

AD-A277 962



Spacecraft Environmental Anomalies Expert System

23 February 1994

Prepared by

H. C. KOONS and D. J. GORNEY
Space and Environment Technology Center
Technology Operations

Prepared for

SPACE AND MISSILE SYSTEMS CENTER
AIR FORCE MATERIEL COMMAND
2430 E. El Segundo Boulevard
Los Angeles Air Force Base, CA 90245

1078/ **94-10615**



DTIC
ELECTE
APR 08 1994
S G D

Engineering and Technology Group

DTIC QUALITY INSPECTED 3

 **THE AEROSPACE
CORPORATION**

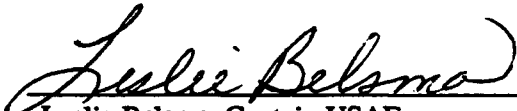
APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

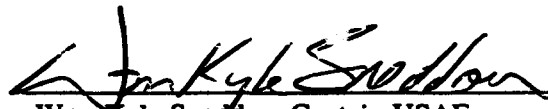
94-4-7-009

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. F04701-93-C-0094 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by A. B. Christensen, Principal Director, Space and Environment Technology Center. Capt. Leslie Belsma was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.


Leslie Belsma, Captain USAF
Project Officer


Wm. Kyle Sneedon, Captain USAF
Deputy, Industrial & International Division

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) TR-93(3940)-11			5. MONITORING ORGANIZATION REPORT NUMBER(S) SMC-TR-94-07	
6a. NAME OF PERFORMING ORGANIZATION The Aerospace Corporation Technology Operations		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Space and Missile Systems Center	
6c. ADDRESS (City, State, and ZIP Code) El Segundo, CA 90245-4691			7b. ADDRESS (City, State, and ZIP Code) Los Angeles Air Force Base Los Angeles, CA 90009-2960	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F04701-93-C-0094	
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS	
			PROGRAM ELEMENT NO.	PROJECT NO.
11. TITLE (Include Security Classification) Spacecraft Environmental Anomalies Expert System				
12. PERSONAL AUTHOR(S) Koons, Harry C. and Gorney, David J.				
13a. TYPE OF REPORT		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) 1994 February 23
15. PAGE COUNT 104				
16. SUPPLEMENTARY NOTATION				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Space environment, Satellite anomalies, Expert system, Spacecraft charging, Single-event upsets, radiation dose	
FIELD	GROUP	SUB-GROUP		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) An expert system has been developed by The Aerospace Corporation, Space and Environment Technology Center for use in the diagnosis of satellite anomalies caused by the space environment. The expert system is designed to determine the probable cause of an anomaly from the following candidates: surface charging, bulk charging, single-event effects, total radiation dose, and space-plasma effects. Such anomalies depend on the orbit of the satellite, the local plasma and radiation environment (which is highly variable), the satellite-exposure time, and the "hardness" of the circuits and components in the satellite. The expert system is a rule-based system that uses the Texas Instrument's Personal Consultant Plus expert-system shell. The expert system's knowledgebase includes about 200 rules, as well as a number of databases that contain information on spacecraft and their orbits, previous spacecraft anomalies, and the environment.				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

UNCLASSIFIED

PREFACE

We benefited greatly from technical discussions with Drs. Joe H. Allen, Gary Heckman, and Dan Wilkinson at NOAA; Dr. M. Lauriente at NASA Goddard Spaceflight Center; and with Drs. J. Fennell, A. L. Vampola, and W. A. Kolasinski at The Aerospace Corporation. The Spacecraft Anomaly Manager software used in our expert system is provided by the NOAA National Geophysical Data Center. This work was supported by the Aerospace Sponsored Research Program and by the U. S. Air Force Space and Missile Systems Center under Contract No. F04701-88-C-0089.

Accession For	
NTIS CRA&I	☒
DTIC TAB	☒
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS

INTRODUCTION.....	5
SYSTEM DESCRIPTION	7
CONFIDENCE FACTORS WITHIN THE SEAES EXPERT SYSTEM.....	15
POTENTIAL FOR FUTURE ADDITIONS TO THE SEAES.....	17
SUMMARY.....	19
REFERENCES.....	21
APPENDIX – EXPERT SYSTEM RULE BASE.....	23

FIGURES

1. Typical user environment without the benefit of an expert system.....	7
2. The architecture of the Space Environmental Anomalies Expert System.	8
3. Example of the graphical output available from SAM.....	10
4. Screen for selecting one or more types of problems associated with the anomaly under study.....	10
5. A typical rule relating magnetically-disturbed conditions to the cause surface charging.....	11
6. Technical question regarding the level for the accumulation of energetic electrons in the vehicle.....	12
7. Conclusions screen showing the result of a consultation.....	12
8. A sample rule set for a Gabbard Diagram.	18

TABLE

1. Application of the sample rule set to two example breakups.....	18
--	----

INTRODUCTION

The Spacecraft Environmental Anomalies Expert System (SEAES) is a microcomputer-based expert system that has been developed by The Aerospace Corporation, Space and Environment Technology Center (SETC) to aid in the objective analysis of environmentally induced satellite anomalies. An early version of the system (a prototype system) is described by Koons and Gorney.¹ At its present stage of development SEAES is a rule-based research system.²

On-orbit anomalies in satellite systems or subsystems occur quite often (several hundred are reported each year), and the number, frequency, and severity of the anomalies are likely to grow with the inevitable increases in spacecraft complexity in the future.⁴ Spacecraft anomalies have a wide variety of causes and a wide range of effects and severity. Design errors and inadequate quality control in parts selection and workmanship are examples of pre-flight engineering and construction errors that can lead to later anomalous behavior of components on orbit. Naturally, all mechanical and electrical components are susceptible to failure from excessive wear. Such failures and their effects can be difficult or impossible to anticipate. Many satellite anomalies result directly from improper commanding or operation (human error or ground-system error). For military space systems, the possibility of hostile action must be a consideration as well. Recent studies⁴ have shown that adverse interactions between spacecraft components and the natural space environment can have deleterious consequences comparable in severity and frequency to those caused by any other factor. Indeed, spacecraft anomalies attributable to electrostatic discharges (just one form of environmental interaction) have been known to cause command errors, spurious signals, phantom commands, degraded sensor performance, part failure, and even complete mission loss.⁴ Regardless of the severity of the anomaly, it is important to assess the cause of the problem in a timely and accurate manner so that appropriate corrective action can be taken.

Various aspects of the space environment can cause on-orbit satellite anomalies. The plasma environment (especially around geosynchronous orbit) can cause differential charging of satellite components on the surface of the vehicle.^{4,5,6} Surface charging can exceed breakdown voltages, and electrostatic discharges (ESDs) can occur with the potential to disrupt electronic circuits. Medium-energy electrons in the space-radiation environment can penetrate and become embedded in dielectric components such as cable insulation and circuit boards.⁷ This "bulk charging" phenomenon can result in ESD within the dielectric components, disrupting signals or devices within the affected subsystem.^{8,9} High-energy, trapped, radiation-belt particles, solar-flare protons, and galactic cosmic rays can cause single-event upsets (SEU) within microelectronic devices. The total-radiation dose of this same high-energy radiation leads to degradation of microelectronic devices and sensors. Other aspects of the environment, such as micrometeorites and debris, can cause mechanical disruption of the vehicle.¹¹ Anomalies resulting from any of these environmental causes can lead to transient malfunction or even to non-recoverable loss of the component or subsystem.

Typically, various agencies and individuals become involved in the identification and resolution of spacecraft anomalies. These include (1) the civilian or military satellite operators who must evaluate the anomaly in near real time in order to take the proper corrective action or to "safe" the vehicle; (2) space-environment forecasters, such as the Air Force Space Forecast Center (AFSFC)

or the NOAA Space Environment Services Center (SESC), who must assess the environmental situation in real time and issue warnings and alerts regarding hazardous conditions; (3) satellite contractors, who must assess the susceptibility of their vehicle and incorporate design modifications if the vehicle's on-orbit reliability proves to be inadequate; and (4) scientists and engineers, who develop an understanding of the processes by which the environment interacts with the satellite, with the goal of recommending mitigating procedures for future missions. A major difficulty with spacecraft anomaly diagnosis is that many of the people who must quickly and accurately diagnose the anomaly do not have immediate access to the required data or to the scientific or engineering expertise required to properly assess the role of the space environment in the anomaly. Thus, real-time spacecraft-anomaly diagnosis appears to be an ideal application for an expert system that can gather, format, display, and utilize appropriate data consistent with logical rules based on state-of-the-art engineering and scientific expertise. The objectivity in this approach is obtained by applying a consistent set of rules, the knowledgebase, to the inputs provided by the user. The results of consultations may differ as the user inputs or the databases available to the user differ.

SYSTEM DESCRIPTION

SEAES has been developed using a commercial expert-system shell, Texas Instrument's Personal Consultant Plus, and has been implemented for development and test on an IBM-compatible personal computer. The basic architecture of the system is designed to conform as much as possible to the working environment in which the system will ultimately be used while taking advantage of the data-processing, data-display, and decision-making functions of the personal-computer system. The design makes use of existing data sets.

Figure 1 shows the typical user environment without the benefit of an expert system. A user (anyone responsible for the diagnosis of a satellite anomaly) generally has access to a number of databases and to some amount of expertise. The databases might be computer-based or in the form of technical literature; the data might be on-site or at other agencies. The most pertinent data are the space-environment data, which include historical and real-time data on the space environment; the spacecraft-attributes data, which contain information on the vehicles (this might include component information, ephemerides, etc.); and spacecraft-anomaly data contain-

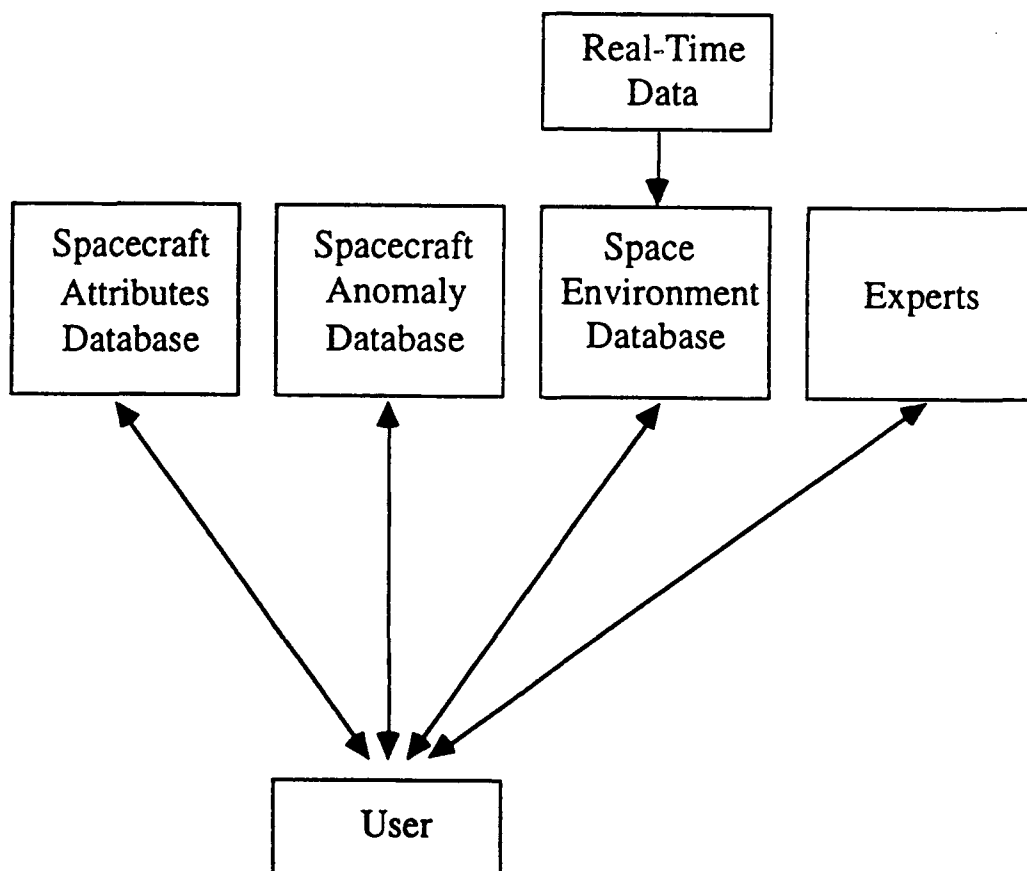


Figure 1. Typical user environment without the benefit of an expert system.

ing records of previous anomalies on the vehicle in question. Expert opinions are usually available over the phone or in consultations after the fact. Even under the best of circumstances the user has a formidable task to acquire and digest the information pertinent to his diagnosis. Often the user is not an expert in the space environment and its interaction with space vehicles and, thus, may not know what information is available or even what information is pertinent.

SEAES contains both an expert and a novice mode. The novice mode contains more descriptive material and antecedent rules that explain the conclusions reached by the system. It is primarily intended as a learning tool. Figure 2 shows the architecture of SEAES. The expert system not only provides access to a consolidated interactive knowledgebase, but also provides procedures to access and display information from the databases. The four databases shown in Fig. 2 represent different techniques for storing and accessing data. The Anomaly database is a dBASE III PLUS file provided by the National Geophysical Data Center in Boulder, CO. It presently contains information on approximately 3000 historical anomalies. The Attributes database consists of a dBASE III PLUS file for a small selection of satellites. It contains launch dates and orbital information. The Environment database is an ASCII text file that contains an historical record of the geophysical parameter known as Kp, the planetary magnetic index. Kp is a measure of the severity of magnetic storms within the Earth's magnetosphere. This file is accessed by a C-language interface between the expert system and the ASCII file.

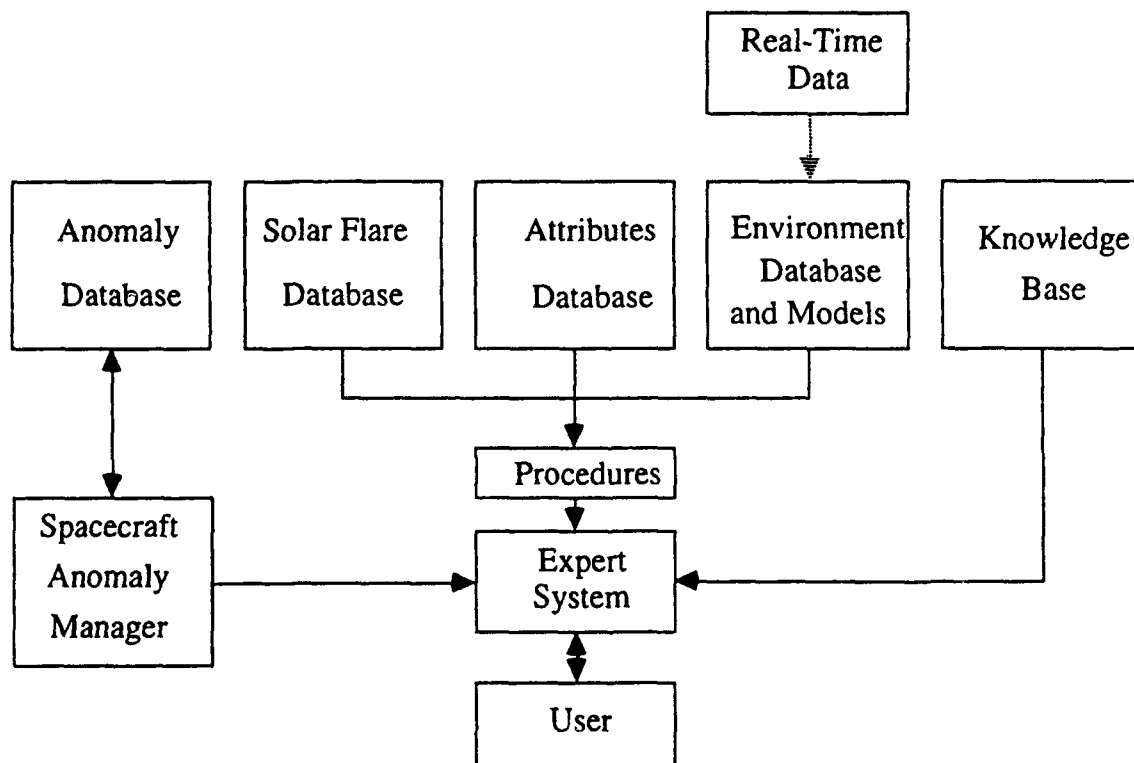


Figure 2. The architecture of the Space Environmental Anomalies Expert System.

The Environment database can be automatically updated for recent values of Kp. This feature has been tested but not yet implemented in the research system. Recent data can be collected by a remote computer from the satellite broadcasts by the Space Environment Services Center, Boulder, CO. They are stored in a text file similar to the Environment database. When requested by a user, the most recent data in the file can be automatically transferred via telephone modem to the consultation computer for consideration in the consultation.

The Solar Flare database is a dBASE III PLUS data file containing the date and time-of-occurrence of X-Class solar X-ray flares. The user can request a report of such flares that occurred near the time of the anomaly.

The user selects the databases that he wishes to use during the consultation. This permits a flexible configuration at different sites where one or more of the databases may not be available. In practice, the expert system could be operated (albeit with diminished effectiveness) even if one or more of the prescribed databases were unavailable.

If the user chooses to use the Anomaly database, the expert system automatically queries the database via a dBASE III interface and obtains a list of the satellites contained in the database. It then presents the satellite selection screen to the user. Many of the names are coded to conceal the identity of the actual vehicle. Two types of reports are generated. A Satellite report lists all of the anomalies in the database for a single vehicle. This can be used to search for the recurrence of similar anomalies on the same or related spacecraft. The recurrence of anomalies in specific local-time sectors or in limited regions of the orbit for example is an indication of a possible environmental cause. A Date report lists all of the anomalies in the database for a three-day time period around the date entered by the user. Frequently more than one vehicle is affected by a severe geomagnetic storm. The occurrence of similar anomalies on more than one vehicle in a short time period is another indication of a possible environmental cause.

The expert system provides the user access to the Spacecraft Anomaly Manager (SAM) software, which has been developed by the National Geophysical Data Center. The SAM program provides a full range of functions for managing, displaying, and analyzing the data, including functions to examine single anomalies or sets of anomalies for environmental relationships. Histograms of local time and seasonal frequency-of-occurrence provided by this program can reveal distinct patterns for spacecraft that are susceptible to static-charge buildup and ESD. Figure 3 shows one example of the graphical output available from the SAM. The SAM program also provides a means of updating the Anomaly database after the expert-system consultation.

The knowledgebase, currently consisting of about 200 rules, has been constructed based on personal interviews with space scientists and engineers who are experts in each of the fields covered by the expert system. The expert system is arranged into frames that allow the knowledgebase structure to be divided into logically different, but related, segments. The frames include the causes of the anomaly, such as surface charging, bulk charging, single-event effects, total-radiation dose, and space-plasma effects, as well as frames to instantiate the various reports and graphs produced by the system. This organization allows the system to be easily expanded to include a broader range of environmental causes of anomalies.

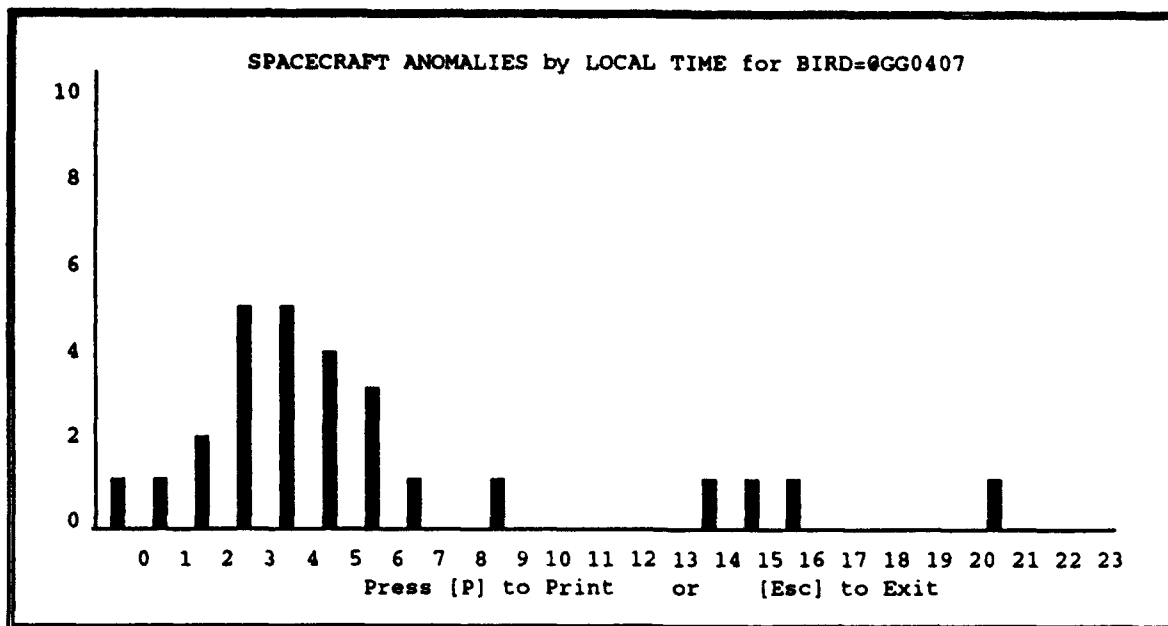


Figure 3. Example of the graphical output available from SAM.

Expert users prefer to see a graphical display of the environmental parameters in addition to the values extracted by the expert system in its normal processing of the rules. This assists them in understanding the state of the environment at the time of an anomaly. For this purpose, the expert system provides a graphic display of Kp for the time period from 12 days before the date of the anomaly to 1 day after the date of the anomaly. This allows the user to see recent levels of activity, thus putting the time period of the anomaly in perspective.

As progress is made through the consultation, a number of specific questions are asked. Figure 4 shows the screen for selecting one or more types of problems associated with the anomaly under

Select all of the types of problems that are associated with this anomaly.

--	☐	PHANTOM_COMMAND
--	☐	LOGIC_UPSET
--	☐	ELECTRICAL
--	☐	MECHANICAL
--	☒	SENSOR
--	☐	SOFTWARE
--	☐	MEMORY
--	☐	THERMAL
--	☐	PART_FAILURE
--	☐	TELEMETRY_ERROR
--	☐	SYSTEM_FAILURE
--	☐	MISSION_FAILURE
--	☐	OTHER

1. Use arrow keys or first letter of item to position cursor.
2. Select all applicable responses.
3. After making selections, press RETURN/ENTER to continue.

Figure 4. Screen for selecting one or more types of problems associated with the anomaly under study.

study. The responses to this screen are used to instantiate one or more of the frames for the five environmental causes of anomalies.

The expert system uses the backward-chaining inference method to establish the facts that it needs to determine the probable cause or causes of an anomaly. The knowledge is contained in a set of rules in the form: IF *premise* THEN *conclusion*. It also uses certainty factors to measure the certainty or confidence that one has in a fact or a rule. A typical rule relating the magnetically disturbed conditions to the cause surface-charging is shown in Fig. 5. The rule uses three parameters — RECURRENCE, PERIODICITY, and MAG_STATE_CURRENT. The definition of the RECURRENCE parameter is also shown in Fig. 5. The expert system collects facts from the user by means of questions. Figure 6 shows a technical question regarding the level for the accumulation of energetic electrons in the vehicle. This requires access to satellite environmental data plus an analysis or expert opinion to relate the measurements from the satellite making the measurements to the one experiencing the anomaly. Help is always available by pressing a function key on the computer keyboard. The help window then appears as shown in Fig. 6. The help window contains a more detailed explanation of the question and a person or organization to contact for assistance.

If the accumulated fluence is unknown, the user is asked if he wishes to view a graph of the daily average flux of relativistic electrons at geosynchronous orbit. If the response is "YES," then a graph of the flux of >3 MeV electrons is displayed for a time period from 12 days prior to the anomaly to 1 day after the anomaly. The flux is calculated using a neural-network model that

```

RULE059
=====
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (anomalies recur during magnetically disturbed
times)
If 1) the recurrence of the anomaly, and
   2) the recurrence is MAGNETICALLY_DISTURBED, and
   3) the level of magnetic activity in the magnetosphere is
DISTURBED,
Then there is suggestive evidence (50%) that the cause of the anomaly is
SURFACE_CHARGING.

IF   :: (RECURRENCE AND PERIODICITY = MAGNETICALLY_DISTURBED AND
        MAG_STATE_CURRENT = DISTURBED )
THEN :: (CAUSE = SURFACE_CHARGING CF 50)

RECURRENCE
=====
TRANSLATION :: (the recurrence of the anomaly)
PROMPT :: ("Has this type of anomaly occurred several times (at
least 4 or 5 times) on this spacecraft?" )
TYPE :: YES/NO
USED-BY :: (RULE024 RULE025 RULE040 RULE059 RULE019 RULE020
RULE110 RULE165 RULE054 RULE188 RULE189 RULE190 RULE191 RULE192 RULE193
RULE194 RULE039 RULE201 RULE043 )
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

Figure 5. A typical rule relating magnetically disturbed conditions to the cause surface-charging.

Select the appropriate level for the accumulated fluence of energetic electrons above 300 keV for several days prior to the anomaly.

VERY_HIGH
HIGH
INTERMEDIATE
LOW
UNKNOWN

Help:

The accumulated fluence of penetrating electrons is the integral of the electron flux above 300 keV for several days before the anomaly. It is measured in units of (electrons/cm²). For assistance in determining the fluence contact D. Gorney (310/336-6821) at the Aerospace Corp.

VERY_HIGH	>10 ¹²	HIGH	10 ¹¹ - 10 ¹²
INTERMEDIATE	10 ¹⁰ - 10 ¹¹	LOW	<10 ¹⁰

** End - RETURN/ENTER to continue

1. Use the arrow keys or first letter of item to position the cursor.
2. Press RETURN/ENTER to continue.

Figure 6. Technical question regarding the level for the accumulation of energetic electrons in the vehicle.

predicts the daily averaged electron flux based on the daily sum of the planetary magnetic index ΣKp .¹⁰ The graph assists the user in determining if bulk charging is the cause of the anomaly.

Single-event upsets are caused by the deposition of energy in digital devices when a very energetic particle passes through the device. The probability of an anomaly thus depends on the hardness of the device as well as on the environment. A list of device types is presented for the user's selection if the Single Event Upset frame is instantiated. A series of rules in this frame contains qualitative information on the hardness of each type of technology as determined by laboratory measurements of their upset cross sections.

The result of a consultation is given on a conclusions screen such as the one shown in Fig. 7. A confidence level is given for each possible cause. Note that a negative conclusion is listed when-

Conclusions:

The cause of the anomaly is as follows: SURFACE_CHARGING (90%)
Not BULK_CHARGING (72%)

** End - RETURN/ENTER to continue

Figure 7. Conclusions screen showing the result of a consultation.

ever a specific cause can be ruled out. "Unknown" is also a possible and plausible conclusion, depending on the amount of data available.

The user may then review the consultation with the option to modify one or more of his responses to see how they affect the conclusion. Also, the user may choose to re-enter the Spacecraft Anomaly Manager program to update the Anomaly database based on the results of the consultation.

The performance and functionality of the system has been tested on historical cases from the Anomaly database, on anomalies that occurred on the SCATHA spacecraft, and on a number of operational spacecraft.

The Appendix contains a listing of the expert-system parameters and the rule base. The rules are listed in both the Abbreviated Rule Language (ARL) and in plain English. The listing is organized by frame.

CONFIDENCE FACTORS WITHIN THE SEAES EXPERT SYSTEM

In addition to determining the likely cause or causes of a satellite anomaly based on available data, SEAES expresses its conclusions in terms of a confidence (or certainty) factor (CF). A tabulation of the confidence factors for each cause is maintained throughout the consultation as a standard feature of the expert-system shell. Confidence factors offer valuable information to a user. In satellite-anomaly diagnoses, conclusions are rarely black or white, and it is informative to know whether a given conclusion is merely suggestive or fairly certain. In SEAES, the confidence factors are displayed only at the conclusion of a consultation. They are expressed in percentage units, ranging from -100% (a certain negative result) through 0% (no information) to 100% (a certain positive result).

In a consultation, uncertainty can arise in two ways. First, the facts or data can have some associated uncertainty. For example, when a user is asked if a set of satellite anomalies tends to recur in a particular pattern, he might wish to qualify his response with a confidence factor. Second, even when data are certain, the implication of the data might be somewhat uncertain. For example, an expert might regard a positive response to the recurrence pattern of satellite anomalies as providing only suggestive evidence to the conclusion that the anomalies can be attributed to a particular cause. From the standpoint of a logical rule (IF: *data*, THEN: *conclusion*), the first source of uncertainty arises from the "IF" portion of the rule, while the second type of uncertainty arises from the "THEN" portion of the rule. Thus, the confidence factor associated with a particular rule (CF_{rule}) is

$$CF_{rule} = (CF_{if} * CF_{then}) / 100, \quad (1)$$

where CF_{if} represents the uncertainty of the input and CF_{then} represents the uncertainty in the conclusion given that the input is absolutely true. For example, if the user is 60% confident in the validity of his input, and an affirmation of the rule implies 50% confidence in a particular conclusion, then the resulting confidence factor is 30%.

In practice, many individual rules combine to determine a final conclusion. Therefore, confidence factors are updated continuously throughout a consultation in order to increase or decrease confidence in a particular conclusion as inputs are provided that either corroborate or contradict the conclusion. Within the expert system, a previous confidence level ($CF_{previous}$) is modified on the basis of a new rule through the following relationship:

$$CF_{new} = CF_{previous} + CF_{rule} * (100 - CF_{previous}) / 100 \quad (2)$$

Here CF_{new} represents the updated (or cumulative) confidence factor. For example, if the previous confidence factor had been 30%, and a new rule introduced an added confidence of 50%,

then the cumulative confidence factor would be $CF_{\text{new}} = 30 + 50 * (100 - 30) / 100 = 65\%$. Confidence factors for each cause are updated in this manner by every rule that pertains to the cause.

In practice, conclusions with confidence factors less than 20% are not displayed. Conclusions with confidence factors between 20% and 50% are considered to represent a "weakly suggestive" result, 50% to 80% a "suggestive" result, and 80% to 100% a "strongly suggestive" result.

POTENTIAL FOR FUTURE ADDITIONS TO THE SEAES

The architecture of SEAES is such that other causes could be added if a satisfactory rule base were developed. Some examples that have been considered are ionospheric scintillation (pertinent to commanding errors and noisy telemetry links) and orbital debris (pertinent to mechanical breakups or damage). Rules and databases are being compiled for each of these categories, and frames will be added to the expert system after verification and testing has been completed.

As an example of our approach to the addition of new frames, consider the case of orbital debris diagnosis. The rationale for including orbital debris in an analysis of satellite anomalies is that debris is an ever-increasing threat to spacecraft.¹¹ The effects of orbital debris on spacecraft range from minor erosion of surfaces to more severe mechanical damage or even breakup in the case of collisions with large objects. From a system design standpoint, it is useful to understand the cause of a mechanical breakup. For example, breakups can be caused by internal component ruptures or explosions of pressurized systems such as fuel, attitude control gases, or batteries. Design changes would be called for in these cases. Design mitigation would not be appropriate for collisional breakups, however. While orbital debris databases offer some guidelines for assessing the probabilities of collisions for spacecraft, they do not offer any insight into a particular occurrence of a breakup. An expert system would be able to help the user interpret the available databases in terms of the particular anomaly under study. Furthermore, it is possible to examine orbital data on the resulting fragments to specifically identify the cause of the breakup as being due to collision or explosion.

A common and useful data display for understanding satellite breakups is the Gabbard Diagram.¹¹ The Gabbard Diagram plots orbital data (specifically, the apogee and perigee altitudes versus the orbital period) for each of the trackable fragments following a breakup. The distribution, symmetry, and scatter of the points can all be used in analysis of the event. These rules can be incorporated into a knowledgebase that, when applied to actual data, can be used to assess the nature of a breakup.

A sample rule set (not yet verified within the context of an expert system) is shown in Fig. 8.¹¹ This rule set is meant to discriminate between the breakup of a spacecraft caused by a collision or by an explosion. The quantities b and A_1 are parameters of a numerical fit to a Gabbard diagram.

A set of rules such as those shown in Fig. 8 can be added easily as a separate frame of the expert system. Similarly, rule sets for other causes, such as ionospheric scintillation or others, can be added as well. The individual rules would be addressed independently, and confidence factors for the cause of the breakup would be computed as discussed earlier. Table 1 shows example applications of this rule set to two breakups, one thought to be due to collision and the other to an explosion. Note that the cumulative confidence factors for the cause produces a "suggestive" result in each case.

Perform exponential fit to Gabbard diagram:

If $b < 2.0$ then CAUSE=COLLISION CF25

If $b > 2.0$ then CAUSE=EXPLOSION CF25

Perform polynomial fit to Gabbard diagram:

If $A_1 < .15$ then CAUSE=COLLISION CF25

If $A_1 > .15$ then CAUSE=EXPLOSION CF25

Dispersion of large pieces: If any fragments larger than 1 m^2 are dispersed over 50% of the total range of fragments, then CAUSE=EXPLOSION CF10 ELSE CAUSE=COLLISION CF10.

Asymmetry of large fragments: If fragments larger than 1 m^2 are asymmetrically distributed about the parent, then CAUSE=EXPLOSION CF15 ELSE CAUSE=COLLISION CF15.

Orderedness of dispersion: If the Gabbard diagram is very ordered, then CAUSE=COLLISION CF15 ELSE CAUSE=EXPLOSION CF15.

Velocity analysis: If average velocity imparted decreases as fragment size increases, then CAUSE=COLLISION CF10 ELSE CAUSE=EXPLOSION CF10.

Figure 8. A sample rule set for a Gabbard Diagram.

Table 1. Application of the sample rule set to two example breakups.

Satellite	Exponential	Polynomial	Dispersion	Asymmetry	Order	Delta V	Cause
1981-53A	$b=1.07$	$A_1=-0.064$	Yes	Yes	Yes	Yes	Collision ^a
1977-65B	$b=4.13$	$A_1=-0.207$	Yes	No	No	No	Explosion ^b

^aConfidence Factor for Satellite 1981-53A is 69%

^bConfidence Factor for Satellite 1977-65B is 63%

SUMMARY

The Spacecraft Environmental Anomalies Expert System has been developed and tested by The Aerospace Corporation, Space and Environment Technology Center. The system is a research system that aids in the analysis of satellite anomalies that may be caused by interactions with the space environment. Currently, the system deals with anomalies caused by electrostatic discharges resulting from surface or bulk charging, single-event upsets, total radiation dose, and space-plasma effects. It includes four databases and a knowledgebase consisting of about 200 rules. The system also contains software to access, display, and modify the data. Frames can be added easily to the expert system. It is anticipated that orbital debris and ionospheric scintillation are likely topics for treatment in future versions of this system. The expert system is now being tested at operational sites and is available on EnviroNET,¹ a centralized, computer-based information database on natural and induced space environments.¹² Potential users of the system include space environment forecasters at the Air Force Space Forecast Center, civilian and military satellite operators, and spacecraft contractors.

¹ For information on EnviroNET, contact the EnviroNET Office at the Goddard Space Flight Center, Tel: (301) 286-5690.

REFERENCES

1. Koons, H. C. and Gorney, D. J., "Spacecraft Environmental Anomalies Expert System," *Proceedings of the NASA Conference on Artificial Intelligence for Space Applications*, NASA CP-3013, 1988, pp. 457-467.
2. Waterman, Donald A., *A Guide to Expert Systems*, Addison-Wesley Publishing Co., New York, NY, 1986.
3. Robinson, P. A., "Spacecraft Environmental Anomalies Handbook," AFGL-TR-89-0222, Air Force Geophysics Laboratory, Hanscom, Mass., Aug. 1989.
4. Fennell, J. F., Koons, H. C., Leung, M. S., and Mizera, P. F., "A Review of SCATHA Satellite Results: Charging and Discharging," ESA-SP-198, European Space Agency, Noordwijk, The Netherlands, 1983.
5. Mullen, E. G., Gussenhoven, M. S., and Garret, H. B., "A 'Worst-Case Spacecraft Environment as Observed by SCATHA on 24 April 1979," AFGL-TR-81-0231, Air Force Geophysics Laboratory, Hanscom, Mass., 1981.
6. Mizera, P. F. and Boyd, G. "A Summary of Spacecraft Charging Results," *Journal of Spacecraft and Rockets*, Vol. 20, Sept.-Oct. 1983, pp. 438-443.
7. Vampola, A. L., "Thick Dielectric Charging on High-Altitude Spacecraft," *Journal of Electrostatics*, Vol. 20, Jan. 1987, pp. 21-30.
8. Wennaas, E. P., "Spacecraft Charging Effects by the High Energy Natural Environment," *IEEE Transactions on Nuclear Science*, Vol. NS-24, 1977, pp. 2281-2284.
9. Beers, B. L., "Radiation Induced Signals in Cables," *IEEE Transactions on Nuclear Science*, Vol. NS-24, 1977, pp. 2429-2434.
10. Koons, H. C. and Gorney, D. J., "A Neural Network Model of the Relativistic Electron Flux at Geosynchronous Orbit," *Journal of Geophysical Research*, Vol. 96, No. A4, 1991, pp. 5549-5556.
11. Johnson, N. L. and McNight, D. S., *Artificial Space Debris*, Orbit Book Company, Malabar, Florida, 1987.
12. Vampola, A. L., Hall, W. N., and Lauriente, M., "EnviroNET: An Interactive Space Environment Information Resource," *Proceedings of the Conference on High-Energy Radiation Background in Space*, AIP Conference Proceedings 186, Sanibel, FL, 1987.

APPENDIX

EXPERT SYSTEM RULE BASE

DOMAIN :: "SPACECRAFT ENVIRONMENTAL ANOMALIES"
ROOT FRAME :: ROOT

=====
Global KB data
=====

FRAME STRUCTURE ::

ROOT
 BULK_CHARGING
 SEU
 SOLAR_FLARE
 SURFACE_CHARGING
 TOTAL_DOSE
 ANOMALY_DB
 VEHICLE_RPT
 DATE_RPT
 PLOTKP
 PARTICLES/PLASMA
 PLOTENET

KB Files :: (PLOTENET "ANOMALY.k1" PARTICLES/PLASMA "ANOMALY.k2" PLOTKP "
 ANOMALY.k3" SOLAR_FLARE "ANOMALY.k4" SAM_SFT "ANOMALY.k5"
 DATE_RPT "ANOMALY.k6" VEHICLE_RPT "ANOMALY.k7" ANOMALY_DB "
 ANOMALY.k8" TOTAL_DOSE "ANOMALY.k9" SURFACE_CHARGING "
 ANOMALY.k10" SEU "ANOMALY.k11" BULK_CHARGING "ANOMALY.k12")

Parameter groups :: (PLOTENET-PARMS PARTICLES/PLASMA-PARMS PLOTKP-PARMS
 SOLAR_FLARE-PARMS DATE_RPT-PARMS VEHICLE_RPT-PARMS
 ANOMALY_DB-PARMS TOTAL_DOSE-PARMS
 SURFACE_CHARGING-PARMS SEU-PARMS BULK_CHARGING-PARMS
 ROOT-PARMS)

Rule groups :: (PLOTENET-RULES PARTICLES/PLASMA-RULES PLOTKP-RULES
 SOLAR_FLARE-RULES DATE_RPT-RULES VEHICLE_RPT-RULES
 ANOMALY_DB-RULES TOTAL_DOSE-RULES SURFACE_CHARGING-RULES
 SEU-RULES BULK_CHARGING-RULES ROOT-RULES META-RULES)

Number of rules :: 204

Number of meta-rules :: 0

Variables :: (\$\$TITLE DOMAIN RUNTIME)

TEXTAGS :: ()

Functions :: (DOSCALL DOSCLS GET_JDATE GET_KP GET_KPMAX INTERVAL
 THREE_HR_INTERVAL)

```
=====
Frame :: ROOT
=====
```

```
IDENTIFIER :: ROOT-
GOALS :: (ORBIT PLOT-KP PLOT-ENET REPORTS CONSIDER_CAUSE CAUSE)
INITIALDATA :: (MODE DATABASE DATE UNIVERSAL_TIME_HR UNIVERSAL_TIME_MIN
LOCAL_TIME_HR LOCAL_TIME_MIN LONGITUDE SATELLITE PROBLEM
)
PROMPTEVER :: ( "
" :ATTR (YELLOW HIGH) "Spacecraft
Environmental Anomalies" :LINE 3 :ATTR (WHITE HIGH) "
This program helps you determine if the cause of a"
:LINE " spacecraft anomaly is related to the
space environment." :LINE 2 " The causes of
anomalies covered by this research system are" :LINE "
surface charging, bulk charging, single event upsets,
" :LINE " total radiation dose, energetic
particle phenomena, and" :LINE " space plasma
effects." )
DISPLAYRESULTS :: (CAUSE)
PARMGROUP :: ROOT-PARMS
RULEGROUPS :: (ROOT-RULES)
FORM-HEADER :: ("Please enter the following information for this anomaly
(press RETURN for" :LINE "UNKNOWN):" )
OFFSPRING :: (BULK_CHARGING SEU SURFACE_CHARGING TOTAL_DOSE ANOMALY_DB
PLOTKP PARTICLES/PLASMA PLOTENET )
ROOT-PARMS :: (ALTITUDE APOGEE CAUSE CHECK_ELECTRICAL CONSIDER_CAUSE
DATABASE DATE FLUENCE INCL INCLINATION INTERVAL_NUMBER
IRON JULIAN_DATE JULIAN_LAUNCH_DATE LAUNCH_DATE
LOCAL_TIME LOCAL_TIME_HR LOCAL_TIME_MIN LONGITUDE
LT_RECUR LT_SECTOR MODE ORBIT PERIGEE PERIODICITY
PLOT-ENET PLOT-KP PROBLEM RECURRENCE REPORTS SATELLITE
UNIVERSAL_TIME_HR UNIVERSAL_TIME_INTERVAL
UNIVERSAL_TIME_MIN )
ROOT-RULES :: (RULE041 RULE097 RULE102 RULE103 RULE104 RULE105 RULE109
RULE115 RULE116 RULE132 RULE133 RULE134 RULE135 RULE136
RULE137 RULE138 RULE139 RULE140 RULE141 RULE142 RULE143
RULE172 RULE173 RULE174 RULE175 RULE176 RULE177 RULE178
RULE179 RULE180 RULE181 RULE182 RULE183 RULE184 RULE185
RULE186 RULE187 )
```

=====
ROOT-PARMS
=====

ALTITUDE

=====

TRANSLATION :: (The altitude of the satellite)
PROMPT :: (Select the altitude of the satellite.)
TYPE :: SINGLEVALUED
EXPECT :: (GEOSYNCHRONOUS LOW_ALTITUDE INTERMEDIATE_ALTITUDE
 HIGH_ALTITUDE INTERPLANETARY OTHER)
UPDATED-BY :: (RULE102 RULE133 RULE134 RULE135 RULE136 RULE132 RULE137)
ANTECEDENT-IN :: (RULE026 RULE030)
USED-BY :: (RULE017 RULE016 RULE041 RULE090 RULE165 RULE143)
HELP :: (Low altitude orbits are primarily within the ionosphere, i.e.
 below 1000 km. Intermediate altitude orbits are primarily
 within the Van Allen radiation belts, i.e. altitudes from 1000
 km to 30,000 km. High altitude orbits extend well beyond
 geosynchronous orbit, e.g. apogees from 10 to 20 earth radii.
 Interplanetary orbits cover all spacecraft that operate
 outside of the earth's magnetosphere.)

APOGEE

=====

TRANSLATION :: (the apogee of the satellite)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE173 RULE174 RULE175 RULE176 RULE177 RULE178 RULE179
 RULE180 RULE181 RULE182 RULE183 RULE184 RULE185 RULE186
 RULE187)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (100 100000)

CAUSE

=====

TRANSLATION :: (the cause of the anomaly)
TYPE :: MULTIVALUED
UPDATED-BY :: (RULE017 RULE021 RULE022 RULE037 RULE016 RULE024 RULE025
 RULE040 RULE006 RULE007 RULE008 RULE033 RULE032 RULE028
 RULE023 RULE005 RULE058 RULE059 RULE068 RULE088 RULE070
 RULE072 RULE085 RULE098 RULE113 RULE112 RULE120 RULE121
 RULE122 RULE123 RULE145 RULE146 RULE147 RULE109 RULE019
 RULE020 RULE110 RULE066 RULE165 RULE170 RULE167 RULE166
 RULE168 RULE169 RULE111 RULE054 RULE188 RULE189 RULE190
 RULE191 RULE192 RULE055 RULE056 RULE057 RULE193 RULE194
 RULE039 RULE201 RULE202 RULE203 RULE043 RULE035 RULE036
 RULE171 SREFMARK RULE086 RULE087 RULE078)
UPDATED-IN :: (RULE026)
ANTECEDENT-IN :: (RULE027)
USED-BY :: (SREFMARK RULE086 RULE087 RULE078)

CHECK_ELECTRICAL

=====

TRANSLATION :: (an electrical anomaly in a thermal or mechanical subsystem)
PROMPT :: ("Can the problem be attributed to an electrical device in the mechanical or" :LINE "thermal subsystem?")
TYPE :: YES/NO
USED-BY :: (RULE109)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

CONSIDER_CAUSE

=====

TRANSLATION :: (the possible causes of the anomaly that you wish to consider)
PROMPT :: ("Select all of the causes that you wish to consider for this anomaly.")
TYPE :: ASK-ALL
EXPECT :: (ALL BULK_CHARGING SURFACE_CHARGING SEU TOTAL_DOSE PARTICLES/PLASMA)
UPDATED-BY :: (RULE172)
HELP :: ("You may limit your consultation to a subset of" :LINE "the causes by selecting only those which you wish" :LINE "to consider. If you want to consider all causes" :LINE "you must select ALL.")

DATABASE

=====

TRANSLATION :: (a database available to the user)
PROMPT :: (Select all of the databases that are available for this system.)
TYPE :: ASK-ALL
EXPECT :: (ANOMALY FLARE KP)
ANTECEDENT-IN :: (RULE053)
USED-BY :: (RULE164 SREFMARK RULE060 RULE052)
HELP :: ("The ANOMALY database is the NOAA Satellite" :LINE "Anomaly database from the National Geophysical" :LINE "Data Center."
:LINE 2 "The FLARE database contains X class x-ray flares"
:LINE 2 "The KP database contains values of the planetary"
:LINE "magnetic index, Kp, since 1932.")

DATE

=====

TRANSLATION :: (the date on which the anomaly occurred)
PROMPT :: ("The Greenwich date on which the anomaly occurred. Use the following" :LINE "format" :ATTR (YELLOW HIGH) "MONTH-DAY-YEAR"
:ATTR (WHITE HIGH) ". For example enter March 29, 1987 as"
:ATTR (YELLOW HIGH) "3-29-87" :ATTR (WHITE HIGH) ".")
TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT
USED-BY :: (RULE115)
FORM-SPEC :: (4 1 6 1 8)

FLUENCE

=====

TRANSLATION :: (The integrated flux of > 3 MeV electrons at geosynchronous orbit)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE195)
USED-BY :: (RULE200 RULE199 RULE198 RULE197)

INCL

====

TRANSLATION :: (inclination of the satellite as read from a Dbase III
file)

TYPE :: SINGLEVALUED

USED-BY :: (RULE138 RULE139 RULE140 RULE141 RULE142 RULE173 RULE174
RULE175 RULE176 RULE177 RULE178 RULE179 RULE180 RULE181
RULE182 RULE183 RULE184 RULE185 RULE186 RULE187)

INCLINATION

=====

TRANSLATION :: (the inclination of the plane of the orbit with respect
to the earth's equatorial plane)

PROMPT :: (Select the inclination of the satellite with respect to the
earth's equatorial plane.)

TYPE :: SINGLEVALUED

EXPECT :: (EQUATORIAL LOW_INCLINATION HIGH_INCLINATION POLAR OTHER)

UPDATED-BY :: (RULE041 RULE133 RULE134 RULE135 RULE136 RULE132 RULE138
RULE139 RULE140 RULE141 RULE142 RULE137)

ANTECEDENT-IN :: (RULE026 RULE030)

USED-BY :: (RULE017 RULE016 RULE091 RULE089)

HELP :: ("Low inclination orbits are below 30 deg. High" :LINE "
inclination orbits are above 60 deg. Polar orbits" :LINE "are
above 80 deg. Interplanetary orbits are" :LINE "undefined.")

CERTAINTY-FACTOR-RANGE :: UNKNOWN

INTERVAL_NUMBER

=====

TRANSLATION :: (the number of the KP interval for the day)

PROMPT :: (Enter the Kp interval number for the day)

TYPE :: SINGLEVALUED

EXPECT :: INTEGER

UPDATED-IN :: (RULE097)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

RANGE :: (1 8)

CONTAINED-IN :: (RULE097)

IRON

====

TRANSLATION :: (the International Reference Number for the satellite)

PROMPT :: ("Select the International Reference Number for the satellite
that has" :LINE "experienced the anomaly.")

TYPE :: SINGLEVALUED

EXPECT :: (((DBASE-RETRIEVE SATELLIT (QUAL NAME <> DUMMY) NAME)))

NOTUSED :: "THIS PARAMETER IS NOT CURRENTLY USED 2/8/90"

CERTAINTY-FACTOR-RANGE :: UNKNOWN

JULIAN_DATE

=====

TRANSLATION :: (the Julian date)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE115)

USED-BY :: (RULE163 RULE164 RULE051 RULE047 SREFMARK RULE060 RULE052)

CONTAINED-IN :: (RULE163 RULE051)

JULIAN_LAUNCH_DATE

=====

TRANSLATION :: (the Julian date on which the satellite was launched)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE116)

LAUNCH_DATE

=====

TRANSLATION :: (the date the satellite was launched)
PROMPT :: ("Enter the date on which the satellite was launched. Use the following" :LINE "format:" :ATTR (YELLOW HIGH) " MONTH-DAY-YEAR." :ATTR (WHITE HIGH) " For example enter March 29, 1987 as" :ATTR (YELLOW HIGH) "3-29-87.")
TYPE :: SINGLEVALUED
EXPECT :: SINGLE-LINE-INPUT
USED-BY :: (RULE116)
HELP :: ("The launch date is required to compute the total" :LINE " radiation dose to the vehicle from the time it" :LINE "was launched until the anomaly occurred." :LINE "If you only know an approximate date enter it in" :LINE "the full date format. Use the center of a time" :LINE "period for an approximate date. For example enter" :LINE "March 1987 as 3-15-87. Enter the third quarter" :LINE "of 1986 as 8-15-86.")
CERTAINTY-FACTOR-RANGE :: UNKNOWN

LOCAL_TIME

=====

TRANSLATION :: (the local time at the satellite)
PROMPT :: ("Enter the local time at the satellite in the form 21.5 for 21:30 LT.")
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
UPDATED-BY :: (RULE103 RULE105)
UPDATED-IN :: (SREFMARK RULE104)
ANTECEDENT-IN :: (SREFMARK RULE104)
USED-BY :: (RULE098)
HELP :: ("The local time at the satellite is the time on" :LINE "the ground at the nadir, i.e. the point that is" :LINE "vertically downward from the vehicle.")
CERTAINTY-FACTOR-RANGE :: UNKNOWN
CONTAINED-IN :: (SREFMARK RULE104)
RANGE :: (0 23.99)

LOCAL_TIME_HR

=====

PROMPT :: (Local Time hr:)
TYPE :: SINGLEVALUED
EXPECT :: INTEGER
USED-BY :: (RULE105)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
FORM-SPEC :: (10 1 10 16 2)
RANGE :: (0 23)
CONTAINED-IN :: (RULE105)

LOCAL_TIME_MIN

=====

PROMPT :: (min:)
TYPE :: SINGLEVALUED
EXPECT :: INTEGER
CONTAINED-IN :: (RULE105)
DEFAULT :: (0)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
FORM-SPEC :: (10 19 10 24 2)
RANGE :: (0 59)

LONGITUDE

=====

TRANSLATION :: (the east longitude of the satellite at the time of the anomaly)
PROMPT :: (East Longitude (degrees):)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE103)
RANGE :: (0 359)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
FORM-SPEC :: (12 1 12 27 5)
CONTAINED-IN :: (RULE103 RULE143)

LT_RECUR

=====

TRANSLATION :: (the recurrence of an anomaly in a specific local-time sector.)
PROMPT :: ("Indicate the degree of certainty that you have that this type of anomaly has" :LINE "a strong tendency to recur in one local time sector, for example the" :LINE "nightside or the dayside of the earth?")
TYPE :: YES/NO
USED-BY :: (RULE019 RULE020 RULE110 RULE054 RULE188 RULE189 RULE190 RULE191 RULE192 RULE193 RULE194 RULE043)
HELP :: (The anomaly should have occurred a few times (i.e. six or more) before you have confidence that the recurrence is related to a specific local-time sector. Generally we are asking if the anomaly has a very strong tendency to occur within a 12 hour range in local time.)
CERTAINTY-FACTOR-RANGE :: POSITIVE

LT_SECTOR

=====

TRANSLATION :: (the local time sector, dayside or nightside, at the time of the anomaly)
PROMPT :: (Select YES for the local time quadrants in which this type of anomaly has occurred.)
TYPE :: ASK-ALL
EXPECT :: (MIDNIGHT DAWN NOON DUSK)
USED-BY :: (RULE054 RULE188 RULE189 RULE190 RULE191 RULE192 RULE193 RULE194 RULE043)
HELP :: (The local time quadrants are defined as follows: :LINE :TAB
Midnight is 21:00 to 03:00 :LINE :TAB Dawn is 03:00 to 09:00
:LINE :TAB Noon is 09:00 to 15:00 :LINE :TAB Dusk is 15:00 to 21:00.)

MODE

====

TRANSLATION :: (the way in which the program responds to the user)
PROMPT :: (Select the level of experience for this consultation.)
TYPE :: SINGLEVALUED
EXPECT :: (EXPERT NOVICE)
ANTECEDENT-IN :: (RULE029 RULE027)
USED-BY :: (RULE172)
HELP :: (In the NOVICE mode additional text material will be given
after some selections. This will introduce the novice user to
the phenomena and provide assistance in obtaining the most
important data required to reach a conclusion with a high
degree of confidence.)

ORBIT

=====

TRANSLATION :: (the orbit of the satellite)
PROMPT :: ("Select the closest orbit for the satellite that had the
anomaly.")
TYPE :: SINGLEVALUED
EXPECT :: (DMSP ERBS GEOSAT GEOSYNC GPS IRAS LANDSAT LOW1 LOW2 MOLNIYA
NOVA STS28HI STS28LO STS57HI STS57LOW TIROS)
UPDATED-BY :: (RULE173 RULE174 RULE175 RULE176 RULE177 RULE178 RULE179
RULE180 RULE181 RULE182 RULE183 RULE184 RULE185 RULE186
RULE187)
USED-BY :: (RULE133 RULE134 RULE135 RULE136 RULE132 RULE151 RULE152
RULE153 RULE154 RULE155 RULE156 RULE150 RULE117 RULE144
RULE158 RULE157 RULE160 RULE161 RULE162 RULE159 RULE137)
HELP :: ("Perigee x Apogee and Inclination for selected" :LINE "orbits."
:LINE " km x km deg" :LINE " 120 x 400 90.0 LOW1" :LINE "
170 x 230 96.0 LOW2" :LINE " 250 x 250 57.0 STS57LOW"
:LINE " 300 x 300 28.5 STS28LOW" :LINE " 350 x 350 57.0
STS57HI" :LINE " 500 x 500 28.5 STS28HI" :LINE " 601 x
605 57.0 ERBS" :LINE " 699 x 700 98.2 LANDSAT" :LINE "
782 x 786 108.0 GEOSAT" :LINE " 808 x 826 98.7 TIROS"
:LINE " 815 x 830 99.0 DMSP" :LINE " 890 x 909 99.1
IRAS" :LINE " 1150 x 1198 90.1 NOVA" :LINE " 500 x 39500
64.9 MOLNIYA" :LINE "19900 x 20474 63.4 GPS" :LINE "35800 x
35800 0.0 GEOSYNC")
CERTAINTY-FACTOR-RANGE :: UNKNOWN

PERIGEE

=====

TRANSLATION :: (the perigee of the satellite)
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE173 RULE174 RULE175 RULE176 RULE177 RULE178 RULE179
RULE180 RULE181 RULE182 RULE183 RULE184 RULE185 RULE186
RULE187)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (100 1000000)

PERIODICITY

=====

TRANSLATION :: (the recurrence)

PROMPT :: (Set your confidence level for all of the times that have
been identified for the recurrence of this specific anomaly.
)

TYPE :: ASK-ALL

EXPECT :: (SATELLITE_SPIN_PERIOD DIURNAL SOLAR_ROTATION SOLAR_CYCLE
SPRING/FALL MAGNETICALLY_DISTURBED OF_HIGH_PENETRATING_FLUX
)

USED-BY :: (RULE024 RULE025 RULE040 RULE058 RULE059 RULE113 RULE112
RULE111 RULE057 RULE039 RULE201)

HELP :: ("If the satellite is spinning, an anomaly ccurring" :LINE "at
the spin period may be related to solar" :LINE "illumination. A
diurnal (24-hr) period suggests a" :LINE "local time
dependence. A solar rotaion (27-day)" :LINE "period correlates
with the rotation period of the" :LINE "sun and may be related
to solar flares. Solar" :LINE "cycle (11-year) periodicities
may be related to" :LINE "solar flares, atmospheric drag,
increases in" :LINE "atomic oxygen at low altitudes, or an
increase in" :LINE "magnetospheric substorms. Geosynchronous"
:LINE "satellites are within the shadow of the earth" :LINE "
during their eclipse seasons in the spring and" :LINE "fall.
Anomalies in the spring and fall suggest a" :LINE "solar
illumination, surface charging, or thermal" :LINE "cause.")

CERTAINTY-FACTOR-RANGE :: POSITIVE

PLOT-ENET

=====

TRANSLATION :: (plot the graph of ~MeV electron flux at geosync)

TYPE :: YES/NO

UPDATED-BY :: (RULE195)

PLOT-KP

=====

TRANSLATION :: (plot the graph of Kp for the date requested)

TYPE :: YES/NO

UPDATED-BY :: (RULE107)

PROBLEM

=====

TRANSLATION :: (the type of anomaly that occurred)

PROMPT :: ("Select all of the types of problems that are associated with
this anomaly.")

TYPE :: ASK-ALL

EXPECT :: (PHANTOM_COMMAND LOGIC_UPSET ELECTRICAL MECHANICAL SENSOR
SOFTWARE MEMORY THERMAL PART_FAILURE TELEMETRY_ERROR
SYSTEM_FAILURE MISSION_FAILURE OTHER)

USED-BY :: (RULE109 RULE066 RULE170 RULE167 RULE166 RULE168 RULE169)

RECURRENCE

=====

TRANSLATION :: (the recurrence of the anomaly)

PROMPT :: ("Has this type of anomaly occurred several times (at least 4
or 5 times) on this spacecraft?")

TYPE :: YES/NO

USED-BY :: (RULE024 RULE025 RULE040 RULE059 RULE019 RULE020 RULE110
RULE165 RULE054 RULE188 RULE189 RULE190 RULE191 RULE192
RULE193 RULE194 RULE039 RULE201 RULE043)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

REPORTS

TRANSLATION :: (dBase reports)
TYPE :: YES/NO
UPDATED-BY :: (RULE204)

SATELLITE

TRANSLATION :: (the name of the satellite)
PROMPT :: (Select the name of the satellite that has experienced the
 anomaly.)
TYPE :: SINGLEVALUED
EXPECT :: (((DBASE-RETRIEVE SATELLIT (QUAL NAME <> DUMMY) NAME)))
USED-BY :: (RULE102 RULE143)
ACTIVE-VALUE :: (DO-ALL (DBASE-MRETRIEVE INCL "satellit" (QUAL NAME =
 SATELLITE) INCL APOGEE "satellit" (QUAL NAME =
 SATELLITE) APOGEE PERIGEE "satellit" (QUAL NAME =
 SATELLITE) PERIGEE LAUNCH_DATE "satellit" (QUAL NAME
 = SATELLITE) LNCH_DATE))
CONTAINED-IN :: (RULE143)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

UNIVERSAL_TIME_HR

TRANSLATION :: (Universal Time hr:)
PROMPT :: (Universal Time hr:)
TYPE :: SINGLEVALUED
EXPECT :: INTEGER
ANTECEDENT-IN :: (RULE097)
USED-BY :: (RULE103)
CONTAINED-IN :: (RULE097 RULE103)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
FORM-SPEC :: (8 1 8 20 2)
RANGE :: (0 23)

UNIVERSAL_TIME_INTERVAL

TRANSLATION :: (the local time interval in which the anomaly occurred)
PROMPT :: (Select the local time interval in which the present anomaly
 occurred. The intervals are given in hours for the beginning
 and end of the interval.)
TYPE :: SINGLEVALUED
EXPECT :: (0-3 3-6 6-9 9-12 12-15 15-18 18-21 21-24)
UPDATED-IN :: (RULE097)
USED-BY :: (SREFMARK RULE060 RULE052)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

UNIVERSAL_TIME_MIN

TRANSLATION :: (the minutes after the hour for the universal time)
PROMPT :: (min:)
TYPE :: SINGLEVALUED
EXPECT :: INTEGER
DEFAULT :: (0)
CONTAINED-IN :: (RULE103)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
FORM-SPEC :: (8 23 8 28 2)
RANGE :: (0 59)

```

=====
ROOT-RULES
=====

```

RULE041

```
=====
```

```

SUBJECT :: ROOT-RULES
DESCRIPTION :: (relates geosynchronous to equatorial)
If The altitude of the satellite is GEOSYNCHRONOUS,
Then it is definite (100%) that the inclination of the plane of the orbit
with respect to the earth's equatorial plane is EQUATORIAL.

```

```

IF :: (ALTITUDE = GEOSYNCHRONOUS)
THEN :: (INCLINATION = EQUATORIAL)

```

RULE097

```
=====
```

```

SUBJECT :: ROOT-RULES
ANTECEDENT :: YES
DESCRIPTION :: (gets the UT 3-hour interval from the UT hour)
If Universal Time hr: is known,
Then 1) it is definite (100%) that the number of the KP interval for the day
is the 3-hour interval number for the KP index, and
2) it is definite (100%) that the local time interval in which the
anomaly occurred is return the three hour interval in the form
THREE_HR_INTERVAL INTERVAL_NUMBER for KP index.

```

```

IF :: (UNIVERSAL_TIME_HR IS KNOWN)
THEN :: (INTERVAL_NUMBER = (INTERVAL UNIVERSAL_TIME_HR) AND
UNIVERSAL_TIME_INTERVAL = (THREE_HR_INTERVAL INTERVAL_NUMBER)
)

```

RULE102

```
=====
```

```

SUBJECT :: ROOT-RULES
DESCRIPTION :: (relates geosyn satellite to geosynchronous orbit)
If the name of the satellite is GEOSYNC,
Then it is definite (100%) that The altitude of the satellite is
GEOSYNCHRONOUS.

```

```

IF :: (SATELLITE = GEOSYNC)
THEN :: (ALTITUDE = GEOSYNCHRONOUS)

```

RULE103

```
=====
```

```

SUBJECT :: ROOT-RULES
DESCRIPTION :: (calculates local time from UT and longitude)
If 1) the east longitude of the satellite at the time of the anomaly is
greater than or equal to 0, and
2) Universal Time hr: is greater than or equal to 0,
Then it is definite (100%) that the local time at the satellite is [[Universal
Time hr: plus [the minutes after the hour for the universal time divided by 60
]] plus [the east longitude of the satellite at the time of the anomaly
divided
by 15]].

```

```

IF :: (LONGITUDE >= 0 AND UNIVERSAL_TIME_HR >= 0)
THEN :: (LOCAL_TIME = ((UNIVERSAL_TIME_HR + (UNIVERSAL_TIME_MIN / 60))
+ (LONGITUDE / 15) ) )

```


RULE104

=====

SUBJECT :: ROOT-RULES

ANTECEDENT :: YES

DESCRIPTION :: (scales local time to 0 to 23)

If the local time at the satellite is greater than or equal to 24,
Then it is definite (100%) that the local time at the satellite is [the local
time at the satellite minus 24].

IF :: (LOCAL_TIME >= 24)

THEN :: (LOCAL_TIME = (LOCAL_TIME - 24))

RULE105

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (calculates local time from the hour and minute)

If LOCAL_TIME_HR is greater than or equal to 0,
Then it is definite (100%) that the local time at the satellite is [
LOCAL_TIME_HR plus [LOCAL_TIME_MIN divided by 60]].

IF :: (LOCAL_TIME_HR >= 0)

THEN :: (LOCAL_TIME = (LOCAL_TIME_HR + (LOCAL_TIME_MIN / 60)))

RULE109

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Cause for mechanical and thermal problems)

If 1) 1) the type of anomaly that occurred is MECHANICAL, or
2) the type of anomaly that occurred is THERMAL, and
2) the type of anomaly that occurred is not ELECTRICAL, and
3) an electrical anomaly in a thermal or mechanical subsystem,
Then 1) there is strongly suggestive evidence (90%) that the cause of the
anomaly is not SURFACE_CHARGING, and
2) there is strongly suggestive evidence (90%) that the cause of the
anomaly is not BULK_CHARGING, and
3) there is strongly suggestive evidence (90%) that the cause of the
anomaly is not SEU, and
4) there is strongly suggestive evidence (90%) that the cause of the
anomaly is not TOTAL_DOSE.

IF :: ((PROBLEM = MECHANICAL OR PROBLEM = THERMAL) AND PROBLEM !=
ELECTRICAL AND CHECK_ELECTRICAL)

THEN :: (CAUSE != SURFACE_CHARGING CF 90 AND CAUSE != BULK_CHARGING CF
90 AND CAUSE != SEU CF 90 AND CAUSE != TOTAL_DOSE CF 90)

RULE115

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (DOSCALL calculates the Julian date from the string
DATE. DATE is passed to JDATE.EXE. The result is
returned as a ling in file JDATE.DAT. The value is
imported into the parameter JULIAN_DATE.)

If the date on which the anomaly occurred is known,
Then 1) , and
2) retrieve data from an external source.

IF :: (DATE IS KNOWN)

THEN :: ((DOSCALL JDATE DATE) AND READ-DOS-FILE "JDATE.DAT" INDEX 1
JULIAN_DATE)

```

RULE116
=====
SUBJECT :: ROOT-RULES
DESCRIPTION :: (DOSCALL calculates the Julian date from the string
                LAUNCH_DATE. LAUNCH_DATE is passed to JDATE.EXE. The
                result is returned as a long in file JDATE.DAT. The
                value is then imported into the parameter JDATE. )
If the date the satellite was launched is known,
Then 1) , and
     2) retrieve data from an external source.

IF :: (LAUNCH_DATE IS KNOWN)
THEN :: ((DOSCALL JDATE LAUNCH_DATE) AND READ-DOS-FILE "JDATE.DAT"
        INDEX 1 JULIAN_LAUNCH_DATE )

RULE132
=====
SUBJECT :: ROOT-RULES
DESCRIPTION :: (Relates geosynchronous orbits with altitude.)
If the orbit of the satellite is GEOSYNC,
Then 1) it is definite (100%) that The altitude of the satellite is
     GEOSYNCHRONOUS, and
     2) it is definite (100%) that the inclination of the plane of the orbit
        with respect to the earth's equatorial plane is EQUATORIAL.

IF :: (ORBIT = GEOSYNC)
THEN :: (ALTITUDE = GEOSYNCHRONOUS AND INCLINATION = EQUATORIAL)

RULE133
=====
SUBJECT :: ROOT-RULES
DESCRIPTION :: (Low altitude polar orbits)
If 1) the orbit of the satellite is LOW1, or
   2) the orbit of the satellite is LOW2,
Then 1) it is definite (100%) that The altitude of the satellite is
     LOW_ALTITUDE, and
     2) it is definite (100%) that the inclination of the plane of the orbit
        with respect to the earth's equatorial plane is POLAR.

IF :: (ORBIT = LOW1 OR ORBIT = LOW2)
THEN :: (ALTITUDE = LOW_ALTITUDE AND INCLINATION = POLAR)

RULE134
=====
SUBJECT :: ROOT-RULES
DESCRIPTION :: (28 deg shuttle orbit)
If 1) the orbit of the satellite is STS28LOW, or
   2) the orbit of the satellite is STS28HI,
Then 1) it is definite (100%) that The altitude of the satellite is
     LOW_ALTITUDE, and
     2) it is definite (100%) that the inclination of the plane of the orbit
        with respect to the earth's equatorial plane is LOW_INCLINATION.

IF :: (ORBIT = STS28LOW OR ORBIT = STS28HI)
THEN :: (ALTITUDE = LOW_ALTITUDE AND INCLINATION = LOW_INCLINATION)

```

RULE135

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (57 deg shuttle and erbs orbit)

- If 1) the orbit of the satellite is STS57LOW, or
 2) the orbit of the satellite is STS57HI, or
 3) the orbit of the satellite is ERBS,
 Then 1) it is definite (100%) that The altitude of the satellite is
 LOW_ALTITUDE, and
 2) it is definite (100%) that the inclination of the plane of the orbit
 with respect to the earth's equatorial plane is HIGH_INCLINATION.

IF :: (ORBIT = STS57LOW OR ORBIT = STS57HI OR ORBIT = ERBS)

THEN :: (ALTITUDE = LOW_ALTITUDE AND INCLINATION = HIGH_INCLINATION)

RULE136

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (low altitude weather satellite type orbits)

- If 1) the orbit of the satellite is LANDSAT, or
 2) the orbit of the satellite is GEOSAT, or
 3) the orbit of the satellite is TIROS, or
 4) the orbit of the satellite is DMSP, or
 5) the orbit of the satellite is IRAS, or
 6) the orbit of the satellite is NOVA,
 Then 1) it is definite (100%) that The altitude of the satellite is
 LOW_ALTITUDE, and
 2) it is definite (100%) that the inclination of the plane of the orbit
 with respect to the earth's equatorial plane is HIGH_INCLINATION.

IF :: (ORBIT = LANDSAT OR ORBIT = GEOSAT OR ORBIT = TIROS OR ORBIT =
 DMSP OR ORBIT = IRAS OR ORBIT = NOVA)

THEN :: (ALTITUDE = LOW_ALTITUDE AND INCLINATION = HIGH_INCLINATION)

RULE137

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (molniya and gps orbits)

- If 1) the orbit of the satellite is MOLNIYA, or
 2) the orbit of the satellite is GPS,
 Then 1) it is definite (100%) that The altitude of the satellite is
 INTERMEDIATE_ALTITUDE, and
 2) it is definite (100%) that the inclination of the plane of the orbit
 with respect to the earth's equatorial plane is HIGH_INCLINATION.

IF :: (ORBIT = MOLNIYA OR ORBIT = GPS)

THEN :: (ALTITUDE = INTERMEDIATE_ALTITUDE AND INCLINATION =
 HIGH_INCLINATION)

RULE138

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (defines equatorial inclination)

- If inclination of the satellite as read from a Dbase III file is less than 5
 but greater than or equal to -5,
 Then it is definite (100%) that the inclination of the plane of the orbit with
 respect to the earth's equatorial plane is EQUATORIAL.

IF :: (INCL BT -5 5)

THEN :: (INCLINATION = EQUATORIAL)

RULE139

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (defines low inclination)

- If 1) inclination of the satellite as read from a Dbase III file is less than 30 but greater than or equal to 5, or
2) inclination of the satellite as read from a Dbase III file is less than -30 but greater than or equal to -5,

Then it is definite (100%) that the inclination of the plane of the orbit with respect to the earth's equatorial plane is LOW_INCLINATION.

IF :: (INCL BT 5 30 OR INCL BT -5 -30)

THEN :: (INCLINATION = LOW_INCLINATION)

RULE140

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (defines intermediate inclination)

- If 1) inclination of the satellite as read from a Dbase III file is less than 60 but greater than or equal to 30, or
2) inclination of the satellite as read from a Dbase III file is less than -60 but greater than or equal to -30,

Then it is definite (100%) that the inclination of the plane of the orbit with respect to the earth's equatorial plane is INTERMEDIATE_INCLINATION.

IF :: (INCL BT 30 60 OR INCL BT -30 -60)

THEN :: (INCLINATION = INTERMEDIATE_INCLINATION)

RULE141

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (defines high inclination)

- If 1) inclination of the satellite as read from a Dbase III file is less than 80 but greater than or equal to 60, or
2) inclination of the satellite as read from a Dbase III file is less than -80 but greater than or equal to -60,

Then it is definite (100%) that the inclination of the plane of the orbit with respect to the earth's equatorial plane is HIGH_INCLINATION.

IF :: (INCL BT 60 80 OR INCL BT -60 -80)

THEN :: (INCLINATION = HIGH_INCLINATION)

RULE142

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (defines polar inclination)

- If 1) inclination of the satellite as read from a Dbase III file is less than 90 but greater than or equal to 80, or
2) inclination of the satellite as read from a Dbase III file is less than -90 but greater than or equal to -80,

Then it is definite (100%) that the inclination of the plane of the orbit with respect to the earth's equatorial plane is POLAR.

IF :: (INCL BT 80 90 OR INCL BT -80 -90)

THEN :: (INCLINATION = POLAR)

RULE143

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Retrieve satellite longitude from data base)

If 1) the name of the satellite is known, and
2) The altitude of the satellite is GEOSYNCHRONOUS,
Then retrieve data base values for several parameters.

IF :: (SATELLITE IS KNOWN AND ALTITUDE = GEOSYNCHRONOUS)

THEN :: (DBASE-MRETRIEVE LONGITUDE "satellit" (QUAL NAME = SATELLITE)
LONG)

RULE172

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (In novice mode consider all causes)

If the way in which the program responds to the user is NOVICE,
Then it is definite (100%) that the possible causes of the anomaly that you
wish to consider is ALL.

IF :: (MODE = NOVICE)

THEN :: (CONSIDER_CAUSE = ALL)

RULE173

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for LOW1 orbit)

If 1) the perigee of the satellite is less than 145 but greater than or
equal to 96, and
2) the apogee of the satellite is less than 480 but greater than or equal
to 320, and
3) inclination of the satellite as read from a Dbase III file is less
than 100 but greater than or equal to 80,
Then it is definite (100%) that the orbit of the satellite is LOW1.

IF :: (PERIGEE BT 96 145 AND APOGEE BT 320 480 AND INCL BT 80 100)

THEN :: (ORBIT = LOW1)

RULE174

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for LOW2 orbit)

If 1) the perigee of the satellite is less than 205 but greater than or
equal to 135, and
2) the apogee of the satellite is less than 276 but greater than or equal
to 185, and
3) inclination of the satellite as read from a Dbase III file is less
than 105 but greater than or equal to 85,
Then it is definite (100%) that the orbit of the satellite is LOW2.

IF :: (PERIGEE BT 135 205 AND APOGEE BT 185 276 AND INCL BT 85 105)

THEN :: (ORBIT = LOW2)

RULE175

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for STS57L orbit)

If 1) the perigee of the satellite is less than 300 but greater than or equal to 200, and
 2) the apogee of the satellite is less than 300 but greater than or equal to 200, and
 3) inclination of the satellite as read from a Dbase III file is less than 70 but greater than or equal to 45,
 Then it is definite (100%) that the orbit of the satellite is STS57L.

IF :: (PERIGEE BT 200 300 AND APOGEE BT 200 300 AND INCL BT 45 70)
 THEN :: (ORBIT = STS57L)

RULE176

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for STS28L orbit)

If 1) the perigee of the satellite is less than 360 but greater than or equal to 240, and
 2) the apogee of the satellite is less than 360 but greater than or equal to 240, and
 3) inclination of the satellite as read from a Dbase III file is less than 35 but greater than or equal to 20,
 Then it is definite (100%) that the orbit of the satellite is STS28L.

IF :: (PERIGEE BT 240 360 AND APOGEE BT 240 360 AND INCL BT 20 35)
 THEN :: (ORBIT = STS28L)

RULE177

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for STS57H orbit)

If 1) the perigee of the satellite is less than 420 but greater than or equal to 280, and
 2) the apogee of the satellite is less than 420 but greater than or equal to 280, and
 3) inclination of the satellite as read from a Dbase III file is less than 70 but greater than or equal to 45,
 Then it is definite (100%) that the orbit of the satellite is STS57H.

IF :: (PERIGEE BT 280 420 AND APOGEE BT 280 420 AND INCL BT 45 70)
 THEN :: (ORBIT = STS57H)

RULE178

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for STS28H orbit)

If 1) the perigee of the satellite is less than 600 but greater than or equal to 400, and
 2) the apogee of the satellite is less than 600 but greater than or equal to 400, and
 3) inclination of the satellite as read from a Dbase III file is less than 35 but greater than or equal to 20,
 Then it is definite (100%) that the orbit of the satellite is STS28H.

IF :: (PERIGEE BT 400 600 AND APOGEE BT 400 600 AND INCL BT 20 35)
 THEN :: (ORBIT = STS28H)

RULE179

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for ERBS orbit)

If 1) the perigee of the satellite is less than 720 but greater than or equal to 480, and
2) the apogee of the satellite is less than 720 but greater than or equal to 480, and
3) inclination of the satellite as read from a Dbase III file is less than 70 but greater than or equal to 45,
Then it is definite (100%) that the orbit of the satellite is ERBS.

IF :: (PERIGEE BT 480 720 AND APOGEE BT 480 720 AND INCL BT 45 70)
THEN :: (ORBIT = ERBS)

RULE180

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for LANDSAT orbit)

If 1) the perigee of the satellite is less than 770 but greater than or equal to 630, and
2) the apogee of the satellite is less than 770 but greater than or equal to 630, and
3) inclination of the satellite as read from a Dbase III file is less than 105 but greater than or equal to 90,
Then it is definite (100%) that the orbit of the satellite is LANDSAT.

IF :: (PERIGEE BT 630 770 AND APOGEE BT 630 770 AND INCL BT 90 105)
THEN :: (ORBIT = LANDSAT)

RULE181

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for DMSP and TIROS orbit)

If 1) the perigee of the satellite is less than 900 but greater than or equal to 735, and
2) the apogee of the satellite is less than 920 but greater than or equal to 750, and
3) inclination of the satellite as read from a Dbase III file is less than 110 but greater than or equal to 90,
Then it is definite (100%) that the orbit of the satellite is DMSP.

IF :: (PERIGEE BT 735 900 AND APOGEE BT 750 920 AND INCL BT 90 110)
THEN :: (ORBIT = DMSP)

RULE182

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for GEOSAT orbit)

If 1) the perigee of the satellite is less than 860 but greater than or equal to 700, and
2) the apogee of the satellite is less than 860 but greater than or equal to 700, and
3) inclination of the satellite as read from a Dbase III file is less than 120 but greater than or equal to 95,
Then it is definite (100%) that the orbit of the satellite is GEOSAT.

IF :: (PERIGEE BT 700 860 AND APOGEE BT 700 860 AND INCL BT 95 120)
THEN :: (ORBIT = GEOSAT)

RULE183

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for IRAS orbit)

- If
- 1) the perigee of the satellite is less than 980 but greater than or equal to 800, and
 - 2) the apogee of the satellite is less than 1000 but greater than or equal to 820, and
 - 3) inclination of the satellite as read from a Dbase III file is less than 110 but greater than or equal to 90,

Then it is definite (100%) that the orbit of the satellite is IRAS.

IF :: (PERIGEE BT 800 980 AND APOGEE BT 820 1000 AND INCL BT 90 110)

THEN :: (ORBIT = IRAS)

RULE184

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for NOVA orbit)

- If
- 1) the perigee of the satellite is less than 1265 but greater than or equal to 1035, and
 - 2) the apogee of the satellite is less than 1320 but greater than or equal to 1080, and
 - 3) inclination of the satellite as read from a Dbase III file is less than 99 but greater than or equal to 81,

Then it is definite (100%) that the orbit of the satellite is NOVA.

IF :: (PERIGEE BT 1035 1265 AND APOGEE BT 1080 1320 AND INCL BT 81 99

)

THEN :: (ORBIT = NOVA)

RULE185

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for MOLNIYA orbit)

- If
- 1) the perigee of the satellite is less than 600 but greater than or equal to 400, and
 - 2) the apogee of the satellite is less than 47500 but greater than or equal to 31600, and
 - 3) inclination of the satellite as read from a Dbase III file is less than 78 but greater than or equal to 52,

Then it is definite (100%) that the orbit of the satellite is MOLNIYA.

IF :: (PERIGEE BT 400 600 AND APOGEE BT 31600 47500 AND INCL BT 52 78

)

THEN :: (ORBIT = MOLNIYA)

RULE186

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for GPS orbit)

If 1) the perigee of the satellite is less than 23800 but greater than or equal to 15900, and
2) the apogee of the satellite is less than 24600 but greater than or equal to 16300, and
3) inclination of the satellite as read from a Dbase III file is less than 75 but greater than or equal to 50,
Then it is definite (100%) that the orbit of the satellite is GPS.

IF :: (PERIGEE BT 15900 23800 AND APOGEE BT 16300 24600 AND INCL BT 50 75)

THEN :: (ORBIT = GPS)

RULE187

=====

SUBJECT :: ROOT-RULES

DESCRIPTION :: (Parameters for GEOSYNC orbit)

If 1) the perigee of the satellite is less than 43000 but greater than or equal to 28600, and
2) the apogee of the satellite is less than 43000 but greater than or equal to 28600, and
3) inclination of the satellite as read from a Dbase III file is less than 10 but greater than or equal to 0,
Then it is definite (100%) that the orbit of the satellite is GEOSYNC.

IF :: (PERIGEE BT 28600 43000 AND APOGEE BT 28600 43000 AND INCL BT 0 10)

THEN :: (ORBIT = GEOSYNC)

```
=====
Frame :: BULK_CHARGING
=====
```

```
IDENTIFIER :: "BULK_CHARGING-"
TRANSLATION :: (to determine if the cause of the anomaly is bulk charging
)
PARENTS :: (ROOT)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
($OR
(SAME FRAME CONSIDER_CAUSE BULK_CHARGING)
(SAME FRAME CONSIDER_CAUSE ALL)))
DISPLAYRESULTS :: YES
PARMGROUP :: BULK_CHARGING-PARMS
RULEGROUPS :: (BULK_CHARGING-RULES)
BULK_CHARGING-PARMS :: (ACCUM_FLUEN AP DAYS_FOR_KPMAX HARDNESS
KPMAX_RECENT MAG_STATE_RECENT OTHER_SAT PEN_FLUX
SAME_ORBIT )
BULK_CHARGING-RULES :: (RULE002 RULE003 RULE004 RULE005 RULE006 RULE007
RULE008 RULE016 RULE017 RULE019 RULE020 RULE021
RULE022 RULE023 RULE024 RULE025 RULE026 RULE027
RULE028 RULE029 RULE030 RULE032 RULE033 RULE035
RULE036 RULE037 RULE038 RULE039 RULE040 RULE052
RULE053 RULE094 RULE095 RULE096 RULE148 RULE196
RULE197 RULE198 RULE199 RULE200 RULE201 RULE202
)
```

```
=====
BULK_CHARGING-PARMS
=====
```

```
ACCUM_FLUEN
=====
```

```
TRANSLATION :: (the seven-day accumulated fluence of penetrating
electrons )
PROMPT :: (Select the appropriate level for the :ATTR (YELLOW)
accumulated fluence :ATTR (WHITE) of energetic electrons
above 300 keV for several days prior to the anomaly. )
TYPE :: SINGLEVALUED
EXPECT :: (VERY_HIGH HIGH INTERMEDIATE LOW)
ASKFIRST :: YES
UPDATED-BY :: (RULE200 RULE199 RULE198 RULE197)
ANTECEDENT-IN :: (RULE038 RULE029 RULE030)
USED-BY :: (RULE006 RULE007 RULE008 RULE033 RULE032 RULE028 RULE023
RULE005 RULE196 RULE039 RULE201 RULE202 RULE035 RULE036 )
HELP :: ("The accumulated fluence of penetrating electrons" :LINE "is
the integral of the electron flux above 300" :LINE "keV for
several days before the anomaly. It is" :LINE "measured in
units of [electrons/cm^2]. The" :LINE "ranges can be estimated
from the following" :LINE "table if 300 keV or 3 MeV fluences
are" :LINE "available. For assistance in determining the"
:LINE "fluence contact D. Gorney (213/336-6821) in the" :LINE "
Space Sciences Laboratory at the Aerospace" :LINE
```

"Corporation."

```

:LINE 2 :ATTR (YELLOW HIGH) " " :ATTR (CYAN HIGH)

> 300 keV > 3 MeV" :LINE :ATTR (YELLOW HIGH) "
VERY_HIGH: > 10^12 > 2x10^9" :LINE "HIGH:
10^11 - 10^12 2x10^8 - 2x10^9" :LINE "INTERMEDIATE: 10^10 -
10^11 2x10^7 - 2x10^8" :LINE "LOW: < 10^10
< 2x10^7" )
CERTAINTY-FACTOR-RANGE :: UNKNOWN

AP
==
TRANSLATION :: (the three hour planetary index Ap)
PROMPT :: (Enter a value between 0 and 400 for the maximum value of the
planetary magnetic index Ap in the three day period
preceding the anomaly. If unknown press RETURN. )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
USED-BY :: (RULE094 RULE095 RULE096)
HELP :: (The average amplitude, Ap, of the geomagnetic field is
published by the World Data Center A for Solar-Terrestrial
Physics, NOAA, Boulder, Colorado. It may be found in the
Journal of Geophysical Research. For information write to
Helen E. Coffey, NOAA E/GC2, 325 Broadway, Boulder, Colorado
80303. )
CERTAINTY-FACTOR-RANGE :: UNKNOWN
RANGE :: (0 400)

DAYS_FOR_KPMAX
=====
TRANSLATION :: (the number of days to be checked for KP)
TYPE :: SINGLEVALUED
UPDATED-IN :: (RULE053)

HARDNESS
=====
TRANSLATION :: (the hardness of the vehicle to penetrating electrons
with energies greater than 2 MeV. )
PROMPT :: ("Select your confidence level in the" :ATTR (YELLOW HIGH) "
hardness" :ATTR (WHITE HIGH) "of the vehicle" :ATTR (YELLOW
HIGH ) "against bulk" :LINE "charging" :ATTR (WHITE HIGH) "
from No meaning very soft to Yes meaning very hard." )
TYPE :: SINGLEVALUED
EXPECT :: (HARDNESS)
USED-BY :: (RULE035 RULE036)
HELP :: ("The following conditions are likely to increase the
probability of bulk charging or the coupling of energy from
such discharges into nearby circuitry: (a) exposure of bare
cables or circuit boards to the space environment; (b) large
areas of metallization on circuit boards left ungrounded; and
(c) spare conductors in cables left unterminated at both ends.
Any of these conditions indicate a soft vehicle." )
CERTAINTY-FACTOR-RANGE :: FULL

```

KPMAX_RECENT

=====

TRANSLATION :: (the maximum value of the three-hour, planetary,
magnetic index Kp during a several day period preceding
the anomaly)

PROMPT :: ("Enter the" :ATTR (YELLOW HIGH) "maximum value of" :ATTR (WHITE HIGH) "the planetary magnetic index" :ATTR (YELLOW HIGH) "Kp" :LINE :ATTR (WHITE HIGH) "during the" :ATTR (YELLOW HIGH) "72-hour period preceding" :ATTR (WHITE HIGH) "the anomaly." :LINE "The range is 0.0 to 9.0")

TYPE :: SINGLEVALUED

EXPECT :: POSITIVE-NUMBER

UPDATED-BY :: (SREFMARK RULE060 RULE052)

UPDATED-IN :: (SREFMARK RULE148)

ANTECEDENT-IN :: (SREFMARK RULE148)

USED-BY :: (RULE002 RULE003 RULE004 SREFMARK RULE052)

HELP :: ("The geomagnetic planetary 3-hour-range indices," :LINE "Kp, are published by the World Data Center A for" :LINE "Solar-Terrestrial Physics, NOAA, Boulder," :LINE "Colorado. They may be found in the Journal of" :LINE "Geophysical Research. For information write to" :LINE "Helen E. Coffey, NOAA E/GC2, 325 Broadway," :LINE "Boulder, Colorado 80303.")

CONTAINED-IN :: (SREFMARK RULE052)

RANGE :: (0 9)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

MAG_STATE_RECENT

=====

TRANSLATION :: (the level of magnetic activity in the magnetosphere)

PROMPT :: (Select the level of magnetic activity in the magnetosphere
for two to three days prior to the time of the anomaly.)

TYPE :: SINGLEVALUED

EXPECT :: (QUIET NORMAL DISTURBED)

UPDATED-BY :: (RULE094 RULE095 RULE096 RULE002 RULE003 RULE004)

ANTECEDENT-IN :: (RULE038)

USED-BY :: (RULE021 RULE022 RULE040)

HELP :: (Space scientists use a variety of magnetic indices such as Kp and Ap to indicate the level of magnetic activity in the magnetosphere. This information is readily available from the World Data Center A in Boulder, Colorado. An indication that the magnetosphere is strongly disturbed is the presence of visual auroras at latitudes significantly equatorward of the normal auroral zone.)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

OTHER_SAT

=====

TRANSLATION :: (another satellite that had an anomaly at about the same time)

PROMPT :: (Did another satellite experience an anomaly that is definitely known to be caused by bulk charging at about the same time?)

TYPE :: YES/NO

USED-BY :: (RULE037)

HELP :: (Satellites that have been in orbit for some time may have collected a statistically significant history of anomalies related to bulk charging. The occurrence of a bulk charging anomaly on such a satellite at the same time is important information because it indicates that high electron fluences were present without a direct measurement of the electrons. A satellite anomaly database is maintained at the National Geophysical Data Center, NOAA, Boulder, Colorado. Contact Joe H. Allen "(303) 499 - 9636.")

CERTAINTY-FACTOR-RANGE :: UNKNOWN

PEN_FLUX

=====

TRANSLATION :: (the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly)

PROMPT :: (Select the level that best describes the flux of penetrating electrons for the seven days prior to the anomaly.)

TYPE :: SINGLEVALUED

EXPECT :: (VERY_HIGH HIGH INTERMEDIATE LOW)

ASKFIRST :: YES

ANTECEDENT-IN :: (RULE038 RULE030)

USED-BY :: (RULE033 RULE032 RULE028 RULE023 RULE196 RULE039)

HELP :: ("The integral flux of penetrating electrons" :LINE "may be measured at any energy above 300 keV." :LINE "The maximum value during several days before the" :LINE "anomaly should be used. It is measured in units" :LINE "of [electrons/cm^2-sec-str]. For assistance" :LINE "in determining the flux contact D. Gorney" :LINE "(213/336-6821) in the Space Sciences Laboratory" :LINE "at the Aerospace Corporation. Typical values for" :LINE

electrons greater than 300 keV and 3 MeV are:" :LINE 2 "
" :ATTR (CYAN HIGH) "> 300 keV > 3 MeV"
:LINE :ATTR (YELLOW HIGH) " VERY_HIGH: > 2x10^6
> 500" :LINE " HIGH: 2x10^5 - 2x10^6 50 - 500"
:LINE " INTERMEDIATE: 2x10^4 - 2x10^5 5 - 50" :LINE "
LOW: < 2x10^4 < 5")

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SAME_ORBIT

=====

TRANSLATION :: (in the same orbit as the satellite with the anomaly)

PROMPT :: (Were the electron measurements that you have used to indicate the level of the electron fluence or the electron flux acquired in the same orbit and local time as the satellite which had the anomaly?)

TYPE :: YES/NO

ANTECEDENT-IN :: (RULE030)

USED-BY :: (RULE202)

HELP :: (For example electron measurements used to diagnose an anomaly on a geosynchronous satellite are best made from the same or another geosynchronous satellite. :LINE 2 If the electron flux

measurements are not made in the same orbit as the satellite
with the anomaly then there is reduced confidence in the use
of the measurements to diagnose the anomaly.)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====
BULK_CHARGING-RULES
=====

RULE002

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (148)

DESCRIPTION :: (sets MAG_STATE_RECENT disturbed for Kp > 4)

If the maximum value of the three-hour, planetary, magnetic index Kp during
a several day period preceding the anomaly is greater than 4,
Then it is definite (100%) that the level of magnetic activity in the
magnetosphere is DISTURBED.

IF :: (KPMAX_RECENT > 4)

THEN :: (MAG_STATE_RECENT = DISTURBED)

RULE003

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (148)

DESCRIPTION :: (Sets MAG_STATE_RECENT quiet for Kp < 3)

If the maximum value of the three-hour, planetary, magnetic index Kp during
a several day period preceding the anomaly is less than 3,
Then it is definite (100%) that the level of magnetic activity in the
magnetosphere is QUIET.

IF :: (KPMAX_RECENT < 3)

THEN :: (MAG_STATE_RECENT = QUIET)

RULE004

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (148)

DESCRIPTION :: (Sets MAG_STATE_RECENT normal for intermediate ranges of
Kp)

- If
- 1) the maximum value of the three-hour, planetary, magnetic index Kp
during a several day period preceding the anomaly is greater than or
equal to 3, and
 - 2) the maximum value of the three-hour, planetary, magnetic index Kp
during a several day period preceding the anomaly is less than or
equal to 4,

Then it is definite (100%) that the level of magnetic activity in the
magnetosphere is NORMAL.

IF :: (KPMAX_RECENT >= 3 AND KPMAX_RECENT <= 4)

THEN :: (MAG_STATE_RECENT = NORMAL)

RULE005

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (accumulated fluence is very high)

If the seven-day accumulated fluence of penetrating electrons is VERY_HIGH,
Then there is suggestive evidence (60%) that the cause of the anomaly is
BULK_CHARGING.

IF :: (ACCUM_FLUEN = VERY_HIGH)

THEN :: (CAUSE = BULK_CHARGING CF 60)

RULE006

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (accumulated fluence is high)

If the seven-day accumulated fluence of penetrating electrons is HIGH,
Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is BULK_CHARGING.

IF :: (ACCUM_FLUEN = HIGH)

THEN :: (CAUSE = BULK_CHARGING CF 20)

RULE007

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (accumulate fluence is intermediate)

If the seven-day accumulated fluence of penetrating electrons is
INTERMEDIATE,
Then there is weakly suggestive evidence (30%) that the cause of the anomaly
is not BULK_CHARGING.

IF :: (ACCUM_FLUEN = INTERMEDIATE)

THEN :: (CAUSE != BULK_CHARGING CF 30)

RULE008

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (accumulated fluence is low)

If the seven-day accumulated fluence of penetrating electrons is LOW,
Then there is strongly suggestive evidence (90%) that the cause of the anomaly
is not BULK_CHARGING.

IF :: (ACCUM_FLUEN = LOW)

THEN :: (CAUSE != BULK_CHARGING CF 90)

RULE016

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (Orbits that pass through the horns of the radiation belts)

If 1) 1) The altitude of the satellite is LOW_ALTITUDE, or
 2) The altitude of the satellite is INTERMEDIATE_ALTITUDE, and
 2) 1) the inclination of the plane of the orbit with respect to the earth's equatorial plane is HIGH_INCLINATION, or
 2) the inclination of the plane of the orbit with respect to the earth's equatorial plane is POLAR,
 Then there is weakly suggestive evidence (30%) that the cause of the anomaly is not BULK_CHARGING.

IF :: ((ALTITUDE = LOW_ALTITUDE OR ALTITUDE = INTERMEDIATE_ALTITUDE)
 AND (INCLINATION = HIGH_INCLINATION OR INCLINATION = POLAR))
 THEN :: (CAUSE != BULK_CHARGING CF 30)

RULE017

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (Selects ! BULK_CHARGING for low altitude, low inclination satellites or interplanetary satellites)

If 1) 1) The altitude of the satellite is LOW_ALTITUDE, and
 2) 1) the inclination of the plane of the orbit with respect to the earth's equatorial plane is EQUATORIAL, or
 2) the inclination of the plane of the orbit with respect to the earth's equatorial plane is LOW_INCLINATION, or
 2) The altitude of the satellite is INTERPLANETARY,
 Then it is definite (100%) that the cause of the anomaly is not BULK_CHARGING.

IF :: ((ALTITUDE = LOW_ALTITUDE AND (INCLINATION = EQUATORIAL OR INCLINATION = LOW_INCLINATION)) OR ALTITUDE = INTERPLANETARY)
 THEN :: (CAUSE != BULK_CHARGING)

RULE019

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (LT_RECUR rules out bulk charging)

If 1) the recurrence of the anomaly, and
 2) the recurrence of an anomaly in a specific local-time sector.,
 Then there is weakly suggestive evidence (20%) that the cause of the anomaly is not BULK_CHARGING.

IF :: (RECURRENCE AND LT_RECUR)
 THEN :: (CAUSE != BULK_CHARGING CF 20)

RULE020

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (No local time recurrence pattern)

If 1) the recurrence of the anomaly, and
2) the recurrence of an anomaly in a specific local-time sector. is not true,

Then there is weakly suggestive evidence (5%) that the cause of the anomaly is BULK_CHARGING.

IF :: (RECURRENCE AND ! LT_RECUR)

THEN :: (CAUSE = BULK_CHARGING CF 5)

RULE021

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (quiet magnetosphere then BULK_CHARGING CF -50)

If the level of magnetic activity in the magnetosphere is QUIET,
Then there is suggestive evidence (50%) that the cause of the anomaly is not BULK_CHARGING.

IF :: (MAG_STATE_RECENT = QUIET)

THEN :: (CAUSE != BULK_CHARGING CF 50)

RULE022

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (if magnetosphere disturbed then BULK_CHARGING CF 10)

If the level of magnetic activity in the magnetosphere is DISTURBED,
Then there is weakly suggestive evidence (10%) that the cause of the anomaly is BULK_CHARGING.

IF :: (MAG_STATE_RECENT = DISTURBED)

THEN :: (CAUSE = BULK_CHARGING CF 10)

RULE023

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (low penetrating flux)

If 1) the seven-day accumulated fluence of penetrating electrons is not known, and
2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is LOW,

Then there is suggestive evidence (75%) that the cause of the anomaly is not BULK_CHARGING.

IF :: (ACCUM_FLUEN IS NOTKNOWN AND PEN_FLUX = LOW)

THEN :: (CAUSE != BULK_CHARGING CF 75)

RULE024

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (periodicities not related to BULK_CHARGING)

If 1) the recurrence of the anomaly, and

2) 1) the recurrence is SATELLITE_SPIN_PERIOD, or

2) the recurrence is 24_HR, or

3) the recurrence is SPRING/FALL,

Then it is definite (100%) that the cause of the anomaly is not BULK_CHARGING.

IF :: (RECURRENCE AND (PERIODICITY = SATELLITE_SPIN_PERIOD OR
PERIODICITY = 24_HR OR PERIODICITY = SPRING/FALL))

THEN :: (CAUSE != BULK_CHARGING)

RULE025

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (27_DAY periodicity)

If 1) the recurrence of the anomaly, and

2) the recurrence is 27_DAY,

Then there is weakly suggestive evidence (5%) that the cause of the anomaly is BULK_CHARGING.

IF :: (RECURRENCE AND PERIODICITY = 27_DAY)

THEN :: (CAUSE = BULK_CHARGING CF 5)

RULE026

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (print message for non bulk charging orbits)

If 1) 1) The altitude of the satellite is LOW_ALTITUDE, and

2) 1) the inclination of the plane of the orbit with respect to the
earth's equatorial plane is LOW_INCLINATION, or

2) the inclination of the plane of the orbit with respect to the
earth's equatorial plane is EQUATORIAL, or

2) The altitude of the satellite is INTERPLANETARY,

Then 1) it is definite (100%) that the cause of the anomaly is not
BULK_CHARGING, and

2) inform the user of this decision.

IF :: ((ALTITUDE = LOW_ALTITUDE AND (INCLINATION = LOW_INCLINATION OR
INCLINATION = EQUATORIAL)) OR ALTITUDE = INTERPLANETARY)

THEN :: (CAUSE != BULK_CHARGING AND PRINT "BULK CHARGING DOES NOT OCCUR
IN THE ORBIT YOU HAVE SELECTED. ")

RULE027

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (If BULK_CHARGING, prints description of phenomena)

If 1) the cause of the anomaly is BULK_CHARGING, and
2) the way in which the program responds to the user is NOVICE,
Then inform the user of this decision.

IF :: (CAUSE = BULK_CHARGING AND MODE = NOVICE)

THEN :: (PRINT "Bulk charging is primarily caused by electrons with energies of a few hundred keV to a few MeV. These energetic electrons can penetrate thin shielding (e.g. spacecraft skin, cable shielding etc.) and deposit charge in cables, circuit boards, and conductors. Depending on the fluence of the primary electrons and the conductivity of the dielectric, the material may experience a discharge which may couple into sensitive circuits. In typical dielectrics, the breakdown may occur with fluences of the order of 10^{11} to 10^{12} electrons/cm². These fluxes maximize at altitudes several earth radii below geosynchronous orbit following large magnetic storms.")

RULE028

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (very high penetrating flux)

If 1) the seven-day accumulated fluence of penetrating electrons is not known, and
2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is VERY_HIGH,
Then there is suggestive evidence (50%) that the cause of the anomaly is BULK_CHARGING.

IF :: (ACCUM_FLUEN IS NOTKNOWN AND PEN_FLUX = VERY_HIGH)

THEN :: (CAUSE = BULK_CHARGING CF 50)

RULE029

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (msg that ACCUM_FLUEN AND PEN_FLUX are important)

If 1) the way in which the program responds to the user is NOVICE, and
2) the seven-day accumulated fluence of penetrating electrons is not known,
Then inform the user of this decision.

IF :: (MODE = NOVICE AND ACCUM_FLUEN IS NOTKNOWN)

THEN :: (PRINT "The accumulated fluence of energetic electrons is one of the most important parameters used in determining if the cause of an anomaly is bulk charging. Contact D. J. Gorney (213) 336-6821 in the Space Sciences Laboratory at The Aerospace Corporation for assistance in determining the fluence at the time of the anomaly.")

RULE030

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (Orbit - flux inconsistency)

- If 1) 1) the seven-day accumulated fluence of penetrating electrons is VERY_HIGH, or
 2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is VERY_HIGH, and
 2) in the same orbit as the satellite with the anomaly, and
 3) 1) 1) The altitude of the satellite is LOW_ALTITUDE, and
 2) 1) the inclination of the plane of the orbit with respect to the earth's equatorial plane is EQUATORIAL, or
 2) the inclination of the plane of the orbit with respect to the earth's equatorial plane is LOW_INCLINATION, or
 2) The altitude of the satellite is INTERPLANETARY,

Then inform the user of this decision.

IF :: ((ACCUM_FLUEN = VERY_HIGH OR PEN_FLUX = VERY_HIGH) AND
 SAME_ORBIT AND ((ALTITUDE = LOW_ALTITUDE AND (INCLINATION =
 EQUATORIAL OR INCLINATION = LOW_INCLINATION)) OR ALTITUDE =
 INTERPLANETARY))

THEN :: (PRINT "The accumulated fluence or flux of penetrating electrons
 that you have entered is inconsistent with the orbit you have
 selected. Please review your data and start the consultation
 again.")

RULE032

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (high penetrating flux)

- If 1) the seven-day accumulated fluence of penetrating electrons is not known, and
 2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is HIGH,

Then there is weakly suggestive evidence (15%) that the cause of the anomaly is BULK_CHARGING.

IF :: (ACCUM_FLUEN IS NOTKNOWN AND PEN_FLUX = HIGH)

THEN :: (CAUSE = BULK_CHARGING CF 15)

RULE033

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (intermediate penetrating flux)

- If 1) the seven-day accumulated fluence of penetrating electrons is not known, and
 2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is INTERMEDIATE,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly is not BULK_CHARGING.

IF :: (ACCUM_FLUEN IS NOTKNOWN AND PEN_FLUX = INTERMEDIATE)

THEN :: (CAUSE != BULK_CHARGING CF 20)

RULE035

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (hard vehicle with flux or fluence known)

If 1) 1) the seven-day accumulated fluence of penetrating electrons is
VERY_HIGH, or

2) the seven-day accumulated fluence of penetrating electrons is
HIGH,

and

2) the hardness of the vehicle to penetrating electrons with energies
greater than 2 MeV. is ,

Then there is weakly suggestive evidence (30%) that the cause of the anomaly
is not BULK_CHARGING.

IF :: ((ACCUM_FLUEN = VERY_HIGH OR ACCUM_FLUEN = HIGH) AND HARDNESS =
)

THEN :: (CAUSE != BULK_CHARGING CF 30)

RULE036

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (soft vehicle with known flux or fluence)

If 1) 1) the seven-day accumulated fluence of penetrating electrons is
VERY_HIGH, or

2) the seven-day accumulated fluence of penetrating electrons is
HIGH,

and

2) there is evidence that the hardness of the vehicle to penetrating
electrons with energies greater than 2 MeV. is is not true,

Then there is weakly suggestive evidence (30%) that the cause of the anomaly
is BULK_CHARGING.

IF :: ((ACCUM_FLUEN = VERY_HIGH OR ACCUM_FLUEN = HIGH) AND HARDNESS
IS THOUGHTNOT)

THEN :: (CAUSE = BULK_CHARGING CF 30)

RULE037

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (another satellite had a bulk charging anomaly)

If another satellite that had an anomaly at about the same time,

Then there is weakly suggestive evidence (10%) that the cause of the anomaly
is BULK_CHARGING.

IF :: (OTHER_SAT)

THEN :: (CAUSE = BULK_CHARGING CF 10)

RULE038

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (FLUX - MAG_STATE INCONSISTENCY)

If 1) 1) the seven-day accumulated fluence of penetrating electrons is VERY_HIGH, or
2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is VERY_HIGH, and
2) the level of magnetic activity in the magnetosphere is QUIET,
Then inform the user of this decision.

IF :: ((ACCUM_FLUEN = VERY_HIGH OR PEN_FLUX = VERY_HIGH) AND
MAG_STATE_RECENT = QUIET)

THEN :: (PRINT "The accumulated fluence or flux of penetrating electrons that you have entered is inconsistent with the level of magnetic activity you have selected. Please review your data and start the consultation again.")

RULE039

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (recurs when fluxes high)

If 1) the recurrence of the anomaly, and
2) the recurrence is OF_HIGH_PENETRATING_FLUX, and
3) the seven-day accumulated fluence of penetrating electrons is not known, and
4) 1) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is HIGH, or
2) the flux of penetrating electrons with energies greater than 300 keV for the three days prior to the anomaly is VERY_HIGH,

Then there is suggestive evidence (60%) that the cause of the anomaly is BULK_CHARGING.

IF :: (RECURRENCE AND PERIODICITY = OF_HIGH_PENETRATING_FLUX AND
ACCUM_FLUEN IS NOTKNOWN AND (PEN_FLUX = HIGH OR PEN_FLUX = VERY_HIGH))

THEN :: (CAUSE = BULK_CHARGING CF 60)

RULE040

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (recurs when magnetically disturbed)

If 1) the recurrence of the anomaly, and
2) the recurrence is MAGNETICALLY_DISTURBED, and
3) the level of magnetic activity in the magnetosphere is DISTURBED,
Then there is weakly suggestive evidence (10%) that the cause of the anomaly is BULK_CHARGING.

IF :: (RECURRENCE AND PERIODICITY = MAGNETICALLY_DISTURBED AND
MAG_STATE_RECENT = DISTURBED)

THEN :: (CAUSE = BULK_CHARGING CF 10)

RULE052

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (calls adaptor function to get Kpmax from historical database)

If 1) a database available to the user is KP, and
2) the Julian date is known, and
3) the local time interval in which the anomaly occurred is known, and
4) the maximum value of the three-hour, planetary, magnetic index Kp during a several day period preceding the anomaly is not known,

Then 1) , and
2) retrieve data from an external source, and
3) inform the user of this decision.

IF :: (DATABASE = KP AND JULIAN_DATE IS KNOWN AND
UNIVERSAL_TIME_INTERVAL IS KNOWN AND KPMAX_RECENT IS NOTKNOWN
)

THEN :: ((DOSCALL GETKP JULIAN_DATE UNIVERSAL_TIME_INTERVAL) AND
READ-DOS-FILE "kpdata.dat" KP_CURRENT KPMAX_RECENT AND PRINT "
The" :ATTR (QUOTE (YELLOW)) "maximum value for Kp" :ATTR (QUOTE (WHITE)) "during the four day period ending with the date of the anomaly was" :ATTR (QUOTE (YELLOW)) KPMAX_RECENT :ATTR (QUOTE (WHITE)) "." :LINE 2 "The convention used is the following: Kp of 3- = 2.7, Kp of 3 is 3.0, and Kp of 3+ is 3.3.")

RULE053

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (sets a value for DAYS_FOR_KPMAX)

If a database available to the user is KP,
Then it is definite (100%) that the number of days to be checked for KP is 3.

IF :: (DATABASE = KP)

THEN :: (DAYS_FOR_KPMAX = 3)

RULE094

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (RULE002 RULE003 RULE004)

DESCRIPTION :: (magstate recent is disturbed for Ap > 30)

If the three hour planetary index Ap is greater than 30,
Then it is definite (100%) that the level of magnetic activity in the magnetosphere is DISTURBED.

IF :: (AP > 30)

THEN :: (MAG_STATE_RECENT = DISTURBED)

RULE095

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (RULE002 RULE003 RULE004)

DESCRIPTION :: (mag_state_recent is quiet for Ap < 10)

If the three hour planetary index Ap is less than 10,
Then it is definite (100%) that the level of magnetic activity in the magnetosphere is QUIET.

IF :: (AP < 10)

THEN :: (MAG_STATE_RECENT = QUIET)

RULE096

=====

SUBJECT :: BULK_CHARGING-RULES

DOBEFORE :: (RULE002 RULE003 RULE004)

DESCRIPTION :: (mag_state_recent is normal for intermediate values of
Ap)

If 1) the three hour planetary index Ap is greater than or equal to 10, and
2) the three hour planetary index Ap is less than or equal to 30,
Then it is definite (100%) that the level of magnetic activity in the
magnetosphere is NORMAL.

IF :: (AP >= 10 AND AP <= 30)

THEN :: (MAG_STATE_RECENT = NORMAL)

RULE148

=====

SUBJECT :: BULK_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (Handles Kpmax_recent = -1)

If the maximum value of the three-hour, planetary, magnetic index Kp during
a several day period preceding the anomaly is -1,
Then it is definite (100%) that the maximum value of the three-hour,
planetary, magnetic index Kp during a several day period preceding the anomaly
is UNKNOWN.

IF :: (KPMAX_RECENT = -1)

THEN :: (KPMAX_RECENT = UNKNOWN)

RULE196

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (plot electron flux if flux and fluence are unknown)

If 1) the seven-day accumulated fluence of penetrating electrons is UNKNOWN,
and
2) the flux of penetrating electrons with energies greater than 300 keV
for the three days prior to the anomaly is UNKNOWN,
Then instantiate the frame draw a graph of the electron flux at geosynchronous
derived from neural network model if appropriate.

IF :: (ACCUM_FLUEN = UNKNOWN AND PEN_FLUX = UNKNOWN)

THEN :: (CONSIDERFRAME PLOTENET)

RULE197

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (log fluence greater than 9.2)

If The integrated flux of > 3 MeV electrons at geosynchronous orbit is
greater than or equal to 9.2,
Then it is definite (100%) that the seven-day accumulated fluence of
penetrating electrons is VERY_HIGH.

IF :: (FLUENCE >= 9.2)

THEN :: (ACCUM_FLUEN = VERY_HIGH)

RULE198

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (log fluence between 8.2 and 9.2)

If The integrated flux of > 3 MeV electrons at geosynchronous orbit is less than 9.2 but greater than or equal to 8.2,
Then it is definite (100%) that the seven-day accumulated fluence of penetrating electrons is HIGH.

IF :: (FLUENCE BT 8.2 9.2)

THEN :: (ACCUM_FLUEN = HIGH)

RULE199

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (log fluence between 7.2 and 8.2)

If The integrated flux of > 3 MeV electrons at geosynchronous orbit is less than 8.2 but greater than or equal to 7.2,
Then it is definite (100%) that the seven-day accumulated fluence of penetrating electrons is INTERMEDIATE.

IF :: (FLUENCE BT 7.2 8.2)

THEN :: (ACCUM_FLUEN = INTERMEDIATE)

RULE200

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (log fluence < 7.2)

If The integrated flux of > 3 MeV electrons at geosynchronous orbit is less than 7.2,
Then it is definite (100%) that the seven-day accumulated fluence of penetrating electrons is LOW.

IF :: (FLUENCE < 7.2)

THEN :: (ACCUM_FLUEN = LOW)

RULE201

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (recurs when fluence high)

If 1) the recurrence of the anomaly, and
2) the recurrence is OF_HIGH_PENETRATING_FLUX, and
3) 1) the seven-day accumulated fluence of penetrating electrons is HIGH,

or

2) the seven-day accumulated fluence of penetrating electrons is VERY_HIGH,

Then there is suggestive evidence (60%) that the cause of the anomaly is BULK_CHARGING.

IF :: (RECURRENCE AND PERIODICITY = OF_HIGH_PENETRATING_FLUX AND (ACCUM_FLUEN = HIGH OR ACCUM_FLUEN = VERY_HIGH))

THEN :: (CAUSE = BULK_CHARGING CF 60)

RULE202

=====

SUBJECT :: BULK_CHARGING-RULES

DESCRIPTION :: (Increases CF in bulk charging if electrons are measured
in the same orbit)

If 1) 1) the seven-day accumulated fluence of penetrating electrons is
HIGH,

or

2) the seven-day accumulated fluence of penetrating electrons is
VERY_HIGH, and

2) in the same orbit as the satellite with the anomaly,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is BULK_CHARGING.

IF :: ((ACCUM_FLUEN = HIGH OR ACCUM_FLUEN = VERY_HIGH) AND SAME_ORBIT
)

THEN :: (CAUSE = BULK_CHARGING CF 20)

```

=====
Frame :: SEU
=====

```

```

IDENTIFIER :: "SEU-"
TRANSLATION :: (to determine if the cause of the anomaly is a single
                event upset )
PARENTS :: (ROOT)
GOALS :: (FLARE_REPORT X1_FLARE)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            ($OR
             (SAME FRAME CONSIDER_CAUSE SEU)
             (SAME FRAME CONSIDER_CAUSE ALL)))
PARMGROUP :: SEU-PARMS
RULEGROUPS :: (SEU-RULES)
OFFSPRING :: (SOLAR_FLARE)
SEU-PARMS :: (DEVICE DIG_RESET FLARE_REPORT GALACTIC_COSMIC_RAYS LATCHUP
              LATITUDINAL_DEPENDENCE LIGHTLY_SHIELDED MEM_ANOMALY
              MEM_RESET PART_PERFORMANCE POLAR_CAP POWER_LOSS
              SEU_TECHNOLOGY SHIELDED_HEAVY_NUCLEI SHIELDED_SECONDARIES
              SOUTH_ATLANTIC_ANOMALY TM_ANOMALY TM_RESET
              TRAPPED_HEAVY_NUCLEI TRAPPED_PROTONS X1_FLARE )
SEU-RULES :: (RULE066 RULE068 RULE070 RULE072 RULE074 RULE075 RULE079
              RULE080 RULE081 RULE082 RULE083 RULE084 RULE085 RULE086
              RULE087 RULE088 RULE089 RULE090 RULE091 RULE111 RULE165 )

```

```

=====
SEU-PARMS
=====

```

DEVICE

```

=====
TRANSLATION :: (the type of part in which the anomaly occurred)
PROMPT :: (Select the most accurate description of the device in which
           the anomaly occurred. )
TYPE :: SINGLEVALUED
EXPECT :: (MICROPROCESSOR MEMORY DIGITAL_DEVICE ANALOG_DEVICE
          POWER_TRANSISTOR HYBRID_CIRCUIT BI-STABLE_CIRCUIT OTHER )
USED-BY :: (RULE068 RULE088 RULE085)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

DIG_RESET

```

=====
TRANSLATION :: (the anomaly could be corrected by resetting a digital
                device )
PROMPT :: (Are the erroneous telemetry values corrected by resetting
           the subsystem containing the digital device? )
TYPE :: YES/NO
USED-BY :: (RULE088)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

FLARE_REPORT

=====

TRANSLATION :: (a printout of the solar xray flares near the date)
TYPE :: YES/NO
UPDATED-BY :: (RULE164)

GALACTIC_COSMIC_RAYS

=====

TRANSLATION :: (the spacecraft is susceptible to upsets from galactic cosmic rays)
PROMPT :: (Is the payload susceptible to upsets from galactic cosmic rays?)
TYPE :: YES/NO
CERTAINTY-FACTOR-RANGE :: UNKNOWN

LATCHUP

=====

TRANSLATION :: (the device is known to be susceptible to latchup)
PROMPT :: (Is the device known to be susceptible to latchup?)
TYPE :: YES/NO
CERTAINTY-FACTOR-RANGE :: UNKNOWN

LATITUDINAL_DEPENDENCE

=====

TRANSLATION :: (the anomaly has a dependence on latitude)
PROMPT :: ("Does this type of anomaly depend on the latitude of the vehicle." :LINE "Specifically do" :ATTR (YELLOW HIGH) "more anomalies" :ATTR (WHITE HIGH) "occur" :ATTR (YELLOW HIGH) "at higher latitudes" :ATTR (WHITE HIGH) "than at lower" :LINE " latitudes.")
TYPE :: YES/NO
USED-BY :: (RULE165)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

LIGHTLY_SHIELDED

=====

TRANSLATION :: (the payload is shielded by 100 mils (A1) or so of shielding)
PROMPT :: (Is the payload shielded by 100 mils (A1) or less?)
TYPE :: YES/NO
USED-BY :: (RULE077)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

MEM_ANOMALY

=====

TRANSLATION :: (the type of software or memory anomaly that occurred)
PROMPT :: (Select all of the types of problems that were associated with this software or memory anomaly.)
TYPE :: ASK-ALL
EXPECT :: (ERRONEOUS_INSTRUCTION ERRONEOUS_DATA_WORD INFINITE_LOOP ADDRESS_REGISTER_OUT_OF_RANGE OTHER)
USED-BY :: (RULE068)

MEM_RESET

=====

TRANSLATION :: (the memory anomaly could be corrected by a reset)
PROMPT :: (Are the memory anomalies corrected by resetting the memory subsystem?)
TYPE :: YES/NO
USED-BY :: (RULE068)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

PART_PERFORMANCE

=====

TRANSLATION :: (the susceptibility of a part to soft errors and latchup)
PROMPT :: (Select the term that best describes the susceptibility of the devices in the circuit in which the anomaly occurred.)
TYPE :: SINGLEVALUED
EXPECT :: (SOFT MEDIUM HARD)
UPDATED-BY :: (RULE084 RULE083 RULE082 RULE081 RULE080 RULE079)
USED-BY :: (SREFMARK RULE086 RULE087)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

POLAR_CAP

=====

TRANSLATION :: (the spacecraft is in the polar region where solar and interplanetary particles have direct access to low altitudes)
PROMPT :: (Did the anomaly occur while the spacecraft was in the polar cap?)
TYPE :: YES/NO
UPDATED-BY :: (RULE075 RULE089)
USED-BY :: (RULE074 SREFMARK RULE078)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

POWER_LOSS

=====

TRANSLATION :: (a sudden loss of power occurred in a power transistor circuit)
PROMPT :: (Did a :ATTR (YELLOW) sudden :ATTR (WHITE) loss of power occur in a power transistor circuit?)
TYPE :: YES/NO
USED-BY :: (RULE085)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

SEU_TECHNOLOGY

=====

TRANSLATION :: (the technology used in the manufacture of the device)
PROMPT :: (Select the technology which best describes the softest devices in the circuit experiencing the anomaly.)
TYPE :: SINGLEVALUED
EXPECT :: (ADV_CMOS ADV_HCMOS ADV_SCHOTTKY CMOS CMOS/EPI CMOS/SOS HCMOS LOC/MOS MOS NMOS NMOS/CMOS NMOS/EPI NMOS/SOS PMOS IIL TTL ALS/TTL ECL/TTL L/TTL LS/TTL S/TTL SCHOTTKY OTHER)
USED-BY :: (RULE084 RULE083 RULE082 RULE081 RULE080 RULE079)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

SHIELDED_HEAVY_NUCLEI

=====

TRANSLATION :: (the spacecraft is shielded against trapped heavy nuclei
)
PROMPT :: (Is the spacecraft shielded against trapped heavy nuclei?)
TYPE :: YES/NO
CERTAINTY-FACTOR-RANGE :: UNKNOWN

SHIELDED_SECONDARIES

=====

TRANSLATION :: (the spacecraft is shielded against proton produced
secondaries)
PROMPT :: (Is the spacecraft shielded against proton produced
secondaries?)
TYPE :: YES/NO
CERTAINTY-FACTOR-RANGE :: UNKNOWN

SOUTH_ATLANTIC_ANOMALY

=====

TRANSLATION :: (the spacecraft is in the region of the geomagnetic
field anomaly in the South Atlantic near the coast of
Brazil)
PROMPT :: (Did the problem occur while the spacecraft was near the
South Atlantic Anomaly?)
TYPE :: YES/NO
UPDATED-BY :: (RULE074 RULE091 RULE090)
USED-BY :: (RULE075 RULE070 RULE072)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

TM_ANOMALY

=====

TRANSLATION :: (the type of telemetry anomaly that occurred)
PROMPT :: (Select all of the types of problems that were associated
with this telemetry anomaly.)
TYPE :: ASK-ALL
EXPECT :: (ERRONEOUS_BIT ERRONEOUS_WORD LOSS_OF_FRAME_SYNC
LOSS_OF_SUBCOM_SYNC CHANGE_IN_FRAME_COUNTER OTHER)
USED-BY :: (RULE066)

TM_RESET

=====

TRANSLATION :: (the telemetry anomaly could be corrected by a reset)
PROMPT :: (Are the erroneous telemetry values corrected by resetting
the telemetry subsystem?)
TYPE :: YES/NO
USED-BY :: (RULE066)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

TRAPPED_HEAVY_NUCLEI

=====

TRANSLATION :: (the spacecraft is susceptible to heavy nuclei such as
iron trapped in the radiation belts)
PROMPT :: (Is the spacecraft susceptible to upsets from trapped heavy
nuclei?)
TYPE :: YES/NO
USED-BY :: (RULE072)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

TRAPPED_PROTONS

=====

TRANSLATION :: (the spacecraft is susceptible to protons trapped in the earth's radiation belts)

PROMPT :: ("Indicate the degree to which the spacecraft is susceptible to upsets from" :LINE "proton produced secondaries.")

TYPE :: YES/NO

USED-BY :: (RULE070 RULE072 RULE145 RULE146 RULE147)

CERTAINTY-FACTOR-RANGE :: POSITIVE

X1_FLARE

=====

TRANSLATION :: (a type X1 solar x-ray flare has occurred)

PROMPT :: ("If a very large solar" :ATTR (YELLOW HIGH) "x-ray flare," :ATTR (WHITE HIGH) "type" :ATTR (YELLOW HIGH) "X1," :ATTR (WHITE HIGH) "occurred" :LINE "prior to the anomaly, select the appropriate time period" :LINE "between the anomaly and the beginning of the flare." :LINE 2 "Otherwise select NONE or UNKNOWN.")

TYPE :: SINGLEVALUED

EXPECT :: (1-HOUR 24-HOURS 3-DAYS LONGER NONE)

USED-BY :: (RULE145 RULE146 RULE147 SREFMARK RULE078)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====

SEU-RULES

=====

RULE066

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (soft error because T/M reset)

If 1) the type of anomaly that occurred is TELEMETRY_ERROR, and
2) the type of telemetry anomaly that occurred is not OTHER, and
3) the telemetry anomaly could be corrected by a reset,
Then there is suggestive evidence (60%) that the cause of the anomaly is SEU.

IF :: (PROBLEM = TELEMETRY_ERROR AND TM_ANOMALY != OTHER AND TM_RESET)

THEN :: (CAUSE = SEU CF 60)

RULE068

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (soft error in memory)

If 1) the type of part in which the anomaly occurred is MEMORY, and
2) the type of software or memory anomaly that occurred is not OTHER, and
3) the memory anomaly could be corrected by a reset,
Then there is suggestive evidence (60%) that the cause of the anomaly is SEU.

IF :: (DEVICE = MEMORY AND MEM_ANOMALY != OTHER AND MEM_RESET)

THEN :: (CAUSE = SEU CF 60)

RULE070

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (trapped protons in the south atlantic anomaly)

- If
- 1) the spacecraft is susceptible to protons trapped in the earth's radiation belts, and
 - 2) the spacecraft is in the region of the geomagnetic field anomaly in the South Atlantic near the coast of Brazil,

Then there is suggestive evidence (50%) that the cause of the anomaly is SEU.

IF :: (TRAPPED_PROTONS AND SOUTH_ATLANTIC_ANOMALY)

THEN :: (CAUSE = SEU CF 50)

RULE072

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (trapped heavy nuclei in south atlantic anomaly)

- If
- 1) the spacecraft is susceptible to heavy nuclei such as iron trapped in the radiation belts, and
 - 2) the spacecraft is not susceptible to protons trapped in the earth's radiation belts, and
 - 3) the spacecraft is in the region of the geomagnetic field anomaly in the South Atlantic near the coast of Brazil,

Then there is weakly suggestive evidence (5%) that the cause of the anomaly is SEU.

IF :: (TRAPPED_HEAVY_NUCLEI AND ! TRAPPED_PROTONS AND
SOUTH_ATLANTIC_ANOMALY)

THEN :: (CAUSE = SEU CF 5)

RULE074

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (polar cap excludes south atlantic anomaly)

If the spacecraft is in the polar region where solar and interplanetary particles have direct access to low altitudes,
Then it is definite (100%) that the spacecraft is not in the region of the geomagnetic field anomaly in the South Atlantic near the coast of Brazil.

IF :: (POLAR_CAP)

THEN :: (! SOUTH_ATLANTIC_ANOMALY)

RULE075

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (south atlantic anomaly excludes polar cap)

If the spacecraft is in the region of the geomagnetic field anomaly in the South Atlantic near the coast of Brazil,
Then it is definite (100%) that the spacecraft is not in the polar region where solar and interplanetary particles have direct access to low altitudes.

IF :: (SOUTH_ATLANTIC_ANOMALY)

THEN :: (! POLAR_CAP)

RULE079

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (CMOS)

If the technology used in the manufacture of the device is CMOS,

- Then
- 1) there is weakly suggestive evidence (12%) that the susceptibility of a part to soft errors and latchup is SOFT, and
 - 2) there is weakly suggestive evidence (20%) that the susceptibility of a part to soft errors and latchup is MEDIUM, and
 - 3) there is suggestive evidence (68%) that the susceptibility of a part to soft errors and latchup is HARD.

IF :: (SEU_TECHNOLOGY = CMOS)

THEN :: (PART_PERFORMANCE = SOFT CF 12 AND PART_PERFORMANCE = MEDIUM CF 20 AND PART_PERFORMANCE = HARD CF 68)

RULE080

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (CMOS/EPI)

If the technology used in the manufacture of the device is CMOS/EPI,

- Then
- 1) there is weakly suggestive evidence (15%) that the susceptibility of a part to soft errors and latchup is SOFT, and
 - 2) there is weakly suggestive evidence (45%) that the susceptibility of a part to soft errors and latchup is MEDIUM, and
 - 3) there is weakly suggestive evidence (45%) that the susceptibility of a part to soft errors and latchup is HARD.

IF :: (SEU_TECHNOLOGY = CMOS/EPI)

THEN :: (PART_PERFORMANCE = SOFT CF 15 AND PART_PERFORMANCE = MEDIUM CF 45 AND PART_PERFORMANCE = HARD CF 45)

RULE081

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (CMOS/SOS)

If the technology used in the manufacture of the device is CMOS/SOS,

- Then
- 1) there is weakly suggestive evidence (20%) that the susceptibility of a part to soft errors and latchup is MEDIUM, and
 - 2) there is strongly suggestive evidence (80%) that the susceptibility of a part to soft errors and latchup is HARD.

IF :: (SEU_TECHNOLOGY = CMOS/SOS)

THEN :: (PART_PERFORMANCE = MEDIUM CF 20 AND PART_PERFORMANCE = HARD CF 80)

RULE082

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (NMOS, NMOS/CMOS, LS/TTL, S/TTL)

If

- 1) the technology used in the manufacture of the device is NMOS, or

2) the technology used in the manufacture of the device is NMOS/CMOS, or

3) the technology used in the manufacture of the device is LS/TTL, or

4) the technology used in the manufacture of the device is S/TTL,

Then it is definite (100%) that the susceptibility of a part to soft errors and latchup is SOFT.

IF :: (SEU_TECHNOLOGY = NMOS OR SEU_TECHNOLOGY = NMOS/CMOS OR

SEU_TECHNOLOGY = LS/TTL OR SEU_TECHNOLOGY = S/TTL)

THEN :: (PART_PERFORMANCE = SOFT)

RULE083

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (TTL)

If the technology used in the manufacture of the device is TTL,
Then 1) there is suggestive evidence (67%) that the susceptibility of a part to soft errors and latchup is SOFT, and
2) there is weakly suggestive evidence (33%) that the susceptibility of a part to soft errors and latchup is HARD.

IF :: (SEU_TECHNOLOGY = TTL)

THEN :: (PART_PERFORMANCE = SOFT CF 67 AND PART_PERFORMANCE = HARD CF 33)

RULE084

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (L/TTL)

If the technology used in the manufacture of the device is L/TTL,
Then 1) there is weakly suggestive evidence (15%) that the susceptibility of a part to soft errors and latchup is SOFT, and
2) there is suggestive evidence (60%) that the susceptibility of a part to soft errors and latchup is MEDIUM, and
3) there is weakly suggestive evidence (25%) that the susceptibility of a part to soft errors and latchup is HARD.

IF :: (SEU_TECHNOLOGY = L/TTL)

THEN :: (PART_PERFORMANCE = SOFT CF 15 AND PART_PERFORMANCE = MEDIUM CF 60 AND PART_PERFORMANCE = HARD CF 25)

RULE085

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (power loss in a power transistor)

If 1) the type of part in which the anomaly occurred is POWER_TRANSISTOR,
and

2) a sudden loss of power occurred in a power transistor circuit,
Then there is weakly suggestive evidence (25%) that the cause of the anomaly is SEU.

IF :: (DEVICE = POWER_TRANSISTOR AND POWER_LOSS)

THEN :: (CAUSE = SEU CF 25)

RULE086

=====

SUBJECT :: SEU-RULES

DESCRIPTION :: (increases confidence in seu if parts are soft)

If 1) the cause of the anomaly is SEU, and
2) the susceptibility of a part to soft errors and latchup is SOFT,
Then there is weakly suggestive evidence (30%) that the cause of the anomaly is SEU.

IF :: (CAUSE = SEU AND PART_PERFORMANCE = SOFT)

THEN :: (CAUSE = SEU CF 30)

RULE087

=====

SUBJECT :: SEU-RULES
 DESCRIPTION :: (decreases confidence in seu if parts are hard)
 If 1) the cause of the anomaly is SEU, and
 2) the susceptibility of a part to soft errors and latchup is HARD,
 Then there is weakly suggestive evidence (30%) that the cause of the anomaly
 is not SEU.

IF :: (CAUSE = SEU AND PART_PERFORMANCE = HARD)
 THEN :: (CAUSE != SEU CF 30)

RULE088

=====

SUBJECT :: SEU-RULES
 DESCRIPTION :: (digital device that resets)
 If 1) the type of part in which the anomaly occurred is DIGITAL_DEVICE, and
 2) the anomaly could be corrected by resetting a digital device,
 Then there is weakly suggestive evidence (40%) that the cause of the anomaly
 is SEU.

IF :: (DEVICE = DIGITAL_DEVICE AND DIG_RESET)
 THEN :: (CAUSE = SEU CF 40)

RULE089

=====

SUBJECT :: SEU-RULES
 DESCRIPTION :: (spacecraft not in polar cap)
 If 1) the inclination of the plane of the orbit with respect to the earth's
 equatorial plane is EQUATORIAL, or
 2) the inclination of the plane of the orbit with respect to the earth's
 equatorial plane is LOW_INCLINATION,
 Then it is definite (100%) that the spacecraft is not in the polar region
 where solar and interplanetary particles have direct access to low altitudes.

IF :: (INCLINATION = EQUATORIAL OR INCLINATION = LOW_INCLINATION)
 THEN :: (! POLAR_CAP)

RULE090

=====

SUBJECT :: SEU-RULES
 DESCRIPTION :: (south atlantic anomaly implies low altitude)
 If The altitude of the satellite is not LOW_ALTITUDE,
 Then it is definite (100%) that the spacecraft is not in the region of the
 geomagnetic field anomaly in the South Atlantic near the coast of Brazil.

IF :: (ALTITUDE != LOW_ALTITUDE)
 THEN :: (! SOUTH_ATLANTIC_ANOMALY)

RULE091

=====

SUBJECT :: SEU-RULES
 DESCRIPTION :: (spacecraft not in South Atlantic Anomaly)
 If the inclination of the plane of the orbit with respect to the earth's
 equatorial plane is EQUATORIAL,
 Then it is definite (100%) that the spacecraft is not in the region of the
 geomagnetic field anomaly in the South Atlantic near the coast of Brazil.

IF :: (INCLINATION = EQUATORIAL)
 THEN :: (! SOUTH_ATLANTIC_ANOMALY)

RULE111

=====

SUBJECT :: SEU-RULES

EXPLANATION :: ("Known requires a confidence level greater than 20%. If
there is any" :LINE "periodicity greater than 20% then
the cause is not SEU.")

DESCRIPTION :: (SEU not related to satellite spin period.)

SOURCE :: "J. B. Blake"

If the recurrence is known,

Then it is definite (100%) that the cause of the anomaly is not SEU.

IF :: (PERIODICITY IS KNOWN)

THEN :: (CAUSE != SEU)

RULE165

=====

SUBJECT :: SEU-RULES

SOURCE :: "J.B. Blake"

If 1) the recurrence of the anomaly, and

2) The altitude of the satellite is LOW_ALTITUDE, and

3) the anomaly has a dependence on latitude,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is SEU.

IF :: (RECURRENCE AND ALTITUDE = LOW_ALTITUDE AND
LATITUDINAL_DEPENDENCE)

THEN :: (CAUSE = SEU CF 20)

```

=====
Frame :: SOLAR_FLARE
=====

```

```

IDENTIFIER :: "SOLAR_FLARE-"
TRANSLATION :: (a type X1 solar x-ray flare)
PARENTS :: (SEU ROOT)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            ($OR
              (SAME FRAME CONSIDER_CAUSE SEU)
              (SAME FRAME CONSIDER_CAUSE ALL)))
PARMGROUP :: SOLAR_FLARE-PARMS
RULEGROUPS :: (SOLAR_FLARE-RULES)
SOLAR_FLARE-PARMS  :: (DO_REPORT FLARE_OPERATION JSTART_FLARE JSTOP_FLARE
                       SOLAR_FLARE_PARTICLES )
SOLAR_FLARE-RULES  :: (RULE077 RULE078 RULE092 RULE145 RULE146 RULE147
                       RULE163 RULE164 )

```

```

=====
SOLAR_FLARE-PARMS
=====

```

DO_REPORT

```

=====
TRANSLATION :: (users answer about whether or not to print a flare
                report )
PROMPT :: ("Do you want a report of the solar flares that occurred
           around the date of" :LINE "this anomaly?" )
TYPE :: YES/NO
USED-BY :: (RULE164)

```

FLARE_OPERATION

```

=====
TRANSLATION :: (the spacecraft is designed to operate during a major
                solar flare )
PROMPT :: (Is this spacecraft designed to operate during a major solar
           flare? )
TYPE :: YES/NO
UPDATED-BY :: (RULE077)
USED-BY :: (RULE092)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

JSTART_FLARE

```

=====
TRANSLATION :: (the starting Julian date for the flare report)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE163)
CONTAINED-IN :: (RULE164)

```

JSTOP_FLARE

=====

TRANSLATION :: (the ending Julian date for the flare report)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE163)
CONTAINED-IN :: (RULE164)

SOLAR_FLARE_PARTICLES

=====

TRANSLATION :: (the spacecraft is susceptible to upsets from solar
flare particles)
PROMPT :: (Is the spacecraft susceptible to upsets from solar flare
particles?)
TYPE :: YES/NO
UPDATED-BY :: (RULE077 RULE092)
USED-BY :: (SREFMARK RULE078)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====

SOLAR_FLARE-RULES

=====

RULE077

=====

SUBJECT :: SOLAR_FLARE-RULES
DESCRIPTION :: (soft parts lightly shielded are susceptible to solar
flares)

If the payload is shielded by 100 mils Al or so of shielding,
Then 1) it is definite (100%) that the spacecraft is susceptible to upsets
from solar flare particles, and
2) it is definite (100%) that the spacecraft is not designed to operate
during a major solar flare.

IF :: (LIGHTLY_SHIELDED)
THEN :: (SOLAR_FLARE_PARTICLES AND ! FLARE_OPERATION)

RULE078

=====

SUBJECT :: SOLAR_FLARE-RULES
EXPLANATION :: (This confidence level adds to the confidence that CAUSE
is SEU from the SEU frame.)

DESCRIPTION :: (solar flare and shielded vehicle)

If 1) it is suspected that the cause of the anomaly is SEU, and
2) a type X1 solar x-ray flare has occurred is 1_HOUR, and
3) the spacecraft is in the polar region where solar and interplanetary
particles have direct access to low altitudes, and
4) the spacecraft is susceptible to upsets from solar flare particles,
Then there is suggestive evidence (50%) that the cause of the anomaly is SEU.

IF :: (CAUSE IS NOTDEFIS SEU AND X1_FLARE = 1_HOUR AND POLAR_CAP AND
SOLAR_FLARE_PARTICLES)
THEN :: (CAUSE = SEU CF 50)

RULE092

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (spacecraft susceptible to solar flare particles)

If the spacecraft is not designed to operate during a major solar flare,
Then it is definite (100%) that the spacecraft is susceptible to upsets from
solar flare particles.

IF :: (! FLARE_OPERATION)

THEN :: (SOLAR_FLARE_PARTICLES)

RULE145

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (x-ray flare within 1 hour)

If 1) the spacecraft is susceptible to protons trapped in the earth's
radiation belts, and

2) a type X1 solar x-ray flare has occurred is 1_HOUR,

Then there is strongly suggestive evidence (80%) that the cause of the anomaly
is SEU.

IF :: (TRAPPED_PROTONS AND X1_FLARE = 1_HOUR)

THEN :: (CAUSE = SEU CF 80)

RULE146

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (x-ray flare within 24 hours)

If 1) the spacecraft is susceptible to protons trapped in the earth's
radiation belts, and

2) a type X1 solar x-ray flare has occurred is 24_HOURS,

Then there is suggestive evidence (50%) that the cause of the anomaly is SEU.

IF :: (TRAPPED_PROTONS AND X1_FLARE = 24_HOURS)

THEN :: (CAUSE = SEU CF 50)

RULE147

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (x-ray flare within 3 days)

If 1) the spacecraft is susceptible to protons trapped in the earth's
radiation belts, and

2) a type X1 solar x-ray flare has occurred is 3_DAYS,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is SEU.

IF :: (TRAPPED_PROTONS AND X1_FLARE = 3_DAYS)

THEN :: (CAUSE = SEU CF 20)

RULE163

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (defines JSTART_FLARE and JSTOP_FLARE)

If the Julian date is known,

Then 1) it is definite (100%) that the starting Julian date for the flare report is [the Julian date minus 5], and

2) it is definite (100%) that the ending Julian date for the flare report is [the Julian date plus 1].

IF :: (JULIAN_DATE IS KNOWN)

THEN :: (JSTART_FLARE = (JULIAN_DATE - 5) AND JSTOP_FLARE = (JULIAN_DATE + 1))

RULE164

=====

SUBJECT :: SOLAR_FLARE-RULES

DESCRIPTION :: (prints flare report)

If 1) a database available to the user is FLARE, and

2) users answer about whether or not to print a flare report, and

3) the Julian date is known,

Then 1) inform the user of this decision, and

2) produce a printed report of data base flares formatted using flarerpt, and

3) it is definite (100%) that a printout of the solar xray flares near the date.

IF :: (DATABASE = FLARE AND DO_REPORT AND JULIAN_DATE IS KNOWN)

THEN :: (PRINT "A list of X-class solar xray flares about the date of the anomaly will be printed." AND DBASE-REPORT "flares" "flarerpt" (QUAL JDATE > JSTART_FLARE AND JDATE < JSTOP_FLARE) AND FLARE_REPORT)


```
=====
Frame :: SURFACE_CHARGING
=====
```

```
IDENTIFIER :: "SURFACE_CHARGING-"
TRANSLATION :: (to determine if the cause of the anomaly is surface
                charging )
PARENTS :: (ROOT)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            ($OR
             (SAME FRAME CONSIDER_CAUSE SURFACE_CHARGING)
             (SAME FRAME CONSIDER_CAUSE ALL)))
DISPLAYRESULTS :: YES
PARMGROUP :: SURFACE_CHARGING-PARMS
RULEGROUPS :: (SURFACE_CHARGING-RULES)
SURFACE_CHARGING-PARMS :: (ECLIPSE KP_CURRENT MAG_STATE_CURRENT SUBSTORM
                           )
SURFACE_CHARGING-RULES :: (RULE043 RULE054 RULE055 RULE056 RULE057
                           RULE058 RULE059 RULE060 RULE061 RULE062
                           RULE063 RULE098 RULE149 RULE188 RULE189
                           RULE190 RULE191 RULE192 RULE193 RULE194 )
```

```
=====
SURFACE_CHARGING-PARMS
=====
```

ECLIPSE

```
=====
TRANSLATION :: (pass into the shadow of the Earth)
PROMPT :: ("Does this type of anomaly tend to occur when the spacecraft
           is in the shadow" :LINE "of the Earth or at about the time of
           a terminator crossing?" )
TYPE :: YES/NO
USED-BY :: (RULE193)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
```

KP_CURRENT

```
=====
TRANSLATION :: (the three-hour, planetary, magnetic index Kp)
PROMPT :: ("Enter the value for the planetary magnetic index" :ATTR (
           YELLOW HIGH ) "Kp" :ATTR (WHITE HIGH) "for the three hour"
           :LINE "interval" :ATTR (YELLOW HIGH) "at the time of the
           anomaly." :ATTR (WHITE HIGH) "If the anomaly occurred" :LINE
           shortly after the start of a new three-hour interval select"
           :LINE "the value for the preceding interval. Range is 0.0 to
           9.0" )
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
UPDATED-BY :: (SREFMARK RULE060 RULE052)
UPDATED-IN :: (SREFMARK RULE149)
ANTECEDENT-IN :: (SREFMARK RULE149)
USED-BY :: (RULE062 RULE063 RULE061 SREFMARK RULE060)
HELP :: (The geomagnetic planetary 3-hour-range indices, Kp, are
```

published by the World Data Center A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado. They may be found in the Journal of Geophysical Research. For information write to Helen E. Coffey, NOAA E/GC2, 325 Broadway, Boulder, Colorado 80303.)

RANGE :: (0 9)

CONTAINED-IN :: (SREFMARK RULE060)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SOURCE :: (WORLD DATA CENTER A OR THE JOURNAL OF GEOPHYSICAL RESEARCH, SPACE PHYSICS)

MAG_STATE_CURRENT

=====

TRANSLATION :: (the level of magnetic activity in the magnetosphere)

PROMPT :: (Select the level of magnetic activity in the magnetosphere at the time of the anomaly.)

TYPE :: SINGLEVALUED

EXPECT :: (QUIET NORMAL DISTURBED)

UPDATED-BY :: (RULE062 RULE063 RULE061)

USED-BY :: (RULE059 RULE055 RULE056)

HELP :: ("This information may be obtained from the Space" :LINE "
Environment Services Center, NOAA, Environmental" :LINE "
Research Laboratories, 325 Broadway, Boulder," :LINE "Colorado
80303.")

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SUBSTORM

=====

TRANSLATION :: (a moderate magnetic storm)

PROMPT :: ("Does this type of anomaly tend to occur during a magnetic
substorm?")

TYPE :: YES/NO

USED-BY :: (RULE194)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====

SURFACE_CHARGING-RULES

=====

RULE043

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (suggestive positive evidence by quadrant)

SOURCE :: "ATM 89(4483)-01"

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3) 1) 1) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not NOON, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is not DUSK, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is not MIDNIGHT, or
 - 2) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of

the anomaly is not NOON, and
 4) the local time sector, dayside or nightside, at the time of
 the anomaly is not DUSK,
 Then there is suggestive evidence (50%) that the cause of the anomaly is
 SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR = DAWN AND LT_SECTOR
      != NOON AND LT_SECTOR != DUSK AND LT_SECTOR != MIDNIGHT ) OR (
      LT_SECTOR = MIDNIGHT AND LT_SECTOR != DAWN AND LT_SECTOR !=
      NOON AND LT_SECTOR != DUSK ) ) )
THEN  :: (CAUSE = SURFACE_CHARGING CF 50)
```

RULE054

=====

```
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (strongly suggestive evidence by quadrant)
SOURCE :: "ATM 89(4483)-01"
```

If

- 1) the recurrence of the anomaly, and
- 2) the recurrence of an anomaly in a specific local-time sector., and
- 3) the local time sector, dayside or nightside, at the time of the
 anomaly is MIDNIGHT, and
- 4) the local time sector, dayside or nightside, at the time of the
 anomaly is DAWN, and
- 5) the local time sector, dayside or nightside, at the time of the
 anomaly is not NOON, and
- 6) the local time sector, dayside or nightside, at the time of the
 anomaly is not DUSK,

Then there is strongly suggestive evidence (80%) that the cause of the anomaly
 is SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND LT_SECTOR = MIDNIGHT AND LT_SECTOR
      = DAWN AND LT_SECTOR != NOON AND LT_SECTOR != DUSK )
THEN  :: (CAUSE = SURFACE_CHARGING CF 80)
```

RULE055

=====

```
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (current mag state is quiet)
SOURCE :: "H.C. KOONS"
```

If the level of magnetic activity in the magnetosphere is QUIET,
 Then there is suggestive evidence (50%) that the cause of the anomaly is not
 SURFACE_CHARGING.

```
IF    :: (MAG_STATE_CURRENT = QUIET)
THEN  :: (CAUSE != SURFACE_CHARGING CF 50)
```

RULE056

=====

```
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (current mag state is disturbed)
SOURCE :: "H.C. KOONS"
```

If the level of magnetic activity in the magnetosphere is DISTURBED,
 Then there is weakly suggestive evidence (20%) that the cause of the anomaly
 is SURFACE_CHARGING.

```
IF    :: (MAG_STATE_CURRENT = DISTURBED)
THEN  :: (CAUSE = SURFACE_CHARGING CF 20)
```

RULE057

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (periodicity is equal to satellite spin period)

SOURCE :: "AFGL-TR-81-0270 PROCEEDINGS OF SPACECRAFT CHARGING TECHNOLOGY
CONFERENCE III"

If the recurrence is SATELLITE_SPIN_PERIOD,
Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is SURFACE_CHARGING.

IF :: (PERIODICITY = SATELLITE_SPIN_PERIOD)

THEN :: (CAUSE = SURFACE_CHARGING CF 20)

RULE058

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (periodicity is 27 day solar cycle)

NOTE :: "27 days is the solar rotation period. It is the fundamental
period for solar flares and related magnetospheric storms."

If the recurrence is 27_DAY,
Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is SURFACE_CHARGING.

IF :: (PERIODICITY = 27_DAY)

THEN :: (CAUSE = SURFACE_CHARGING CF 20)

RULE059

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (anomalies recur during magnetically disturbed times)

If 1) the recurrence of the anomaly, and
2) the recurrence is MAGNETICALLY_DISTURBED, and
3) the level of magnetic activity in the magnetosphere is DISTURBED,
Then there is suggestive evidence (50%) that the cause of the anomaly is
SURFACE_CHARGING.

IF :: (RECURRENCE AND PERIODICITY = MAGNETICALLY_DISTURBED AND
MAG_STATE_CURRENT = DISTURBED)

THEN :: (CAUSE = SURFACE_CHARGING CF 50)

RULE060

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (DOSCALL to obtain Kp from historical environment database)

If 1) the Julian date is known, and
2) a database available to the user is KP, and
3) the local time interval in which the anomaly occurred is known, and
4) the three-hour, planetary, magnetic index Kp is not known,
Then 1) , and
2) retrieve data from an external source, and
3) inform the user of this decision.

IF :: (JULIAN_DATE IS KNOWN AND DATABASE = KP AND
UNIVERSAL_TIME_INTERVAL IS KNOWN AND KP_CURRENT IS NOTKNOWN)
THEN :: ((DOSCALL GETKP JULIAN_DATE UNIVERSAL_TIME_INTERVAL) AND
READ-DOS-FILE "kpdata.dat" KP_CURRENT KPMAX_RECENT AND PRINT "
The" :ATTR (QUOTE (YELLOW)) "value for Kp" :ATTR (QUOTE (WHITE
)) "at the time of the anomaly was" :ATTR (QUOTE (YELLOW))
KP_CURRENT :ATTR (QUOTE (WHITE)) "." :LINE 2 "The convention
used is the following: Kp of 3- = 2.7, Kp of 3 is 3.0, and Kp
of 3+ is 3.3.")

RULE061

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (current mag state disturbed if Kp >= 4-)

SOURCE :: "ATM 89(4483)-01"

If the three-hour, planetary, magnetic index Kp is greater than or equal to 3.7,
Then it is definite (100%) that the level of magnetic activity in the magnetosphere is DISTURBED.

IF :: (KP_CURRENT >= 3.7)
THEN :: (MAG_STATE_CURRENT = DISTURBED)

RULE062

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (current mag state quiet if Kp <= 1+)

SOURCE :: "ATM 89(4483)-01"

If the three-hour, planetary, magnetic index Kp is less than or equal to 1.3,

Then it is definite (100%) that the level of magnetic activity in the magnetosphere is QUIET.

IF :: (KP_CURRENT <= 1.3)
THEN :: (MAG_STATE_CURRENT = QUIET)

RULE063

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (current mag state normal if Kp > 1+ and Kp < 3-)

SOURCE :: "ATM 89(4483)-01"

If 1) the three-hour, planetary, magnetic index Kp is greater than 1.3, and
2) the three-hour, planetary, magnetic index Kp is less than 2.7,
Then it is definite (100%) that the level of magnetic activity in the
magnetosphere is NORMAL.

IF :: (KP_CURRENT > 1.3 AND KP_CURRENT < 2.7)

THEN :: (MAG_STATE_CURRENT = NORMAL)

RULE098

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (surface charging does not occur between 1200 and 1800
LT)

If 1) the local time at the satellite is greater than or equal to 12., and
2) the local time at the satellite is less than or equal to 18.,
Then there is strongly suggestive evidence (90%) that the cause of the anomaly
is not SURFACE_CHARGING.

IF :: (LOCAL_TIME >= 12. AND LOCAL_TIME <= 18.)

THEN :: (CAUSE != SURFACE_CHARGING CF 90)

RULE149

=====

SUBJECT :: SURFACE_CHARGING-RULES

ANTECEDENT :: YES

DESCRIPTION :: (Handles Kp_current = -1)

If the three-hour, planetary, magnetic index Kp is -1,
Then it is definite (100%) that the three-hour, planetary, magnetic index Kp
is UNKNOWN.

IF :: (KP_CURRENT = -1)

THEN :: (KP_CURRENT = UNKNOWN)

RULE188

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (suggestive negative evidence based on quadrant)

SOURCE :: "ATM 89(4483)-01"

If 1) the recurrence of the anomaly, and
2) the recurrence of an anomaly in a specific local-time sector., and
3) 1) 1) the local time sector, dayside or nightside, at the time of
the anomaly is NOON, and
2) the local time sector, dayside or nightside, at the time of
the anomaly is not DAWN, and
3) the local time sector, dayside or nightside, at the time of
the anomaly is not DUSK, and
4) the local time sector, dayside or nightside, at the time of
the anomaly is not MIDNIGHT, or
2) 1) the local time sector, dayside or nightside, at the time of
the anomaly is DUSK, and
2) the local time sector, dayside or nightside, at the time of
the anomaly is not DAWN, and
3) the local time sector, dayside or nightside, at the time of
the anomaly is not NOON, and
4) the local time sector, dayside or nightside, at the time of

the anomaly is not MIDNIGHT,
Then there is suggestive evidence (50%) that the cause of the anomaly is not
SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR = NOON AND LT_SECTOR
      != DAWN AND LT_SECTOR != DUSK AND LT_SECTOR != MIDNIGHT ) OR (
      LT_SECTOR = DUSK AND LT_SECTOR != DAWN AND LT_SECTOR != NOON
      AND LT_SECTOR != MIDNIGHT ) ) )
THEN  :: (CAUSE != SURFACE_CHARGING CF 50)
```

RULE189

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (weakly suggestive negative evidence based on quadrants)

SOURCE :: "ATM 89(4483)-01"

If

- 1) the recurrence of the anomaly, and
- 2) the recurrence of an anomaly in a specific local-time sector., and
- 3)
 - 1) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is not DUSK, or
 - 2) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is not NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK, or
 - 3) 1) the local time sector, dayside or nightside, at the time of the anomaly is not MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is not DUSK, or
 - 4) 1) the local time sector, dayside or nightside, at the time of the anomaly is not MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is not NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly is not SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR = MIDNIGHT AND
      LT_SECTOR != DAWN AND LT_SECTOR = NOON AND LT_SECTOR != DUSK )
      OR (LT_SECTOR = MIDNIGHT AND LT_SECTOR != DAWN AND LT_SECTOR
      != NOON AND LT_SECTOR = DUSK ) OR (LT_SECTOR != MIDNIGHT AND
      LT_SECTOR = DAWN AND LT_SECTOR = NOON AND LT_SECTOR != DUSK )
      OR (LT_SECTOR != MIDNIGHT AND LT_SECTOR = DAWN AND LT_SECTOR
      != NOON AND LT_SECTOR = DUSK ) ) )
THEN  :: (CAUSE != SURFACE_CHARGING CF 20)
```

RULE190

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (negative evidence based on quadrants)

SOURCE :: "ATM 89(4483)-01"

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3) 1) 1) the local time sector, dayside or nightside, at the time of the anomaly is not MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK, or
 - 2) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK,

Then it is definite (100%) that the cause of the anomaly is not
SURFACE_CHARGING.

IF :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR != MIDNIGHT AND
LT_SECTOR != DAWN AND LT_SECTOR = NOON AND LT_SECTOR = DUSK)
OR (LT_SECTOR = MIDNIGHT AND LT_SECTOR = DAWN AND LT_SECTOR =
NOON AND LT_SECTOR = DUSK)))
THEN :: (CAUSE != SURFACE_CHARGING)

RULE191

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (weakly suggestive positive evidence based on quadrants)

SOURCE :: "ATM 89(4483)-01"

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3) 1) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is not DUSK, or
 - 2) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is not NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK,

Then there is weakly suggestive evidence (20%) that the cause of the anomaly is SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR = MIDNIGHT AND
      LT_SECTOR = DAWN AND LT_SECTOR = NOON AND LT_SECTOR != DUSK )
      OR (LT_SECTOR = MIDNIGHT AND LT_SECTOR = DAWN AND LT_SECTOR !=
      NOON AND LT_SECTOR = DUSK ) ) )
THEN  :: (CAUSE = SURFACE_CHARGING CF 20)
```

RULE192

=====

```
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (strongly suggestive negative evidence based on
      quadrants )
```

```
SOURCE :: "ATM 89(4483)-01"
```

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3)
 - 1) 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is not DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK, or
 - 2)
 - 1) the local time sector, dayside or nightside, at the time of the anomaly is not MIDNIGHT, and
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is NOON, and
 - 4) the local time sector, dayside or nightside, at the time of the anomaly is DUSK,

Then there is strongly suggestive evidence (80%) that the cause of the anomaly is not SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND ((LT_SECTOR = MIDNIGHT AND
      LT_SECTOR != DAWN AND LT_SECTOR = NOON AND LT_SECTOR = DUSK )
      OR (LT_SECTOR != MIDNIGHT AND LT_SECTOR = DAWN AND LT_SECTOR =
      NOON AND LT_SECTOR = DUSK ) ) )
THEN  :: (CAUSE != SURFACE_CHARGING CF 80)
```

RULE193

=====

```
SUBJECT :: SURFACE_CHARGING-RULES
DESCRIPTION :: (spacecraft in eclipse)
SOURCE :: "H.C. Koons based on a number of discharges on SCATHA in
      eclipse or immediately after a terminator crossing."
```

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, and
 - 4) pass into the shadow of the Earth,

Then there is weakly suggestive evidence (30%) that the cause of the anomaly is SURFACE_CHARGING.

```
IF    :: (RECURRENCE AND LT_RECUR AND LT_SECTOR = MIDNIGHT AND ECLIPSE)
THEN  :: (CAUSE = SURFACE_CHARGING CF 30)
```

RULE194

=====

SUBJECT :: SURFACE_CHARGING-RULES

DESCRIPTION :: (correlation with substorms)

SOURCE :: "H.C. Koons"

- If
- 1) the recurrence of the anomaly, and
 - 2) the recurrence of an anomaly in a specific local-time sector., and
 - 3)
 - 1) the local time sector, dayside or nightside, at the time of the anomaly is MIDNIGHT, or
 - 2) the local time sector, dayside or nightside, at the time of the anomaly is DAWN, and
 - 4) a moderate magnetic storm,

Then there is weakly suggestive evidence (30%) that the cause of the anomaly is SURFACE_CHARGING.

IF :: (RECURRENCE AND LT_RECUR AND (LT_SECTOR = MIDNIGHT OR LT_SECTOR
= DAWN) AND SUBSTORM)

THEN :: (CAUSE = SURFACE_CHARGING CF 30)

```

=====
Frame :: TOTAL_DOSE
=====

```

```

IDENTIFIER :: "TOTAL_DOSE-"
TRANSLATION :: (to determine if the cause of the anomaly is a failure due
                to total radiation dose )
PARENTS :: (ROOT)
INITIALDATA :: (YEARS_SINCE_LAUNCH)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            ($OR
             (SAME FRAME CONSIDER_CAUSE TOTAL_DOSE)
             (SAME FRAME CONSIDER_CAUSE ALL)))
DISPLAYRESULTS :: YES
PARMGROUP :: TOTAL_DOSE-PARMS
RULEGROUPS :: (TOTAL_DOSE-RULES)
TOTAL_DOSE-PARMS :: (DOSE_10 DOSE_100 DOSE_20 DOSE_200 DOSE_50
                    DOSE_RATE_10 DOSE_RATE_100 DOSE_RATE_20
                    DOSE_RATE_200 DOSE_RATE_50 PREVIOUS_TD_ANOMALIES
                    SHIELDING TOTAL_DOSE_TECHNOLOGY
                    TOTAL_DOSE_THRESHOLD TOTAL_RADIATION_DOSE
                    YEARS_SINCE_LAUNCH )
TOTAL_DOSE-RULES :: (RULE110 RULE112 RULE113 RULE117 RULE118 RULE119
                    RULE120 RULE121 RULE122 RULE123 RULE124 RULE125
                    RULE126 RULE127 RULE128 RULE129 RULE130 RULE131
                    RULE144 RULE150 RULE151 RULE152 RULE153 RULE154
                    RULE155 RULE156 RULE157 RULE158 RULE159 RULE160
                    RULE161 RULE162 RULE171 )

```

```

=====
TOTAL_DOSE-PARMS
=====

```

```

DOSE_10
=====
TRANSLATION :: (the esimated total dose since launch under 10 mils of
                aluminum )
TYPE :: SINGLEVALUED
METHOD :: (TIMES (VAL1 FRAME DOSE_RATE_10) (VAL1 FRAME
        YEARS_SINCE_LAUNCH ) )
CONTAINED-IN :: (RULE126)

```

```

DOSE_100
=====
TRANSLATION :: (the estimated dose since launch under 125 mils of
                aluminum )
TYPE :: SINGLEVALUED
INVALID :: YES
CONTAINED-IN :: (RULE127)
METHOD :: (TIMES (VAL1 FRAME DOSE_RATE_100) (VAL1 FRAME
        YEARS_SINCE_LAUNCH ) )

```

DOSE_20

=====

TRANSLATION :: (the esimated total dose since launch under 20 mils of
aluminum)

TYPE :: SINGLEVALUED

METHOD :: (TIMES (VAL1 FRAME DOSE_RATE_20) (VAL1 FRAME
YEARS_SINCE_LAUNCH))

DOSE_200

=====

TRANSLATION :: (the estimated dose since launch under 250 mils of
aluminum)

TYPE :: SINGLEVALUED

CONTAINED-IN :: (RULE125)

METHOD :: (TIMES (VAL1 FRAME DOSE_RATE_200) (VAL1 FRAME
YEARS_SINCE_LAUNCH))

DOSE_50

=====

TRANSLATION :: (the esimated total dose since launch under 50 mils of
aluminum)

TYPE :: SINGLEVALUED

METHOD :: (TIMES (VAL1 FRAME DOSE_RATE_50) (VAL1 FRAME
YEARS_SINCE_LAUNCH))

CONTAINED-IN :: (RULE124)

DOSE_RATE_10

=====

TRANSLATION :: (the radiation dose per year under 10 mils of aluminum)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE150
RULE117 RULE144 RULE158 RULE157 RULE160 RULE161 RULE162
RULE159)

DOSE_RATE_100

=====

TRANSLATION :: (the dose per year under 125 mils of aluminum)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE150
RULE117 RULE144 RULE158 RULE157 RULE160 RULE161 RULE162
RULE159)

DOSE_RATE_20

=====

TRANSLATION :: (the radiation dose per year under 20 mils of aluminum)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE150
RULE117 RULE144 RULE158 RULE157 RULE160 RULE161 RULE162
RULE159)

DOSE_RATE_200

=====

TRANSLATION :: (the dose per year under 250 mils of aluminum)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE150
RULE117 RULE144 RULE158 RULE157 RULE160 RULE161 RULE162
RULE159)

DOSE_RATE_50

=====

TRANSLATION :: (the radiation dose per year under 50 mils of aluminum)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE150
RULE117 RULE144 RULE158 RULE157 RULE160 RULE161 RULE162
RULE159)

PREVIOUS_TD_ANOMALIES

=====

TRANSLATION :: (subsystem has had previous anomalies attributed to
total radiation dose)
PROMPT :: ("Has the subsystem in which this anomaly occurred had a
previous anomaly" :LINE "attributed to total radiation dose?"
)
TYPE :: YES/NO
CERTAINTY-FACTOR-RANGE :: UNKNOWN

SHIELDING

=====

TRANSLATION :: (the thickness of the radiation shielding to total
radiation dose)
PROMPT :: ("Select the term that best describes the radiation shielding
of the circuit" :LINE "that experienced the anomaly.")
TYPE :: SINGLEVALUED
EXPECT :: (UNSHIELDED VERY_LIGHTLY_SHIELDED LIGHTLY_SHIELDED
INTERMEDIATELY_SHIELDED HEAVILY_SHIELDED
VERY_HEAVILY_SHIELDED)
ASKFIRST :: YES
UPDATED-BY :: (SREFMARK RULE118)
USED-BY :: (RULE124 RULE125 RULE126 RULE127 SREFMARK RULE118)
HELP :: ("Shielding is defined in terms of the equivalent" :LINE "
thickness of aluminum." :LINE 2 "< 10 mils.....UNSHIELDED"
:LINE "10 to 20 mils....VERY_LIGHTLY_SHIELDED" :LINE "20 to 50
mils....LIGHTLY_SHIELDED" :LINE "50 to 100
mils....INTERMEDIATELY_SHIELDED" :LINE "100 to 200
mils...HEAVILY_SHIELDED" :LINE "> 200
mils.....VERY_HEAVILY_SHIELDED")
CERTAINTY-FACTOR-RANGE :: UNKNOWN

TOTAL_DOSE_TECHNOLOGY

=====

TRANSLATION :: (the technology used in the manufacture of the device)
PROMPT :: ("Select the technology which best describes the softest
devices to total" :LINE "radiation dose in the circuit
experiencing the anomaly. The devices are" :LINE "listed
from hardest down to softest.")
TYPE :: SINGLEVALUED
EXPECT :: (ECL AMORPHOUS_TTL LST^2L I^2L LINEAR ICS MNOS MNOS/SOS CMOS
PMOS CMOS/SOS VMOS NMOS POWER_TRANSISTORS CCD BUBBLE_MEMORY
PRECISION_CRYSTALS)
USED-BY :: (RULE119 RULE128 RULE129 RULE131 RULE130)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

TOTAL_DOSE_THRESHOLD

=====

TRANSLATION :: (the radiation dose at which a particular technology
begins to fail)

TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE119 RULE128 RULE129 RULE131 RULE130)

USED-BY :: (RULE120 RULE121 RULE122 RULE123)

TOTAL_RADIATION_DOSE

=====

PROMPT :: ("Enter the estimated total radiation dose that has been
experienced by" :LINE "the parts in the circuit experiencing
this anomaly. The units are Rad (Si).")

TYPE :: SINGLEVALUED

EXPECT :: POSITIVE-NUMBER

UPDATED-BY :: (RULE124 RULE125 RULE126 RULE127)

USED-BY :: (RULE120 RULE121 RULE122 RULE123)

HELP :: ("The total radiation dose to the failed device" :LINE "since
launch must be given in rads. If the" :LINE "value is not
known, press Enter. If you do" :LINE "not know the value you
should enter the" :LINE "apogee and perigee of the vehicle

when"

:LINE "prompted. The program will then estimate the" :LINE "
total radiation dose for the closest standard" :LINE "orbit
contained in its database.")

CERTAINTY-FACTOR-RANGE :: UNKNOWN

RANGE :: (0 1.e20)

YEARS_SINCE_LAUNCH

=====

TRANSLATION :: (the number of years since launch)

TYPE :: SINGLEVALUED

USED-BY :: (RULE171)

METHOD :: (FQUOTIENT (DIFFERENCE (VAL1 FRAME JULIAN_DATE) (VAL1 FRAME
JULIAN_LAUNCH_DATE)) 365)

=====

TOTAL_DOSE-RULES

=====

RULE110

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Local time recurrence rules out total radiation dose.)

If 1) the recurrence of the anomaly, and

2) the recurrence of an anomaly in a specific local-time sector.,

Then it is definite (100%) that the cause of the anomaly is not TOTAL_DOSE.

IF :: (RECURRENCE AND LT_RECUR)

THEN :: (CAUSE != TOTAL_DOSE)

```

RULE112
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Total dose not related to short term periodicities.)
If 1) the recurrence is SATELLITE_SPIN_PERIOD, or
   2) the recurrence is DIURNAL, or
   3) the recurrence is SOLAR_ROTATION,
Then it is definite (100%) that the cause of the anomaly is not TOTAL_DOSE.

IF :: (PERIODICITY = SATELLITE_SPIN_PERIOD OR PERIODICITY = DIURNAL
      OR PERIODICITY = SOLAR_ROTATION )
THEN :: (CAUSE != TOTAL_DOSE)

```

```

RULE113
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Spring/fall periodicity not likely to be caused by
               total dose. )
If the recurrence is SPRING/FALL,
Then there is suggestive evidence (75%) that the cause of the anomaly is not
TOTAL_DOSE.

IF :: (PERIODICITY = SPRING/FALL)
THEN :: (CAUSE != TOTAL_DOSE CF 75)

```

```

RULE117
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Dose rate in GPS orbit.)
If the orbit of the satellite is GPS,
Then 1) it is definite (100%) that the radiation dose per year under 10 mils
      of aluminum is 3800000., and
      2) it is definite (100%) that the radiation dose per year under 20 mils
      of aluminum is 1840000., and
      3) it is definite (100%) that the radiation dose per year under 50 mils
      of aluminum is 562000., and
      4) it is definite (100%) that the dose per year under 125 mils of
      aluminum is 149000., and
      5) it is definite (100%) that the dose per year under 250 mils of
      aluminum is 14300..

IF :: (ORBIT = GPS)
THEN :: (DOSE_RATE_10 = 3800000. AND DOSE_RATE_20 = 1840000. AND
        DOSE_RATE_50 = 562000. AND DOSE_RATE_100 = 149000. AND
        DOSE_RATE_200 = 14300. )

```

```

RULE118
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Unknown shielding is set to unshielded.)
If the thickness of the radiation shielding to total radiation dose is not
known,
Then 1) it is definite (100%) that the thickness of the radiation shielding to
      total radiation dose is UNSHIELDED, and
      2) inform the user of this decision.

IF :: (SHIELDING IS NOTKNOWN)
THEN :: (SHIELDING = UNSHIELDED AND PRINT "We have assumed that the
      circuit is unshielded to give a worst-case answer for total
      radiation dose." )

```

RULE119

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Technology with a 10^4 total dose threshold.)

If 1) the technology used in the manufacture of the device is CCD, or
 2) the technology used in the manufacture of the device is PMOS, or
 3) the technology used in the manufacture of the device is CMOS, or
 4) the technology used in the manufacture of the device is MNOS/SOS, or
 5) the technology used in the manufacture of the device is MNOS, or
 6) the technology used in the manufacture of the device is
 POWER_TRANSISTORS,

Then it is definite (100%) that the radiation dose at which a particular technology begins to fail is 10000..

IF :: (TOTAL_DOSE_TECHNOLOGY = CCD OR TOTAL_DOSE_TECHNOLOGY = PMOS OR
 TOTAL_DOSE_TECHNOLOGY = CMOS OR TOTAL_DOSE_TECHNOLOGY =
 MNOS/SOS OR TOTAL_DOSE_TECHNOLOGY = MNOS OR
 TOTAL_DOSE_TECHNOLOGY = POWER_TRANSISTORS)
 THEN :: (TOTAL_DOSE_THRESHOLD = 10000.)

RULE120

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose below threshold)

If TOTAL_RADIATION_DOSE is less than or equal to the radiation dose at which a particular technology begins to fail,
 Then there is strongly suggestive evidence (80%) that the cause of the anomaly is not TOTAL_DOSE.

IF :: (TOTAL_RADIATION_DOSE <= TOTAL_DOSE_THRESHOLD)
 THEN :: (CAUSE != TOTAL_DOSE CF 80)

RULE121

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose between threshold and five times threshold)

If TOTAL_RADIATION_DOSE is less than [5 times the radiation dose at which a particular technology begins to fail] but greater than or equal to the radiation dose at which a particular technology begins to fail,
 Then there is weakly suggestive evidence (30%) that the cause of the anomaly is TOTAL_DOSE.

IF :: (TOTAL_RADIATION_DOSE BT TOTAL_DOSE_THRESHOLD (5 *
 TOTAL_DOSE_THRESHOLD))
 THEN :: (CAUSE = TOTAL_DOSE CF 30)

RULE122

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose between five and ten times threshold.)

If TOTAL_RADIATION_DOSE is less than [10 times the radiation dose at which a particular technology begins to fail] but greater than or equal to [5 times the radiation dose at which a particular technology begins to fail],
 Then there is suggestive evidence (60%) that the cause of the anomaly is TOTAL_DOSE.

IF :: (TOTAL_RADIATION_DOSE BT (5 * TOTAL_DOSE_THRESHOLD) (10 *
 TOTAL_DOSE_THRESHOLD))
 THEN :: (CAUSE = TOTAL_DOSE CF 60)


```

RULE123
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Dose greater than ten times threshold.)
If TOTAL_RADIATION_DOSE is greater than [10 times the radiation dose at
which a particular technology begins to fail],
Then there is strongly suggestive evidence (90%) that the cause of the anomaly
is TOTAL_DOSE.

IF :: (TOTAL_RADIATION_DOSE > (10 * TOTAL_DOSE_THRESHOLD))
THEN :: (CAUSE = TOTAL_DOSE CF 90)

RULE124
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Define lightly_shielded)
If the thickness of the radiation shielding to total radiation dose is
LIGHTLY_SHIELDED,
Then it is definite (100%) that TOTAL_RADIATION_DOSE is the esimated total
dose since launch under 50 mils of aluminum.

IF :: (SHIELDING = LIGHTLY_SHIELDED)
THEN :: (TOTAL_RADIATION_DOSE = (VALUE DOSE_50))

RULE125
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Define heavily shielded)
If the thickness of the radiation shielding to total radiation dose is
HEAVILY_SHIELDED,
Then it is definite (100%) that TOTAL_RADIATION_DOSE is the estimated dose
since launch under 250 mils of aluminum.

IF :: (SHIELDING = HEAVILY_SHIELDED)
THEN :: (TOTAL_RADIATION_DOSE = (VALUE DOSE_200))

RULE126
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Define unshielded.)
If the thickness of the radiation shielding to total radiation dose is
UNSHIELDED,
Then it is definite (100%) that TOTAL_RADIATION_DOSE is the esimated total
dose since launch under 10 mils of aluminum.

IF :: (SHIELDING = UNSHIELDED)
THEN :: (TOTAL_RADIATION_DOSE = (VALUE DOSE_10))

RULE127
=====
SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Define intermediately shielded)
If the thickness of the radiation shielding to total radiation dose is
INTERMEDIATELY_SHIELDED,
Then it is definite (100%) that TOTAL_RADIATION_DOSE is the estimated dose
since launch under 125 mils of aluminum.

IF :: (SHIELDING = INTERMEDIATELY_SHIELDED)
THEN :: (TOTAL_RADIATION_DOSE = (VALUE DOSE_100))

```

RULE128

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Technology with a 10^2 total dose threshold.)

If the technology used in the manufacture of the device is
PRECISION_CRYSTALS,
Then it is definite (100%) that the radiation dose at which a particular
technology begins to fail is 100..

IF :: (TOTAL_DOSE_TECHNOLOGY = PRECISION_CRYSTALS)
THEN :: (TOTAL_DOSE_THRESHOLD = 100.)

RULE129

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Technology with a 10^3 total dose threshold.)

If 1) the technology used in the manufacture of the device is NMOS, or
2) the technology used in the manufacture of the device is BUBBLE_MEMORY,
or
3) the technology used in the manufacture of the device is VMOS, or
4) the technology used in the manufacture of the device is CMOS/SOS,
Then it is definite (100%) that the radiation dose at which a particular
technology begins to fail is 1000..

IF :: (TOTAL_DOSE_TECHNOLOGY = NMOS OR TOTAL_DOSE_TECHNOLOGY =
BUBBLE_MEMORY OR TOTAL_DOSE_TECHNOLOGY = VMOS OR
TOTAL_DOSE_TECHNOLOGY = CMOS/SOS)
THEN :: (TOTAL_DOSE_THRESHOLD = 1000.)

RULE130

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Technology with a 10^5 total dose threshold.)

If 1) the technology used in the manufacture of the device is LINEAR_ICS, or

2) the technology used in the manufacture of the device is I^2L ,
Then it is definite (100%) that the radiation dose at which a particular
technology begins to fail is 100000..

IF :: (TOTAL_DOSE_TECHNOLOGY = LINEAR_ICS OR TOTAL_DOSE_TECHNOLOGY =
 I^2L)
THEN :: (TOTAL_DOSE_THRESHOLD = 100000.)

RULE131

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Technology with a 10^6 total dose threshold.)

If 1) the technology used in the manufacture of the device is LST^2L , or
2) the technology used in the manufacture of the device is AMORPHOUS_TTL,
or
3) the technology used in the manufacture of the device is ECL,
Then it is definite (100%) that the radiation dose at which a particular
technology begins to fail is 1000000..

IF :: (TOTAL_DOSE_TECHNOLOGY = LST^2L OR TOTAL_DOSE_TECHNOLOGY =
AMORPHOUS_TTL OR TOTAL_DOSE_TECHNOLOGY = ECL)
THEN :: (TOTAL_DOSE_THRESHOLD = 1000000.)

RULE144

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in geosync orbit)

If the orbit of the satellite is GEOSYNC,

Then 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 5000000., and
2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 1700000., and
3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 220000., and
4) it is definite (100%) that the dose per year under 125 mils of aluminum is 30000., and
5) it is definite (100%) that the dose per year under 250 mils of aluminum is 1333..

IF :: (ORBIT = GEOSYNC)

THEN :: (DOSE_RATE_10 = 5000000. AND DOSE_RATE_20 = 1700000. AND
DOSE_RATE_50 = 220000. AND DOSE_RATE_100 = 30000. AND
DOSE_RATE_200 = 1333.)

RULE150

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose for a Molniya orbit)

If the orbit of the satellite is MOLNIYA,

Then 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 2000000., and
2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 600000., and
3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 105000., and
4) it is definite (100%) that the dose per year under 125 mils of aluminum is 26000., and
5) it is definite (100%) that the dose per year under 250 mils of aluminum is 3900..

IF :: (ORBIT = MOLNIYA)

THEN :: (DOSE_RATE_10 = 2000000. AND DOSE_RATE_20 = 600000. AND
DOSE_RATE_50 = 105000. AND DOSE_RATE_100 = 26000. AND
DOSE_RATE_200 = 3900.)

RULE151

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in Landsat Orbit)

If the orbit of the satellite is LANDSAT,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 20000., and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 7200, and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 1800, and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 490, and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 0.

IF :: (ORBIT = LANDSAT)

THEN :: (DOSE_RATE_10 = 20000. AND DOSE_RATE_20 = 7200 AND DOSE_RATE_50 = 1800 AND DOSE_RATE_100 = 490 AND DOSE_RATE_200 = 0)

RULE152

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in LOW1 orbit.)

If the orbit of the satellite is LOW1,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 3160, and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 2130, and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 1490, and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 1290, and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 1200.

IF :: (ORBIT = LOW1)

THEN :: (DOSE_RATE_10 = 3160 AND DOSE_RATE_20 = 2130 AND DOSE_RATE_50 = 1490 AND DOSE_RATE_100 = 1290 AND DOSE_RATE_200 = 1200)

RULE153

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in LOW2 orbit)

If the orbit of the satellite is LOW2,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 2000, and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 900, and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 300, and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 100, and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 0.

IF :: (ORBIT = LOW2)

THEN :: (DOSE_RATE_10 = 2000 AND DOSE_RATE_20 = 900 AND DOSE_RATE_50 = 300 AND DOSE_RATE_100 = 100 AND DOSE_RATE_200 = 0)

RULE154

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in STS28HI orbit)

If the orbit of the satellite is STS28HI,

Then 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 2000, and
2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 560, and
3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 100, and
4) it is definite (100%) that the dose per year under 125 mils of aluminum is 0, and
5) it is definite (100%) that the dose per year under 250 mils of aluminum is 0.

IF :: (ORBIT = STS28HI)

THEN :: (DOSE_RATE_10 = 2000 AND DOSE_RATE_20 = 560 AND DOSE_RATE_50 = 100 AND DOSE_RATE_100 = 0 AND DOSE_RATE_200 = 0)

RULE155

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in STS28LOW orbit)

If the orbit of the satellite is STS28LOW,

Then 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 0, and
2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 0, and
3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 0, and
4) it is definite (100%) that the dose per year under 125 mils of aluminum is 0, and
5) it is definite (100%) that the dose per year under 250 mils of aluminum is 0.

IF :: (ORBIT = STS28LOW)

THEN :: (DOSE_RATE_10 = 0 AND DOSE_RATE_20 = 0 AND DOSE_RATE_50 = 0 AND DOSE_RATE_100 = 0 AND DOSE_RATE_200 = 0)

RULE156

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in NOVA orbit)

If the orbit of the satellite is NOVA,

Then 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 133000., and
2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 42200., and
3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 8980., and
4) it is definite (100%) that the dose per year under 125 mils of aluminum is 3400., and
5) it is definite (100%) that the dose per year under 250 mils of aluminum is 1430..

IF :: (ORBIT = NOVA)

THEN :: (DOSE_RATE_10 = 133000. AND DOSE_RATE_20 = 42200. AND DOSE_RATE_50 = 8980. AND DOSE_RATE_100 = 3400. AND DOSE_RATE_200 = 1430.)

RULE157

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose for IRAS orbit)

If the orbit of the satellite is GEOSAT,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 30505., and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 11140., and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 2840., and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 723, and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 100.

IF :: (ORBIT = GEOSAT)

THEN :: (DOSE_RATE_10 = 30505. AND DOSE_RATE_20 = 11140. AND
DOSE_RATE_50 = 2840. AND DOSE_RATE_100 = 723 AND DOSE_RATE_200
= 100)

RULE158

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose for DMSP or TIROS orbit)

If 1) the orbit of the satellite is DMSP, or

2) the orbit of the satellite is TIROS,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 31600., and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 10750., and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 2550., and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 490, and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 100.

IF :: (ORBIT = DMSP OR ORBIT = TIROS)

THEN :: (DOSE_RATE_10 = 31600. AND DOSE_RATE_20 = 10750. AND
DOSE_RATE_50 = 2550. AND DOSE_RATE_100 = 490 AND DOSE_RATE_200
= 100)

RULE159

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Dose in IRAS orbit)

If the orbit of the satellite is IRAS,

- Then
- 1) it is definite (100%) that the radiation dose per year under 10 mils of aluminum is 43000., and
 - 2) it is definite (100%) that the radiation dose per year under 20 mils of aluminum is 14000., and
 - 3) it is definite (100%) that the radiation dose per year under 50 mils of aluminum is 3000., and
 - 4) it is definite (100%) that the dose per year under 125 mils of aluminum is 800., and
 - 5) it is definite (100%) that the dose per year under 250 mils of aluminum is 100.

```

IF      :: (ORBIT = IRAS)
THEN    :: (DOSE_RATE_10 = 43000. AND DOSE_RATE_20 = 14000. AND
            DOSE_RATE_50 = 3000. AND DOSE_RATE_100 = 800. AND
            DOSE_RATE_200 = 100 )

```

RULE160

=====

```

SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Dose for STS57LOW orbit)
If the orbit of the satellite is STS57LOW,
Then 1) it is definite (100%) that the radiation dose per year under 10 mils
      of aluminum is 1333, and
      2) it is definite (100%) that the radiation dose per year under 20 mils
      of aluminum is 605, and
      3) it is definite (100%) that the radiation dose per year under 50 mils
      of aluminum is 205, and
      4) it is definite (100%) that the dose per year under 125 mils of
      aluminum is 100, and
      5) it is definite (100%) that the dose per year under 250 mils of
      aluminum is 0.

```

```

IF      :: (ORBIT = STS57LOW)
THEN    :: (DOSE_RATE_10 = 1333 AND DOSE_RATE_20 = 605 AND DOSE_RATE_50 =
            205 AND DOSE_RATE_100 = 100 AND DOSE_RATE_200 = 0 )

```

RULE161

=====

```

SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Dose for STS57HI orbit)
If the orbit of the satellite is STS57HI,
Then 1) it is definite (100%) that the radiation dose per year under 10 mils
      of aluminum is 2550, and
      2) it is definite (100%) that the radiation dose per year under 20 mils
      of aluminum is 1075, and
      3) it is definite (100%) that the radiation dose per year under 50 mils
      of aluminum is 330, and
      4) it is definite (100%) that the dose per year under 125 mils of
      aluminum is 100, and
      5) it is definite (100%) that the dose per year under 250 mils of
      aluminum is 0.

```

```

IF      :: (ORBIT = STS57HI)
THEN    :: (DOSE_RATE_10 = 2550 AND DOSE_RATE_20 = 1075 AND DOSE_RATE_50 =
            330 AND DOSE_RATE_100 = 100 AND DOSE_RATE_200 = 0 )

```

RULE162

=====

```

SUBJECT :: TOTAL_DOSE-RULES
DESCRIPTION :: (Dose for ERBS orbit)
If the orbit of the satellite is ERBS,
Then 1) it is definite (100%) that the radiation dose per year under 10 mils
      of aluminum is 11100., and
      2) it is definite (100%) that the radiation dose per year under 20 mils
      of aluminum is 3920., and
      3) it is definite (100%) that the radiation dose per year under 50 mils
      of aluminum is 1000, and
      4) it is definite (100%) that the dose per year under 125 mils of
      aluminum is 285, and
      5) it is definite (100%) that the dose per year under 250 mils of
      aluminum is 0.

```

```
IF    :: (ORBIT = ERBS)
THEN  :: (DOSE_RATE_10 = 11100. AND DOSE_RATE_20 = 3920. AND
          DOSE_RATE_50 = 1000 AND DOSE_RATE_100 = 285 AND DOSE_RATE_200
          = 0 )
```

RULE171

=====

SUBJECT :: TOTAL_DOSE-RULES

DESCRIPTION :: (Negative years since launch error.)

If the number of years since launch is less than or equal to 0,
Then it is definite (100%) that the cause of the anomaly is not TOTAL_DOSE.

```
IF    :: (YEARS_SINCE_LAUNCH <= 0)
```

```
THEN  :: (CAUSE != TOTAL_DOSE)
```


=====
Frame :: ANOMALY_DB
=====

IDENTIFIER :: "ANOMALY_DB-"
TRANSLATION :: (the satellite anomaly database)
PARENTS :: (ROOT)
GOALS :: (ANOMALY_REPORT DATE_REPORT)
PROMPT1ST :: (PREMISE)
PREMISE :: (\$AND
 (SAME FRAME DATABASE ANOMALY))
PARMGROUP :: ANOMALY_DB-PARMS
RULEGROUPS :: (ANOMALY_DB-RULES)
OFFSPRING :: (VEHICLE_RPT DATE_RPT)
ANOMALY_DB-PARMS :: (ANOMALY_REPORT DATE_REPORT DB_BIRD)
ANOMALY_DB-RULES :: (RULE204)

=====
ANOMALY_DB-PARMS
=====

ANOMALY_REPORT

=====

TRANSLATION :: (a printout of the anomaly report)
TYPE :: YES/NO
UPDATED-BY :: (RULE044)
USED-BY :: (RULE204)

DATE_REPORT

=====

TRANSLATION :: (a printout of the anomalies near the date)
TYPE :: YES/NO
UPDATED-BY :: (RULE047)
USED-BY :: (RULE204)

DB_BIRD

=====

TRANSLATION :: (the name of the satellite in the anomaly database)
PROMPT :: (The name of the satellite in the anomaly database may be
 different from the name in the other databases. Please
 select the name of the satellite for the anomaly report from
 this list. If the name does not appear in this list then the
 satellite is not in the anomaly database. In that case
 choose UNKNOWN.)
TYPE :: SINGLEVALUED
EXPECT :: (((DBASE-RETRIEVE ANOMALY (QUAL BIRD <> DUMMY) BIRD)))
USED-BY :: (RULE044)
CERTAINTY-FACTOR-RANGE :: UNKNOWN
CONTAINED-IN :: (RULE044)

=====

ANOMALY_DB-RULES

=====

RULE204

=====

SUBJECT :: ANOMALY_DB-RULES

If 1) a printout of the anomaly report, and
2) a printout of the anomalies near the date,
Then it is definite (100%) that dBase reports.

IF :: (ANOMALY_REPORT AND DATE_REPORT)
THEN :: (REPORTS)

```

=====
Frame :: VEHICLE_RPT
=====

```

```

IDENTIFIER :: "VEHICLE_RPT-"
TRANSLATION :: (report the historical anomalies for a satellite)
PARENTS :: (ANOMALY_DB ROOT)
PROMPT1ST :: ("Do you want an anomaly report for a satellite?" :LINE 2
              :ATTR (MAGENTA HIGH) "If you answer YES please be patient
              while the list of satellites in the" :LINE "database is
              extracted from dBase for display on the screen." )
PARMGROUP :: VEHICLE_RPT-PARMS
RULEGROUPS :: (VEHICLE_RPT-RULES)
VEHICLE_RPT-PARMS :: ()
VEHICLE_RPT-RULES :: (RULE044)

```

```

=====
VEHICLE_RPT-RULES
=====

```

RULE044

=====

```

SUBJECT :: VEHICLE_RPT-RULES
DESCRIPTION :: (print dbase anomaly report)
If the name of the satellite in the anomaly database is known,
Then 1) inform the user of this decision, and
      2) produce a printed report of data base anomaly formatted using anom4,
      and
      3) it is definite (100%) that a printout of the anomaly report.

IF :: (DB_BIRD IS KNOWN)
THEN :: (PRINT "A list of the anomalies will be printed for" DB_BIRD "."
        AND DBASE-REPORT "anomaly" "anom4" (QUAL BIRD = DB_BIRD) AND
        ANOMALY_REPORT )

```

```
=====
Frame :: DATE_RPT
=====
```

```
IDENTIFIER :: "DATE_RPT-"
TRANSLATION :: (report the anomalies around a given date)
PARENTS :: (ANOMALY_DB ROOT)
PROMPT1ST :: (Do you want a report of the anomalies around the date you
              have entered? )
PARMGROUP :: DATE_RPT-PARMS
RULEGROUPS :: (DATE_RPT-RULES)
DATE_RPT-PARMS :: (JSTART JSTOP)
DATE_RPT-RULES :: (RULE047 RULE051)
```

```
=====
DATE_RPT-PARMS
=====
```

JSTART

```
=====
TRANSLATION :: (the starting Julian date for the date report)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE051)
CONTAINED-IN :: (RULE047)
```

JSTOP

```
=====
TRANSLATION :: (the ending Julian date for the date report)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE051)
CONTAINED-IN :: (RULE047)
```

```
=====
DATE_RPT-RULES
=====
```

RULE047

```
=====
SUBJECT :: DATE_RPT-RULES
DOBEFORE :: (RULE051)
DESCRIPTION :: (print date report)
```

```
If the Julian date is known,
Then 1) inform the user of this decision, and
      2) produce a printed report of data base anomaly formatted using anom4,
         and
      3) it is definite (100%) that a printout of the anomalies near the date.
```

```
IF :: (JULIAN_DATE IS KNOWN)
THEN :: (PRINT "A list of the anomalies about the date you have chosen
           will be printed." AND DBASE-REPORT "anomaly" "anom4" (QUAL
           JDATE > JSTART AND JDATE < JSTOP ) AND DATE_REPORT )
```

RULE051

=====

SUBJECT :: DATE_RPT-RULES

DESCRIPTION :: (defines JSTART and JSTOP)

If the Julian date is known,

Then 1) it is definite (100%) that the starting Julian date for the date report is [the Julian date minus 2], and

2) it is definite (100%) that the ending Julian date for the date report is [the Julian date plus 2].

IF :: (JULIAN_DATE IS KNOWN)

THEN :: (JSTART = (JULIAN_DATE - 2) AND JSTOP = (JULIAN_DATE + 2))

```
=====
Frame :: PLOTKP
=====
```

```
IDENTIFIER :: "PLOTKP-"
TRANSLATION :: (draw a graph of the Planetary Index, Kp)
PARENTS :: (ROOT)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
              (SAME FRAME DATABASE KP)
              (KNOWN FRAME DATE))
PARMGROUP :: PLOTKP-PARMS
RULEGROUPS :: (PLOTKP-RULES)
PLOTKP-PARMS :: (KP-PROMPT)
PLOTKP-RULES :: (RULE107)
```

```
=====
PLOTKP-PARMS
=====
```

```
KP-PROMPT
=====
```

```
PROMPT :: ("Would you like to see a graph of the Planetary Magnetic
           Index, Kp," :LINE "for the time period of this anomaly?" )
TYPE :: YES/NO
USED-BY :: (RULE107)
HELP :: ("Kp is a 3-hour dimensionless quasi-logarithmic" :LINE "index
         of the level of disturbance of the" :LINE "geomagnetic field.
         The "p" subscript denotes" :LINE "a planetary, as opposed to a
         single station," :LINE "index. Kp is based on the K index from
         about" :LINE "12 stations distributed around the world." :LINE
         2 "Kp of 3 to 4 is called Active, 4 to 5" :LINE "signifies a
         minor storm, and greater than 5" :LINE "a major storm." )
```

```
=====
PLOTKP-RULES
=====
```

```
RULE107
=====
```

```
SUBJECT :: PLOTKP-RULES
If KP-PROMPT,
Then 1) , and
     2) it is definite (100%) that plot the graph of Kp for the date
requested.
```

```
IF :: (KP-PROMPT)
THEN :: ((DOSCLS KPLOTDR DATE) AND PLOT-KP)
```

```

=====
Frame :: PARTICLES/PLASMA
=====

```

```

IDENTIFIER :: "PARTICLES/PLASMA-"
TRANSLATION :: (to determine if the anomaly is caused by other particle
                or plasma effects )
PARENTS :: (ROOT)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            ($OR
             (SAME FRAME CONSIDER_CAUSE PARTICLES/PLASMA)
             (SAME FRAME CONSIDER_CAUSE ALL)))
DISPLAYRESULTS :: YES
PARMGROUP :: PARTICLES/PLASMA-PARMS
RULEGROUPS :: (PARTICLES/PLASMA-RULES)
PARTICLES/PLASMA-PARMS :: (BANDED_SPECKLED_DATA FALSE_STAR_TRANSITS
                           HIGH_VOLTAGE_DISCHARGE OROFICE_OSE_ERRORS
                           SOLAR_ARRAY_POWER SOLAR_PROTON_EVENT )
PARTICLES/PLASMA-RULES :: (RULE166 RULE167 RULE168 RULE169 RULE170
                           RULE203 )

```

```

=====
PARTICLES/PLASMA-PARMS
=====

```

BANDED_SPECKLED_DATA

```

=====
TRANSLATION :: (pictorial data that is banded or speckled)
PROMPT :: ("If the sensor data is in a raster format, is the data banded
           or speckled?" )
TYPE :: YES/NO
USED-BY :: (RULE170)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

FALSE_STAR_TRANSITS

```

=====
TRANSLATION :: (false star transits)
PROMPT :: ("Is the anomaly related to false star transits in a star
           sensor?" )
TYPE :: YES/NO
USED-BY :: (RULE167)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

HIGH_VOLTAGE_DISCHARGE

```

=====
TRANSLATION :: (a high voltage discharge)
PROMPT :: ("Can the anomaly be related to a high voltage discharge in a
           subsystem?" )
TYPE :: YES/NO
USED-BY :: (RULE166)
CERTAINTY-FACTOR-RANGE :: UNKNOWN

```

OROFICE

=====

PROMPT :: ("Is there an orofice on the vehicle through which plasma can
flow into" :LINE "electronic circuits?")

TYPE :: YES/NO

USED-BY :: (RULE169)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

OSE_ERRORS

=====

TRANSLATION :: (optical shaft encoder errors)

PROMPT :: (Is the anomaly related to optical shaft encoder errors?)

TYPE :: YES/NO

USED-BY :: (RULE168)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SOLAR_ARRAY_POWER

=====

TRANSLATION :: (the power output from the solar array)

PROMPT :: ("Did a sudden decrease occur in the power output from the
solar array?")

TYPE :: YES/NO

USED-BY :: (RULE203)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

SOLAR_PROTON_EVENT

=====

TRANSLATION :: (a solar particle event containing relativistic protons)

PROMPT :: ("Did a solar proton event preceed the sudden decrease in the
power output from" :LINE "the solar array?")

TYPE :: YES/NO

USED-BY :: (RULE203)

CERTAINTY-FACTOR-RANGE :: UNKNOWN

=====

PARTICLES/PLASMA-RULES

=====

RULE166

=====

SUBJECT :: PARTICLES/PLASMA-RULES

DESCRIPTION :: (High voltage discharge)

If 1) the type of anomaly that occurred is ELECTRICAL, and
2) a high voltage discharge,

Then there is suggestive evidence (50%) that the cause of the anomaly is
PLASMA.

IF :: (PROBLEM = ELECTRICAL AND HIGH_VOLTAGE_DISCHARGE)

THEN :: (CAUSE = PLASMA CF 50)


```

RULE167
=====
SUBJECT :: PARTICLES/PLASMA-RULES
DESCRIPTION :: (False star transits)
If 1) the type of anomaly that occurred is SENSOR, and
   2) false star transits,
Then there is suggestive evidence (50%) that the cause of the anomaly is
PARTICLES.

IF :: (PROBLEM = SENSOR AND FALSE_STAR_TRANSITS)
THEN :: (CAUSE = PARTICLES CF 50)

RULE168
=====
SUBJECT :: PARTICLES/PLASMA-RULES
DESCRIPTION :: (Optical shaft encoder errors)
If 1) the type of anomaly that occurred is SENSOR, and
   2) optical shaft encoder errors,
Then there is suggestive evidence (50%) that the cause of the anomaly is
PARTICLES.

IF :: (PROBLEM = SENSOR AND OSE_ERRORS)
THEN :: (CAUSE = PARTICLES CF 50)

RULE169
=====
SUBJECT :: PARTICLES/PLASMA-RULES
DESCRIPTION :: (Plasma flow into an orofice)
If 1) the type of anomaly that occurred is ELECTRICAL, and
   2) OROFICE,
Then there is weakly suggestive evidence (20%) that the cause of the anomaly
is PLASMA.

IF :: (PROBLEM = ELECTRICAL AND OROFICE)
THEN :: (CAUSE = PLASMA CF 20)

RULE170
=====
SUBJECT :: PARTICLES/PLASMA-RULES
DESCRIPTION :: (Banded or speckled sensor data)
If 1) the type of anomaly that occurred is SENSOR, and
   2) pictorial data that is banded or speckled,
Then there is suggestive evidence (60%) that the cause of the anomaly is
PARTICLES.

IF :: (PROBLEM = SENSOR AND BANDED_SPECKLED_DATA)
THEN :: (CAUSE = PARTICLES CF 60)

RULE203
=====
SUBJECT :: PARTICLES/PLASMA-RULES
DESCRIPTION :: (loss of solar array power during a solar proton event)
If 1) the power output from the solar array, and
   2) a solar particle event containing relativistic protons,
Then there is strongly suggestive evidence (80%) that the cause of the anomaly
is PARTICLES.

IF :: (SOLAR_ARRAY_POWER AND SOLAR_PROTON_EVENT)
THEN :: (CAUSE = PARTICLES CF 80)

```

```

=====
Frame :: PLOTENET
=====

```

```

IDENTIFIER :: "PLOTENET-"
TRANSLATION :: (draw a graph of the electron flux at geosynchronous
                derived from neural network model )
PARENTS :: (ROOT)
GOALS :: (FLUENCE)
PROMPT1ST :: (PREMISE)
PREMISE :: ($AND
            (SAME FRAME DATABASE KP)
            (KNOWN FRAME DATE))
PARMGROUP :: PLOTENET-PARMS
RULEGROUPS :: (PLOTENET-RULES)
PLOTENET-PARMS :: (ENET_PROMPT)
PLOTENET-RULES :: (RULE195)

```

```

=====
PLOTENET-PARMS
=====

```

```

ENET_PROMPT

```

```

=====
PROMPT :: ("Do you wish to see a graph of the relativistic electron,
~MeV, flux" :LINE "at geosynchronous orbit for the time
period of this anomaly?" :LINE 2 "The flux is derived from
the Aerospace neural network model based" :LINE "on the Sum
Kp. The accumulated fluence obtained from this model" :LINE

will then be used to determine if bulk charging is a possible
cause" :LINE "of this anomaly if you answer UNKNOWN when
prompted for the" :LINE "accumulated fluence of greater than
300 keV electrons." )
TYPE :: YES/NO
USED-BY :: (RULE195)

```

```

=====
PLOTENET-RULES
=====

```

```

RULE195

```

```

=====
SUBJECT :: PLOTENET-RULES
DESCRIPTION :: (plot the electron flux from neural network model)

```

```

If ENET_PROMPT,
Then 1) , and
2) it is definite (100%) that plot the graph of ~MeV electron flux at
geosync, and
3) retrieve data from an external source.

```

```

IF :: (ENET_PROMPT)
THEN :: ((DOSCLS PLOTENET DATE) AND PLOT-ENET AND READ-DOS-FILE "
fluence.dat" FLUENCE )

```

TECHNOLOGY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Technology Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual Technology Centers:

Electronics Technology Center: Microelectronics, solid-state device physics, VLSI reliability, compound semiconductors, radiation hardening, data storage technologies, infrared detector devices and testing; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; cw and pulsed chemical laser development, optical resonators, beam control, atmospheric propagation, and laser effects and countermeasures; atomic frequency standards, applied laser spectroscopy, laser chemistry, laser optoelectronics, phase conjugation and coherent imaging, solar cell physics, battery electrochemistry, battery testing and evaluation.

Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; development and analysis of thin films and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; development and evaluation of hardened components; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion; spacecraft structural mechanics, spacecraft survivability and vulnerability assessment; contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; lubrication and surface phenomena.

Space and Environment Technology Center: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation; propellant chemistry, chemical dynamics, environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, and sensor out-of-field-of-view rejection.



**THE AEROSPACE
CORPORATION**

2350 E. El Segundo Boulevard
El Segundo, California 90245-4691
U.S.A.