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**Satellite Contamination and Materials
Outgassing Knowledgebase**

Mr. Jody L. Minor
NASA/Marshall Space Flight Center
Huntsville, Alabama 35812

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SATELLITE CONTAMINATION AND MATERIALS OUTGASSING KNOWLEDGEBASE

Jody L. Minor
 NASA Marshall Space Flight Center
 Huntsville, Alabama 35812 USA

ABSTRACT

Satellite contamination continues to be a design problem that engineers must take into account when developing new satellites. To help with this issue, NASA's Space Environments and Effects (SEE) Program funded the development of the *Satellite Contamination and Materials Outgassing Knowledgebase*. This engineering tool brings together in one location information about the outgassing properties of aerospace materials based upon ground-testing data, the effects of outgassing that has been observed during flight and measurements of the contamination environment by on-orbit instruments.¹ The knowledgebase contains information using the ASTM Standard E-1559 and also consolidates data from missions using quartz-crystal microbalances (QCM's). The data contained in the knowledgebase was shared with NASA by government agencies and industry in the US and international space agencies as well. The term 'knowledgebase' was used because so much information and capability was brought together in one comprehensive engineering design tool. It is the SEE Program's intent to continually add additional material contamination data as it becomes available – creating a dynamic tool

whose value to the user is ever increasing. The SEE Program firmly believes that NASA, and ultimately the entire contamination user community, will greatly benefit from this new engineering tool and highly encourages the community to not only use the tool but add data to it as well.

INTRODUCTION

In early 1997, the SEE Program hosted a technical workshop which asked technical experts from around the US to prioritize contamination issues as a basis for a section in a future NASA Research Announcement (NRA). Listed as a top priority by many experts was the need for a single database of contamination data, especially data based upon the ASTM E-1559-93 testing standard and data obtained from quartz-crystal microbalances (QCM's). QCM's have become industry's top choice for measuring material outgassing properties data and characterizing the on-orbit contamination environment experienced by satellites.²

In 1998, Dr. B. David Green of Physical Sciences, Inc., and Bob Wood of Sverdrup Technology/Arnold Engineering Development Center (AEDC), along with the Applied Physics Lab at Johns Hopkins University were funded by the SEE Program to develop this unique contamination database. The year 2000 saw the final product delivered. It is now called the Satellite Contamination and Materials Outgassing Knowledgebase. The word 'knowledgebase' is used because this tool is much more than just a materials database. It is a comprehensive compilation of materials outgassing information combined with features

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that allow the user to manipulate the data contained therein. Features of this unique engineering design tool include:

- Contamination data obtained using the American Society of Testing and Materials (ASTM) E-1559-93 *Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials* (this data supplements data obtained using the ASTM Standard E-595);
- Data obtained from on-orbit QCM measurements from various spacecraft, including Shuttle and other satellites;
- Specific materials contamination data from the Ballistic Missile Defense Organization (BMDO) Midcourse Space Experiment (MSX) spacecraft;
- PDF format reference material;
- Browser-based plotting capability;
- Global key-word search capability;
- Glossary of terms, and
- On-line help capability.

Information from over 240 materials has been obtained from private industry and government centers from all over the US. Many NASA field

centers have volunteered their data and even the European Space Agency (ESA) has contributed. This is truly one of the most comprehensive collections of materials outgassing information derived from QCM data available today.

This paper will further highlight the contents of this knowledgebase and will provide information as to how one may obtain it through the SEE Program.

MATERIALS OUTGASSING KNOWLEDGEBASE

The Knowledgebase was developed using the Microsoft InterDev® software platform and is compatible with Microsoft Internet Explorer and Netscape Navigator. The hierarchical structure of the Knowledgebase is designed to:

- Minimize processing time to the user;
- Provide quick reference material keyword search and data download capability;
- Provide easy incorporation of new datasets.³

This hierarchical format is very similar to the Explorer program within Microsoft Windows® and should be familiar to most users.

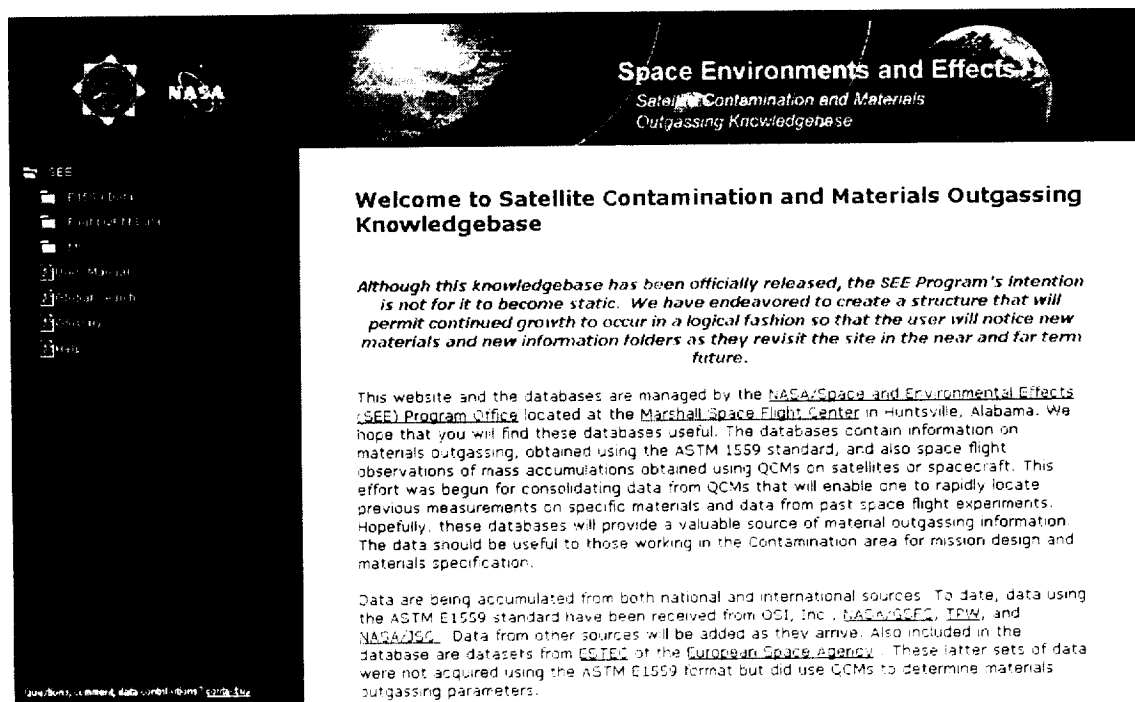


Figure 1. Front Page of Knowledgebase.

The separate ground and flight datasets as well as the online bibliographical publication references (approximately 100 are included) are searchable by keywords that link to the actual files. The plot routines allow the user to select specific data, zoom in/out on the plot axes and print the results at the user's location. All data files are contained in Microsoft Excel spreadsheets (column delimited format) and image files are in JPEG or GIF formats that have compressed versions, in "zip" format, that permit rapid download. The papers, text and figures represent a clear, illustrative summary of the effects observed and conclusions reached through analysis by the responsible researcher.⁴

Datasets

The Knowledgebase's datasets are divided into three main folders:

- Data based upon the ASTM E-1559 testing standard;
- Data obtained on-orbit using QCM's;
- Data obtained from the MSX satellite program.

ASTM E-1559-93

This outgassing data is based upon the ASTM E-1559-93 testing standard. It is intended to supplement the ASTM Standard E595-93, *Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment*. However, no E-595-93 data is listed in the Knowledgebase.

The first level down into the E-1559-93 hierarchical structure brings the user to the "Search" and "Contributors of Data" levels.

Selecting the "Search" option enables the user to search for any material in the Knowledgebase that has been tested using the E-1559 testing standard (see Figures 2 and 3 below). Figure 2 shows the alphabetical list of materials in the Knowledgebase that can be searched. This search can be further narrowed by selecting a QCM temperature operating range in degrees Celsius. In this case, metallized Kapton with a silicon-carbide (SiC) coating has been selected. After the completion of the search, a window is

displayed containing links to the test data, associated data plots, and download and plotting options.

Figures 4 and 5 represent actual test data that was observed by the researcher during the test. It is from this data and these plots that the user will be able to extract the needed information. The test reports also contain comments, test setup/material sample descriptions and may explain any anomalous readings or events that may have occurred during the test. The test report shown for the metallized, SiC coated Kapton (Figure 4) is only one style of test report obtained from the various data contributors, although all test report styles are presented in PDF format. Therefore, not all raw test data is presented in the same style seen in the report in Figure 4.

The plot seen in Figure 5 was provided by the researcher and represents a detailed, specific time-slice of the QCM frequency and operating temperature data. Any specific plots such as this that were provided by the researcher are listed on the search results page. These specific plots are in JPEG or GIF format and may be printed at the user's location using the browser's printing features.

The browser's real-time plotting feature allows the user to custom plot specific test data in terms of QCM operating temperature and frequency versus total test time. This data is generally less specific than the time-slice plots provided by the researcher, but does allow the user to plot multiple QCM data (frequency and operating temperature) on one plot. An example is shown in Figure 6. This data may also be printed at the user's location using the browser's printing features.

The "Contributors of Data" option under the main E-1559 branch lists all the contributors of the data for the E-1559-93 dataset and provides a link to the contributor's email address should the user have a question or comment about the data. Work is currently being performed to link the contributor's name to the actual data that he/she contributed. This will enable the user to be able to contact a specific contributor if there are questions about a particular data set within the Knowledgebase. This updated version should be available in mid-2001.

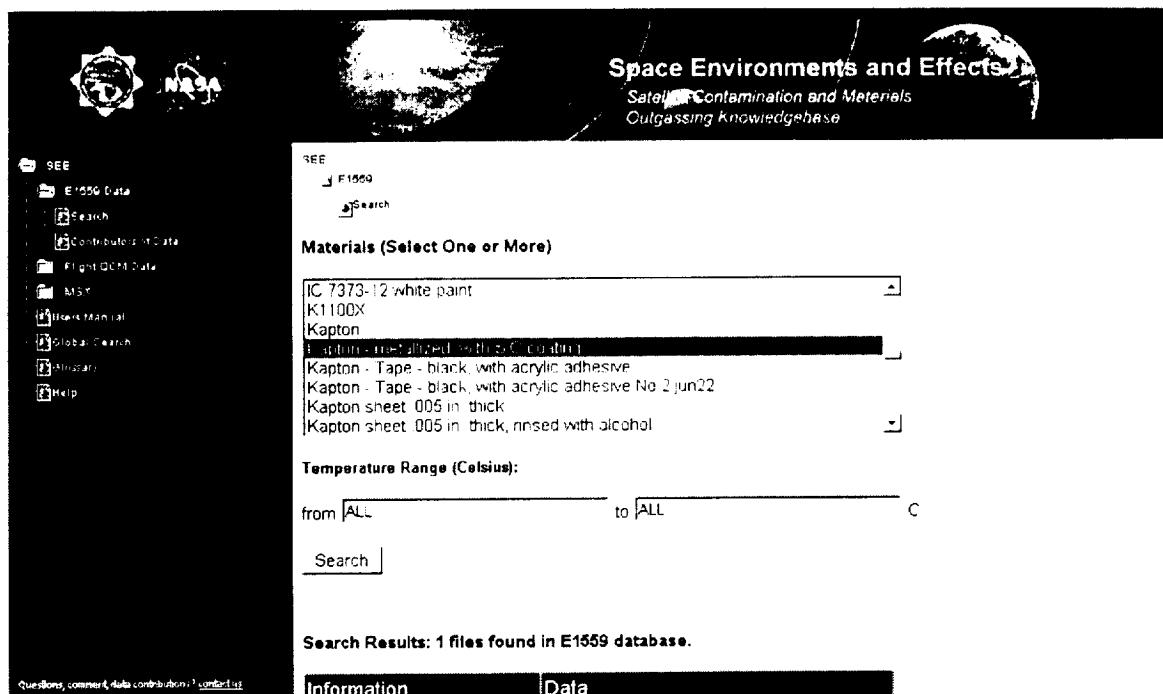


Figure 2. Example of E1559 Data Search Screen

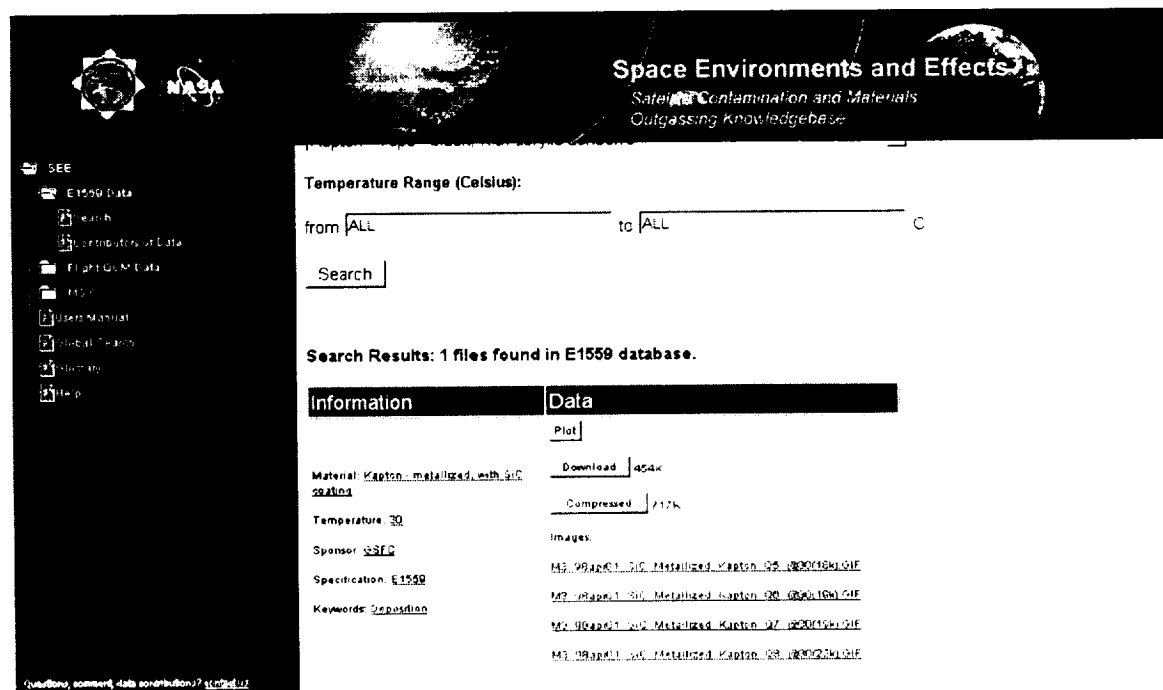


Figure 3. Results of Data Search

Folio #: 980401
Sample #: 1

MOLEKIT3 Test Results Form

Requestor (Name, Code, and Phone):		Project:	Date:
Jack Triolo, CODE 545, 6-2311		2013-500, NGST	5/15/98
Test Coordinator (Name and Phone):		Manufacturer:	
George Meadows, 724.4, 6-1353		Dupont (kapton), IEC Laboratories (SiC coating)	
QCM Crystal Plane to EC Aperture:	Material Type and Name:		
4.50", 114.3mm	Metallized Kapton, .0005" w/SiC coating, 260-270nm, 022498#1		
QCM Crystal to EC Axis:	Sample Dimensions:		
0.795", 20.2mm	125mm by 130mm, 162.5 cm ²		
EC Aperture:			RGA Data:
0.133" dia. by 0.02" long, 3.38mm dia. by 0.51mm long.			N/A
Sample Preparation:			
Sample dusted w/filtered shop air. Sample folded, rolled & wrapped w/0.02" rinsed stainless wire, forming a cylinder, 12mm dia. by 35mm long.			

Pre-Test Substrate Weight:	Pre-Test Sample + Substrate Weight:	Pre-Test Sample Weight:	Sample Delta Weight:
0.0716 grams	0.27311 grams	0.20151 grams	0.00208 grams
Post-Test Substrate Weight:	Post-Test Sample + Substrate Weight:	Post-Test Sample Weight:	Sample %TML
0.0716 grams	0.27103 grams	0.19943 grams	1.0322%

Test Start:	Sample Temperature:	Chamber Pressure, Torr:	Interlock Pressure, Torr:
4/1/98	34.4°C	N/A	5.6 x 10 ⁻⁶
Test Stop:	Sample Temperature:	Chamber Pressure, Torr:	Interlock Pressure, Torr:
4/2/98	30.0°C	N/A	1.7 x 10 ⁻⁸
Sample Temperature:	Temperature Duration:	Chamber Pressure, Torr (Avg., Min., Max):	Interlock Pressure, Torr (Avg., Min., Max):
30.0°C	28 hours	N/A	~3e-8, 1.7e-8, 5.6e-6

QCM #	5	6	7	8
Deposition	-20°C	-100°C	-180°C	-60°C
Reemission	125°C @1°C/min	125°C @1°C/min	125°C @1°C/min	125°C @1°C/min

Data	\\Gmeadows\data_files\molekit3\M3_98apr01_SiC_Metallized_Kapton_@30.xls
File	\\Gmeadows\old_data\molekit3\M3_98apr01_SiC_Metallized_Kapton_@30.xls
Paths	\\Gmeadows\archive_data\molekit3\1998_Files\M3_98apr01.zip

Comments:

The EC was raised into Chamber at 34.4°C, set to 30°C. The interlock was pumped initially with the EC at 34°C and the EC under a vacuum of less than 10⁻³ Torr for 2 minutes. The interlock was vented to 22 Torr with GN₂ and the interlock pumped. The interlock was at <10⁻³ Torr with the EC at 34°C for 3½ minutes before being raised into the chamber.

Anomalies:

The output of QCM8 was somewhat irregular, showing variations of ~2 Hz over the duration of the test.

Figure 4. Example of Data Report Form

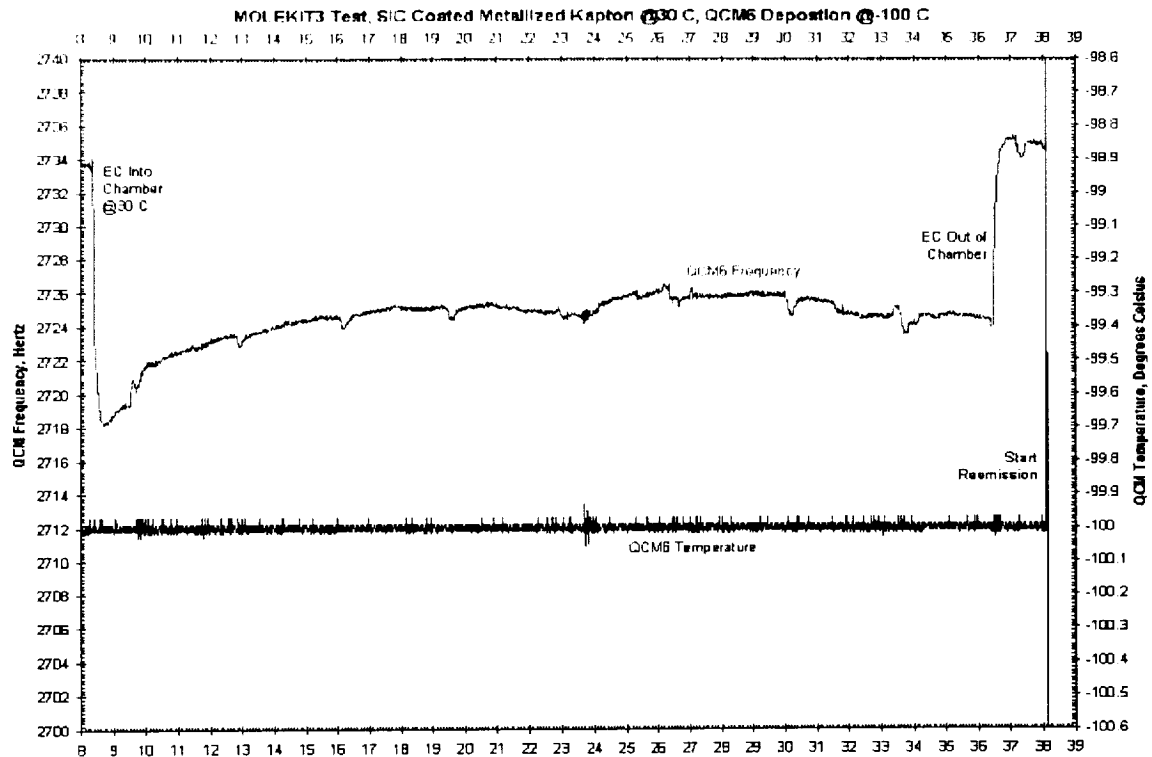


Figure 5. Detailed Time-Slice of QCM Data.

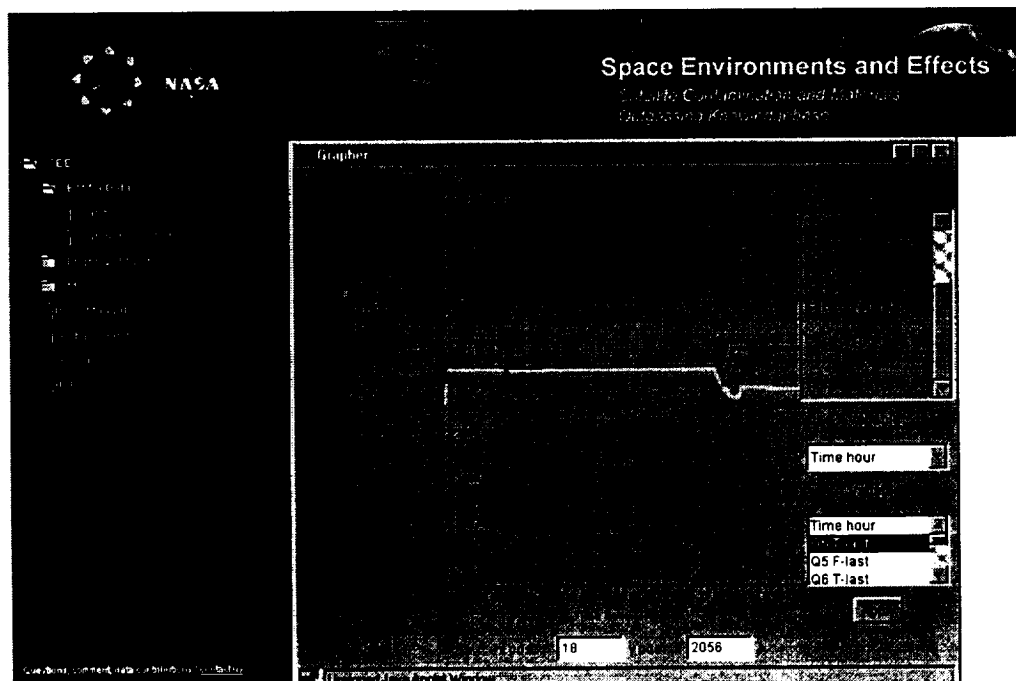


Figure 6. Example of Custom QCM Plot.

Flight QCM Data

QCMs have been flown on many spacecraft for the purpose of on-orbit measurements of contamination levels at various locations on or about a spacecraft⁵. The Knowledgebase has attempted to identify and make available in one location as much QCM flight data as possible. In some instances, raw or processed data was available; other times only papers or reports describing the results were available (also presented in PDF format). Raw or processed data is accessed the same as the data under the E-1559 folder. This flight data has been organized into Shuttle and Satellite subsets under the main Flight QCM Data folder.

Shuttle

NASA's Space Shuttle Program has been flying QCM's as far back as November 1981 aboard the Shuttle Columbia and as recently as STS-82 in February 1997 onboard the Shuttle Discovery, although more recent flights may have flown them as well. Most QCM's flown by the Shuttle, if not all, were part of a larger instrumentation package and were used for either monitoring contamination deposition or the measurement of environmental effects - such as atomic oxygen⁶. The QCM's flown on STS-82 helped measure contamination in the vicinity of the Hubble Space Telescope during the second servicing mission.

The Knowledgebase has identified seven different flight experiments and lists them as subsets under the Shuttle folder:

- Contamination Monitor Package (CMP)
- Evaluation of Oxygen Interaction with Materials Experiment (EOIM-3)
- Induced Environment Contamination Monitor (IECM)
- Plume Impingement Contamination (PIC)
- REturn FLux EXperiment (REFLEX)
- Shuttle Plume Impingement Experiment (SPIE)
- Shuttle Solar Backscatter Ultraviolet (SSBUV)

Each of these flight experiments has either published paper references and/or raw or processed data and is accessed in the same

manner as the E-1559 data.

Satellites

Numerous satellite QCM flight data references have been identified as well. This list is a little more extensive than the Shuttle's and has been further subdivided. Since Russia's MIR Space Station has flown three experiments, those particular experiments are listed under a separate MIR sub-folder:

- Astra-II Experiment
- EuroMir 95 ICA Experiment
- Optical Properties Monitor (OPM)

Because the International Space Station (ISS) is just now being built, it has not yet provided a wide variety of QCM flight experiments. Therefore, the data it did provide is listed under the Satellites sub-folder. As time goes by and ISS performs more experiments, this new data may be further subdivided into its own folder (like the MIR's) under the Satellites folder. The rest of the Satellites folder contains the following QCM flight experiments:

- Deep Space 1
- Discoverer
- Environment Verification Experiment for the Explorer Platform (EVEEP)
- Hubble Space Telescope (HST)
- International Space Station (ISS)
- Long Duration Exposure Facility (LDEF)
- Orbiting Geophysical Observatory (OGO)
- Spacecraft Charging AT High Altitudes (SCATHA)
- Spacelab 1

Once again, all the flight data contributors have also been listed.

MSX

The Midcourse Space Experiment (MSX), the premier space technology satellite of the Ballistic Missile Defense Organization (BMDO)⁷, was launched April 24, 1996, into a 99° inclination, 485-nautical-mile (900 km), near circular orbit for a planned mission duration of four years.⁸ A summarized primary objective of the experiment was to precisely measure the optical signatures from a broad

range of natural phenomena, including the Earth, its upper atmosphere, and celestial objects, as well as man-made targets. MSX carried five temperature-controlled QCM's for measuring mass deposition on external surfaces of the spacecraft.⁹ Analysis of this data will aid future spacecraft designers with new characterizations and a better understanding of the on-orbit mechanisms of optical instrument contamination.



Figure 7. MSX Satellite Sponsored by BMDO.

The Knowledgebase divides the MSX data into five sub-folders:

- Instruments – this folder gives detailed information concerning the optical instruments aboard the spacecraft. Images of the instruments and locations on the spacecraft are also provided.
- Films – this folder is divided in two sub-folders containing information about the satellite's ground preparations and operations of the on-orbit data collection.
- Gases – this folder contains detailed information on the gases measured around the spacecraft during flight. Sub-folders explain provide composition and trend information.
- Particles – this folder contains detailed information on the particles experienced by the spacecraft during flight, including occurrence, size and velocity as well as information on the optical sensors.
- Legacy – this folder provides a legacy of the mission, including spacecraft calibration, ground preparation and contamination modeling.

An executive summary with a detailed 'lessons learned' is provided at the bottom of the MSX folder and includes specific information gathered over the life of the mission.

All data and published-paper reference material is accessed the same way as the E-1559 data.

KNOWLEDGEBASE EXTRA FEATURES

The Knowledgebase also includes:

- An on-line user's manual;
- A global search capability that allows the user to select one or more keywords associated with the contamination subject matter that is used to sort through the published paper reference material;
- Glossary of terms;
- On-line help section designed to offer assistance with some of the technical aspects of the Knowledgebase.

KNOWLEDGEBASE REVISION

In an effort to continually make the Knowledgebase as user-friendly and helpful as possible, the SEE Program initiated a task in March 2001 to increase the usefulness and capability of the Knowledgebase.

This new work includes adding more specific information to the 'Sponsor' fields, cataloging the current materials into specific material types (i.e. films, coatings, honeycombs, etc.), and adding a search capability to the 'Type' and 'Sponsor' data fields in the E1559 database. This new search capability will allow more detailed and faster searches on specific materials and material types. This work will also incorporate some smaller-scale suggestions from users' comments, based upon their use of the Knowledgebase up to this point.

This work should be completed by June, 2001, and represents the SEE Program's commitment to providing the most up-to-date and user friendly products as possible.

EXPORT CONTROL GUIDELINES

The SEE Program's current technology development activities are governed by the US Government's export control regulations. Our technology products are developed mainly for US government, industry and academia customers. However, in certain circumstances, foreign organizations and countries are eligible to receive our products, provided they have a valid Technology Transfer Agreement with NASA Headquarters, subject to the US State Department's approval. But since NASA and the SEE Program are legally barred from competing with US industry, eligible foreign entities must also have a *legitimate and compelling* reason to obtain a requested product. Also, due to the ever changing global political climate, new opportunities may suddenly arise which necessitate relationships and Technology Transfer Agreements with foreign customers.

For more information regarding instructions detailing how to obtain the Knowledgebase, please see the SEE Program's website at:

<http://see.msfc.nasa.gov/>

under the "What's Hot" category, or contact:

Ms. Donna Hardage
NASA/Marshall Space Flight Center
256-544-2342
donna.hardage@msfc.nasa.gov

SUMMARY

NASA's Space Environments and Effects (SEE) Program, in cooperation with its participants, has made significant progress in the area of spacecraft contamination since 1993. As this paper illustrates, the Satellite Contamination and Materials Outgassing Knowledgebase will be an invaluable tool for the spacecraft design community. Our Program hopes to continually add additional materials and let the Knowledgebase evolve to meet the needs of the users. Our Program's success, however, depends upon the feedback from government, industry and academic programs on their anticipated needs and the value of our Program's products to their spacecraft systems development and operational activities.

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