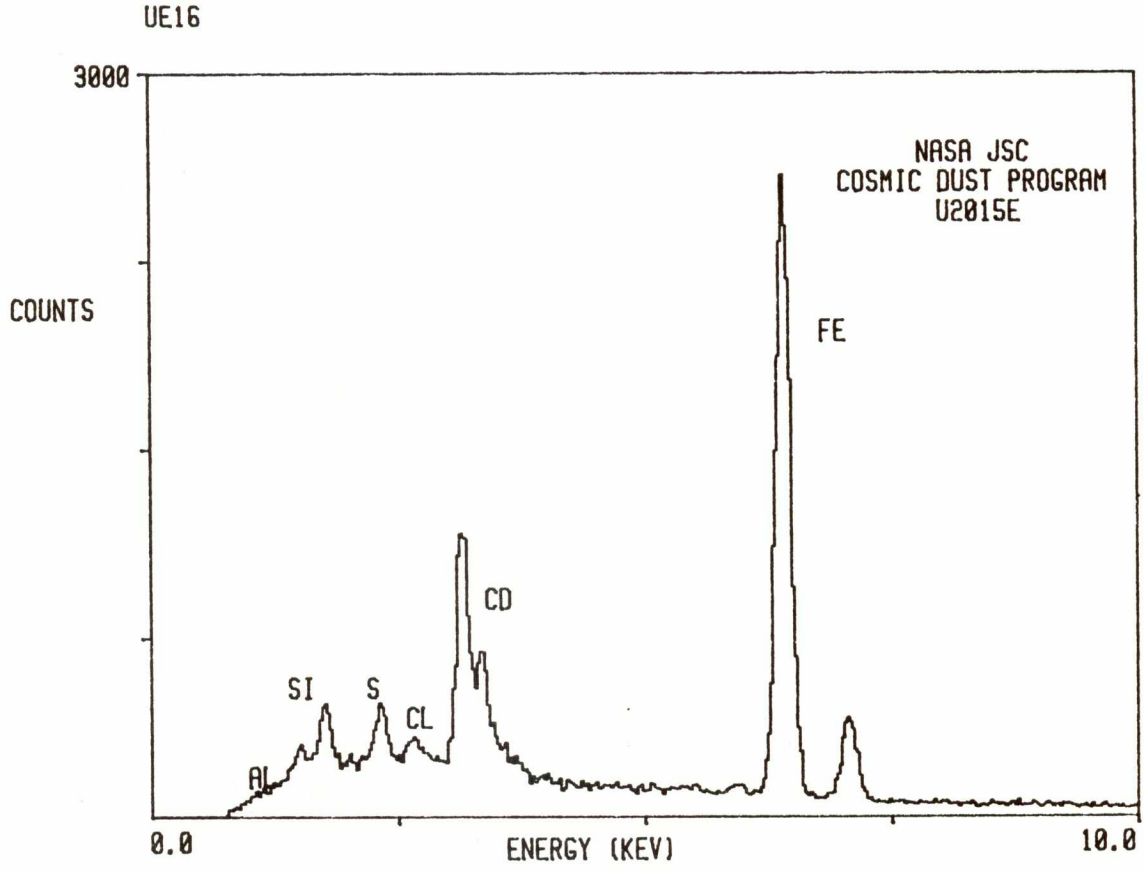


S-84-41401

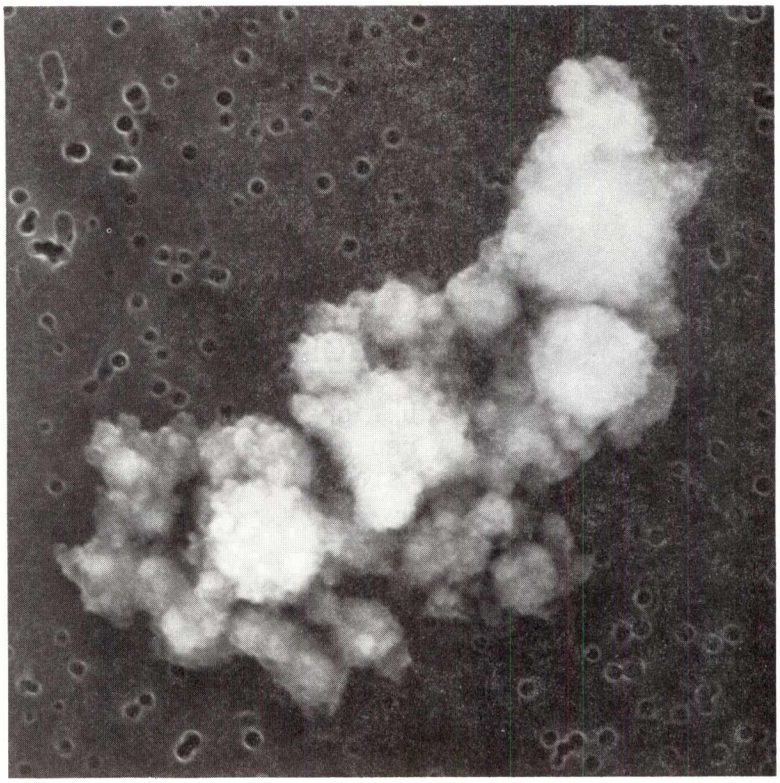
SIZE	SHAPE	TRANS.
26x30	I	TL/O

COLOR	LUSTER
Dk. gray with red edges and "stains"	SV/SM

TYPE	COMMENTS
TCA	



U2015E17

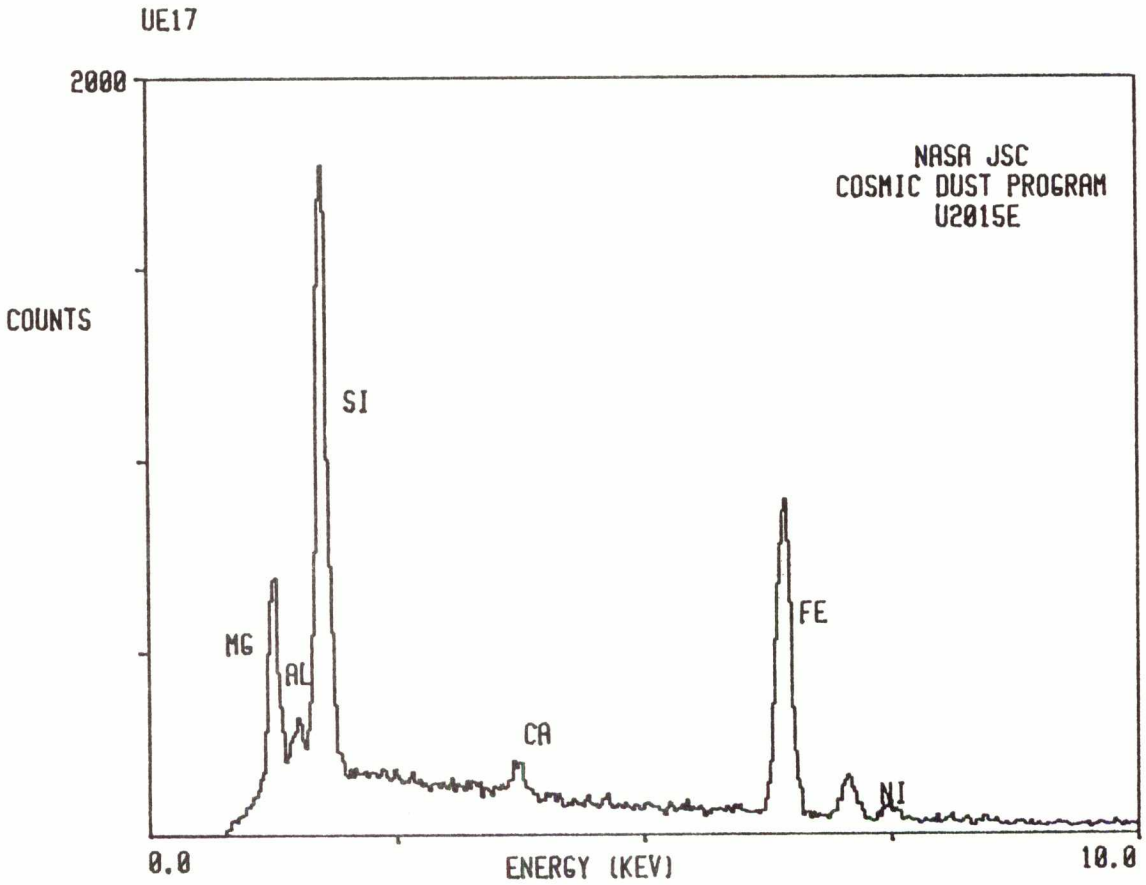


S-84-41384

SIZE	SHAPE	TRANS.
9x17	I	O/TL

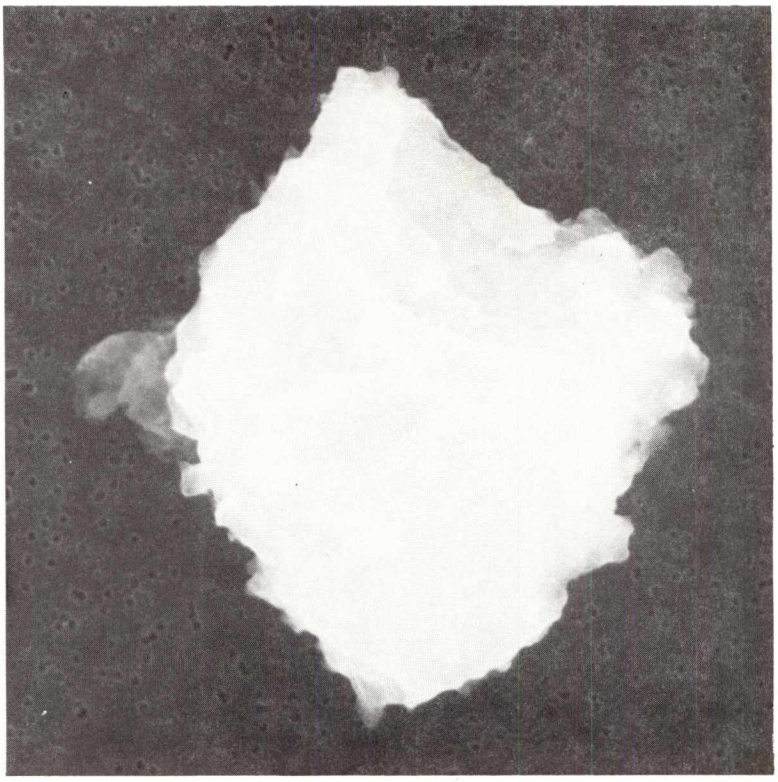
COLOR	LUSTER
Dk. gray to red-brown	D

TYPE	COMMENTS
C	



U2015F

U2015F1

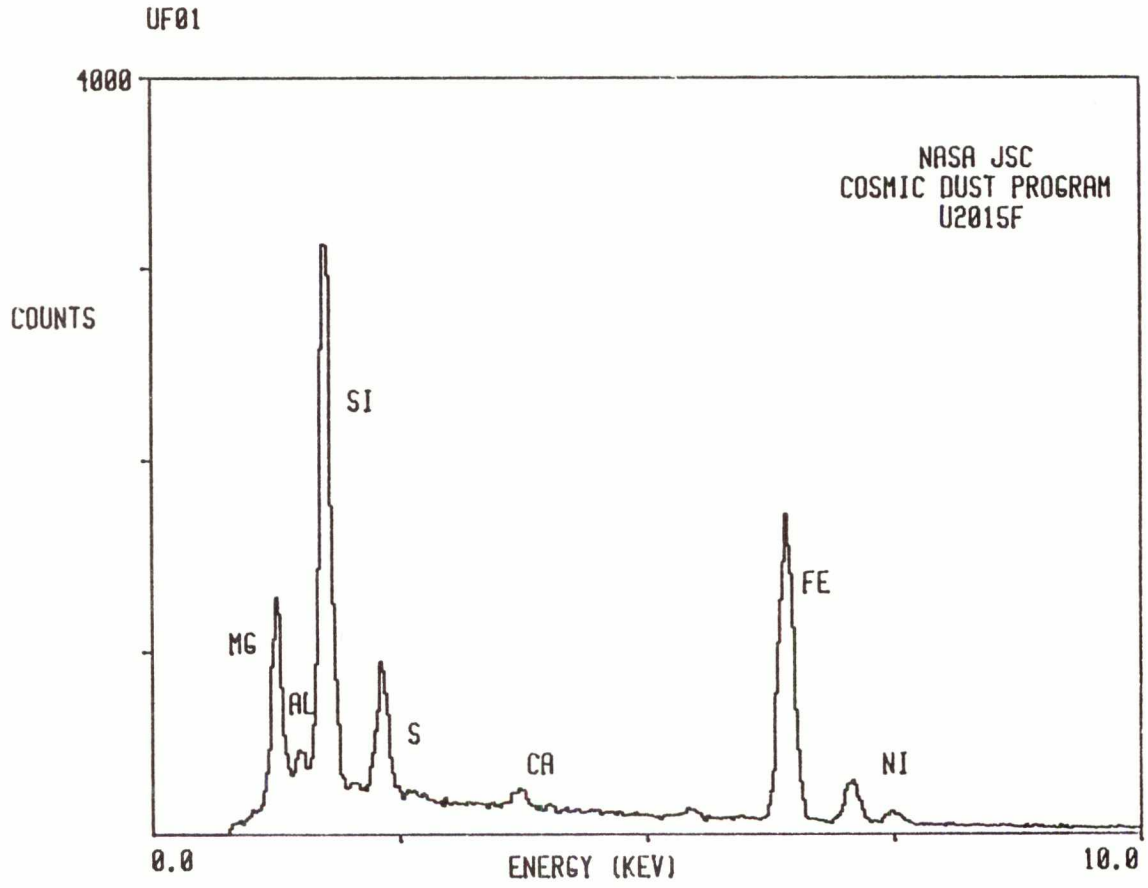


SIZE	SHAPE	TRANS.
19x20	I	0

COLOR	LUSTER
Dk. gray to black	SV/SM

TYPE	COMMENTS
C	

S-84-41435



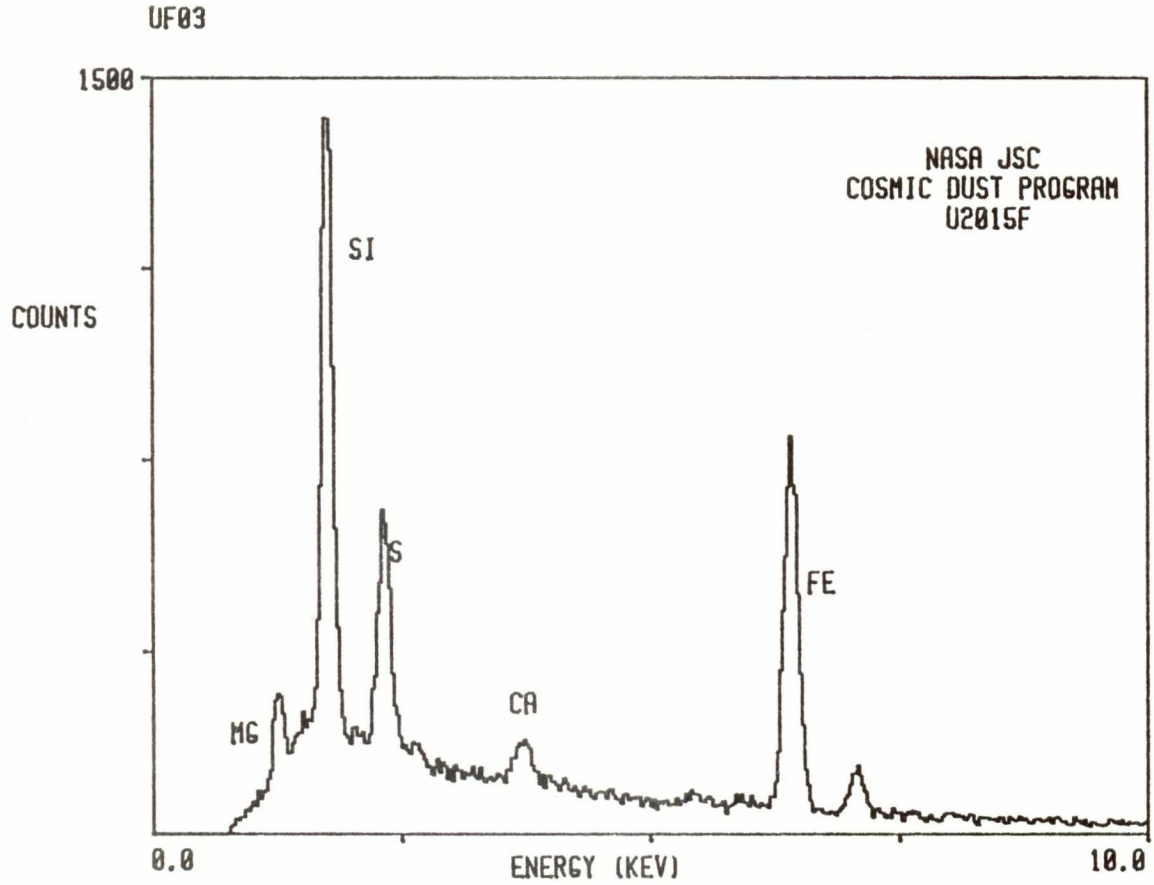
U2015F3

S-84-41438

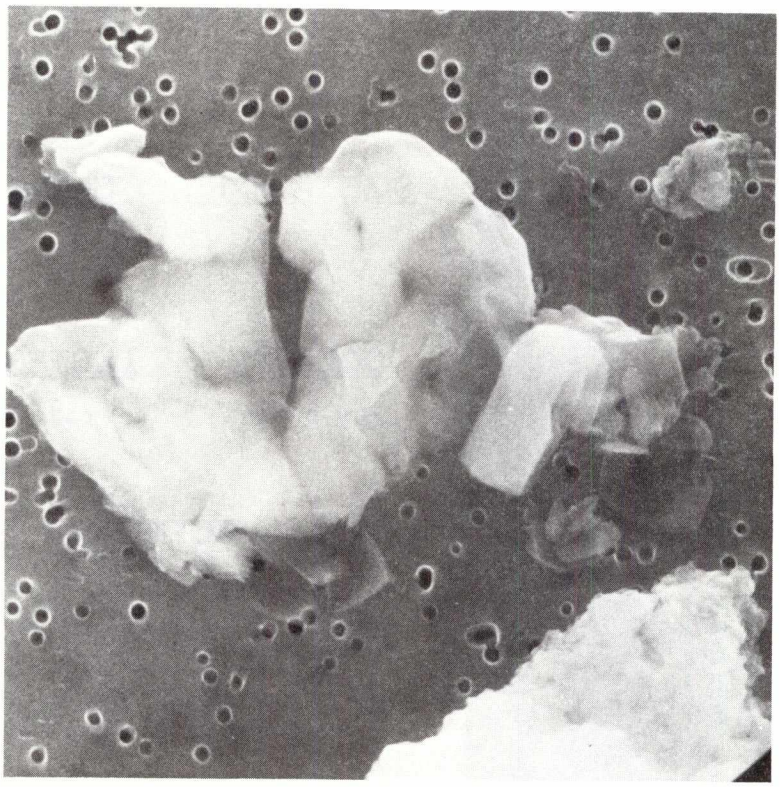
SIZE	SHAPE	TRANS.
13x17	I	O

COLOR	LUSTER
Gray-brown	D/SV

TYPE	COMMENTS
C	



U2015F4

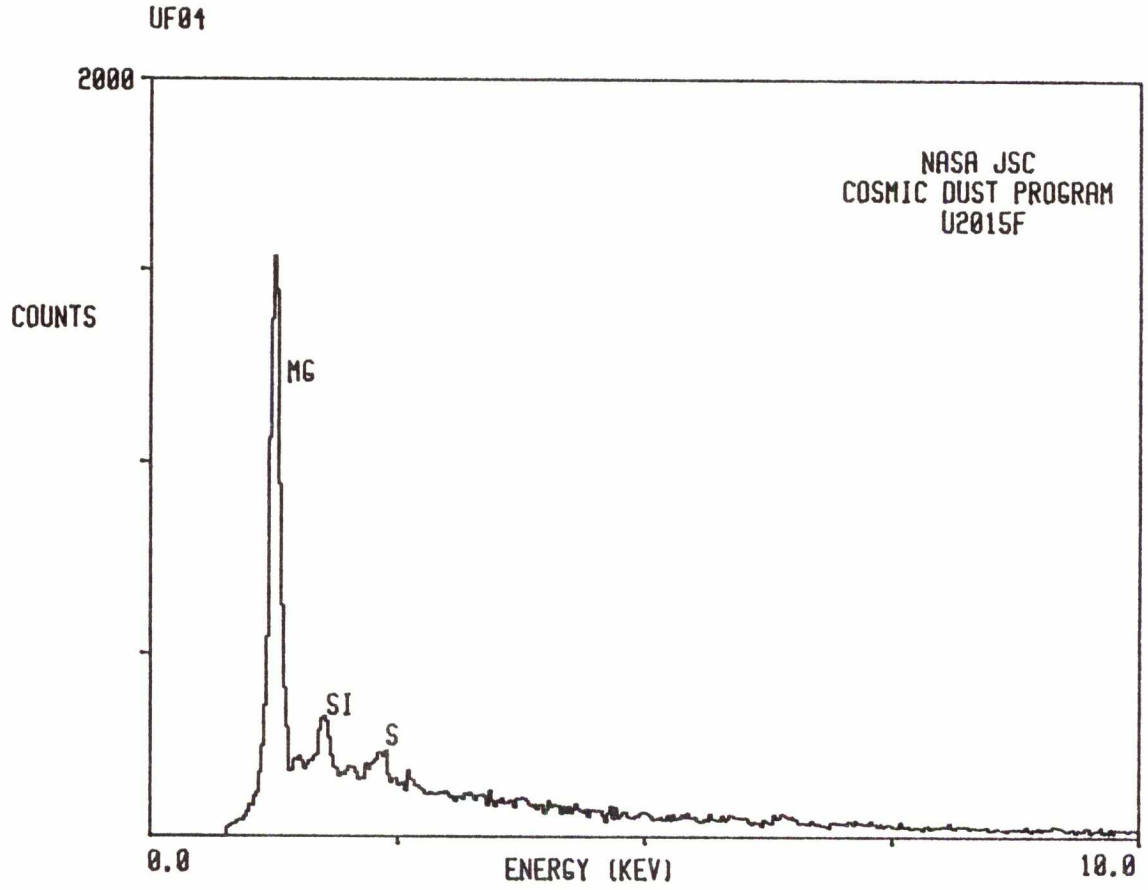


SIZE	SHAPE	TRANS.
10x15	I	T

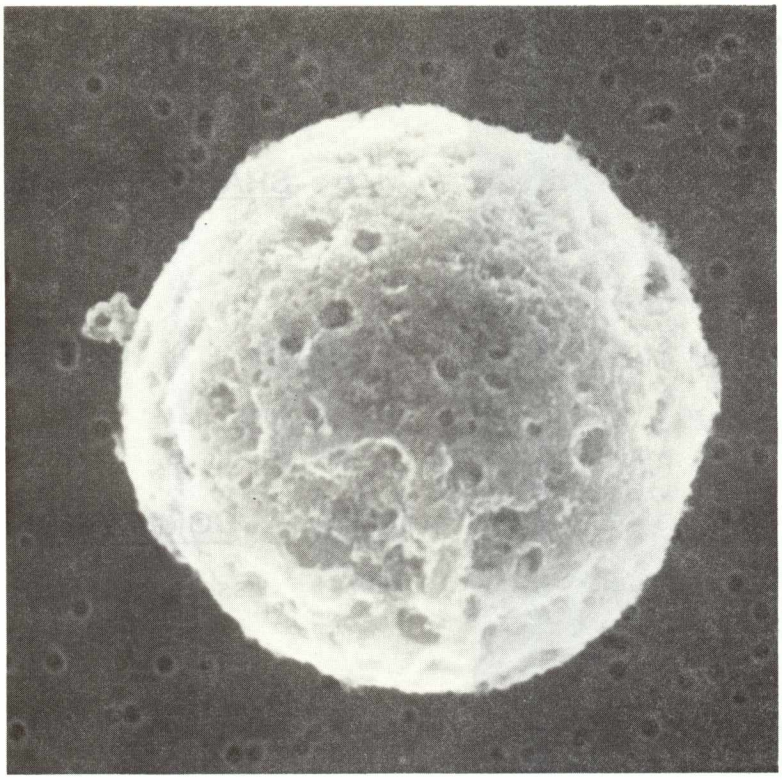
COLOR	LUSTER
CL to pale yellow-gray	V

TYPE	COMMENTS
?	Associated with U2015F3

S-84-41439



U2015F8

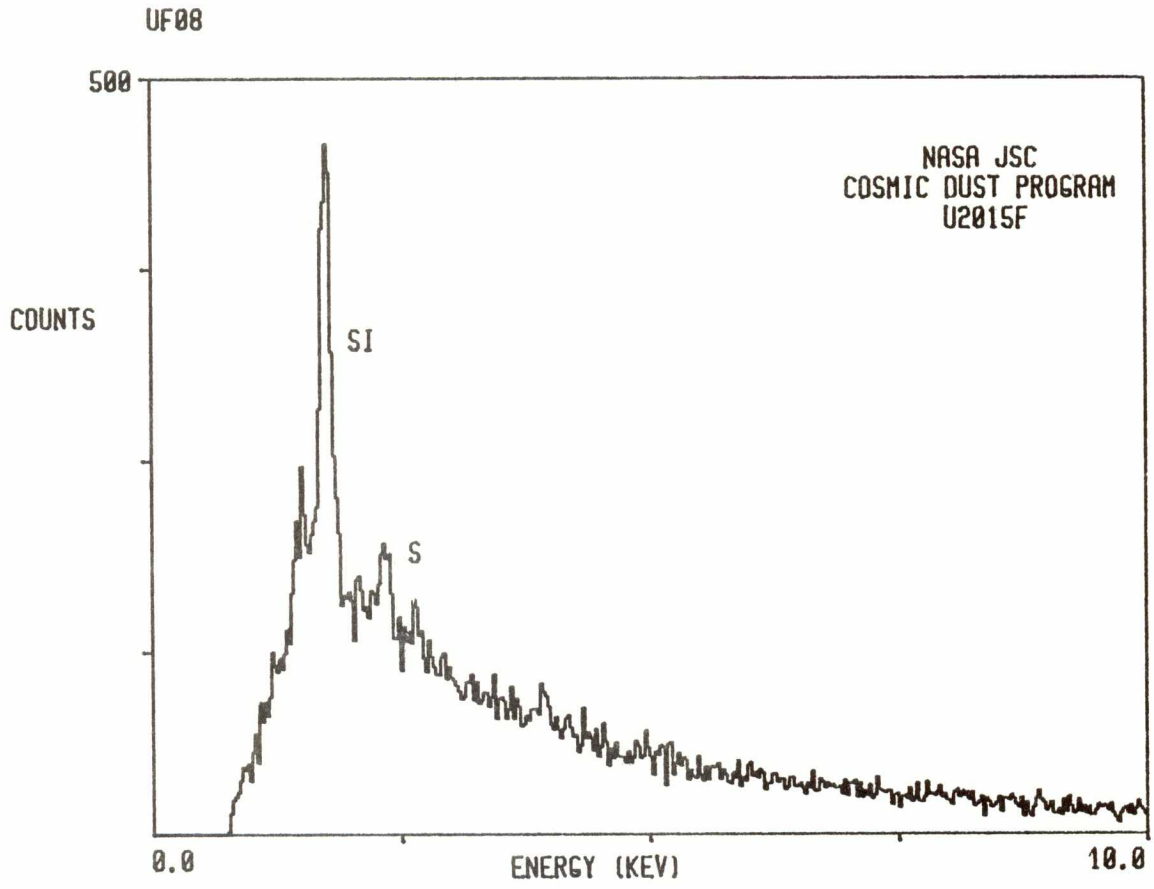


S-84-41442

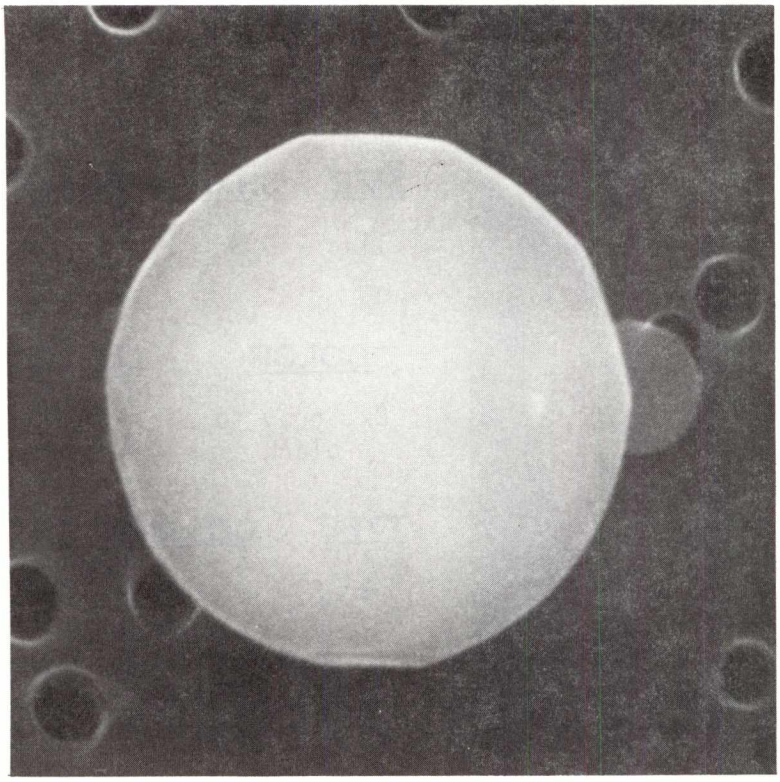
SIZE	SHAPE	TRANS.
11	S	0

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
?	



U2015F9

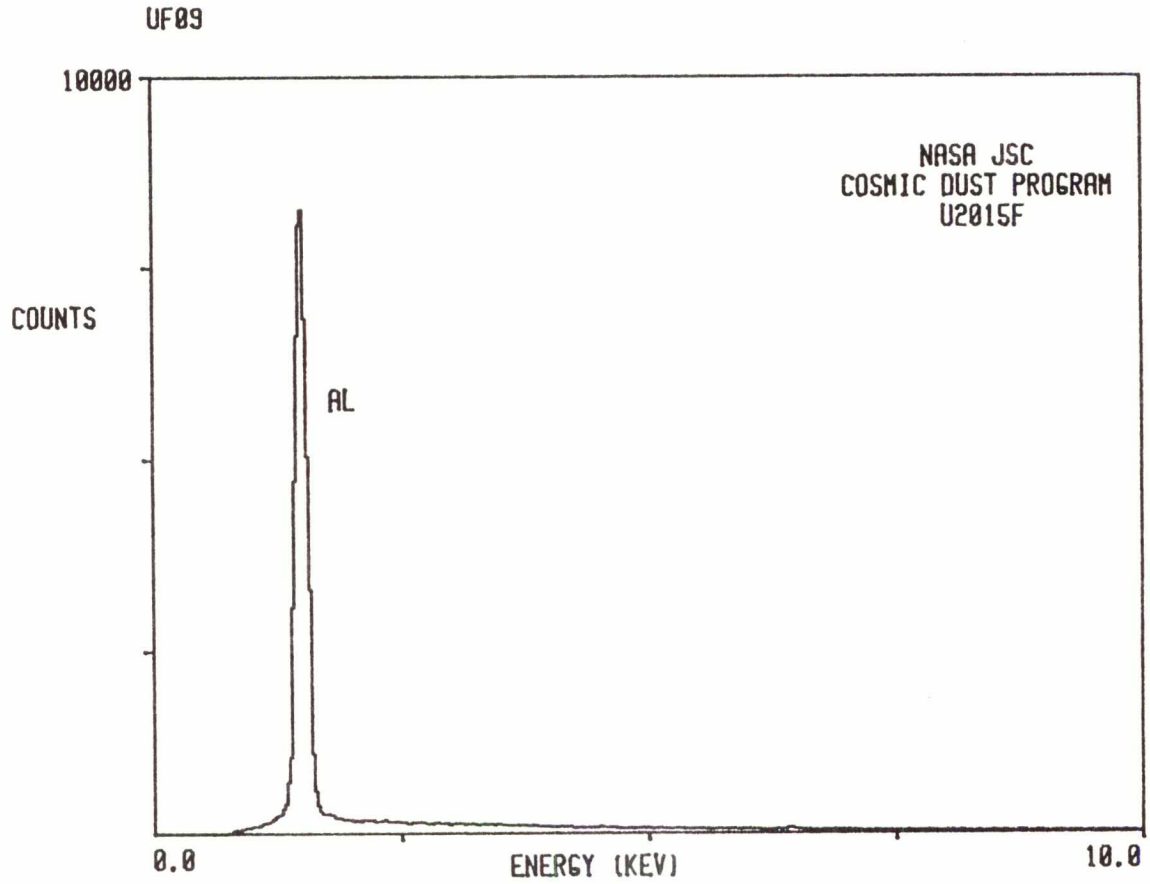


SIZE	SHAPE	TRANS.
3	S	T

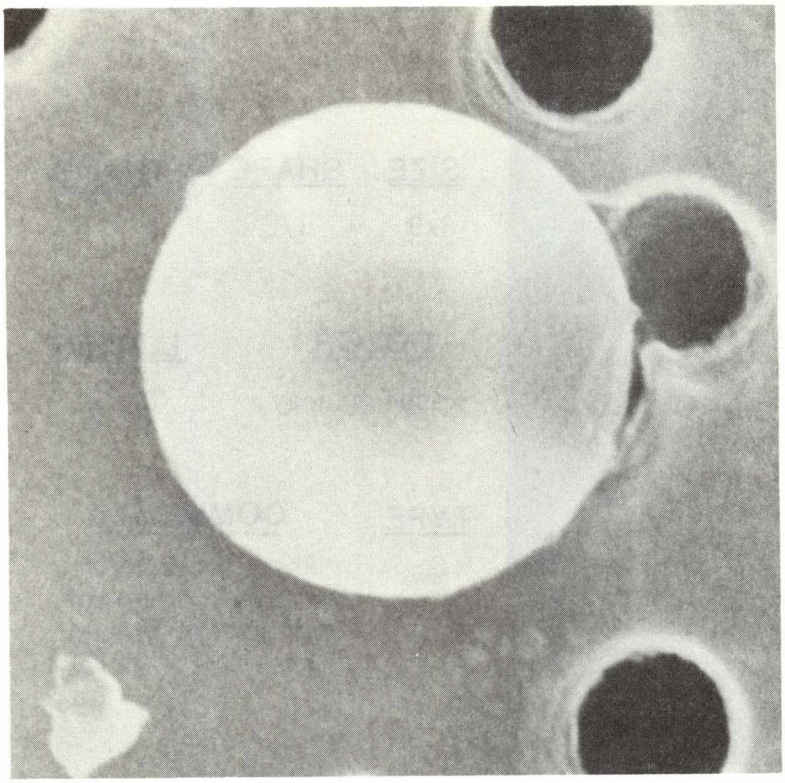
COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
AOS	Associated with U2015F8

S-84-41443



U2015F10

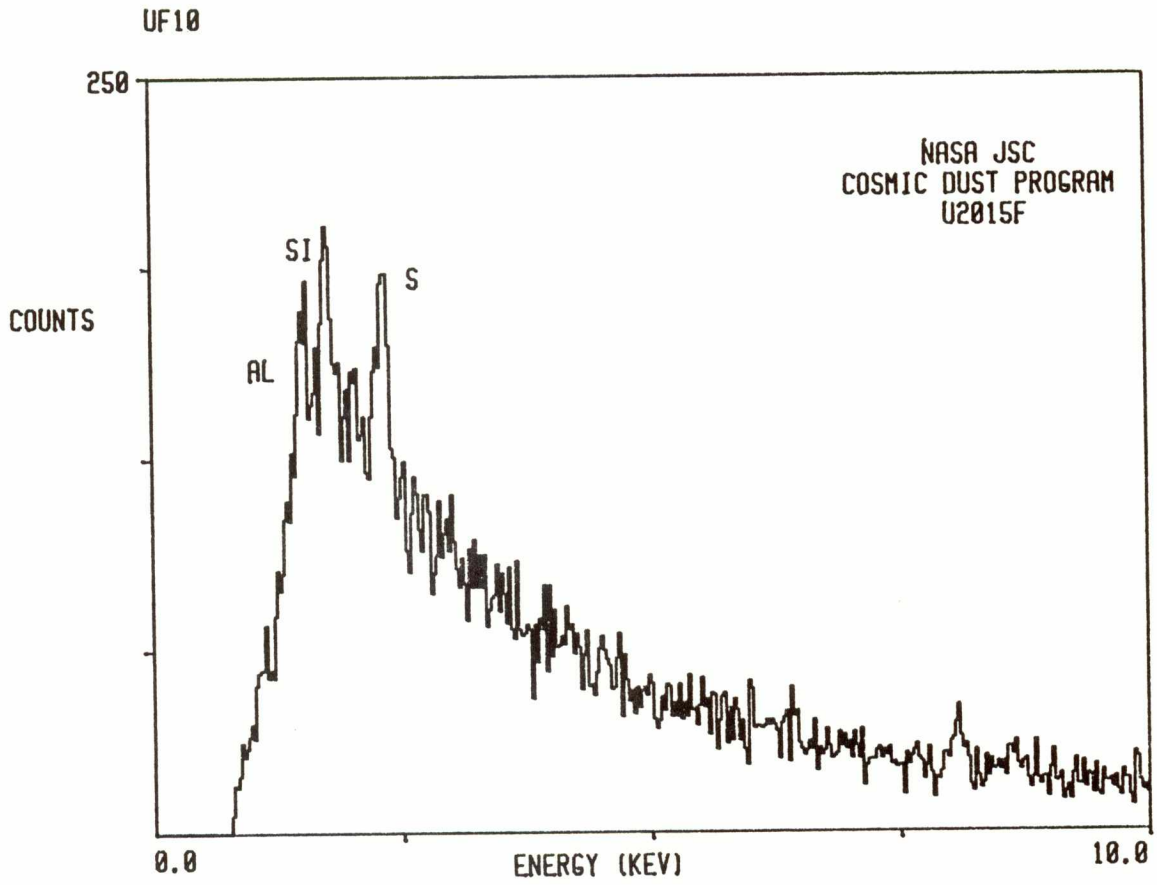


S-84-41440

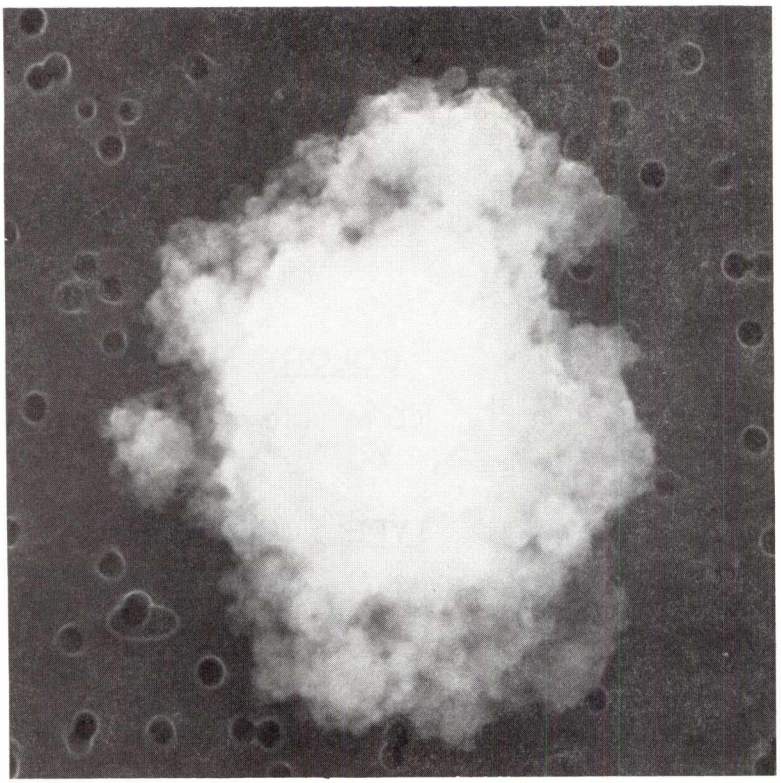
SIZE	SHAPE	TRANS.
1	S	T

COLOR	LUSTER
CL to pale yellow	V

TYPE	COMMENTS
?	Associated with U2015F8



U2015F11

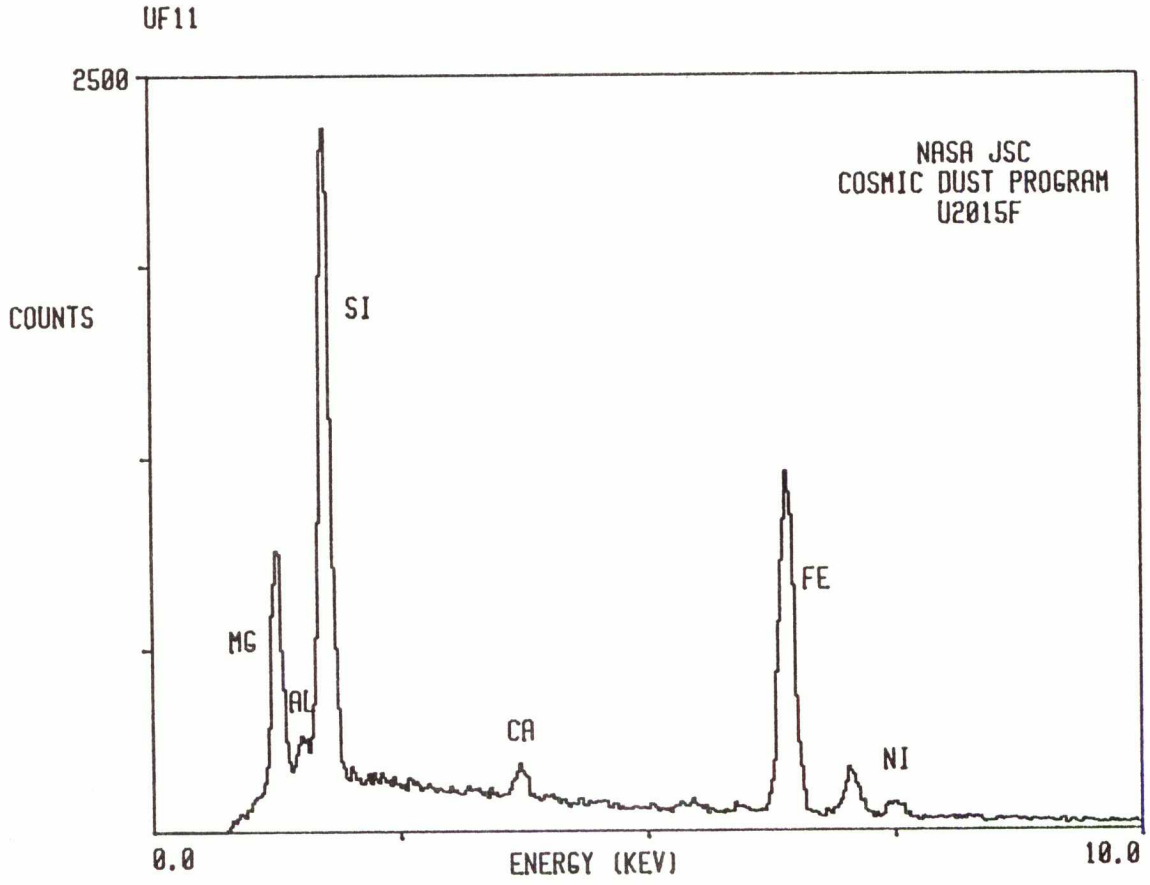


SIZE	SHAPE	TRANS.
8x9	I/E	O

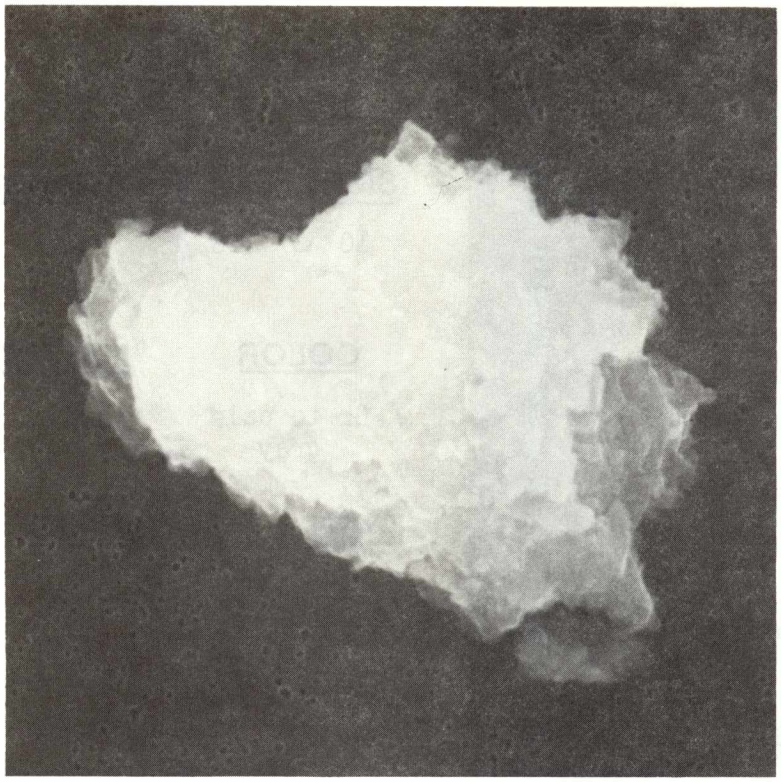
COLOR	LUSTER
Reddish gray	D/SV

TYPE	COMMENTS
C	Associated with smaller fragments of material that resembles U2015D23

S-84-41445



U2015F12

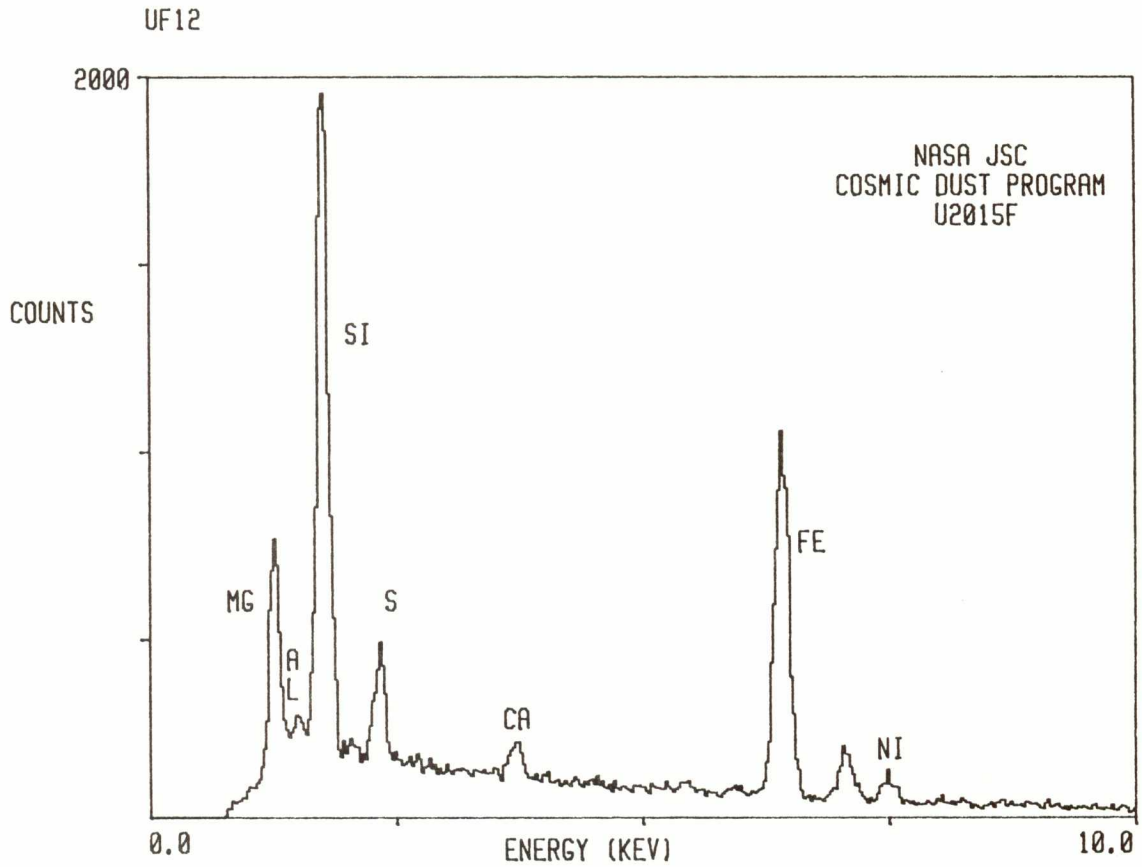


SIZE	SHAPE	TRANS.
17x28	I	0

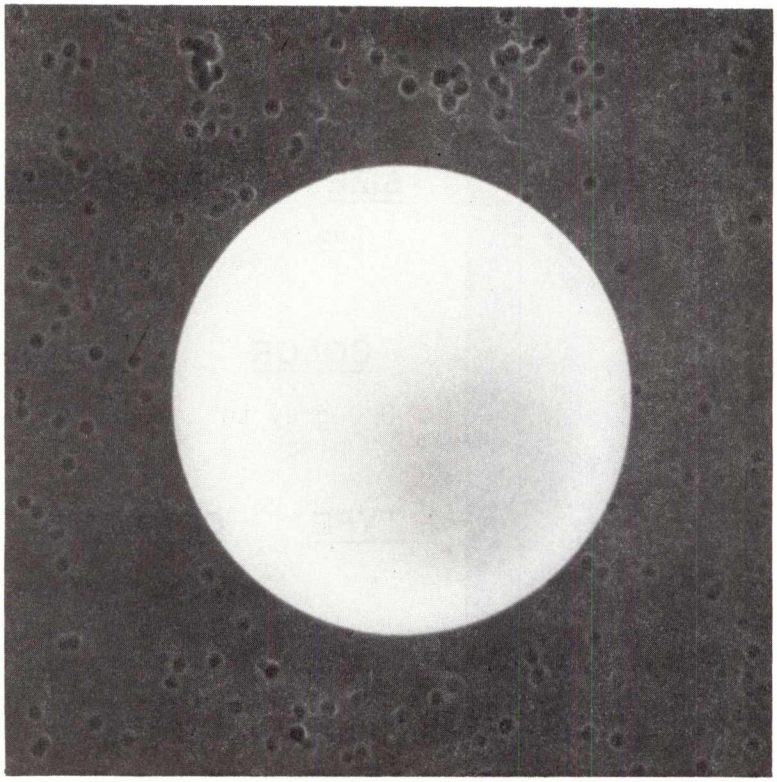
COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C	Largest of three fragments

S-84-41450



U2015F13

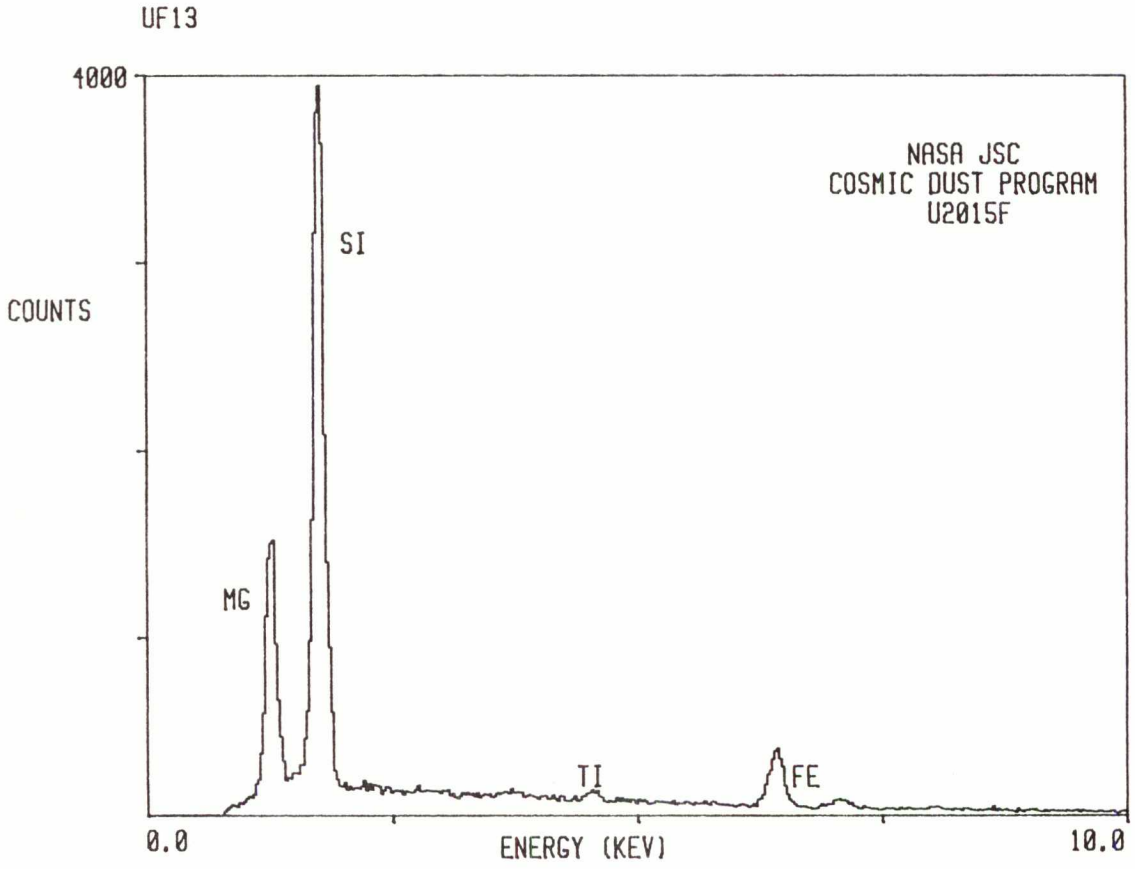


S-84-41452

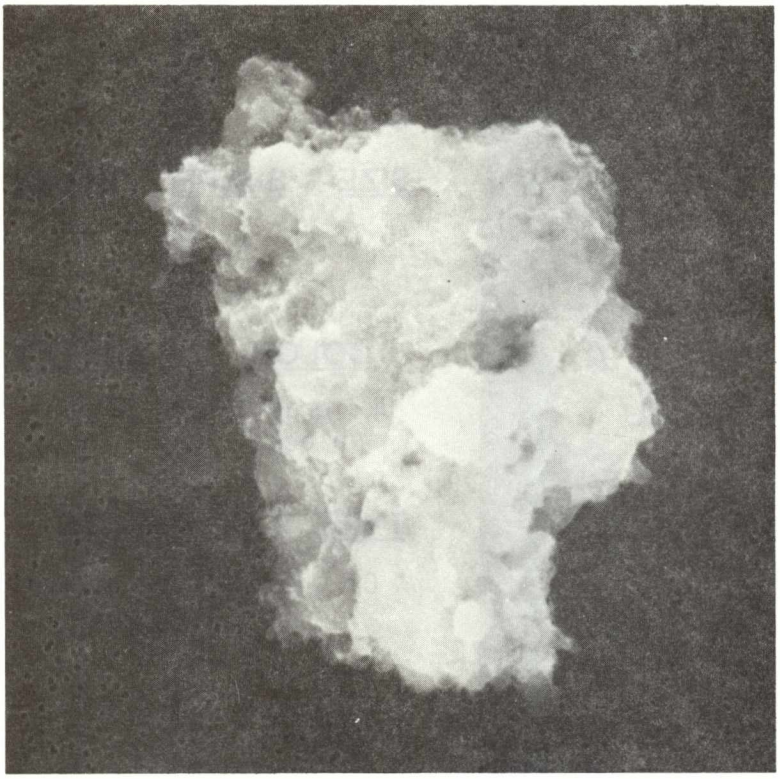
SIZE	SHAPE	TRANS.
10	S	T

COLOR	LUSTER
CL to pale gray	V

TYPE	COMMENTS
C	



U2015F14

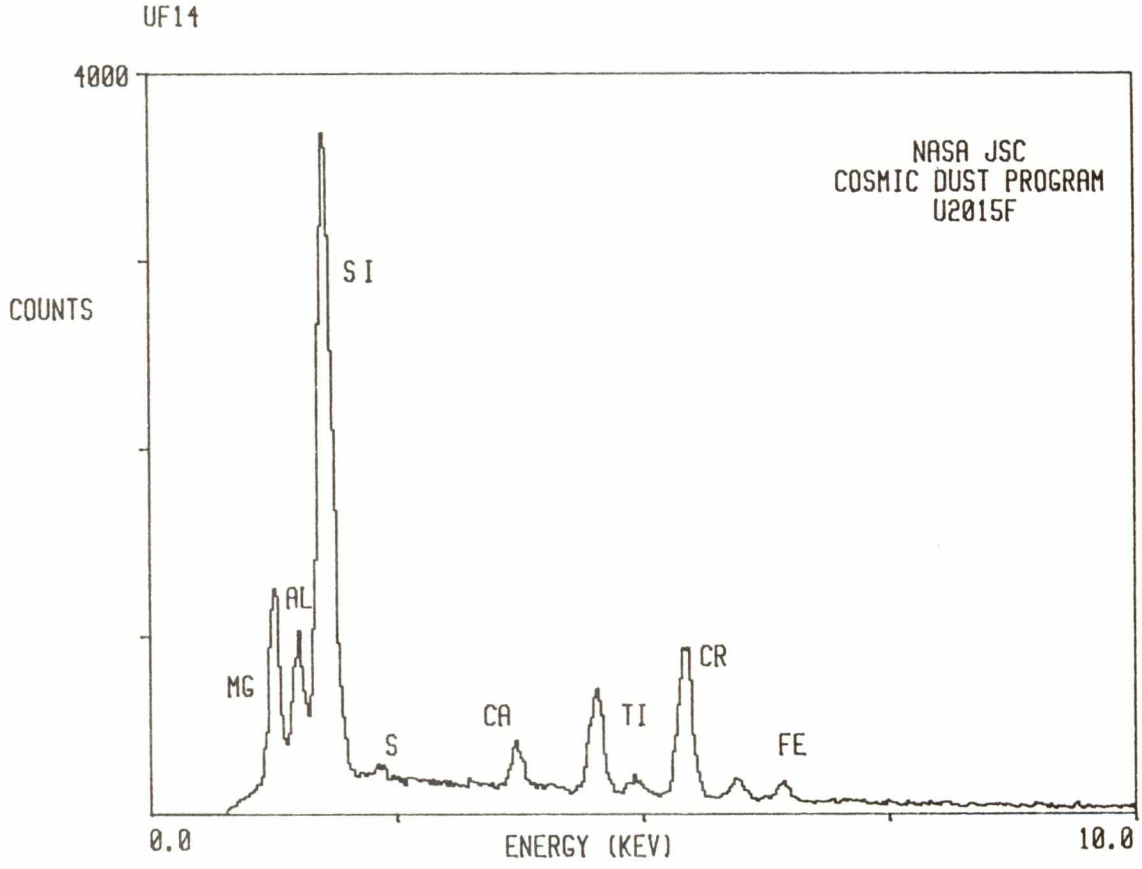


S-84-41453

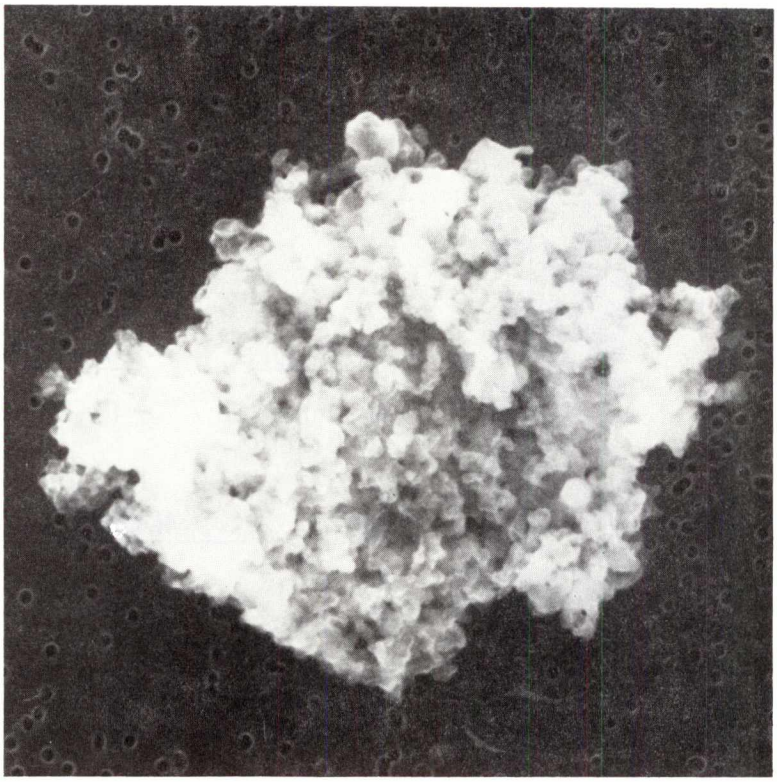
SIZE	SHAPE	TRANS.
18x26	I	O

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
?	



U2015F15

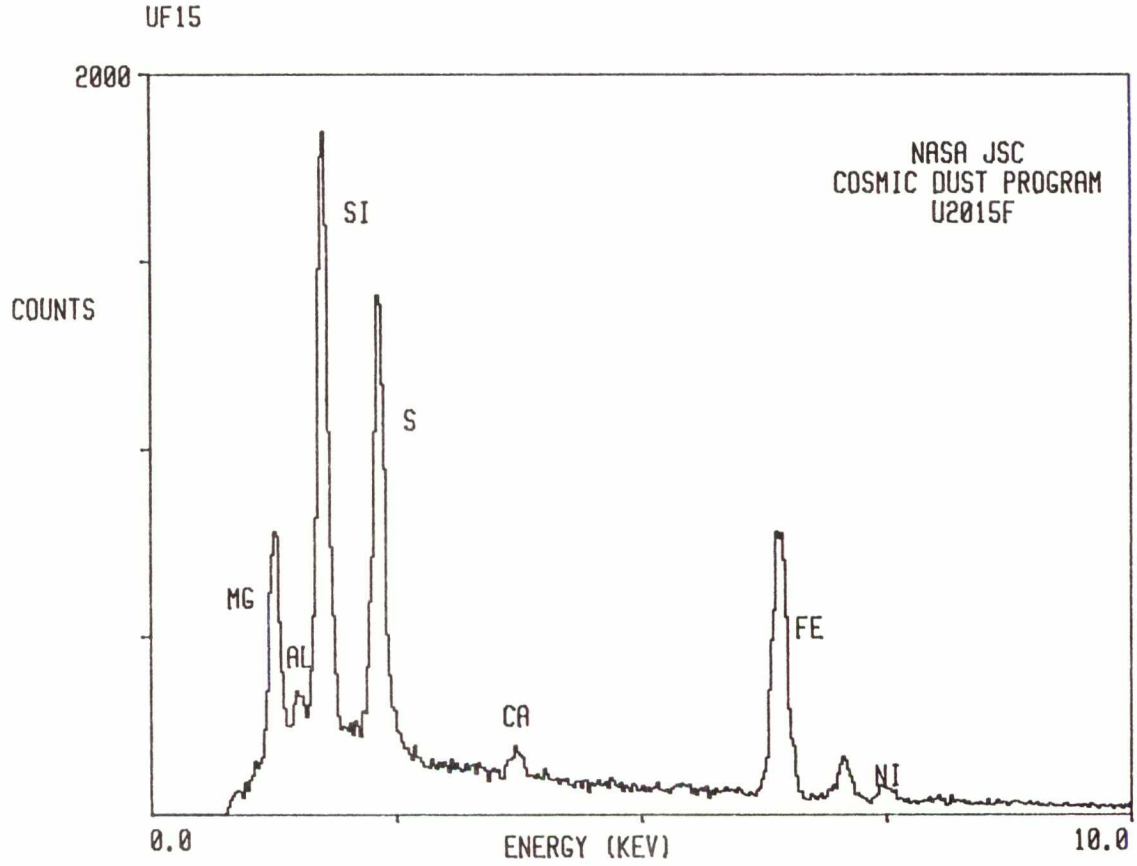


S-84-41454

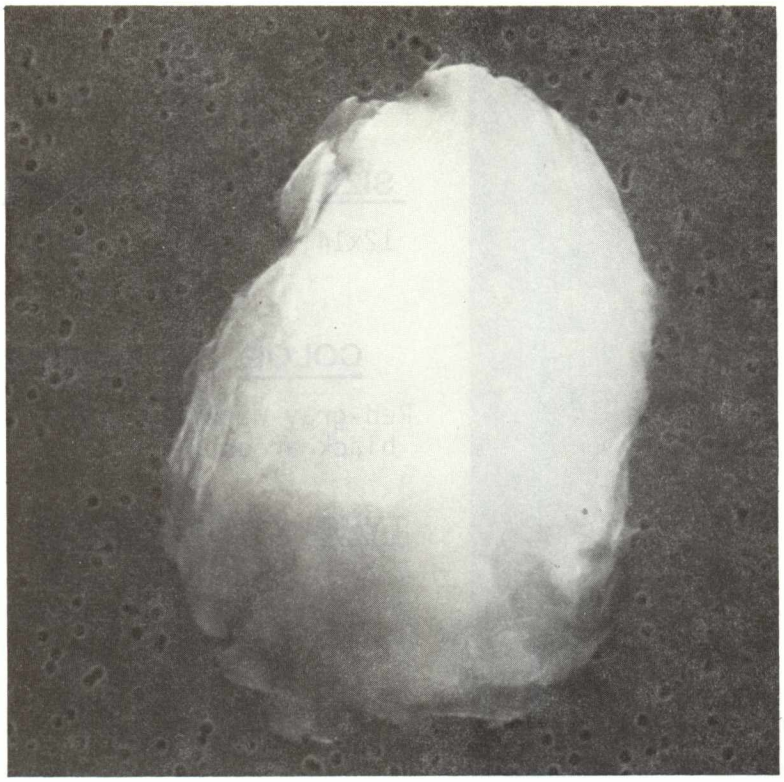
SIZE	SHAPE	TRANS.
15x18	I	0

COLOR	LUSTER
Dk. gray to black	D/SM

TYPE	COMMENTS
C?	Largest of several fragments



U2015F16

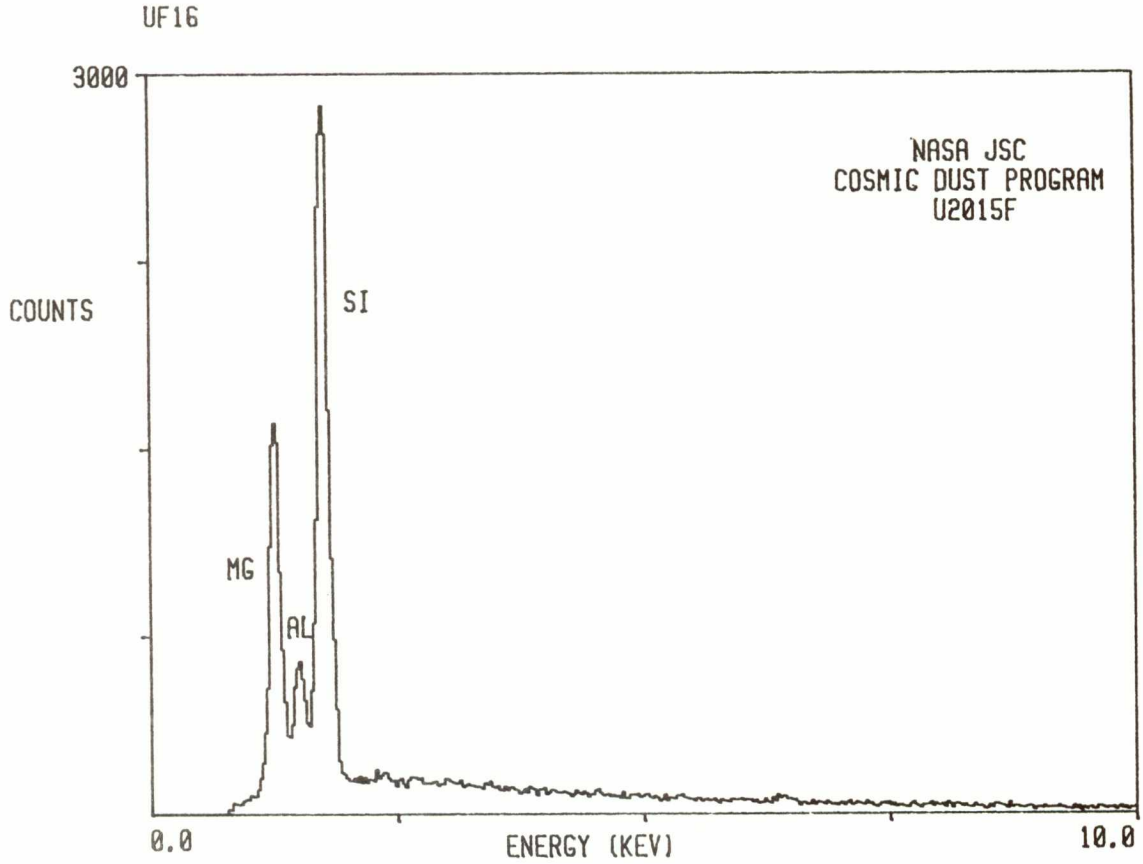


S-84-41455

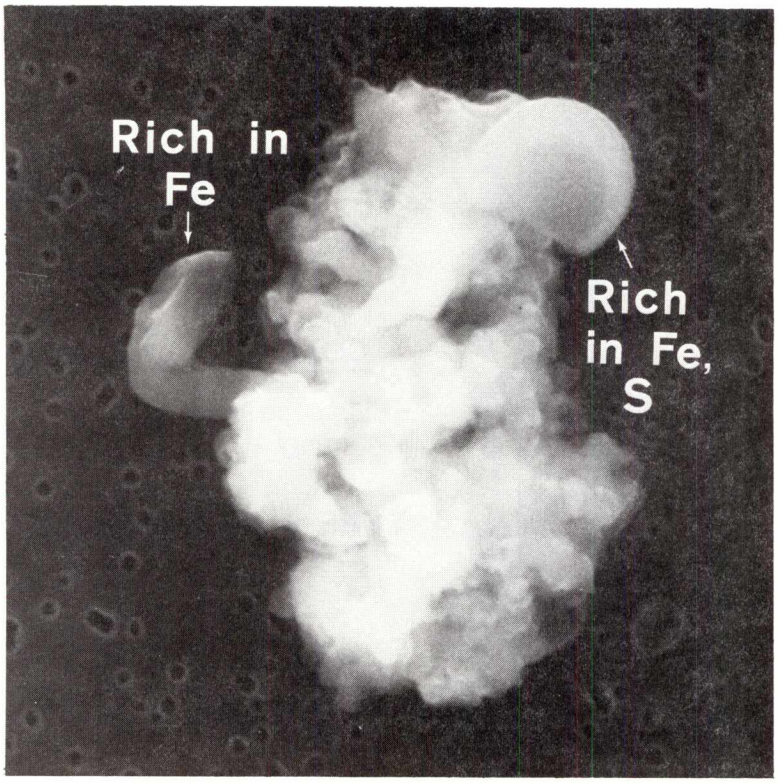
SIZE	SHAPE	TRANS.
15x18	I	T

COLOR	LUSTER
CL to pale gray	V

TYPE	COMMENTS
C?	



U2015F19

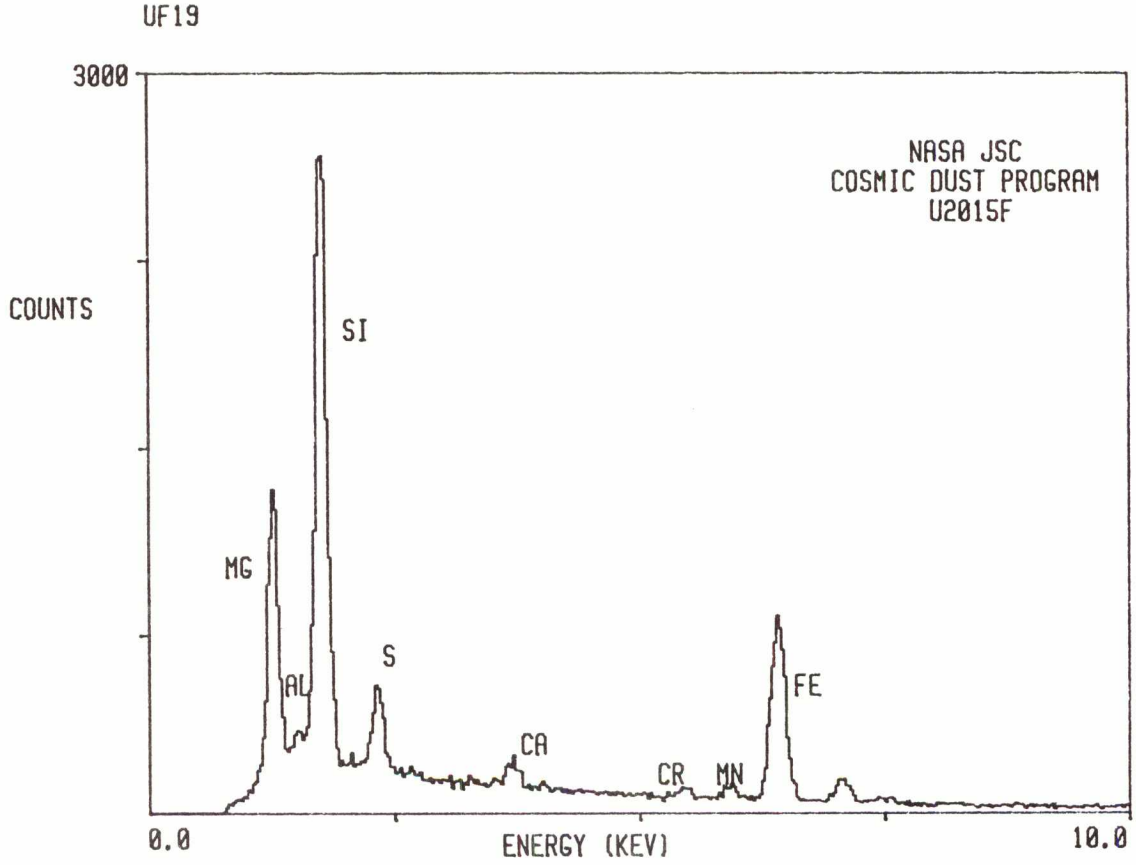


S-84-41458

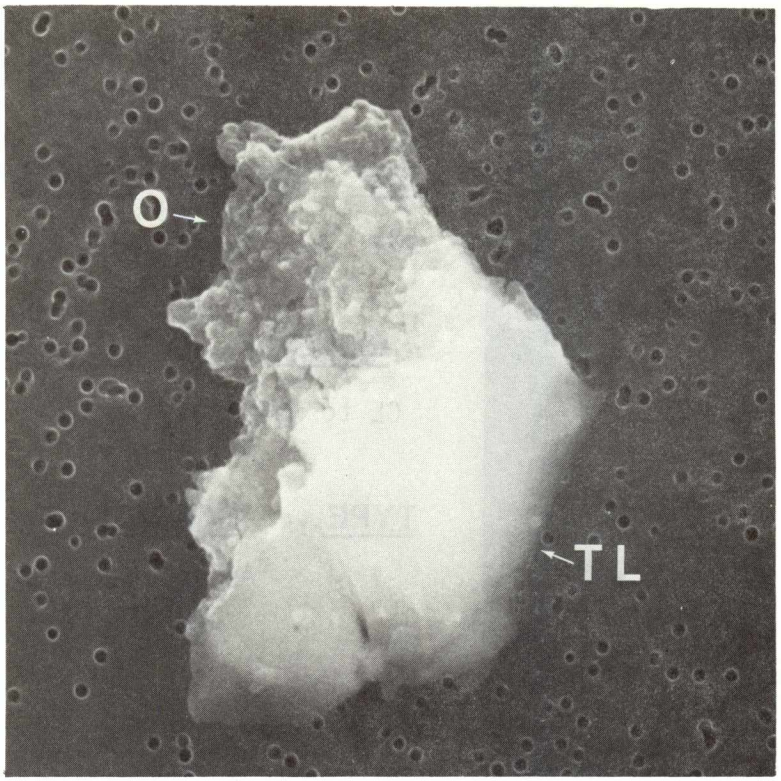
SIZE	SHAPE	TRANS.
12x14	I	O/TL

COLOR	LUSTER
Red-gray with black areas	D/SV

TYPE	COMMENTS
C	Associated with smaller fragments, including one Al-rich sphere of 2 μm size (not shown here)



U2015F20

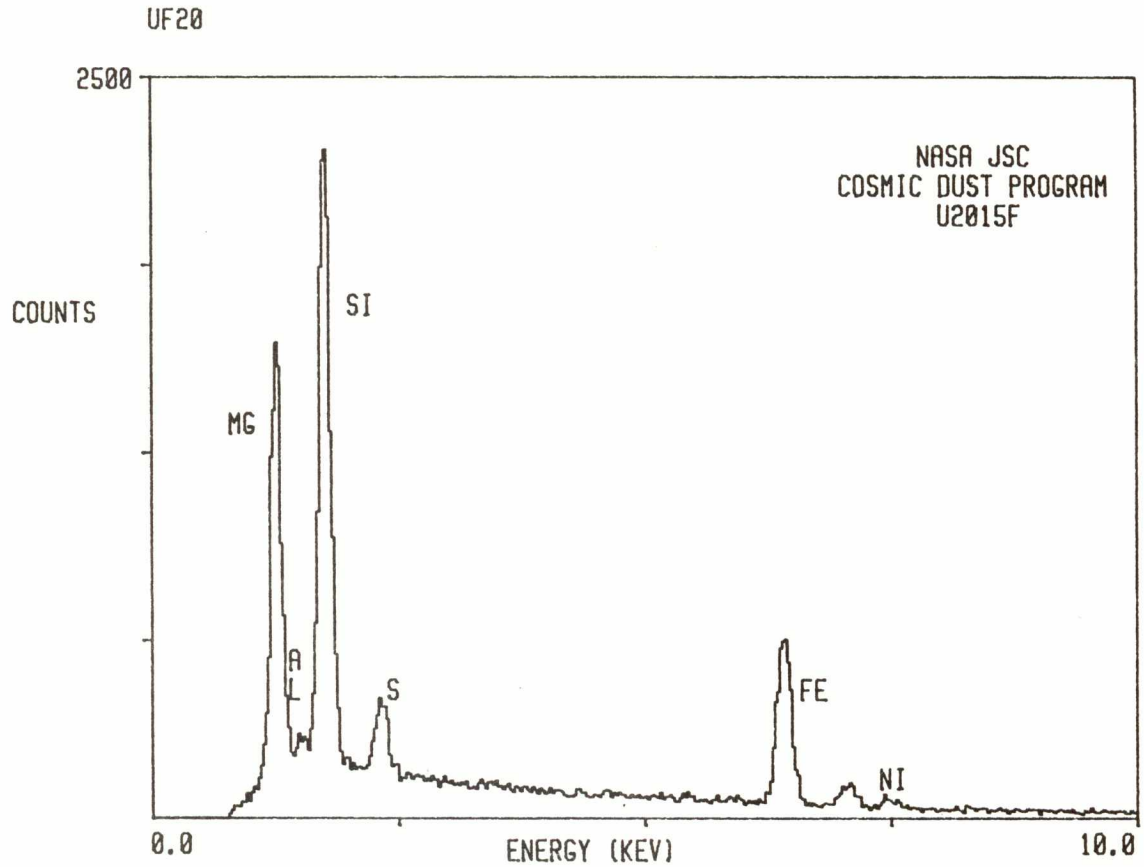


S-84-41463

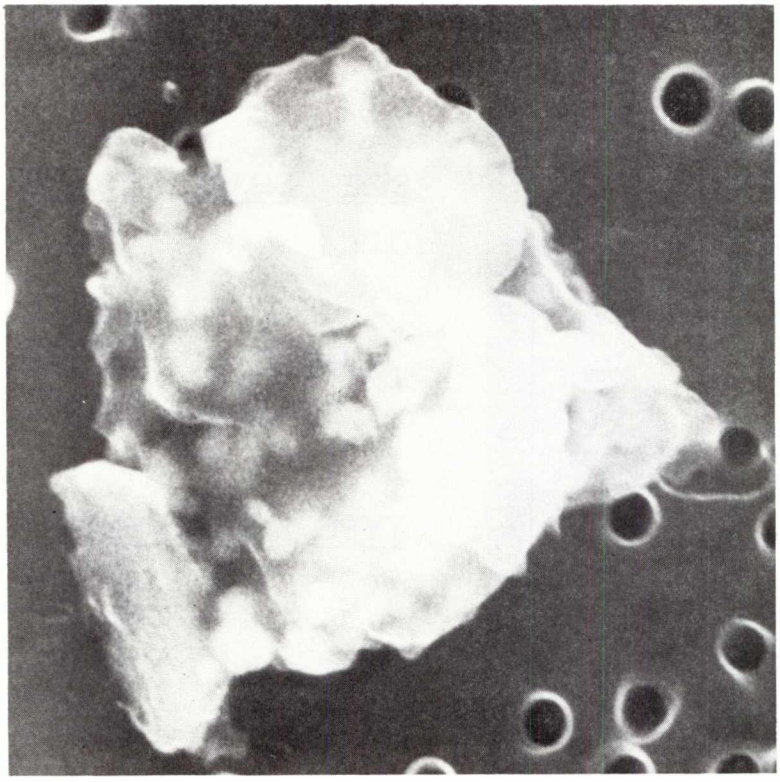
SIZE	SHAPE	TRANS.
11x16	I	TL/O

COLOR	LUSTER
Gray to black	SV/V

TYPE	COMMENTS
C	Associated with U2015F21



U2015F21

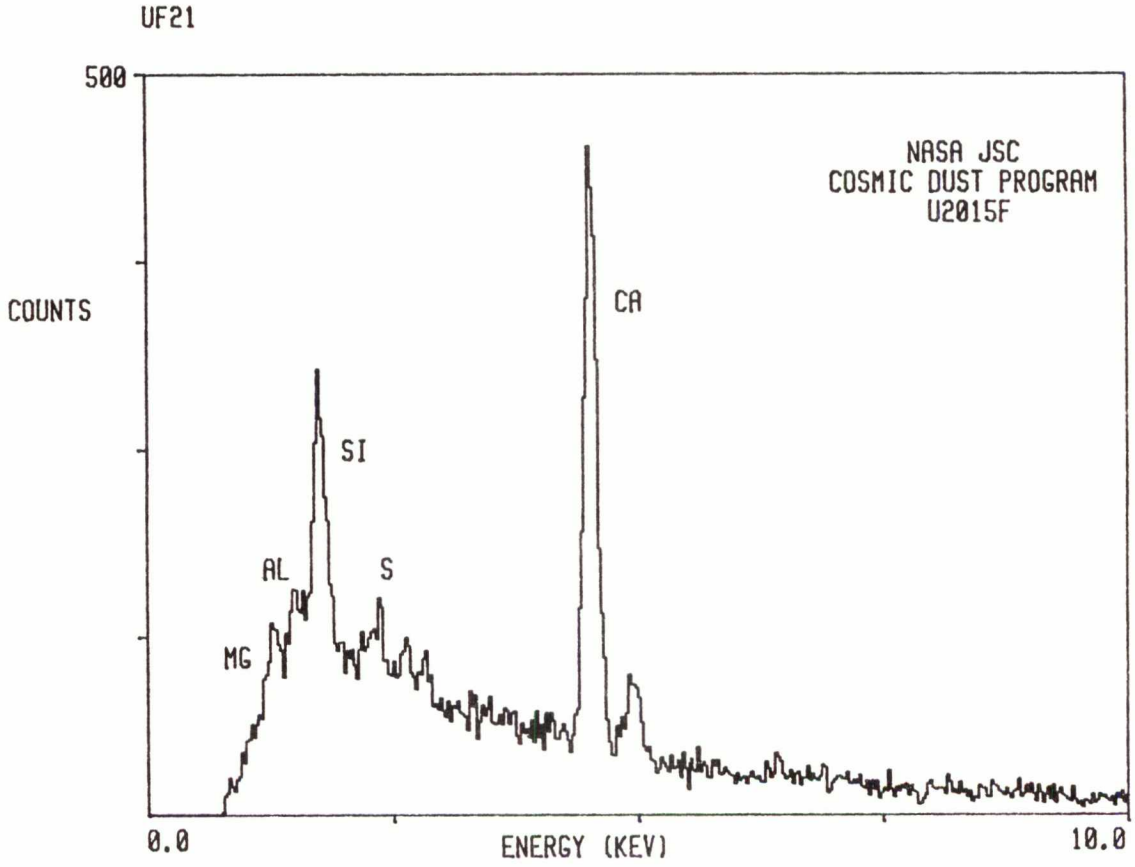


S-84-41464

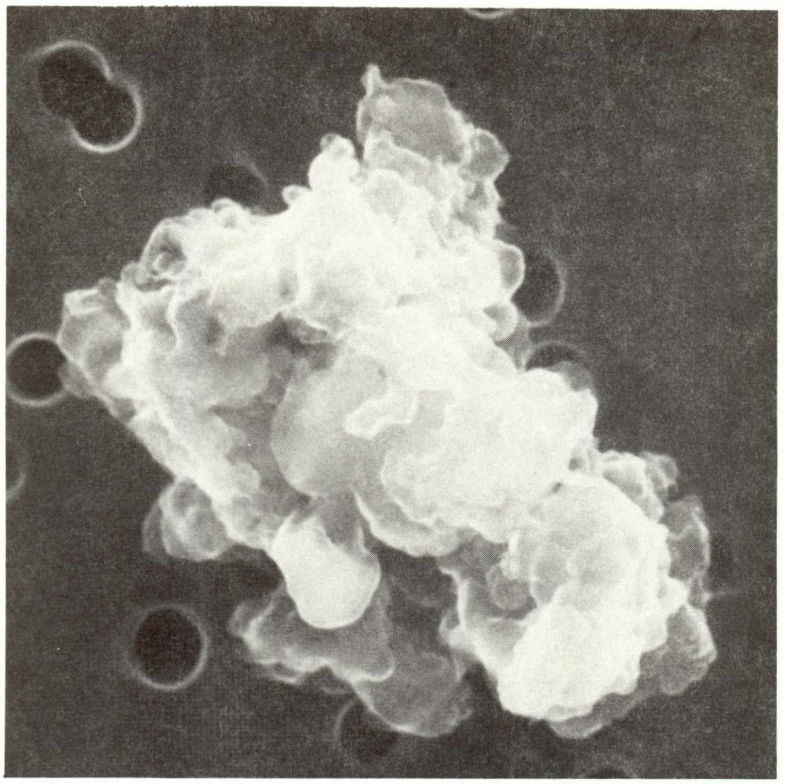
SIZE	SHAPE	TRANS.
5x5	I/E	T

COLOR	LUSTER
CL to white	SV

TYPE	COMMENTS
?	Associated with U2015F20



U2015F22



S-84-41436

SIZE	SHAPE	TRANS.
3x4	I	O

COLOR	LUSTER
Dk. gray to black	D

TYPE	COMMENTS
C