IONIZING RADIATION (TOTAL DOSE) TEST PROCEDURE

1. PURPOSE. This test procedure defines the requirements for testing packaged semiconductor integrated circuits for ionizing radiation (total dose) effects from a cobalt-60 ($^{60}$Co) gamma ray source. In addition this procedure provides an accelerated-aging annealing test for estimating low dose rate ionizing radiation effects on devices. This aging annealing test is important for low dose-rate or certain other applications in which devices may exhibit significant time-dependent effects. This procedure addresses only steady state irradiations, and is not applicable to pulse type irradiations. This test may produce severe degradation of the electrical properties of irradiated devices and thus should be considered a destructive test.

1.1 Definitions. Definitions of terms used in this procedure are given below:

a. Ionizing radiation effects. The changes in the electrical parameters of a device or integrated circuit resulting from radiation-induced charge. It is also referred to as total dose effects.

b. In-flux test. Electrical measurements made on devices during irradiation exposure.

c. Not in-flux test. Electrical measurements made on devices at any time other than during irradiation.

d. Remote tests. Electrical measurements made on devices which are physically removed from the radiation location.

e. Time dependent effects. Significant degradation in electrical parameters caused by the growth or annealing or both of radiation-induced trapped charge after irradiation. Similar effects also take place during irradiation.

f. Accelerated aging annealing test. A procedure utilizing elevated temperature to accelerate time-dependent effects.

2. APPARATUS. The apparatus shall consist of the radiation source, electrical test instrumentation, test circuit board(s), cabling, interconnect board or switching system, an appropriate dosimetry measurement system, and an environmental chamber (if required for time-dependent effects measurements). Adequate precautions shall be observed to obtain an electrical measurement system with sufficient insulation, ample shielding, satisfactory grounding, and suitable low noise characteristics.

2.1 Radiation source. The radiation source used in the test shall be the uniform field of a $^{60}$Co gamma ray source. Uniformity of the radiation field in the volume where devices are irradiated shall be within ±10 percent as measured by the dosimetry system, unless otherwise specified. The intensity of the gamma ray field of the $^{60}$Co source shall be known with an uncertainty of no more than ±5 percent. Field uniformity and intensity can be affected by changes in the location of the device with respect to the radiation source and the presence of radiation absorption and scattering materials.

2.2 Dosimetry system. An appropriate dosimetry system shall be provided which is capable of carrying out the measurements called for in 3.2. The following American Society for Testing and Materials (ASTM) standards or other appropriate standards shall be used:

ASTM E 666 - Standard Method for Calculation of Absorbed Dose from Gamma or X Radiation.


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2.3 Electrical test instruments. All instrumentation used for electrical measurements shall have the stability, accuracy, and resolution required for accurate measurement of the electrical parameters. Any instrumentation required to operate in a radiation environment shall be appropriately shielded.

2.4 Test circuit board(s). Devices to be irradiated shall either be mounted on or connected to circuit boards together with any associated circuitry necessary for device biasing during irradiation or for in-situ measurements. Unless otherwise specified, all device input terminals and any others which may affect the radiation response shall be electrically connected during irradiation, i.e., not left floating. The geometry and materials of the completed board shall allow uniform irradiation of the devices under test. Good design and construction practices shall be used to prevent oscillations, minimize leakage currents, prevent electrical damage, and obtain accurate measurements. Only sockets which are radiation resistant and do not exhibit significant leakages (relative to the devices under test) shall be used to mount devices and associated circuitry to the test board(s). All apparatus used repeatedly in radiation fields shall be checked periodically for physical or electrical degradation. Components which are placed on the test circuit board, other than devices under test, shall be insensitive to the accumulated radiation or they shall be shielded from the radiation. Test fixtures shall be made such that materials will not perturb the uniformity of the radiation field intensity at the devices under test. Leakage current shall be measured out of the radiation field. With no devices installed in the sockets, the test circuit board shall be connected to the test system such that all expected sources of noise and interference are operative. With the maximum specified bias for the test device applied, the leakage current between any two terminals shall not exceed ten percent of the lowest current limit value in the pre-irradiation device specification. Test circuit boards used to bias devices during accelerated aging annealing must be capable of withstanding the temperature requirements of the accelerated aging annealing test and shall be checked before and after testing for physical and electrical degradation.

2.5 Cabling. Cables connecting the test circuit boards in the radiation field to the test instrumentation shall be as short as possible. If long cables are necessary, line drivers may be required. The cables shall have low capacitance and low leakage to ground, and low leakage between wires.

2.6 Interconnect or switching system. This system shall be located external to the radiation environment location, and provides the interface between the test instrumentation and the devices under test. It is part of the entire test system and subject to the limitation specified in 2.4 for leakage between terminals.

2.7 The environmental chamber. The environmental chamber for time-dependent effects testing, if required, shall be capable of maintaining the selected accelerated aging annealing temperature within ±5°C.

1/ Copies may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.
3. **PROCEDURE.** The test devices shall be irradiated and subjected to accelerated aging annealing testing (if required for time-dependent effects testing) as specified by a test plan. This plan shall specify the device description, irradiation conditions, device bias conditions, dosimetry system, operating conditions, measurement parameters and conditions, and accelerated aging annealing test conditions (if required).

3.1 Sample selection and handling. Only devices which have passed the electrical specifications as defined in the test plan shall be submitted to radiation testing. Unless otherwise specified, the test samples shall be randomly selected from the parent population and identically packaged. Each part shall be individually identifiable to enable pre- and post-irradiation comparison. For device types which are ESD-sensitive, proper handling techniques shall be used to prevent damage to the devices.

3.2 Burn-in. For some devices, there are differences in the total dose radiation response before and after burn-in. Unless it has been shown by prior characterization or by design that burn-in has negligible effect (parameters remain within postradiation specified electrical limits) on the total dose radiation response, then one of the following must be done:

3.2.1 The manufacturer shall subject the radiation samples to the specified burn-in conditions prior to conducting total dose radiation testing or

3.2.2 The manufacturer shall develop a correction factor, (which is acceptable to the parties to the test) taking into account the changes in total dose response resulting from subjecting product to burn-in. The correction factor shall then be used to accept product for total dose response without subjecting the test samples to burn-in.

3.3 Dosimetry measurements. The radiation field intensity at the location of the device under test shall be determined prior to testing by dosimetry or by source decay correction calculations, as appropriate, to assure conformance to test level and uniformity requirements. The dose to the device under test shall be determined one of two ways: (1) by measurement during the irradiation with an appropriate dosimeter, or (2) by correcting a previous dosimetry value for the decay of the \(^{60}\)Co source intensity in the intervening time. Appropriate correction shall be made to convert from the measured or calculated dose in the dosimeter material to the dose in the device under test.

3.4 Lead/Aluminum (Pb/Al) container. Test specimens shall be enclosed in a Pb/Al container to minimize dose enhancement effects caused by low-energy, scattered radiation. A minimum of 1.5 mm Pb, surrounding an inner shield of at least 0.7 mm Al, is required. This Pb/Al container produces an approximate charged particle equilibrium for Si and for TLDs such as CaF\(_2\). The radiation field intensity shall be measured inside the Pb/Al container (1) initially, (2) when the source is changed, or (3) when the orientation or configuration of the source, container, or test-fixture is changed. This measurement shall be performed by placing a dosimeter (e.g., a TLD) in the device-irradiation container at the approximate test-device position. If it can be demonstrated that low energy scattered radiation is small enough that it will not cause dosimetry errors due to dose enhancement, the Pb/Al container may be omitted.

3.5 Radiation level(s). The test devices shall be irradiated to the dose level(s) specified in the test plan within ±10 percent. If multiple irradiations are required for a set of test devices, then the post-irradiation electrical parameter measurements shall be performed after each irradiation.

3.6 Radiation dose rate.

* CAUTION: For the application of some bipolar and biCMOS devices to space-level dose rates, testing at condition A dose rates may not provide worst case results. These are devices that fail due to reduced transistor gain. For such devices, the excess base current has been observed to increase at decreasing dose rates. For these devices, testing shall be accomplished at the lowest dose rate of interest in accordance with conditions B or C in order to obtain a conservative estimate of the device performance.

* NOTE: For those bipolar and biCMOS devices where the application involves space level dose rates and the excess base current has been observed to increase at decreasing dose rates, testing may be accomplished at the lowest dose rate of interest in accordance with conditions B or C in order to obtain a conservative estimate of device performance.

3.6.1 Condition A. For condition A (standard condition) the dose rate shall be between 50 and 300 rads(Si)/s [0.5 and 3 Gy/(Si)/s] \(^{60}\)Co 2/. The dose rates may be different for each radiation dose level in a series; however, the dose rate shall not vary by more than ±10 percent during each irradiation.

2/ The Si unit for the quantity absorbed dose is the gray, symbol GY. 100 rads = 1 Gy.
3.6.2 **Condition B.** For condition B, if the maximum dose rate is < 50 rads/(Si)/s in the intended application, the parties to the test may agree to perform the test at a dose rate ≥ the maximum dose rate of the intended application. Unless the exclusions in 3.4.14b 3.12.1b are met, the accelerated aging annealing test of 3.4.12 3.12.2 shall be performed.

3.6.3 **Condition C.** For condition C, (as an alternative) the test may be performed at the dose rate of the intended application if this is agreed to by the parties to the test.

3.7 **Temperature requirements.** Since radiation effects are temperature dependent, devices under test shall be irradiated in an ambient temperature of 24°C ±6°C as measured at a point in the test chamber in close proximity to the test fixture. The electrical measurements shall be performed in an ambient temperature of 25°C ±5°C. If devices are transported to and from a remote electrical measurement site, the temperature of the test devices shall not be allowed to increase by more than 10°C from the irradiation environment. If any other temperature range is required, it shall be specified.

3.8 **Electrical performance measurements.** The electrical parameters to be measured and functional tests to be performed shall be specified in the test plan. As a check on the validity of the measurement system and pre- and post-irradiation data, at least one control sample shall be measured using the operating conditions provided in the governing device specifications. For automatic test equipment, there is no restriction on the test sequence provided that the rise in the device junction temperature is minimized. For manual measurements, the sequence of parameter measurements shall be chosen to allow the shortest possible measurement period. When a series of measurements is made, the tests shall be arranged so that the lowest power dissipation in the device occurs in the earliest measurements and the power dissipation increases with subsequent measurements in the sequence.

The pre- and post-irradiation electrical measurements shall be done on the same measurement system and the same sequence of measurements shall be maintained for each series of electrical measurements of devices in a test sample. Pulse-type measurements of electrical parameters should be used as appropriate to minimize heating and subsequent annealing effects. Devices which will be subjected to the accelerated aging annealing testing (see 3.4.12 3.12) may be given a pre-irradiation burn-in to eliminate burn-in related failures.

3.9 **Test conditions.** The use of in-flux or not in-flux testing shall be specified in the test plan. (This may depend on the intended application for which the data is being obtained.) The use of in-flux testing may help to avoid variations introduced by post-irradiation time dependent effects. However, errors may be incurred for the situation where a device is irradiated in-flux with static bias, but where the electrical testing conditions require the use of dynamic bias for a significant fraction of the total irradiation period. Not-in-flux testing generally allows for more comprehensive electrical testing, but can be misleading if significant post-irradiation time dependent effects occur.

3.9.1 **In-flux testing.** Each test device shall be checked for operation within specifications prior to being irradiated. After the entire system is in place for the in-flux radiation test, it shall be checked for proper interconnections, leakage (see 2.4), and noise level. To assure the proper operation and stability of the test setup, a control device with known parameter values shall be measured at all operational conditions called for in the test plan. This measurement shall be done either before the insertion of test devices or upon completion of the irradiation after removal of the test devices or both.

3.9.2 **Remote testing.** Unless otherwise specified, the bias shall be removed and the device leads placed in conductive foam (or similarly shorted) during transfer from the irradiation source to a remote tester and back again for further irradiation. This minimizes post-irradiation time dependent effects.

3.9.3 **Bias and loading conditions.** Bias conditions for test devices during irradiation or accelerated aging annealing shall be within ±10 percent of those specified by the test plan. The bias applied to the test devices shall be selected to produce the greatest radiation induced damage or the worst-case damage for the intended application, if known. The specified bias shall be maintained on each device in accordance with the test plan. Bias shall be checked immediately before and after irradiation. Care shall be taken in selecting the loading such that the rise in the junction temperature is minimized.
3.10 Post-irradiation procedure. Unless otherwise specified, the following time intervals shall be observed:

a. The time from the end of an irradiation to the start of electrical measurements shall be a maximum of 1 hour.

b. The time to perform the electrical measurements and to return the device for a subsequent irradiation, if any, shall be within two hours of the end of the prior irradiation.

To minimize time dependent effects, these intervals shall be as short as possible. The sequence of parameter measurements shall be maintained constant throughout the tests series.

3.11 Extended room temperature anneal test. The tests of 3.1 through 3.10 are known to be overly conservative for some devices in a very low dose rate environment (e.g. dose rates characteristic of space missions). The extended room temperature anneal test provides an estimate of the performance of a device in a very low dose rate environment even though the testing is performed at a relatively high dose rate (e.g., 50-300 rad/s). The procedure involves irradiating the device per steps 3.1 through 3.10 and post-irradiation subjecting the device under test to a room temperature anneal for an appropriate period of time (see 3.11.2a) to allow leakage-related parameters that may have exceeded their pre-irradiation specification to return to within specification. The procedure is known to lead to a higher rate of device acceptance in cases:

a. where device failure when subjected to the test in 3.1 through 3.10 has been caused by the buildup of trapped positive charge in relatively soft oxides, and

b. where this trapped positive charge anneals at a relatively high rate.

3.11.1 Need to perform an extended room temperature anneal test. The following criteria shall be used to determine whether an extended room temperature anneal test is appropriate:

a. The procedure is appropriate for either MOS or bipolar technology devices.

b. The procedure is appropriate where only parametric failures (i.e., functional failure) occur. The parties to the test shall take appropriate steps to determine that the device under test is subject to only parametric failure over the total ionizing dose testing range.

c. The procedure is appropriate where the natural annealing response of the device under test will serve to correct the out-of-specification of any parametric response. Further, the procedure is known to lead to a higher rate of device acceptance in cases where the expected application irradiation dose rate is sufficiently low that ambient temperature annealing of the radiation induced trapped positive charge can lead to a significant improvement of device behavior. Cases where the expected application dose rate is lower than 0.1 rad/s should be considered candidates for the application of this procedure. The parties to the test shall take appropriate steps to determine that the technology under test can provide the required annealing response over the total ionizing dose testing range.

3.11.2 Extended room temperature anneal test procedure. If the device fails the irradiation and testing specified in 3.1 through 3.10, an additional room temperature annealing test may be performed as follows:

a. Following the irradiation and testing of 3.1 through 3.10, subject the device under test to a room temperature anneal under worst-case static bias conditions. For information on worst case bias see 3.9.3.

b. The test will be carried out in such a fashion that the case of the device under test will have a temperature within the range 24°C ± 6°C.

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c. Where possible, the room temperature anneal should continue for a length of time great enough to allow device parameters that have exceeded their pre-irradiation specification to return to within specification or post-irradiation-parametric limit (PIPL) as established by the manufacturer. However, the time of the room temperature anneal shall not exceed \( t_{\text{max}} \), where

\[
\frac{D_{\text{max}}}{R_{\text{max}}} = \frac{1}{t_{\text{max}}}
\]

\( D_{\text{max}} \) is the total ionizing dose specification for the part and \( R_{\text{max}} \) is the maximum dose rate for the intended use.

d. Test the device under test for electrical performance as specified in 3.7 and 3.8. If the device under test passes electrical performance tests following the extended room temperature anneal, this shall be considered acceptable performance in spite of having previously failed the post-irradiation and electrical tests of 3.1 through 3.10.

3.12 MOS accelerated aging annealing test. The accelerated aging annealing test provides an estimate of worst-case degradation of MOS microcircuits in low dose rate environments. The procedure involves heating the device following irradiation at specified temperature, time and bias conditions. An accelerated aging annealing test (see 3.1.2.1 3.12.2) shall be performed for cases where time dependent effects (TDE) can cause a device to degrade significantly or fail. Only standard testing shall be performed as specified in 3.1 through 3.10 for cases where TDE are known not to cause significant device degradation or failure (see 3.11.1 3.12.1) or where they do not need to be considered, as specified in 3.12.1.

3.12.1 Need to perform accelerated aging annealing test. The parties to the test shall take appropriate steps to determine whether accelerated aging annealing testing is required. The following criteria shall be used:

a. The tests called out in 3.12.2 shall be performed for any device or circuit type that contains MOS circuit elements (i.e., transistors or capacitors).

b. TDE tests may be omitted if:

1. circuits are known not to contain MOS elements by design, or
2. the ionizing dose in the application, if known, is below 5 krad(Si), or
3. the lifetime of the device from the onset of the irradiation in the intended application, if known, is short compared with TDE times, or
4. the test is carried out at the dose rate of the intended application.
5. the device type or IC technology has been demonstrated via characterization testing not to exhibit TDE changes in device parameters greater than experimental error (or greater than an otherwise specified upper limit) and the variables that affect TDE response are demonstrated to be under control for the specific vendor processes, or

At a minimum, the characterization testing in (5) shall include an assessment of TDE on propagation delay, output drive, and minimum operating voltage parameters. Continuing process control of variables affecting TDE may be demonstrated through lot sample tests of the radiation hardness of MOS test structures.

c. This document provides no guidance on the need to perform accelerated aging annealing tests on technologies that do not include MOS circuit elements.

2.12.2 Accelerated aging annealing test procedure. If the device passes the tests in 3.1 through 3.10 or if it passes 3.11 (if that procedure is used) to the total ionizing dose level specified in the test plan or device specification or drawing and the exclusions of 2.12.1 do not apply, the accelerated aging annealing test shall be conducted as follows:

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a. **Overtest.**

1. Irradiate each test device to an additional 0.5-times the specified dose using the standard test conditions (3.1 through 3.10). Note that no electrical testing is required at this time.

2. The additional 0.5-times irradiation in 3.14.2.a-1 3.12.2.a may be omitted if it has been demonstrated via characterization testing that:
   
   a. none of the circuit propagation delay, output drive, and minimum operating voltage parameters recover toward their pre-irradiation value greater than experimental accelerated aging annealing test of 3.14.2.b 3.12.2.b, and
   
   b. the irradiation biases chosen for irradiation and accelerated aging annealing tests are worst-case for the response of these parameters during accelerated aging annealing.

   The characterization testing to establish worst-case irradiation and aging annealing biases shall be performed at the specified level. The testing shall at a minimum include separate exposures under static and dynamic irradiation bias, each followed by worst-case static bias during accelerated aging annealing according to 3.14.2.a 3.12.2.b.

b. **Accelerated aging annealing.** Heat each device under worst-case static bias conditions in an environmental chamber according to one of the following conditions:

1. At 100°C ±5°C for 188 ±12 hours, or

2. At an alternate temperature and time that has been demonstrated via characterization testing to cause equal or greater change in the parameter(s) of interest, e.g., propagation delay, output drive, and minimum operating voltage, in each test device as that caused by 3.14.2.a-1 3.12.2.b, or

3. At an alternate temperature and time which will cause trapped hole annealing of >60% and interface state annealing of <10% as determined via characterization testing of NMOS test transistors from the same process. It shall be demonstrated that the radiation response of test transistors represent that of the device under test.

c. **Electrical testing.** Following the accelerated aging annealing the electrical test measurements shall be performed as specified in 3.8 and 3.9.

3.42 3.13 **Test report.** As a minimum, the report shall include the device type number, serial number, the manufacturer, package type, controlling specification, date code, and any other identifying numbers given by the manufacturer. The bias circuit, parameter measurement circuits, the layout of the test apparatus with details of distances and materials used, and electrical noise and current leakage of the electrical measurement system for in-flux testing shall be reported using drawings or diagrams as appropriate. Each data sheet shall include the test date, the radiation source used, the bias conditions during irradiation, the ambient temperature around the devices during irradiation and electrical testing, the duration of each irradiation, the time between irradiation and the start of the electrical measurements, the duration of the electrical measurements and the time to the next irradiation when step irradiations are used, the irradiation dose rate, electrical test conditions, dosimetry system and procedures and the radiation test levels. The pre- and post-irradiation data shall be recorded for each part and retained with the parent population data in accordance with the requirements of MIL-PRF-38535 or MIL-PRF-38534. Any anomalous incidents during the test shall be fully documented and reported. The accelerated aging annealing procedure, if used, shall be described. Any other radiation test procedures or test data required for the delivery shall be specified in the device specification, drawing or purchase order.

4. **SUMMARY.** The following details shall be specified in the applicable acquisition document as required:

a. Device-type number(s), quantity, and governing specifications (see 3.1).

b. Radiation dosimetry requirements (see 3.3).
c. Radiation test levels including dose and dose rate (see 3.5 and 3.6).
d. Irradiation, electrical test and transport temperatures if other than as specified in 3.7.
e. Electrical parameters to be measured and device operating conditions during measurement (see 3.8).
f. Test conditions, i.e., in-flux or not-in-flux type tests (see 3.9).
g. Bias conditions for devices during irradiation (see 3.9.3).
h. Time intervals of the post-irradiation measurements (see 3.10).

i. Requirement for extended room temperature anneal test, if required (see 3.11).

j. Requirement for accelerated aging annealing test, if required (see 3.14 3.12).

k. Documentation required to be delivered with devices (see 3.12 3.13).
FIGURE 1019-1. Flow diagram for ionizing radiation test procedure.