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THE EFFECTS OF ENVIRONMENTAL FACTORS AND EXPERIMENTAL METHOD ON THE RESULTS OF LOW DOSE RATE MICROPROCESSOR IRRADIATION TESTS

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The effects of environmental factors and experimental method on the results of low dose rate microprocessor irradiation tests

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Abstract

As part of the safety studies of nuclear facilities, a series of experiments have been in progress over a number of years to determine the principal parameters for which allowance needs to be made in the testing of microprocessors in low dose rate nuclear irradiation environments.

This paper contains a brief description of the results already published, followed by a review of the latest results obtained, specifically as concerns the effects of temperature, the origin of the batch, the angle of incidence of the radiation and the test routine used.

I. INTRODUCTION

In nuclear power plants and in reprocessing facilities, the placing of microprocessors in the immediate vicinity of sensors makes it possible to considerably reduce the number of links between sensors and the control room by using multiplexing techniques. However, this arrangement could result, in certain circumstances, in placing such components in environments where they are exposed to low dose rate irradiation.

Low dose rate irradiation tests have been carried out within the CEA as part of safety assessment. These tests are not intended to qualify a particular component or to determine the physical causes of the damage observed. Their purpose is to establish the principal parameters which need to be allowed for when carrying out such tests so that they can be used as a basis for judging methods of validation when an organization or company wishes to install a microprocessor based system in a low irradiation environment.

The originality of the work resides in the low irradiation levels used in the tests and the numerous parameters allowed for in the experiments. These conditions necessitate long periods of exposure, which may explain the small amount of work published in this field, for which [1] describes the tests carried out on RAM chips. The results obtained earlier have been the subject of publications [2, 3 and 4] describing the means of irradiation used and the progressive approach adopted to determine, on separate batches of type 6800 microprocessors, the influence of different parameters (exposure rate, energization, nature of rest routine etc.).

This communication describes the following supplementary original results:

- effect of temperature,
- effect of origin of batch,
- effect of angle of incidence of radiation,
- first results obtained for interpreting the additional failures observed with a random rest routine as compared to other test routines.

II. EXPERIMENTAL METHOD

Before describing the apparatus used, let us briefly consider the results obtained earlier [2] which indicated the orders of magnitude of the exposure doses giving rise to failures. These tests were carried out on both type 2708, 2758 and 2716 ultraviolet light erasable REPROM chips and on type 8085A and 6800 type 8-bit microprocessors. For such components, the effect of gamma radiation is found to be preponderant, with failures occurring from 50 Gy. This dose corresponds, for example, to 2 mGy per hour background radiation which corresponds to the activity which is observed in the containment of a nuclear reactor over a period of three years. The first approach has confirmed the importance of continuing this type of test to determine the parameters affecting the capacity to withstand radiation.

Additional tests [3] carried out on comparable batches of 12 or 24 type 6800 microprocessors have shown that their capacity to withstand exposure is greater when the dose rate is low. Regeneration phenomena are observed over periods of around one month. Energizing the components (without operating them) during irradiation results in failures being observed far earlier and with less scatter over time. On the other hand, operating the microprocessors increases their lifetime in an irradiated environment.

The tests described in this communication only relate to type 6800 microprocessors. The range was deliberately restricted to follow on from the preceding results and to show the phenomena found with the same type of component. It should be noted that the test batches consisted of circuits of different origins uniformly distributed in the different samples subjected to irradiation.

Means of irradiation measurement

The initial tests were carried out in the SILENE and MIRENE research reactors in CEA Valduc and Cobalt-60 sources supplying gamma radiation with an energy level close to 1.25 Mev. In view of the representativeness of the experiments carried out with the Cobalt-60 sources, the results shown here were obtained using sources of the same type.

The exposure dose rates were calculated from the activity of the source and checked by measurement with thermoluminescent powders. The exposure dose rates are expressed in Grays, it being assumed in our approach that the deposition of energy per unit mass takes place in air (1 Gray in air = 100 Rads in air = 115 Roentgens).

III. EFFECT OF TEMPERATURE AND DEBUGGING

During operation, microprocessors are normally mounted on chassis which may be at a temperature higher than the ambient air temperature. Experiments have been carried out to determine whether this parameter is or is not conducive to the proper operation of the components. Figure 1 shows the strong effect of temperature in the two batches irradiated and energized at 10 mGy/h, one at an ambient temperature of 20°C and the other at 50°C. At this exposure dose rate, the first failures are observed at 70 and 200 Gy respectively. This shows that the temperature has a beneficial effect on the behaviour of microprocessors subjected to irradiation.

Other tests which are not described here, specifically involving thermal cycles, also indicate the beneficial effect of temperature.

Tests with batches which underwent high temperature debugging cycles prior to irradiation did not show this parameter to have any significant effect.

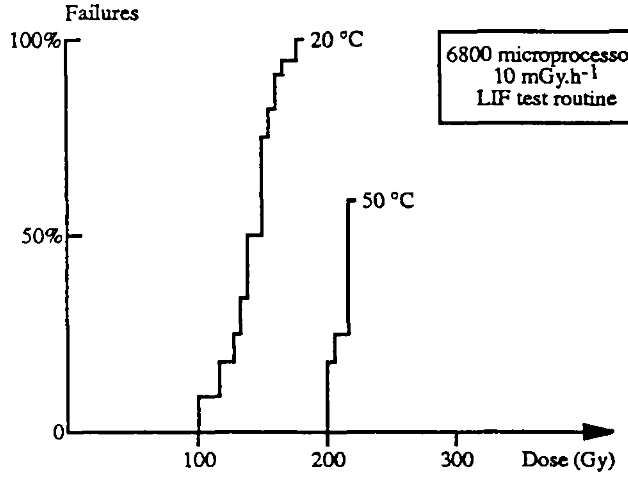

Fig. 1 Effect of temperature

IV. EFFECT OF ORIGIN OF BATCH

After having carried out a number of different tests on a large number of microprocessors divided into uniform batches, the question arises as to the possible influence of the origin of the components. In the different batches tested, a certain number of microprocessors did not reach the failure stage. All the microprocessors with the same external markings were then grouped, forming four sets with identical markings. Each set was comparable to the others as all had the same proportion of microprocessors which had undergone the same tests. For each of these sets, referred as batches in Figure 2, the number of component failures were counted.

The results obtained indicate that depending on the markings, which correspond either to a particular manufacturer, the date of production or the place of packaging, the proportion of the defective components varies greatly, ranging from 30 to 80%. This experiment thus shows that the results vary greatly, depending on what we refer as the origin of the batch.

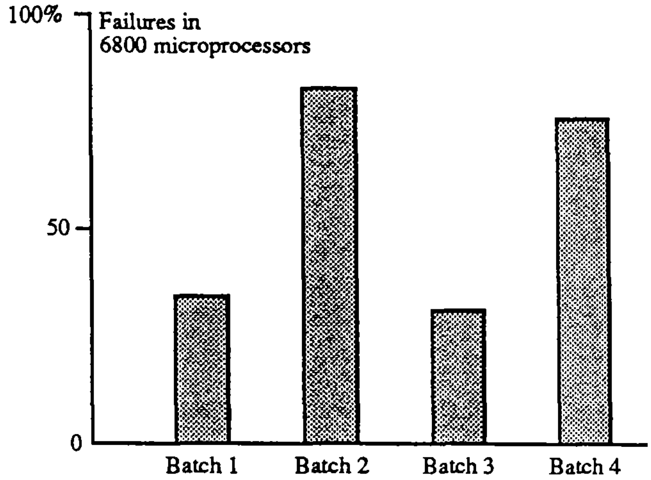

Fig. 2 Proportion of defective components as a function of batch origin

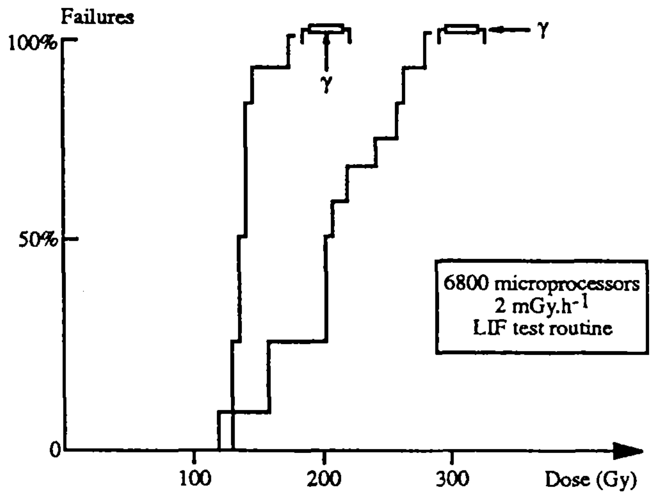

Fig. 3 Effect of the direction of gamma radiation

V. EFFECT OF ANGLE OF INCIDENCE OF IRRADIATION

In all the tests previously carried out the irradiation was perpendicular to the casing. In accordance with the basic objectives, the requirement is to be able to assess the safety of a microprocessor-based system irrespective of the direction of the irradiation. The results in Fig. 3 show that components fail more rapidly if the irradiation is perpendicular than if irradiation is from the side. This indicates that all the results obtained up to now represent a maximum from the point of view of safety studies and irradiation of a microprocessor from the side will tend to increase its lifetime as compared to perpendicular irradiation.

VI. Effect of the Test Routine

The test results shown in [4] obtained with four types of test routines to determine microprocessor failures showed that the LAG test routine using pseudo-randomly selected instructions detected a far greater number of failures than the other three test routines. The latter, referred to as LIF, FAC and UGM, respectively use some 20, 2000 and 100,000 machine instructions. The tests were carried out on some 50 irradiated and unirradiated components. It was noted in the different experiments that the failures observed with the LAG test routine were liable to occur at doses 10 times lower than with the other test routines.

It remained to determine the origin of the additional failures observed so as to be able to determine whether the corresponding failures could effectively be observed in a real situation and thus be prejudicial to the safety of a facility. An additional study has therefore been requested by the Grenoble Automation Laboratory, which developed the LAG test routine, so as to identify the instructions in the pseudo-random sequence which resulted in the detection of defects relative to the control microprocessor. The results of this study show that faults undetected by other test routines correspond to the appearance of the RESET command during specific instructions or instruction sequences. It remains to be determined whether the RESET function is effectively executed correctly even if results which are temporarily inconsistent with those of the control microprocessor are obtained.

The work carried out both on these irradiated microprocessors and on the failures created by laser beam in a random manner directly on the circuitry [5] show that pseudo-random sequences detect not only the different functional failures found with other test routines but also new failures which can be reproduced with other test routines once the sequence is known.

VII. Conclusion

The results of the tests carried out on batches of type 6800 microprocessors when irradiated show the beneficial affect of an increased temperature on the lifetime in a low radiation environment, the importance of the origin of the batch in relation to capacity to withstand irradiation and the conservative nature of the results obtained when components are irradiated perpendicularly (as compared to irradiation from the side).

The quality of the test significantly affects the point at which failures are observed. The random test routine was found to be more effective with failures whose origin could be determined.

VIII. References

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