SECTION 22. A COMPLETE ANALYSIS

22.1. INTRODUCTION

In this document, a large number of methods have been presented for the calculation of local environments and the degree of device degradation in a form more convenient and detailed than was available hitherto. The following is an attempt to show how these techniques can be fitted together to solve a typical spacecraft equipment problem. This exercise will demonstrate that the techniques which have been described provide the basis of a procedure which can be used by engineering design staff.

22.2. SPACECRAFT MISSION AND GEOMETRY ASSUMPTIONS

The problem chosen is that of a small-scale integrated CMOS logic gate in a piece of equipment to be used in a 3-axis stabilised communications satellite with a required lifetime of seven years in geostationary orbit. The device is part of a circuit board contained - as is normal - in a stack of similar boards within an aluminium box, 1 to 2 mm thick. The box lies on a honeycomb platform of mass equivalent to less than 1 mm aluminium and is shadowed from some directions by other boxes which have masses equivalent to more than 7 mm of aluminium.

22.3. OTHER STARTING DATA REQUIRED

- External particle environment
- Electrical circuit criteria for determination of the maximum acceptable performance degradation
- Simplified model of CMOS response to radiation
- Test data

22.4. MISSION DOSE (D_M) CALCULATIONS

The dose reaching the CMOS device is determined by a dose-depth calculation for which a spherical shell is assumed, followed by a sector analysis of the spacecraft parts surrounding the device, as described in Sections 7 and 8. The external particle environment can be obtained by computerised integration of radiation fluxes around the orbit, for example with the UNIRAD program (see Section 2). The dose-depth calculations are best made by computer, e.g. the SHIELDOSE program (see Section 18).

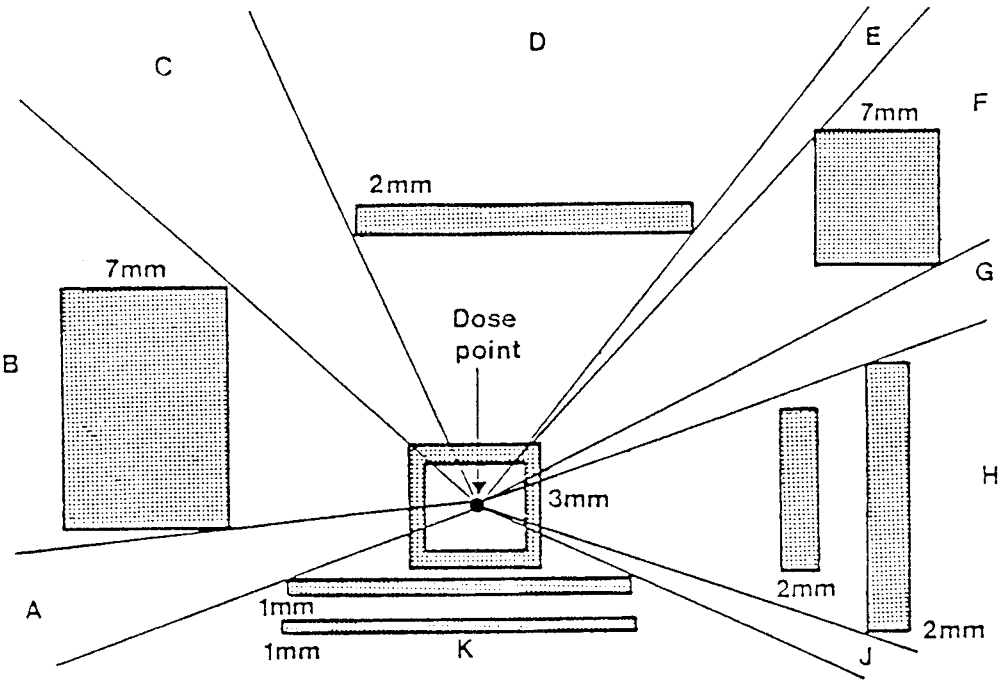
A simplified example of a sector analysis is illustrated in Figure 22.1 which, for simplicity, shows only two dimensions. In this figure:

- The device package and the box cover have been merged and are represented as two 1 mm layers of aluminium;

- Various components above the device are represented as a 2 mm Al slab;
- Local components are represented as two overlapping Al slabs of 2 mm each and
- Two distant boxes are represented as Al blocks of 7 mm each.

Thus, over the angles shown, sectors A to K can each be regarded as filled by a uniform slab of thickness d as listed in the table in Figure 22.1. The 7-year dose for that value of d can be read from the dose- depth curve (inset) and then multiplied by the appropriate "fraction of 4 π". The sum is the Mission Dose, D_M shown here as 13.6 krad (Si) over 7 years.

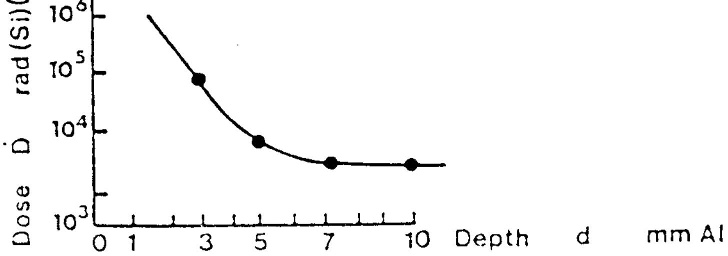
The sector analysis will have to be repeated for other dose points (device locations) in question because the angles subtended at the dose point will, of course, change as the point moves. In view of this need for repetition and the fact that serious errors may be made in manual estimates such as the above, the use of computer calculations is recommended. ESA and many European companies and institutes use the ESABASE system (see Section 18). This allows a detailed geometry database to be maintained for a spacecraft and to be used by contractors, ESA and payload engineers for individual detailed analyses. This procedure has been adopted for the Cluster programme. An example of ESABASE use for sector analysis and radiation assessment may be found in Daly et al (1992).



	d mm Al	fraction of 4π (approx)	7-year dose krad(Si)
A	3	·04	2·4
B	10	·12	·24
C	3	·08	4·8
D	5	·15	·9
E	3	·01	·6

	d mm Al	fraction of 4π (approx)	7-year dose krad(Si)
F	10	·07	·14
G	3	·02	1·2
H	7	·10	·3
J	3	·01	·6
K	5	·40	2·4

Total dose: 13·6 krad(Si) in 7 years



A simplified example of sector analysis for determination of dose deposited at a point within a spacecraft structure.

FIGURE 22.1 - SECTOR ANALYSIS

22.5. MAXIMUM ACCEPTABLE DOSE, D_A (MAX)

The preferable form of test data for a CMOS integrated circuit is the change of V_T as a function of dose for a well-defined d.c. value of V_I higher than 5V. The test doses covered should be as wide as possible but, with the model developed here, even one data point can be used (although, naturally, this gives reduced confidence). Data on the change of quiescent current versus dose can also be used, but are less amenable to analysis and more limited in use. The test data should be for a device which is closely related to the flight unit (of the same "vintage" and make). A value for the initial threshold voltage of the n-channel device is also required.

The following is a suitable procedure for applying the test data to determining D_A (max):

1. Plot ΔV_T versus dose and complete the response curve, if necessary by reference to the simple growth curve models. This can be done by assigning an 'A' value and constructing a simple model response curve for the device. This should be set to yield the best fit to the test data points.

2. If the value of V_I used during the test is not the same as that planned during flight, the model can be used to adjust the prediction curve.

3. If all gates of the logic device will be under cycled bias, some relief can be given.

4. On the adjusted model growth curve, note the dose at which $-\Delta V_{TN}$ approaches the original value of V_{TN}. This is the dose at which the VTNZ condition will cause an increase in I_{SS} (I_{SS} will, of course, begin to increase before the VTNZ condition is reached because a finite current, say 10μA, is used to define V_T). Electrical circuit analysis and a similar analysis of ΔV_{TP} will also indicate doses at which NIR, SSR and LF modes will occur.

5. D_A (max) is the radiation dose (rad (Si)) at which the critical performance parameters, as determined by electrical analysis, reach the "maximum tolerable" level of degradation. If test measurements of the critical performance parameters versus dose are available (e.g. I_{SS} , noise immunity, etc.), then these should be verified by means of the above ΔV_T analysis to ensure that they indicate the same magnitude for D_A (max). A higher dose value for the latter is likely because the simple ΔV_T analysis ignores interface states.

6. Compare D and D_A (max)

   If D_A (max) exceeds the mission dose, D_M, by an order of magnitude or more, use of the device at the dose point concerned can be approved. If the two dose figures lie closer together, more detailed analysis is warranted, including the following approaches, as the situation demands:

   (a) Refined calculation of DM,

   (b) Redesign of layout, thereby increasing built-in protection,

   (c) Redesign of circuit,

   (d) Device technology study,

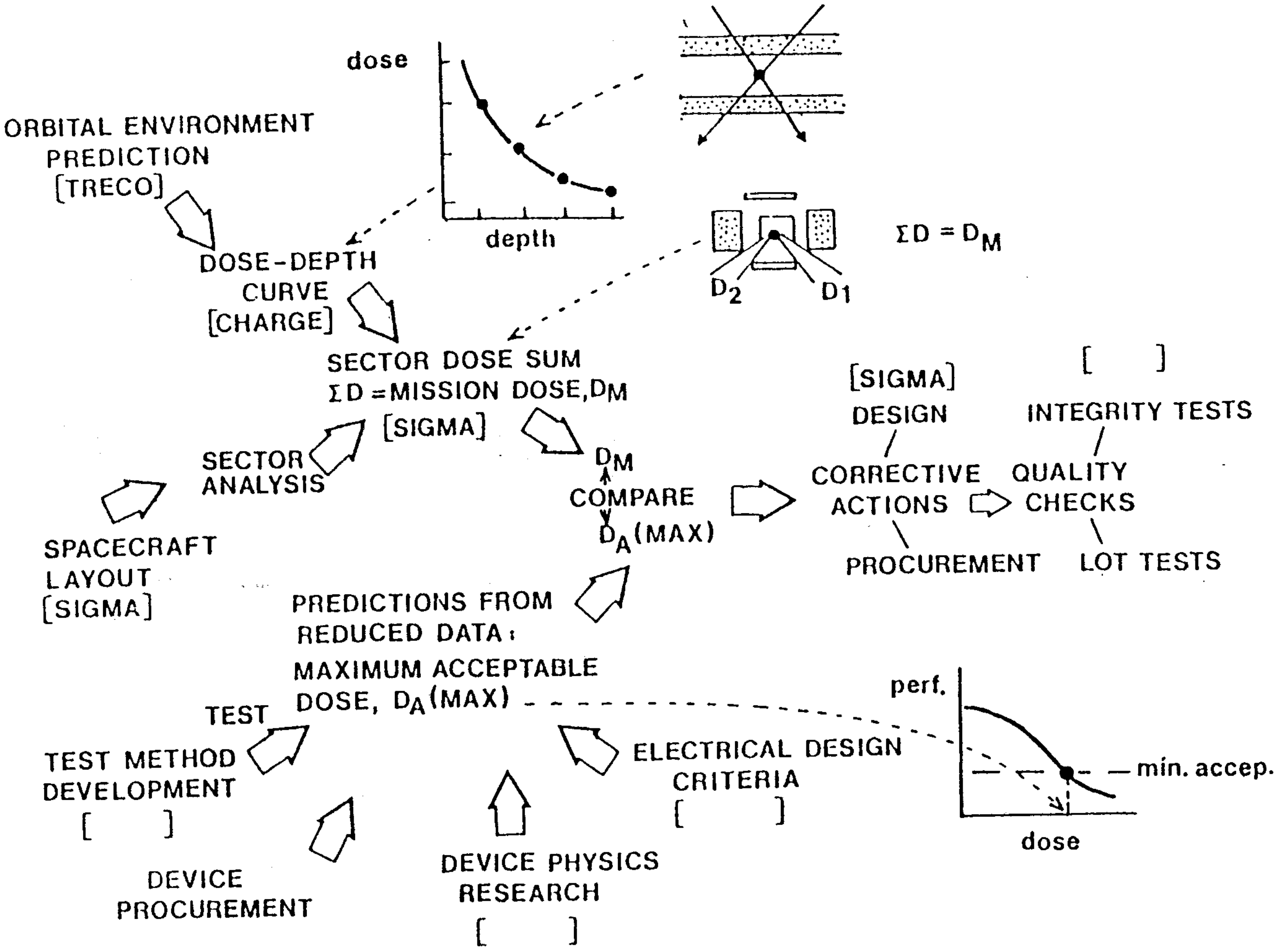
   (e) Trade-off of life versus shield weight.

7. Corrective actions and follow-up

   As a result of the above analyses, corrective design changes and procurement action may be decided. The efficacy of these must be verified at the equipment acceptance stage. Checks for integrity of protection will be easier if the spacecraft layout has been computerised, as in the ESABASE system.

22.6. SUMMARY

Figure 22.2 summarises the procedures described above and also includes the other parts of Radiation Effects activity such as test development and research which go to support the analysis. Where appropriate, the computer program names are shown in brackets; blanks between brackets indicate that the required programs are not yet available.



The interaction of the various stages in the analysis of radiation effects.

FIGURE 22.2 - COMPLETE ANALYSIS - FLOW CHART

REFERENCES

Daly E., H. Evans and C. Tranquille, "The XMM Radiation Environment and its Effects on Payloads", Estec Working Paper EWP 1643 (1992).