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CRYOGENICS RELIABILITY GOALS FROM COMSAT DATA

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I. INTRODUCTION

The cryogenic refrigeration system used in the VLA receiver front end presents the major limitation to front end reliability. It is therefore extremely important to have an estimate of the expected reliability of this system. Unfortunately, most reliability data has come from the undocumented experience of individuals working with similar systems, and their estimates of mean time before failure (MTBF) of a refrigerator/compressor system have ranged from 10,000 to over 30,000 hours. Obviously better data, hard data, is badly needed.

The Communications Satellite Corporation (COMSAT) operates earth stations using close-cycle helium cryogenic refrigerators similar to those used in the VLA front ends. NRAO recently obtained a copy of their repair and maintenance records for ten stations for the period January 1, 1974 to July 1, 1976. These consist of a computer printout describing periodic maintenance operations, repair operations, description of the failure and its cause, and other data. Unfortunately certain desirable information is not included, and the failure and repair descriptions are limited to about a dozen words. For example, it is difficult to tell whether a contamination or leakage failure was sufficiently serious to cause a receiver to be shut down. Moreover, contamination often can't be ascribed to any particular component, and the location of helium leaks wasn't always clear. The number of systems at each location was not given, and it is probable that different numbers of compressors and expanders (cooling heads) were used at each site. A further limitation is that the majority of cryogenic systems used by COMSAT are made by a different manufacturer from those used in the VLA. These limitations are not as great as they seem, however, because the design of all such systems is similar, and the reliability advantages and disadvantages of different systems approximately offset each other. Furthermore, the present VLA cryogenics specialist spent several years working for COMSAT and supplied some of the needed information. In spite of the limitations, this information is the best available on the reliability of these systems.

II. ANALYSIS

According to usual practice in reliability assessment, only random failures were considered. Consequently such things as failures resulting from the breakdown of other components, known flaws, improper repair, wearout and "infant mortality", were not included. Contamination after maintenance was considered as random failure because it sometimes occurs even when a great deal of care is exercised. Contamination, leaks or other minor problems after major repairs were considered non-random failures, related to the failure which necessitated the repair.

It was assumed that contamination and leakage failures were not serious enough to shut down a receiver immediately, unless the records specifically indicated that shutdown occurred. This assumption causes a fairly large uncertainty in the estimation of receiver down-time. However, in our experience, most leakage and almost all contamination is not serious enough to cause an immediate, drastic reduction in refrigeration capacity.

It was estimated that an average of two complete cryogenic refrigeration systems operate simultaneously and continuously at each of the ten earth stations covered by this data. Therefore the data covers 438,000 hours of operation. A total of 41 failures was recorded, of which at least 14 caused or required immediate receiver shut-down. The resulting MTBF for all failures is 10,690 hours; for failures causing receiver shut-down, 31,300 hours.

The number of each type of failure is listed in Appendix 1. It is worthwhile to compare COMSAT's experience to NRAO's. The major single problem experienced by COMSAT was mechanical failures, although the combined leakage and contamination failures exceeded these. Failures were almost evenly divided between the compressor and the expander, although most of the contamination failures of uncertain source would probably be credited to compressor components.

At NRAO the compressor has been the major source of trouble, and the major random failure has been leakage. (Mechanical failures of the pump valves and most of the contamination resulted from poor design and therefore can't be considered random failures.) It is difficult to determine which contamination failures in NRAO systems were indeed random and which were caused by design flaws. It is to be expected, however, that contamination will continue to be a formidable problem. It appears, therefore, that COMSAT's experience is not unlike our own.

III. CONCLUSIONS AND RECOMMENDATIONS

The recommended reliability goals for the VLA cryogenic system are an MTBF of 10,000 hours for all failures, and 15,000 hours for debilitating failures; i.e., those necessitating receiver shut-down before repairs can be performed. The latter is considerably less than the estimate of COMSAT's performance; however, allowance must be made for the large uncertainty in this number. Moreover many failures which do not cause immediate loss of refrigeration must be attended quickly in order to prevent shut-down within a few hours. Some of these will inevitably occur at times when such attention is impossible.

Calculations based on these goals show that the VLA can expect an average of 24 failures per year, sixteen of which will be debilitating. If sufficient spare parts are kept in stock, most of these failures can be corrected in 24 hours; therefore, sixteen antenna-days of receiver down-time will be consumed by cryogenics failures alone. Assuming 15,000 hours MTBF, two or more antennas will be down simultaneously only once every three years.

It is generally agreed that too-frequent maintenance, especially that which requires disturbing the displacer seals in the expander or depressurizing components,is as bad as insufficient maintenance, partly because of increased possibility of contamination or seal leakage. Therefore it will be a necessary but difficult task to devise a maintenance scheme which is optimum for these systems. Moreover, keeping records of maintenance operations on 27 systems will be no small task, and it may be necessary to have some type of automated record-handling system. It may also be necessary to have automatic warning of slowly-dropping helium pressures or rising refrigerator temperatures so problems can be detected before they become serious.

The time when these goals can be realized seems a long way off. However, the majority of the present reliability problems can be attributed to known flaws in the cryogenic system, particularly the compressor, and, discounting these, the number of random failures is not far from recommended goals. The COMSAT data shows that reliability goals which are adequate for the VLA can be achieved.

APPENDIX 1: Location and Types of Failures

Location:

Compressor	15
Expander	14
Elsewhere or unsure[1]	12
TOTAL	41

Type:

Contamination	10
Leaks[2]	11
Mechanical failure	17
Electrical failure	3
TOTAL	41

Receiver Shutdown Necessary: 14

[1]Usually leaky helium lines or contamination without a specified source.
[2]Helium, oil, or both.

APPENDIX 2: Number of Multiple Failures Per Year

A multiple failure is defined as the occurrence of two or more debilitating failures on separate antennas within the time period required to fix one failure. In this event, more than one antenna will be out of service because of cryogenic failures.

The probability of multiple failures is found by determining the probability of two or more failures within a given repair period (24 hours). The probability of such an occurrence per year is determined by considering each period in the year as a Bernoulli trial. The results for various MTBFs and repair times are presented in graphical form.

It is worth noting that MTBFs less than 5,000 hours result in a seriously difficult repair task and a distressing failure rate. Fifteen thousand hours is a point of diminishing returns; improvements beyond this value do not significantly reduce the number of multiple failures.

PROBABILITY AND AVERAGE NUMBER OF MULTIPLE CRYOGENICS FAILURES FOR 27 ANTENNAS.

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AVERAGE REPAIR TIME = 24 HOURS.