SECTION 20. PROCUREMENT OF PARTS

20.1. INTRODUCTION

In the section on equipment practice, a description was given of the engineering principles on which a system could be designed to give the best possible level of radiation tolerance within given mass and cost constraints. However, one problem which requires administrative intervention is the variability of the response to radiation of certain commercially procured components. Commercial semiconductor technology has developed without reference to radiation-induced responses. Earlier sections describe in detail how some electrically similar commercial parts may have very large, uncontrolled variability. The life-time of one sample in a given radiation environment may differ from that of another, electrically identical sample by a factor of 1000. Although some of the requirements for the control of radiation response in device manufacture are now understood, it still remains a challenge to exercise such control of both technical and administrative aspects in spacecraft parts. In this section, the administrative aspects are addressed and recommendations are made for the inclusion of radiation parameters in procurement specifications and device selection procedures.

20.2. SPECIFICATIONS

This section includes a number of comments on Table 20(1). This table contains the recommendations for different types of radiation specification which should form part of the procurement procedures. The word "risk" implies that the margin of safety required will be determined by the seriousness of a given failure. For example, an operational satellite will be assigned larger safety margins than an experimental one. Also, if the spacecraft is earning revenue, then weight-saving assumes major importance. Extra weight which can be devoted to payload (say, communication channels) may yield extra revenue, possibly up to 500,000 U.S. dollars over a 7-year mission. Thus, the item "Spacecraft Mass vs Usable Payload" in column 2 of Table 20(1) is an important factor. In this case, "add-on shielding" must be replaced as far as possible by solutions without weight penalty such as the procurement of hardened parts or the use of built-in shielding. The penalty of procuring hardened devices may be cost rather than weight but, if the facts are known soon enough, a calculation may show that the revenue gained is higher than the cost of hardened devices.

Further consideration of Table 20(1), shows that listed as a factor in making specifications at "Equipment Level" is "total circuit response"; it may or may not be necessary to verify the analysis by irradiation of a whole circuit. In Table 20(1), under "Piece Parts Level", it is implied that many designers may not be aware of the existence of hardened parts which may only be available by special arrangement. There is also a possibility of confusion as to whether a given part is hardened against pulsed nuclear weapon effects or to space electron and proton effects ("Total dose"). Specifications should therefore give guidance on supply sources and the type of hardness required.

20.3. PARTS PROCUREMENT

20.3.1. Introduction

As the preceding sections will have made clear, silicon devices - especially the forms which carry thermally grown silicon dioxide layers - are subject to a variety of serious permanent degradation effects when irradiated. Two very different forms of "damage" are involved: one being true lattice damage in the silicon crystal; the other being the reversible, but long-lived build-up of charge in the oxide (ionisation effect). Most commercial manufacturers do not control the tendency of these oxide films to trap charge. This tendency is strongly influenced by process parameters such as the annealing temperature, growth ambient and growth time. While attempting to improve process yield, the manufacturer may change these frequently. Consequently, the sensitivity of devices to radiation often varies strongly from year to year. Radiation sensitivity must be monitored on a lot-to-lot basis, otherwise the prediction of spacecraft survival time becomes impossible. No well-tried system for the procurement of devices which are radiation tolerant to the standard required for space vehicles has yet been developed. We can therefore only state some principles. Some progress has been made by the U.S. Military who are implementing "Hardness Assurance" procedures. While the neutron requirements are not relevant, it should be noted that the military specifications also include a relevant gamma ray "total dose". In the U.K., the British Standards Institution (1983) is developing a "Radiation-Assessed Device" specification as part of the BS 9000 Series.

TABLE 20(1) - RECOMMENDATIONS AND FACTORS OF IMPORTANCE IN SPACE RADIATION SPECIFICATIONS

"Space radiation" sections of spec's at the following levels should include:	Important factors
SYSTEM LEVEL External environment for given duration Internal environment for given duration and several absorber materials: - Dose versus depth curves - Silicon damage versus depth curves - Degraded spectra for various depths - LET spectra for different shielding Rationale for use of built-in mass (i.e. lay-out) for protecting sensitive boxes Requirements for telemetry of degradation in orbit	- Risk - Mission duration - S/C mass versus usable payload - Specific cost - Siting of sensitive boxes - Tolerable upset rates
SUBSYSTEM LEVEL Mass budget, incl. shielding allowance Rules for worst-case analysis of degradation Latchup and single event upset tolerance Requirements for telemetry of degradation in orbit	- Mass distribution - Siting of sensitive piece parts - Circuit design - IC technology - Add-on mass
EQUIPMENT LEVEL Tolerable degree of degradation in output versus time Equipment level testing (if necessary) Latchup protection and single event upset tolerance Requirements for telemetry of degradation in orbit	- Board mass distribution - IC technology - Piece part test data base - Total circuit response
PIECE PART LEVEL Data base Total dose degradation and single event upset prediction method Detailed derating specifications Indication of hardened component availability Testing method	- Derating - Hardened series - Lot variation - Lot acceptance
MATERIALS LEVEL Lists of especially sensitive materials Testing methods	- Lot variation - External parts

20.3.2. Preliminary evaluation

Unless suitable recent data have been published, all investigations into a particular product will begin with an exploratory radiation test of a small number of parts, probably less than 10 units each, if possible from several batches of variants of the relevant production line. This exploratory test is essential because, in the field of ionisation effects, there are as yet no electrical tests which can give an indication of the sensitivity of oxide layers to ionisation. Despite the existence of prediction models, even the prediction of sensitivity to bulk damage effects may be subject to error. The test results must then be interpreted as far as possible in terms of a physical model which distinguishes between bulk damage and ionisation effects.

The variability of the response from device to device must be characterised by statistical methods to permit determination of the subsequent course of action. Of course, a high absolute level of sensitivity may immediately eliminate consideration of the device for certain applications where degradation cannot be tolerated. Note, however, that many circuit designers leave very large margins of safety in parameters such as h_{FE} (gain) and sometimes use a device with a rated gain of 100 in a function which only requires a gain of 10 or less. Thus, the radiation requirement does not inevitably place severe restrictions on the choice of devices. On the contrary, the test requirement serves mainly to identify a few catastrophically serious cases, the knowledge of which could be obtained in no other way. This statement applies strongly to discrete bipolar circuits and other analogue circuits. A rather special case are the MOS logic circuits, as the safety margins allowed by the IC designer may, for commercial reasons, have been made very small indeed.

20.3.3. Acceptance of supplier

Following the preliminary evaluation of a range of devices, it must be decided whether the variability of radiation sensitivity of products from otherwise acceptable manufacturers is tolerable for a given electrical type. Unlike many other decisions in procurement, this question depends on both the project concerned (i.e. general mission radiation level) and the circuit concerned (i.e. protection provided by box and spacecraft and the margin of degradation which can be tolerated by the designer).

This situation stems from the magnitude of the degradation which radiation can produce in electrical parameters (over 10 times those which are ever produced by normal life tests under electrical or mechanical stress) and the very large difference between radiation dose in "exposed" and protected locations (this is why it was stated recently - and confirmed by several experts - that it is unlikely that any rigid system of agency-wide "approval for radiation" will be instituted for some time). If degradation of a particular supplier's product is tolerable for the project in question, then procurement can - in principle - proceed. If, however, the degradation is no smaller than the available margin of safety, then the batches intended for use in flight equipment are best subjected to sampling.

20.3.4. Truncation of spread

If the variability of degradation is not tolerable for the project in question and no alternative device is available, then some form of preselection of devices must be developed to permit an effective truncation of the distribution in sensitivity. As a rule, one has to choose between two expensive alternatives: either to place further controls on the manufacturer or to adopt an "Irradiate-Anneal" (IRAN) approach. A third alternative is to procure a hardened device, but this applies only to a small proportion of the bipolar and MOS devices which designers are likely to use in space equipment. Provided the "hardening" processes prove compatible with normal commercial practice and contractors press suppliers to adopt this approach, they may grow in number.

20.3.5. Some procedures for device selection

Van Lint and colleagues at Mission Research Corporation (1977) have proposed a rational series of selection steps. Essentially, one establishes a failure budget for each transistor in the system. This is a probability of failure factored by the number of transistors in the whole system and by a design margin, namely a figure near unity which determines whether the degradation is tolerable or not. Test or prediction data are then assumed to have a log-normal probability distribution. One can then determine whether the probability of going outside the design margin (DM 1) falls within the allowed "failure budget". The options are then:

(a) To reject the device in question,
(b) To change the "failure budget", i.e. to shift the "design burden" to another device,
(c) To relocate or shield (but this brings in mechanical designers) in order "to force DM to acceptance condition",
(d) To apply controls to truncate the distribution of sensitivity (as discussed above).

Approach (c) involves, of course, weight budgets and mechanical designers, while (d) will consume time.

20.4. MOS INTEGRATED CIRCUITS - SPECIAL CONSIDERATIONS

Attempts to truncate distributions in MOS structures are unlikely to be successful. Devices from one manufacturer in a given era are either "all bad" or "all good", i.e. the distribution is already a narrow one. With increasing understanding of the underlying effects, it seems clear that any manufacturer should be capable of producing radiation-tolerant MOS devices, using "controlled SiO_2", provided a corporate decision to do so were made. The component specialist of a project must work with a manufacturer who has made this decision. He may also attempt to place a "radiation effects control" specification upon other manufacturers.

20.5. BIPOLAR DEVICES - SPECIAL CONSIDERATIONS

The spread in the radiation response of bipolar transistors is generally broader than for MOS technology. The oxides concerned are not so critical to good performance and hence, compared with MOS technology, less control of oxide growth is exercised. Another complication is that the degradation of gain, produced by the accumulated oxide effects, is strongly dependent upon the collector current or emitter injection level used. While most bipolar digital circuit varieties are fairly insensitive to radiation, problems can still arise; particularly where a mix of processes or lay-out rules are employed within a product family (as recently experienced with ALS devices).

Bipolar Analogue ICs show wide variability depending on the design techniques employed; "super beta" transistors and lateral NPN transistors can give rise to high radiation sensitivity.

20.6. U.S. PROCUREMENT PRACTICES

U.S. spacecraft procurement takes to some extent advantage of the system of military specifications and thus it is significant that there is now a Military Specification (MIL-SPEC) Radiation Requirements Committee as well as hardness assurance work funded by the Defense Nuclear Agency (see, for example, Van Lint and Smyth, 1977). Radiation test procedures now form part of MIL-STD-883 and parts are classified according to the following test levels:-

M: 3 kilorads,

D: 10 kilorads,

R: 100 kilorads,

H: 1 megarad.

These classifications will be included in the part number for JAN 38510 microcircuits and JAN TX/TXV discrete semiconductors.

Although more and more radiation-hardened "standard products" are becoming available as a result of development programmes at the Center for Radiation-Hardened Microelectronics at Sandia Laboratories, the problem of the procurement of radiation-sensitive devices for both military and civil space programmes, is still treated on a case-by-case basis.

20.7. CONCLUSIONS

The procurement of radiation-tolerant systems is strongly affected by parts procurement factors. However, the impact of the radiation environment and the raw environment figures must be defined as appropriate in all levels of engineering and procurement specification. This is not done sufficiently at the moment and leads to a lack of awareness of latent problems until many of the effective options are closed. The response of parts to radiation is much more variable than might be expected from experience of other changes with time in space and, therefore, some unconventional (and often costly) procurement measures have to be considered from time to time.

REFERENCES

V.A.J. van Lint, J.P. Raymond, A.R. Hart and M.L. Price, "Radiation Design Handbook for the Jupiter Probe", MRC/SD-R-14, Mission Research Corp. (1977)

J.B. Smyth and V.A.J. van Lint, IEEE Trans.Nucl.Sci. NS-24 (6), pp. 2093-2097 (Dec. 1977)

A. Wolicki et al, "Hardness Assurance for Electronic Parts: Accomplishments and Plans"; Invited talk IEEE NSREC 85, Monterey, CA (July 1985)

British Standards Institution, "British Standard 900X: Specification of the Basic Requirements for the Assessment of Semiconductor Components for Tolerance to High Energy Radiation", Draft Issue J (Sept. 1983)