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Radiation Hardness Assured Device Development

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Radiation Hardness Assured supplements to four military device detail specifications have been prepared using radiation characterization data on the six device types included in these specifications. The four RHA specifications (M38510/101, S19500/323, S19500/350, and S19500/355) include provisions for six part types; the 741A, LM101A, LM108A, 2N3251A, 2N3868, and the 2N2920.

Group D/E end-points and post-irradiation characteristics are calculated from these data. The methodology for performing these calculations is detailed such that future RHA devices can be developed utilizing this approach.

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INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION.

This report summarizes the work performed under HDL contract No. DAAL02-87-P-4084. The major output of this eight-month effort includes preliminary and final drafts of four proposed radiation hardness assured (RHA) military device specification amendments. The four RHA specifications (M38510/101, S19500/323, S19500/350, and S19500/355) include provisions for six part types: the 741A, LM101A, LM108A, 2N3251A, 2N3868, and 2N2920. The statistical analyses and methodology utilized for the development of these draft RHA mil spec amendments are presented in section 2, along with the RHA characterization data, data analyses, and RHA end-point limits and post-irradiation characteristics developed for these devices. Section 3 reports additional effort in support of the DNA Advisory Group on Hardness Assured Specifications and Standards in the form of recommended draft revisions of RHA device specifications and standards. Recommendations for the development of additional RHA device specifications are also included in this section. The draft RHA amendments for the devices listed above are included in this report as attachments in Appendix A.

1.2 BACKGROUND.

"Hardness assured" refers to devices which have met specific radiation hardness requirements, designed to assure a defined level of post-irradiation performance. A plan for incorporation of such requirements into the military specification system for semiconductor devices has been developed, and the specific changes have been incorporated into the general specifications for semiconductor devices (MIL-S-19500) and for microcircuits (MIL-M-38510), as well as the test standards on which these specifications rely (MIL-STD-750 and MIL-STD-883). Details of these modifications have been reported previously (Refs. 1-3).

The modifications made to MIL-M-38510 and MIL-S-19500 included both qualification (Qual) and quality conformance inspection (QCI) requirements for RHA devices. A series of radiation levels and requirements which include new letter designations and part markings, general sampling plans for radiation testing, and unique lot traceability requirements for hardness assurance are also defined in these specifications. These new requirements reflect the cooperative efforts of the NASA/Space Division Space Parts Working Group (SPWG) Hardness Assurance Subcommittee, Defense Nuclear Agency and the DNA Hardness Assurance Advisory Group, Aerospace Corporation, NASA - Goddard, Harry Diamond Laboratories, Rome Air Development Center, Naval Research Laboratory, Defense Electronic Supply Center, NAVELEX, Naval Weapon

Support Center, Air Force Weapon Lab, Jet Propulsion Lab, and other interested companies, individuals and agencies.

In this earlier work, four new part labels were proposed, corresponding to radiation levels stratified for total dose hardness with minimum neutron fluence levels. The radiation levels corresponding to the part labels, M, D, R, and H are shown in table 1. The levels are independent of the reliability classes. This approach represents the necessary compromise between part type proliferation, anticipated cost impacts, and system requirements. It is based upon the use of existing QPL military specification devices as a source of high reliability parts for hardened system applications. Additional hardness characteristics which are presently under consideration for inclusion in detail specifications include transient dose rate and single-event upset specifications.

The specifications cover only room temperature (25°C nominal) operations. For applications requiring radiation hardness assurance at temperatures other than 25°C ambient, reference can be made to the Military Handbooks for neutron and total dose hardness assurance guidelines (Refs. 4 and 5) and other guideline documents.

Table 1. Hardness Assurance Levels for RHA Devices

PART DESIGNATION	HARDNESS ASSURANCE LEVELS	
	TOTAL DOSE	NEUTRONS*
M	3000 RAD(SI) (30 GY(Si))	2 X 10^{12} n/cm2
D	10^4 RAD (SI)	2 X 10^{12} n/cm^2
R	10^5 RAD (Si)	2 X 10^{12} n/cm^2
H	10^6 RAD (SI)	2 X 10^{12} n/cm^2

*1-MEV SILICON DAMAGE EQUIVALENT

SECTION 2

DEVELOPMENT OF RHA DEVICE SPECIFICATIONS

2.1 INTRODUCTION

The general methodology for preparation of RHA device specifications has been reported previously (Ref. 1-3). A summary of the some of the more important issues for the development of RHA devices is included in Section 3 as a draft input to a Military guideline document for the preparation of RHA specifications. The calculations, performed to derive the specific values in the RHA detail specification supplements in Appendix A, followed the basic methodology prescribed in these reports, and are included in this section of this report. The most significant addition or modification to an existing (i.e.,non-RHA) device detail specification is the table of post-irradiation parameters (functional and parametric values) which the RHA device must satisfy for qualification or quality conformance inspection. These parameters are termed the post-irradiation "end-points" or "end-point limits" and are the specific pass/fail test limits that the RHA Qual and QCI test samples must pass for the lot to be acceptable.

The approach followed include the collection of radiation characterization data, either by the use of existing data or the generation of new radiation data, performing some type of statistical analysis for projecting these data to future lots to be procured, and incorporating these values into new detail specifications, new amendments, or supplements to amendments. The devices included in this effort are mature device types for which non-RHA detail specifications and amendments currently exist. The RHA provisions for these devices are in the form of draft RHA supplements to the latest amendments to these detail specifications.

The steps followed in collecting and analyzing radiation characterization data for the six part types (741A, LM101A, LM108A, 2N3251A, 2N3868, and 2N2920) are reported in this section. Details of the statistical methodology followed for establishing ground-rules for RHA QCI requirements are detailed in this section since this methodology serves as the starting basis for the RHA end-point calculations.

2.2 STATISTICAL ANALYSES OF RHA DATA

2.2.2 Multi-Lot Statistical Limit

The statistical approach described in this work is an extension of the tolerance-interval estimate method, extended for multiple lot procurement such as used in the military device specification system. It is assumed that lot sample acceptance testing by attribute testing [i.e., pass/fail testing such as used in lot tolerance percent defective (LTPD) tests] is mandated because of cost-effectiveness considerations. Statistics from individual lots are combined so that one can estimate the potential impact of hardness assurance on lot "yields." The method allows for the situation where lot-to-lot variations are greater or equal to the variations over individual lots, and, though there are some problems with its accuracy, can be applied to the inverse as well.

The basic approach (Refs. 3,6) is to utilize multiple-lot sample data to compute reasonable parameter failure limits for pass/fail lot acceptance testing. These failure limits can then be used as design limits in circuit applications provided suitable caution is used to account for the statistical basis of these limits. Lot sample data are assumed to be in the form of means and standard deviations of radiation-induced parameter values or parameter delta values (i.e., the difference between post-irradiation and pre-irradiation parameter values). Sample sizes are assumed to be small for cost efficiency reasons (typically on the order of 5 to 15). The basic problem then is to combine the means and standard deviations for lot sample data of various small sample sizes in such a way as to define a "failure" limit or end-point limit from these data.

Lot quality for QCI is typically verified by performing a radiation test on a sample of parts with the requirement that no more that a certain number of failures may occur for the lot to meet the maximum percent defective requirement. The requirement for class B is that 11 parts be tested for neutrons and 22 parts for total dose from each inspection lot with no failures allowed (an 11/0 test which corresponds to an LTPD of 20 per cent). Class S RHA sampling is per wafer (2/0 for LSI and 4/0 for MSI/SSI devices). End-point limits for each important device parameter can then be determined based on the criterion that a given fraction, P_a, of future lots will pass an 11/0 test (or 22/0) with 90 per cent confidence. The analysis here is performed with the usual assumptions that the parameters follow normal or log normal population distributions (Ref. 4). The technique may obviously be modified for those cases where another probability distribution is known to govern the parameters.

An exact analysis following the foregoing procedures would be very difficult and quite unnecessary because of the approximate nature of the distributions. Fortunately there exists a simplified method which gives approximately the same result. The required end-points are selected to produce at least 90 per cent probability of having no failures out of 11 tested parts (more precisely $(0.99)^{11} = 0.895$). The method assumes that the critical post-irradiation parameters approximately follow either a normal or, more likely, a log normal probability distribution. The end-points are then computed by determining a best estimate of the limit where 99 per cent of the parts for each of N lots will pass the test. If x is the critical parameter of interest, the best estimate for the end-point limit which includes 99 per cent of the distribution is:

$$x_{Li} = x_i +/- 2.326 \quad s_i \qquad (1)$$

for parameters which increase or decrease respectively with radiation, where x_{Li} is the end-point limit for the ith lot, x_i is the mean value of x, and s_i is the standard deviation. (The factor 2.326 arises from the fact that 2.326 standard deviations above the mean of a normal distribution includes 99 per cent of the distribution.) For the more usual cases where the post-irradiation parameter follows a log normal distribution, x would represent the logarithm of the parameter. A typical example of a parameter x would be the logarithm of the change in reciprocal gain, $\log[(1/h_{FE})]$.

If a sufficient number of parts are sampled from each lot, the values of the parameter of interest X_L are approximately distributed according to a normal law. An example of such a distribution for seven lots of 2N2907s is shown in Figure 1. The end-point limit, X_{LL}, for the part type is then determined from the point where with 90 per cent confidence, at least a certain fraction, P_a, of future lots will have values of X_L bounded by X_{LL}. The end-point, X_{LL}, is given by the approximation:

$$X_{LL} = X_L + k(N_L, P_a, C = 90\%)s_L \qquad (2)$$

where N_L is the number of lots tested, X_L is the mean for the N_L lots, and s_L is the standard deviation for the N_L lots. The function k is the one-sided tolerance limit. Tables of values for k for various values of N_L and P_a are given by Namenson, et al. (Ref. 4). Values for k for low P_a and small numbers of lots are shown in Table 2.

The validity of the approximation was checked by doing exact calculations on a typical set of data for 2N2222 transistors. The end-point obtained from the method given above was compared with an exact calculation and it was found that the actual confidence that 90 per cent of future lots would pass an 11/0 test was 86 per cent rather than 90 per cent which is sufficient accuracy for the purposes here. Similar checks on other data likewise show that the approximation is satisfactory.

The above calculations apply for estimating the post-neutron end-points from multilot data. A similar calculation applies for total dose end-points. The total dose RHA sampling requirement for class B or JANTXV devices is a 22/0 test. For a part survivability of 0.99, the multi-lot statistical limit requires a projection of only 80 per cent of the future lot passing, compared to 90 percent for a 11/0 test [i.e., $(0.99)^{22} = 0.80$].

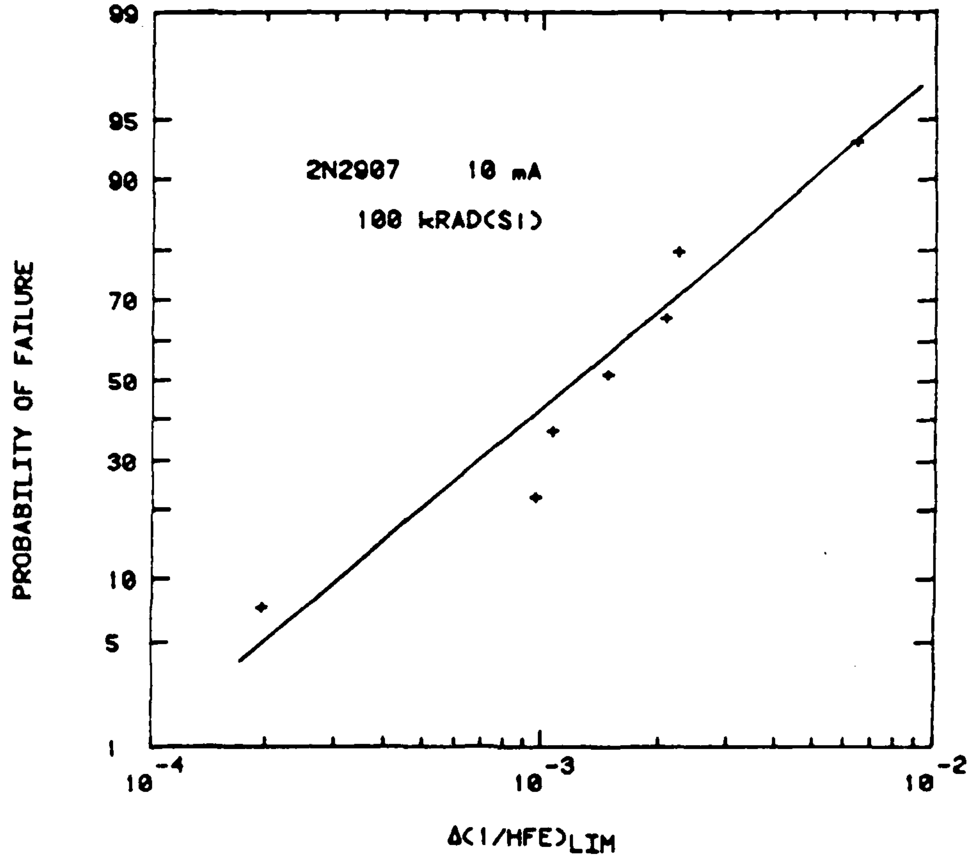


Figure 1. Distribution of Lot Limit in $\Delta(1/h_{FE})$ at 100 krad(Si) for Seven Lots of 2N2907A.

Table 2. One-sided Tolerance Factors for Small No. Lots

P (C = .9)	N	K	P	K (N=5)
50%	2	2.18	.95	3.40
	3	1.09	.90	2.74
	4	0.82	.8	1.98
	5	0.68	.75	1.70
	6	0.602	.6	1.041
	7	0.54	.5	.68
			.4	.362
75%	3	2.602		
	4	1.972		
	5	1.70		
	6	1.54		
	7	1.435		
90%	3	4.26		
	4	3.2		
	5	2.74		
	6	2.49		
	7	2.33		

2.2.2 Combined Environments Limits

The RHA tests defined in the group E/D RHA test tables specify separate tests for neutrons and total dose. The part designator (M, D, R, and H) implies that the part meets both neutron and total dose requirements and can be used in combined neutron and total dose environments. The part user must then find a means to either combine the individual end-point limits for each environment in a statistically valid manner or obtain characterization data (i.e., radiation test) to determine the part's performance in its intended application. Additional testing beyond QCI requirements undermines the purpose of RHA standardization and thus some means of applying attributes tests (go/no go) and specification end-points to combined environments are required.

Specific methods for calculating the combined effects of neutrons and total dose have been recommended (e.g., Refs. 1-3). The approach utilized in this effort is to apply a "worst case" delta for neutron effects to the post-irradiation end-point limits for total dose. This adds some conservatism to the combined effects but yields the most consistent values.

2.2.3 Example Calculations of End-Points

A comparison of the calculated multi-lot end-point limits with the individual lot limits is shown in Figure 2 for four lots of 2N2222A at 2×10^{12} n/cm^2. The estimated pass/fail limit for h_{FE} is calculated for each lot using Eq. (1). This lower limit is shown by the "x" at the lower end of the vertical bar for each lot in the figure. The number of devices in the lot test sample does not enter into this limit provided it is five or more. Assuming the lot limit distribution is approximately normal, the multi-lot lower limit can be computed using Eq. (2) for various lot acceptance probabilities. In this case, the 50 percent and 75 percent lot acceptance probabilities (at 90 percent confidence) are calculated and shown by the dashed lines in Figure 2.

These calculated multi-lot limits can be adjusted to some degree for end-points according to the "best estimate" of RHA yield and post-irradiation degradation to which the part might be used. For example, if a 50 percent gain degradation is acceptable for most applications (as is frequently the case in design derating practices for hardened designs), then the end-points corresponding to the higher acceptance probability could be accepted; the suppliers would have a higher acceptance rate and thus minimize cost impacts.

2.3 DATA STORAGE AND ANALYSIS

The data storage and analysis task for developing the end-point limits and post-irradiation characteristics for the six device types in this effort was primarily performed on a personal computer. Previously, a large computer program running on a VAX was used for crunching the huge volume of data for hundreds of part types. However the cost and manpower involved in the use of this program (Ref. 3) became prohibitive and the decision was made to use small computers for this effort.

2.4 RHA DEVELOPMENT FOR MIL-M-38510/101

MIL-M-38510/101F is the detail specification for eight types of monolithic silicon linear operational amplifiers. Significant radiation data are currently available for only the three most commonly used of these part types: the LM101A (-03), 741 (-01), and LM108A (-04). Most of the data available for these calculations were taken for specific equipment applications. Thus we were faced with the problem that the only set of device parameters common to all the lots were the input parameters, V_{IO}, I_{IO}, and I_{IB}. While these parameters were indeed the most critical to post-irradiation device operation, parameters such as open-loop gain, A_{VS}, and output sink

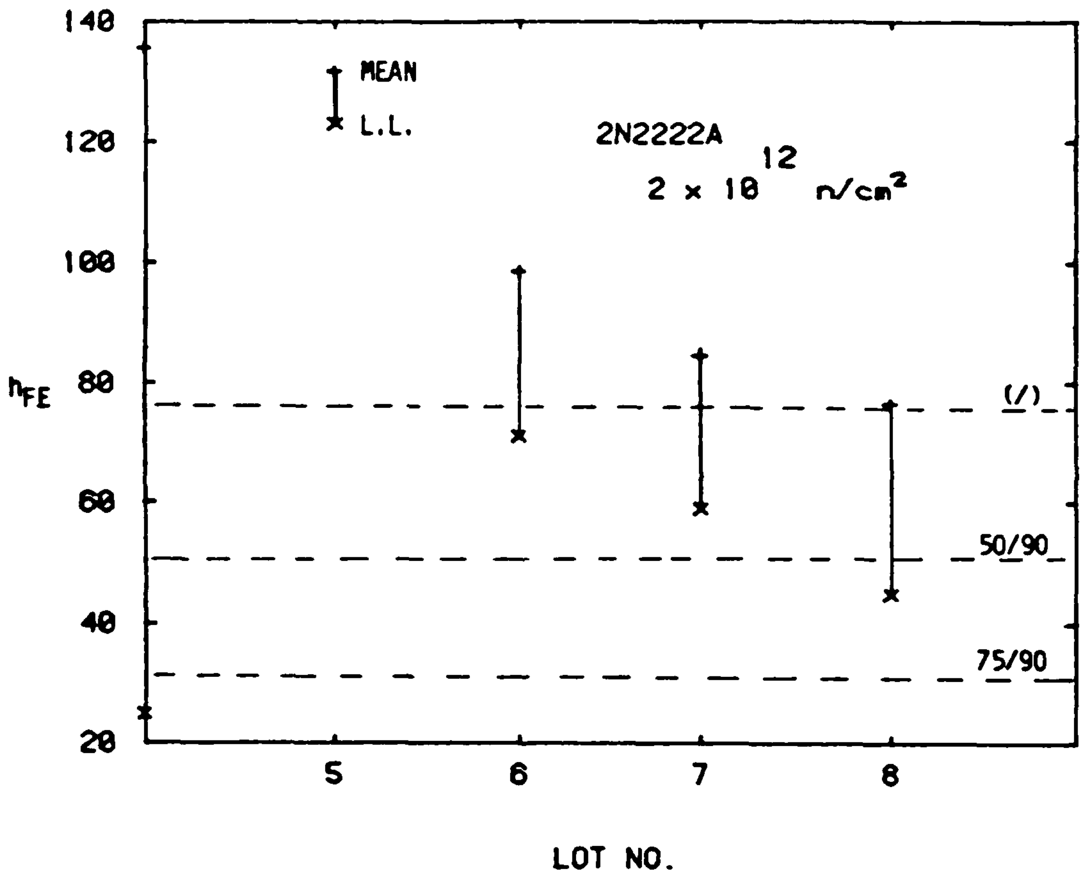


Figure 2. Lot Mean and Lower Limit (L.L.) and Multi-Lot Limit for h_{FE} at 1 mA and a Fluence of 2×10^{12} n/cm^2 for 2N2222A.

current, I_{OS}, can also be sensitive to radiation, but were only reported for some of the lots. This problem is to be expected because uniform standards and specifications for RHA characterization tests are not available or used.

Even though not all the necessary test parameters were The volume of radiation characterization data is much too large to include in detail in this report. A summary of some of the most important radiation characterization data and calculations/estimates of end-point limits and post-irradiation characteristics for each of the three op amps are included in the following sections.

2.4.1 Summary of LM741 Radiation Characterization Data

The LM741 is a general purpose op amp with NPN input transistors and lateral PNP current "mirrors". A substantial amount of data has been reported (see, e.g., Ref. 4). However, radiation characterization data for only a few lots have been reported and stored in databanks in recent years. The two major sources of radiation characterization data for these device types are the Boeing CHAP databank and data stored on the Tektronix S-3260 IC tester. A summary of the multi-lot data extracted from these databanks for neutron and total dose degradation is shown in Table 3. The major parameters in their order of sensitivity are: input bias current (I_{IB}), input offset current (I_{IO}), input offset voltage (V_{IO}), open-loop gain (A_{VS}), and output sink current (I_{OS}). The last column of this table includes the calculated or estimated post-irradiation end-point.

The following approach was used to determine these values:

1) Limits were computed for both + and - inputs for the input bias current. The limit selected was the larger.

2) Limits for offset voltage --- compute upper and lower limits, take larger and either sign.

3) Limits of offset current --- same approach as 2).

4) Limits for open loop gain --- select single load and compute limits similar to h_{FE}.

5) Limits for sink current --- compute limits similar to h_{FE} (constant base current).

2.4.2 Summary of LM101A Radiation Characterization Data

The LM101A is a general purpose operational amplifier with low input currents and temperature drifts. A large amount of radiation characterization data has been collected for the

Table 3. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY LM741.

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT INTER. 8428	2 LOT LIMIT NAT 8234	3 LOT LIMIT NAT 8337	4 LOT LIMIT FSC 8010	END-POINT LIMIT
LM741	10101	VIO		+/- 3 mV	2.0E12					5.0 mV
					3000			1.6		5.0
					1.0E4		0.0	1.7		5.0
					1.0E5		13.0	2.5		20
					1.0E6		600.0			100
		IIO		+/- 30 nA	2.0E12					50 nA
					3000			2.2		50
					1.0E4			3.0		50
					1.0E5		27.0	5.0		50
					1.0E6					100
		IIB		110 nA	2.0E12	DL=360		DL=232		500 nA
					3000		150.0	60.0		200
					1.0E4		170.0	80.0		300
					1.0E5		313.0	137.0		500
					1.0E6		1414.0			1000
		AVS	RL = 2K	50 K	2.0E12					(45K)
			VO = 15V		3000					(45K)
					1.0E4					(45K)
					1.0E5					(45K)
					1.0E6					(45K)
		IOS		60 mA	2.0E12					(55 mA)
					3000					(55)
					1.0E4					(55)
					1.0E5					(55)
					1.0E6					(55)
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

LM101A. Table 4 includes a listing for the 11 lots analyzed. Most of these were taken for specific applications and only the input parameters are common to these data. Total dose data on open loop gain was included in only two lots analyzed. The lot failure limit data for these two lots are shown in Figure 4. In general, A_{VS} degradation was not significant until moderately high doses (above R level), whereupon large changes occurred. On the other hand, input bias currents, I_{IB}, and offset currents, I_{IO}, degraded at much lower doses and exhibited large lot-to-lot variations. This is shown in Figures 5 and 6 for three lots. Figure 5 shows the upper limit for input offset current degradation. The data for one lot exhibited large variations which is likely due to test errors. The input bias current, which displays the most consistent degradation behavior with total dose (Figure 6), also exhibited large variations between lots. The calculated end-points are shown in the last column on page 3 of Table 4.

2.4.3 Summary of LM108A Radiation Characterization Data

The LM108A is a precision operational amplifier which utilizes super-gain NPN transistors in the input stage to achieve very low input parameter values (V_{IO} max of 0.5 mV, I_{IO} max of 0.2 nA, I_{IB} max of 2.0 nA). These high precision performance requirements make the LM108A very sensitive to radiation damage and the typical post-irradiation parameter values exceed these specification limits at low radiation values. This is illustrated in Table 5 which is a matrix of lot failure for several parameters and radiation levels. Table 5 shows the number of devices from each lot whose parameter values exceed the pre-irradiation limits. As expected, the input parameters dominate the failure mode for nearly all lots, both for neutrons and total dose. The results of multi-lot statistical analysis demonstrate that a substantial derating of electrical end-points is required in order that these device pass RHA requirements. This is balanced against the "over-derating" which obviates the performance advantage of the higher initial performance (and initial cost) of this device.

Table 6 is a summary of the lots for which radiation data were analyzed. The data for many of the LM108A lots, for which data were identified (some shown on Table), were not available for this RHA analysis due to problems with the computer data files. Many of the neutron data files had been removed and due to change-over in databases. For example, only two lots of these devices were available for neutron RHA calculations out of over 15 lots identified. The majority of the "lost" lots were unavailable due to their removal from computer databases. However, more than ten lots of LM108As were analyzed earlier for lot failures based on the use of their preirradiation end-point limits. These data, though unavailable for multi-lot analyses, could be used to estimate failure parameter values.

Table 4. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM101A

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT FSC FJ82	2 LOT LIMIT FSC 8346	3 LOT LIMIT SIG 7931	4 LOT LIMIT AMD 8115	END-POINT LIMIT
LM101A	101	-VIO		-2.0 mV	2.0E12	-2.0	-2.1	-1.5	-1.2	(CONT.)
					3000		-2.0			
					1.0E4		-2.4			
					1.0E5		-4.1			
					1.0E6		-6.7			
		+VIO		+2.0 mV	2.0E12	1.3	1.4	2.3	2.1	
					3000		2.6			
					1.0E4		1.8			
					1.0E5		1.2			
					1.0E6		1.5			
		IIO		10 nA	2.0E12	5.3	14.0	11.3	5.7	
					3000		6.0			
					1.0E4		4.6			
					1.0E5		19.0			
					1.0E6		34.0			
		IIB		75 nA	2.0E12	46.0	52.0	85.0	87.0	
					3000		20.0			
					1.0E4		84.0			
					1.0E5		254.0			
					1.0E6		427.0			
		AVS	RL = 2K	50 K	2.0E12					
			VO = 15V		3000					
					1.0E4					
					1.0E5					
					1.0E6					
		IOS		60 mA	2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

Table 4. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM101A (cont.)

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	5 LOT LIMIT FSC 8424	6 LOT LIMIT NAT 0857	7 LOT LIMIT NAT 0858	8 LOT LIMIT NAT 0859	END-POINT LIMIT
LM101A	101	-VIO		-2.0 mV	2.0E12	-1.4				(CONT.)
					3000					
					1.0E4	-1.4	-0.3	-0.7	-1.3	
					1.0E5	-2.2	-0.8	-1.7	-2.3	
					1.0E6		-6.5	-18.5	-4.9	
		+VIO		+2.0 mV	2.0E12	0.1				
					3000					
					1.0E4	-0.2	0.5	0.7	2.0	
					1.0E5	-0.1	0.0	0.9	2.9	
					1.0E6		3.3	2.8	0.0	
		IIO		10 nA	2.0E12	5.5				
					3000					
					1.0E4	1.3	3.3	2.2	2.8	
					1.0E5	4.5	42.0	10.0	-7.0	
					1.0E6		43.4	50.0	-63.0	
		IIB		75 nA	2.0E12	57.0				
					3000					
					1.0E4	48.0	57.0	58.0	52.0	
					1.0E5	116.0	210.0	144.0	81.0	
					1.0E6		583.0	375.0	236.0	
		AVS	RL = 2K	50 K	2.0E12	1.33E+05				
			VO = 15v		3000					
					1.0E4	1.04E+05	2.70E+05	1.60E+05	1.80E+05	
					1.0E5	1.50E+04		1.80E+05	1.92E+05	
					1.0E6			2.00E+03	1.00E+03	
		IOS		60 mA	2.0E12	28.0				
					3000					
					1.0E4	29.0				
					1.0E5	17.0				
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

Table 4. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM101A (cont.)

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	9 LOT LIMIT FSC 8346	10 LOT LIMIT FSC FJ82	11 LOT LIMIT FSC 8011	12 LOT LIMIT	END-POINT LIMIT
LM101A	101	-VIO		-2.0 mV	2.0E12					5 mV
					3000	-2.0	-1.9	3.0		10
					1.0E4	-2.0	-2.1	1.0		10
					1.0E5	-2.1	-2.5	-1.3		15
					1.0E6	-2.2	-3.1	-8.2		25
		+VIO		+2.0 mV	2.0E12					5 mV
					3000	1.3	1.5	9.6		10
					1.0E4	1.0	1.3	5.9		10
					1.0E5	0.3	0.9	0.1		15
					1.0E6	-0.3	0.7	-5.1		25
		IIO		10 nA	2.0E12					20 nA
					3000		57.0			20
					1.0E4		14.0			20
					1.0E5		147.0			175
					1.0E6		280.0			380
		IIB		75 nA	2.0E12					120 nA
					3000	45.0	60.0			100
					1.0E4	71.0	66.0			100
					1.0E5	123.0	228.0			320
					1.0E6	179.0	393.0			760
		AVS	RL = 2K	50 K	2.0E12					45 K
			VO = 15V		3000					45
					1.0E4					45
					1.0E5					5
					1.0E6					---
		IOS		60 mA	2.0E12					(55 mA)
					3000					(55 mA)
					1.0E4					(55 mA)
					1.0E5					(55 mA)
					1.0E6					(55 mA)
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

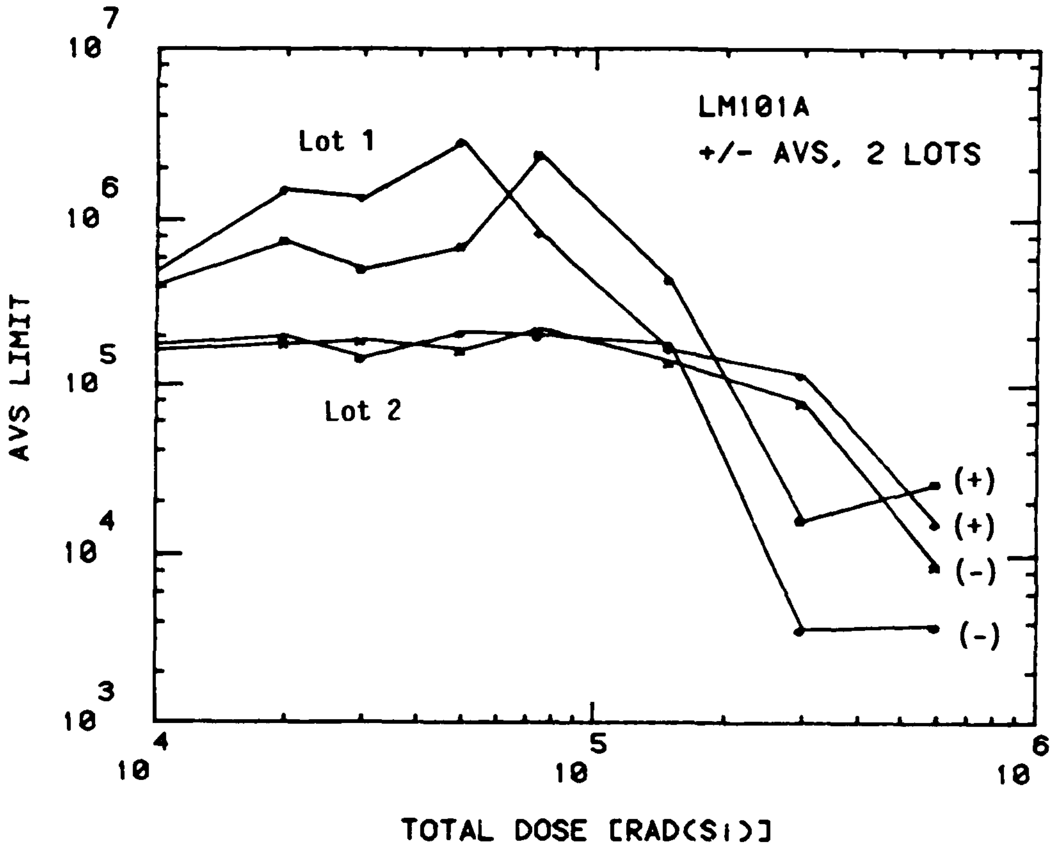


Figure 3. Lot Limit for Open-Loop Gain, A_{VS}, versus Total Dose for Two Lots of LM101A.

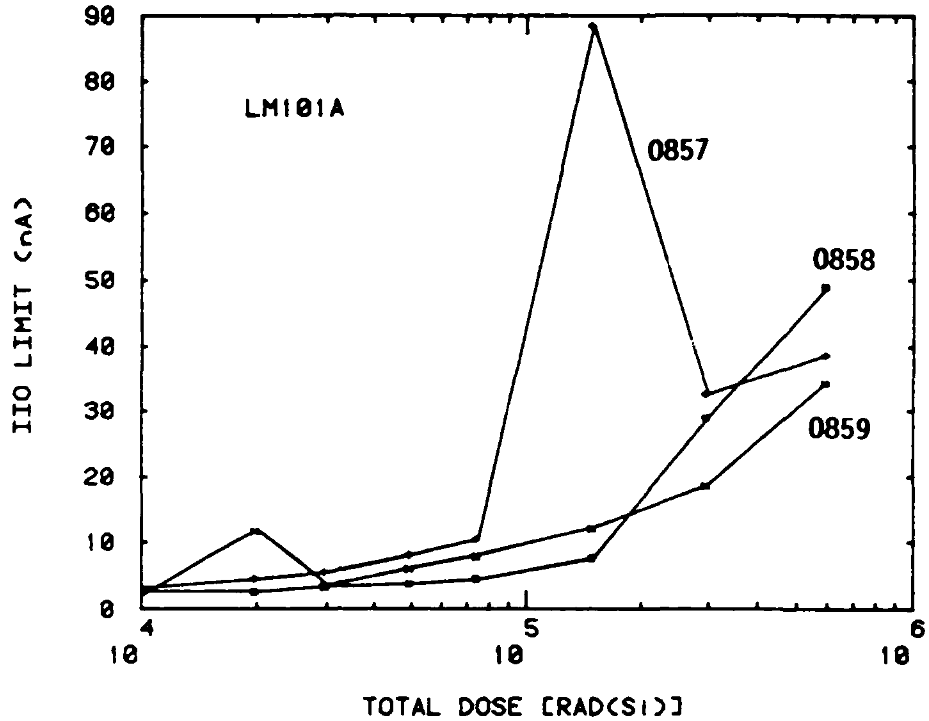


Figure 4. Lot Limit for Input Offset Current, I_{IO}, versus Total Dose for Three Lots of LM101A.

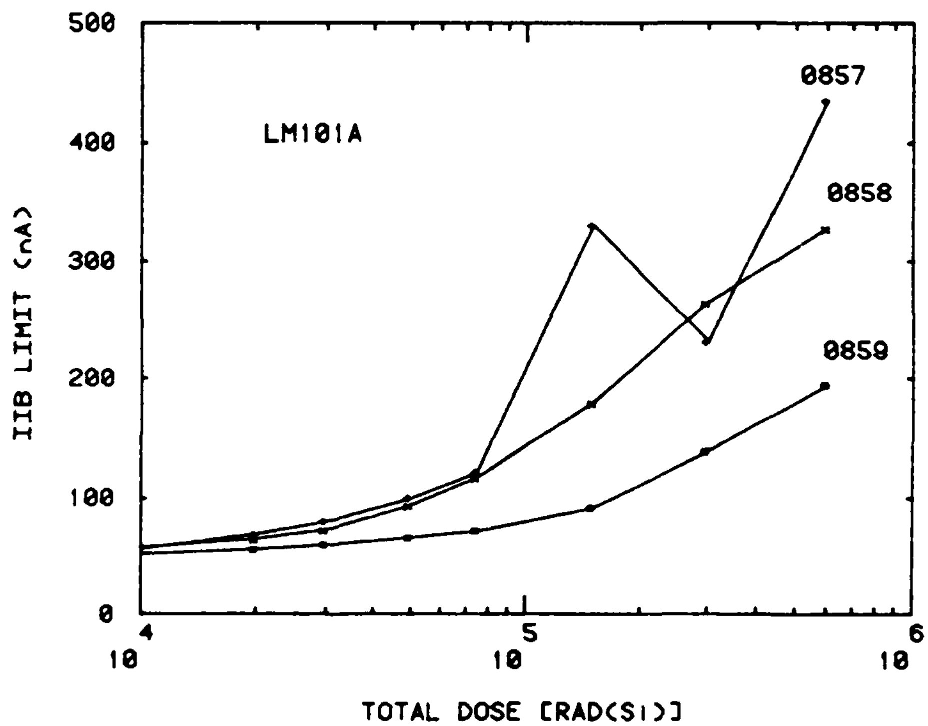


Figure 5. Lot Limit for Input Bias Current, I_{IB}, versus Total Dose for Three Lots of LM101A.

Table 5. EXAMPLE OF LOT SAMPLE FAILURE MATRIX - LM 108A

PART TYPE	MFR	DATE CODE	LOT SIZE	RADIATION LEVEL	N/D	IIB +2 -.1 nA	V_{IO} ±.5mV	I_{IO} ±.2nA	A_{VS} 80K	SR	I_{OS} ±15mA	I_{CC} 600μA
LM108A	FSC	7720	15	5.5×10^{11}	n/cm^2	15	1	8	0		0	0
				1.1×10^{12}		15	1	10	4			0
				4.0×10^{12}		15	9	13	15			0
				6.1×10^{12}		15	15	15	15			0
LM108A	NSC	7642	15	1.6×10^{12}	n/cm^2	15	2	10	2		0	0
				3.1×10^{12}		15	4	8	12		0	0
				8.1×10^{12}		15	15	15	15		0	0
LM108A	AMD	7721	8	1.1×10^{12}	n/cm^2	8	4	4	8		0	0
				3.1×10^{12}		8	8	7	8		0	0
				8.4×10^{12}		8	8	8	8		0	0
LM108A	AMD	8215	5	1×10^4	rad(Si)	0	0	0	0			0
				2×10^4		0	0	0	0			0
				1×10^5		1	1	0	0			0
				3×10^5		1	1	0	0			0
				1×10^6		5	2	0	0			0
				3×10^6		5	5	3	2			0
LM108A	FSC	8348	5	1×10^4	rad(Si)		0		0			0
				5×10^4			2		0			0
				1×10^5			5		5			0
				5×10^5			5		5			0
				1×10^6			5		5			0

Table 6. Summary of LM108A Lots Used for RHA Devices

LOT	MFR	DATE	No	SRCE	PARM	DOSE	FLUENCE
1	AMD	8215D	10	BA	3/5	10-300K	$.5\text{-}7x10^{12}$
2	AMD	8049	10	BA	3/5	5-200K	$7x10^{10}$
3	AMD	8049A	5	BA	3/5		
4	NAT	--	3/6	BA	5/5	10-300K	----
5	AMD	8238/	5	JPL	4/5	75-1000K	----
6	PMI	E9974	5	JPL	4/	75-1000K	----
7	MOT	8143	5	JPL	4/	10-50K	----
8	NAT	0855-1	5	JPL	4/	10-600K	----
9	FSC	8223	4	JPL	4/	10-600K	----
10	AMD	8238-39	5	JPL	4/	75-1000K	----

A sample calculation of the D- and R- level end-points for Subgroup 2, Total Dose, is shown in Table 7 for input bias current for the six devices (lot 4 in Table 6). The device serial number is shown in the first column with the input bias current in nA shown in each column after exposure to the total dose level in rad(Si) shown in the column heading. The log mean and standard deviation and lot limit, XL, are listed beneath the measured data. No end-point could be calculated for the H-level (1 Mrad) due to constraints on extrapolating data more than a factor of two.

Table 7. Example of Lot Limit Estimate for IIB for LM108A

S/N	PRE	10K	30K	60K	100K	200K	300K	1M
31	1.04	1.27	1.49	1.80	2.30	3.10	3.80	(*)
32	0.86	1.15	1.43	1.80	2.20	3.10	3.85	
33	1.29	1.29	1.80	2.20	2.70	3.60	4.30	
21	1.12	1.19	12.70	12.70	4.70			
22	0.50	0.54	0.84	0.85	1.40			
23	1.06	1.18	2.40	2.40	2.90			
L-MEAN		1.09			2.53			---
L-SIG		0.15			0.17			---
XL		2.48 nA			6.35 nA			---

Table 8 is a summary of the individual lot limits for the ten lots of LM108A. The last two columns (page 3 of Table 8) are the multi-lot limits and recommended end-points values.

Table 8. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM108A

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT AMD 8215	2 LOT LIMIT AMD 8049	3 LOT LIMIT AMD 8049	4 LOT LIMIT NAT	END-POINT LIMIT
LM108A	101	VIO		0.5 mV	2.0E12	1.50				(CONT.)
					3000		4.0	0.14	0.66	
					1.0E4		4.8	0.44	1.10	
					1.0E5	2.00	6.5	2.10	1.30	
					1.0E6	3.00	8.2	3.90	0.02	
		IIO		0.2 nA	2.0E12	0.60				
					3000		0.8	0.80	0.20	
					1.0E4		0.8	0.60	0.07	
					1.0E5	0.02	1.3	1.00	0.13	
					1.0E6	0.50	1.7	1.70	0.02	
		IIB		2.0 nA	2.0E12	3.97				
					3000		23.1	5.8	3.30	
					1.0E4		28.0	2.0		
					1.0E5	3.0	40.0	20.0		
					1.0E6	15.0	53.0	39.0		
		AVS		80 K	2.0E12	2.2E+04				
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
		IOS		15 mA	2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

Table 8. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM108A (cont.)

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	5 LOT LIMIT AMD 8238	6 LOT LIMIT PMI E9974	7 LOT LIMIT MOT 8143	8 LOT LIMIT NAT 0855-1	END-POINT LIMIT
LM108A	101	VIO		0.5 mV	2.0E12					(CONT.)
					3000					
					1.0E4			4.80	3.4	
					1.0E5	4.2	0.9		24.0	
					1.0E6	2.1	1.0			
		IIO		0.2 nA	2.0E12					
					3000					
					1.0E4				0.7	
					1.0E5	4.2			8.0	
					1.0E6	10.2				
		IIB		2.0 nA	2.0E12	3.9				
					3000					
					1.0E4			3.9	3.8	
					1.0E5	38.2	13.0		4.3	
					1.0E6	95	25.0			
		AVS		80 K	2.0E12					
					3000					
					1.0E4			3.4E+04	2.4E+04	
					1.0E5		1.8E+04	---	2.4E+02	
					1.0E6					
		IOS		15 mA	2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

Table 8. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR LM108A (cont.)

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	9 LOT LIMIT FSC 8223	10 LOT LIMIT AMD 8238	LOT LIMIT	LOT LIMIT MULTI-LOT LIMIT	END-POINT LIMIT
LM108A	101	VIO		0.5 mV	2.0E12				(1.5)	3 mV
					3000				10.5	10
					1.0E4	1.20			7.5	10
					1.0E5	31.0	0.4		33(7.5)	10
					1.0E6		0.7		9.2	10
		IIO		0.2 nA	2.0E12				(0.6)	2 nA
					3000				2.1	2
					1.0E4	15.70			29.5(1.3)	2
					1.0E5	27.0	1.4		24(8.4)	8
					1.0E6		9.1		13.4	13
		IIB		2.0 nA	2.0E12				(4.4)	10 nA
					3000				(3.6)	20
					1.0E4	25.90			114.0	100
					1.0E5	92.0	21.7		191.0	200
					1.0E6		80.0		245.0	250
		AVS		80 K	2.0E12				2.2E+04	10K
					3000					20K
					1.0E4	2.4E+04			1.2E+04	12K
					1.0E5		6.7E+04		---	5K
					1.0E6					
		IOS		15 mA	2.0E12				12	12 mA
					3000					12
					1.0E4					12
					1.0E5					12
					1.0E6					12
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

2.5 RHA DEVELOPMENT FOR MIL-S-19500/323 (2N3251A)

The 2N3251A is a low power, PNP silicon switching transistor. Radiation characterization data for five lots were analyzed and lot parameter limits are summarized in Table 9. Of the four original lots with post-neutron $V_{CE(SAT)}$ data, only one lot had conditions consistent with the multi-lot analysis. For those cases where data on only one or two lots were available, limit values for delta changes were used to determine the post-irradiation end-point limits.

2.6 RHA DEVELOPMENT FOR S-3295/350 (2N3868)

The 2N3868 is a PNP silicon transistor rated at 3 A and 60 V with an f_T of 60 MHz. Radiation characterization data on 25 parts of one lot (Motorola, D/C 8109) and five parts of a second lot (T.I., D/C 8408) have been analyzed and summarized below. Both lots exhibited large variation in parameter values. The use of absolute parameter statistical limits can result in extremely low (or high depending upon parameter) values for the estimated lot failure limits for non-uniform lots. For these cases, a more realistic failure limit is obtained using limiting values for parameter deltas and applying these delta limits to the pre-irradiation end-point limits. This is the approach used for determining post-irradiation end-points for these devices.

The large variability in initial parameter values and small variability in parameter degradation is demonstrated in the data plotted in Figures 6 and 7 where the range, mean, and standard deviation in parameter values for one lot is shown as a function of total dose. The variations within a single lot sample of five devices were substantially greater than the total dose degradation. The log normal lower limit computed for this lot is unrealistically low at all dose levels and simple statistical methods give unrealistically low values. The summary of end-points calculated using delta limits is shown in Table 10.

2.7 RHA DEVELOPMENT FOR MIL-S-19500/355 (2N2920)

The 2N2920 is a dual unitized NPN silicon transistor with matching h_{FE} and V_{BE} specifications for the transistor pair. Previous drafts of the RHA detail specification for this part lacked the gain matching specifications. Radiation characterization data taken at JPL on gain matching has been analyzed and included in the draft RHA amendment prepared in this effort. The multi-lot limits for h_{FE} and gain ratio are shown in Figures 8, 9 and 10 as a function of total dose. The lower limit for h_{FE} is shown for lot acceptance probabilities of 50%, 75%, and 90%. The large lot-to-lot variability at these

Table 9 MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR 2N3251A

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT MOT JPL 0245	2 LOT LIMIT MOT 8044/ND16	3 LOT LIMIT NAT ND3	4 LOT LIMIT RAY ND6	END-POINT LIMIT
2N3251A	323B	hFE	0.1 mA	80	2.0E12		104	73	76	70
					3000					70
					1.0E4	163	108			70
					1.0E5	92	87			70
					1.0E6		38			40
		hFE	1 mA	90	2.0E12		148	115	127	80
					3000					80
					1.0E4	191	136			80
					1.0E5	134	119			80
					1.0E6		72			60
		hFE	10 mA	100	2.0E12		176	147	157	90
					3000					90
					1.0E4		157			90
					1.0E5		144			90
					1.0E6		107			90
		hFE	50 mA	30	2.0E12			107	104	27
					3000					27
					1.0E4		95			27
					1.0E5		87			27
					1.0E6		69			27
		VCE(SAT)	10 mA/1mA	0.25	2.0E12		0.016 *			0.30
					3000					0.30
					1.0E4		0.08			0.30
					1.0E5		0.09			0.30
					1.0E6		0.10			0.30
		ICBO	40 Vdc	20 nA	2.0E12		---			40
					3000		1.6			40
					1.0E4		3.0			40
					1.0E5		7.0			50
					1.0E6		82.0			100
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6		*DELTA LIM			

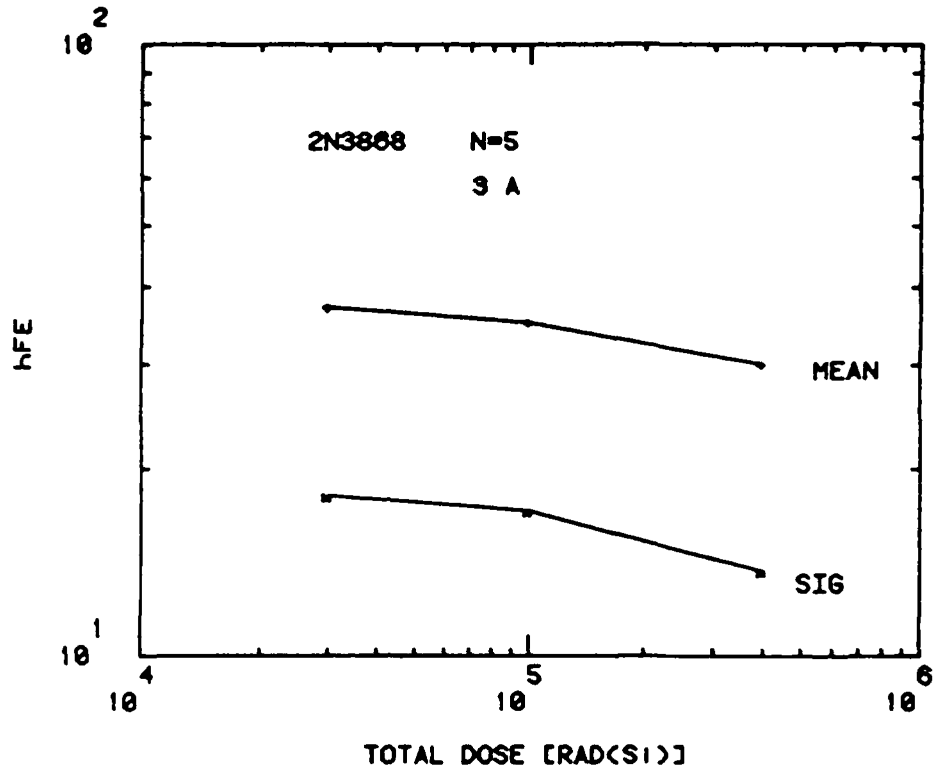


Figure 6 Lot Mean and Standard Deviation versus Total Dose for 2N3868.

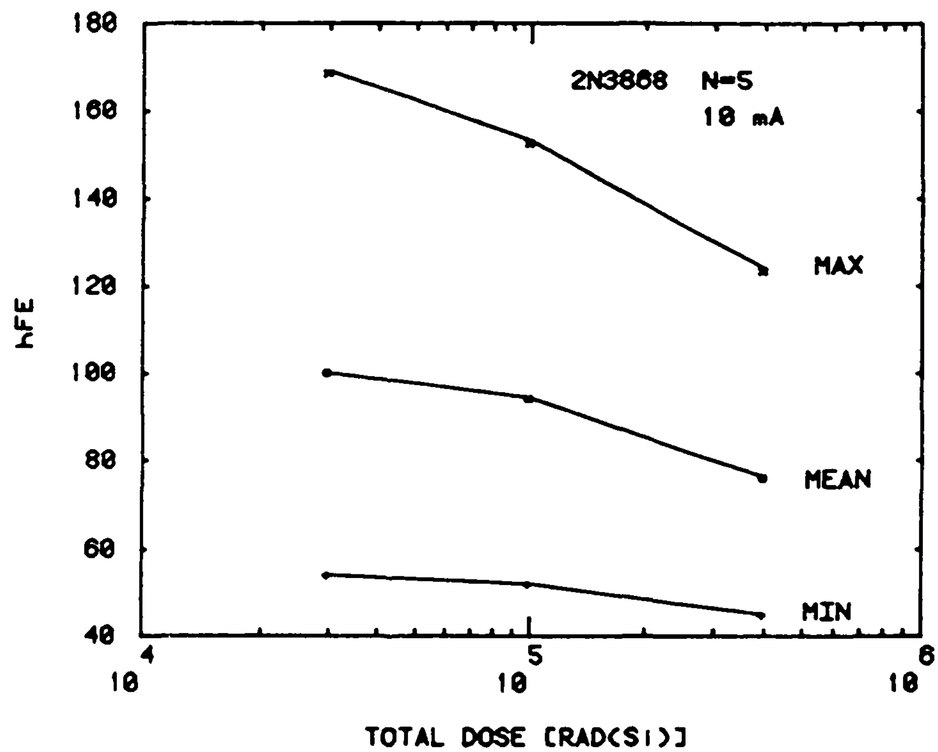


Figure 7 Lot Mean, Max, and Min versus Total Dose for One Lot of 2N3868.

Table 10. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR 2N3868

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT MOT 8109 N=25	2 LOT LIMIT T.I. 8408 N=5	3 LOT LIMIT	4 LOT LIMIT	END-POINT LIMIT
2N3868	350A	hFE	2V / 1.5A	30.00	2.0E12	26				20.00
					3000					27.00
					1.0E4		29			27.00
					1.0E5		28			22.00
					1.0E6		21			10.00
		hFE	5V / 3A	20.00	2.0E12	19				16.00
					3000					18.00
					1.0E4		19			18.00
					1.0E5		18			12.00
					1.0E6		13			5.00
		VCE(SAT)	1.5A/.15A	0.75 Vdc	2.0E12	D=0.12 V				0.90
					3000					0.90
					1.0E4					0.90
					1.0E5					0.90
					1.0E6					1.00
		ICEX	VCB=60 V	-1.0 uA	2.0E12	20 nA				-1.2 uA
			VEB=-2 V		3000					-1.2 uA
					1.0E4					-1.2 uA
					1.0E5		120 nA			-1.2 uA
					1.0E6		120 nA			-2.0 uA
		D(1/hFE)	1.5 A		2.0E12	5.80E-03				1.74E-02
					3000					
					1.0E4		5.00E-04			2.50E-03
					1.0E5		2.60E-03			1.30E-02
					1.0E6		1.50E-02			7.50E-02
		D(1/hFE)	3.0 A		2.0E12	3.60E-03				1.08E-02
					3000					
					1.0E4		1.00E-03			5.00E-03
					1.0E5		6.40E-03			3.20E-02
					1.0E6		3.00E-02			1.50E-01
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

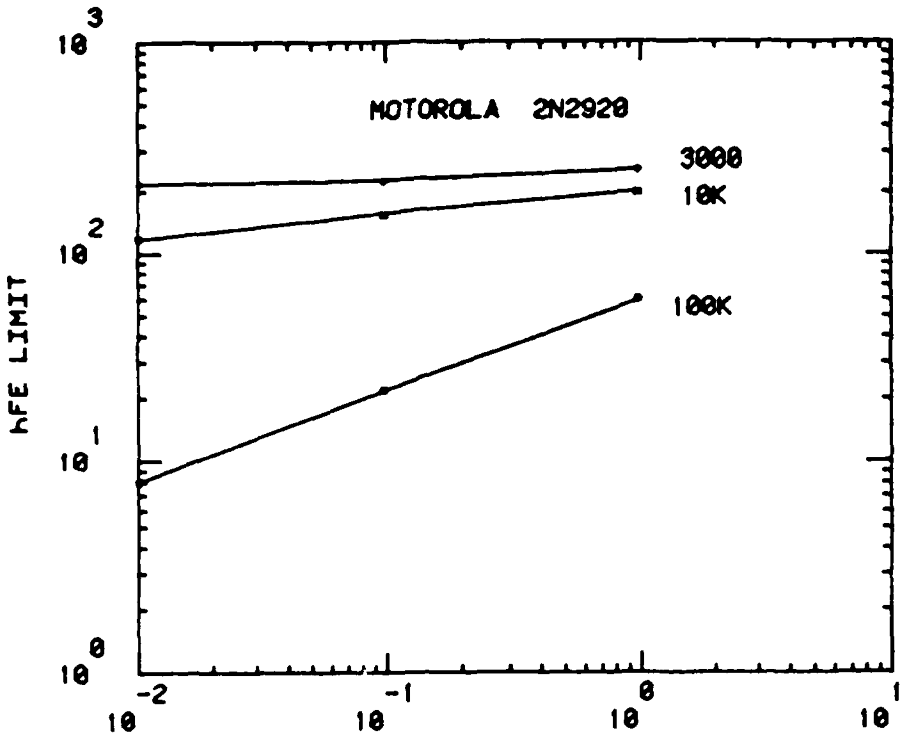


Figure 8. Current Dependence of h_{FE} Limit at M, D, and R Levels for One Lot of 2N2920.

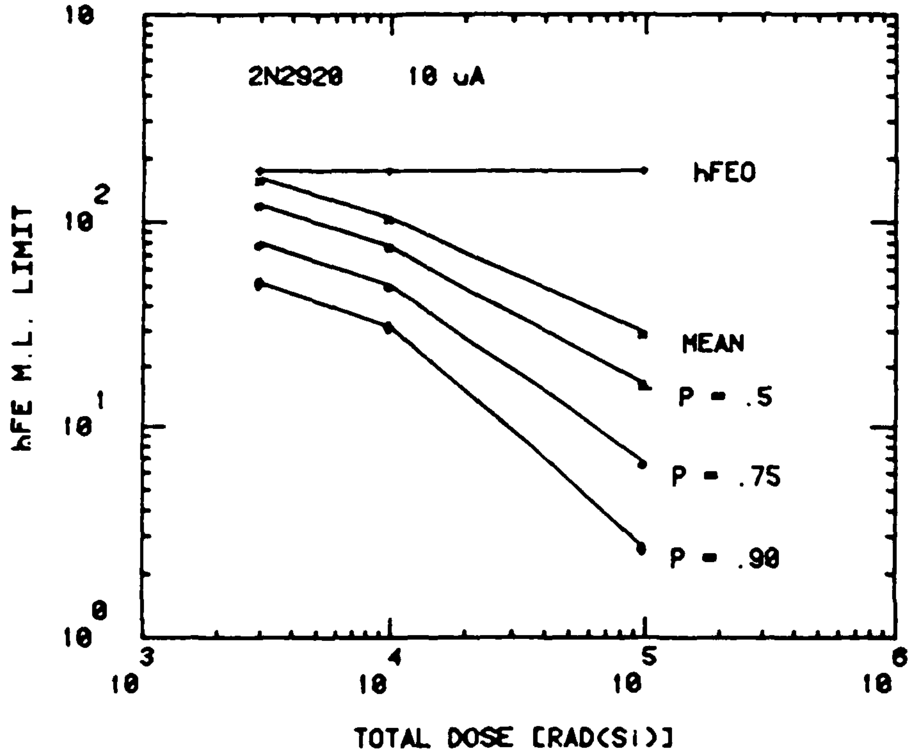


Figure 9. Multi-Lot Limits for h_{FE} at M, D, and R Levels for 50%, 75%, and 90% Lot Acceptance Probabilities, 90% Confidence for 2N2920.

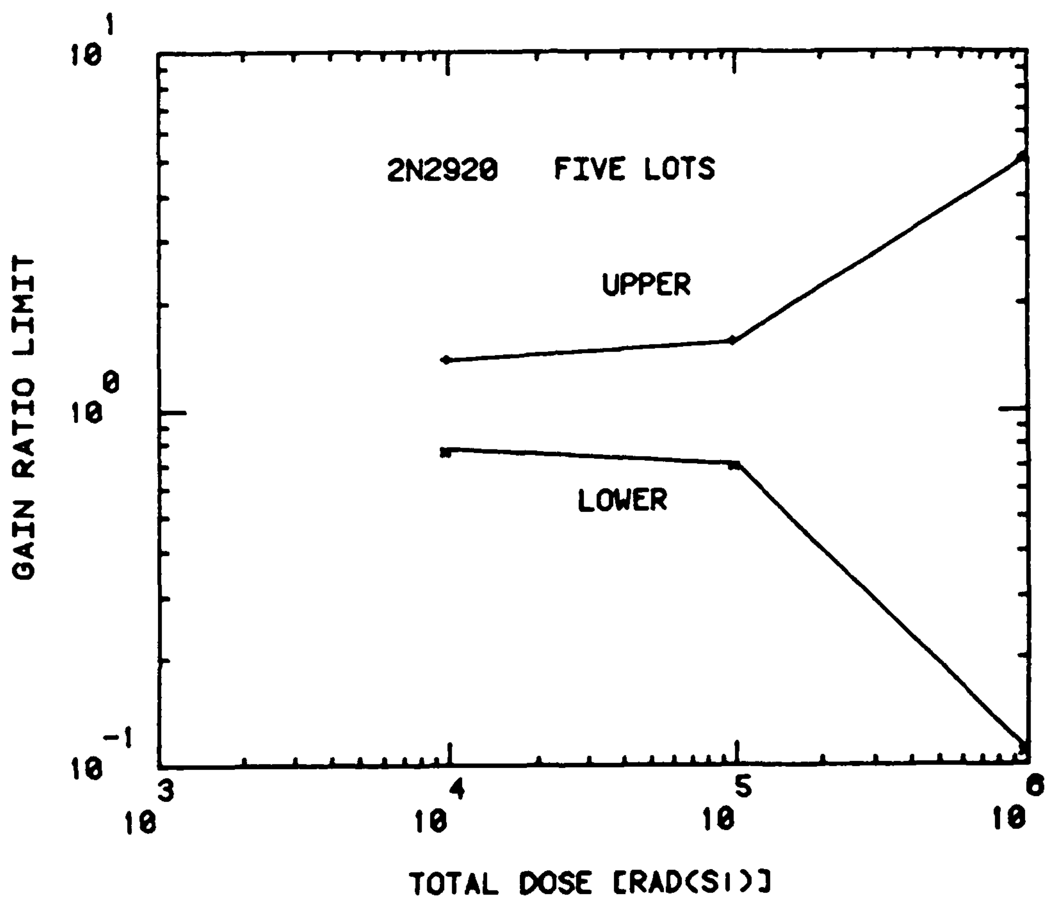


Figure 10 Multi-Lot Limit for Gain Matching Ratio at M, D, and R Levels for Five Lots of 2N2920.

low currents requires that a large derating be used if >90 % future lot acceptance is necessary --- an h_{FE} end-point of less than 3 at 100 krads is required. This low h_{FE} is unacceptable for most applications and we must either substantially lower the acceptance probability or restrict the applicable level to lower values. The same situation applies for the gain matching ratio at 10^6 rad(Si). The 90 percent probability upper and lower limits become impractical. For both of these cases, the end-points must be truncated to a usable value and some degree of vendor/lot selection process will likely occur at R and H levels.

Table 11 is a listing of the sample lots for which radiation characterization data has been analyzed along with their end-point limits.

Table 11. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR 2N2920

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	1 LOT LIMIT TI 0944	2 LOT LIMIT RAY 1115	3 LOT LIMIT TI 0959	4 LOT LIMIT TI 0948	END-POINT LIMIT
2N2920	355	hFE2-1	100 uA	1.10	2.0E12					
		-------			3000					
		hFE2-2			1.0E4	1.17	1.02	1.26	1.07	(CONT.)
					1.0E5	1.34	1.03	1.23	1.04	
					1.0E6	2.20	1.00	1.07	2.21	
		hFE2-1	100 uA	0.90	2.0E12					
		-------			3000					
		hFE2-2			1.0E4	0.93	0.94	0.83	0.91	
					1.0E5	0.79	0.92	0.86	0.86	
					1.0E6	0.59	0.98	0.94	0.21	
		hFE1	10 uA	175	2.0E12					
					3000	177	171			
					1.0E4	130	124			
					1.0E5	50	47			
					1.0E6					
		VCE(SAT)	1mA/100uA	0.3 Vdc	2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
		ICBO	45 Vdc	2.0 nA	2.0E12					
					3000					
					1.0E4					
					1.0E5	0.20			0.21	
					1.0E6	4.00			1.20	
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

Table 11. MULTILOT RADIATION END-POINT LIMIT DATA SUMMARY FOR 2N2920 (cont.)

DEVICE TYPE	SLASH NO.	PARAM.	BIAS	PRE-RAD. END-POINT	STRESS	5 LOT LIMIT MOT 0774	6 LOT LIMIT T.I./NAT 0946/	3 LOT LIMIT T.I. 0802	4 LOT LIMIT MULTI-LOT LIMIT	END-POINT LIMIT
2N2920	355	hFE-1	100 uA	1.10 max	2.0E12					
		-------			3000					
		hFE-2			1.0E4	1.08			1.47	1.40
					1.0E5	1.16			1.61	1.60
					1.0E6	2.20			3.80	2.00
		hFE-1	100 uA	0.90 min	2.0E12					
		-------			3000					
		hFE-2			1.0E4	0.86			0.72	0.70
					1.0E5	0.78			0.63	0.60
					1.0E6	0.78			0.25	0.50
		hFE1	10 uA	175	2.0E12		59			50
					3000	216			78	80
					1.0E4	118			45	50
					1.0E5	8			12	30
					1.0E6					15
		VCE(SAT)	1mA/100uA	0.3 Vdc	2.0E12					0.35
					3000					0.35
					1.0E4					0.35
					1.0E5					0.35
					1.0E6					0.50
		ICBO	45 Vdc	2.0 nA	2.0E12					4
					3000					4
					1.0E4					4
					1.0E5	4.60	0.20	1.80		10
					1.0E6	10.0	1.40	10.0		20
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					
					2.0E12					
					3000					
					1.0E4					
					1.0E5					
					1.0E6					

SECTION 3
DNA ADVISORY COMMITTEE SUPPORT

3.1 GENERAL

A brief summary of the work performed in support of the DNA Advisory Group on Hardness Assured Devices is reported in this section. In addition to supporting the Advisory Group in conjunction with the meetings, specific support was provided in the form of reviews of proposed draft RHA device specifications developed by other parties as well as recommendations concerning RHA specifications in general. Detailed comments were provided on the final draft of TRW's 16K CMOS SRAM RHA Detail Specification, a recommended format for periodic RHA qualification as a means for reducing QCI costs for M- and D-level parts, and a first draft input to the guideline document for preparation of RHA detail device specifications in preparation by Kaman-Tempo. A brief summary of these are included in the following sections.

3.2 REVIEW OF RHA 16K CMOS RAM DETAIL SPECIFICATION

Specific recommendations were submitted on TRW's draft of the RHA detail specification for 16K CMOS RAMs. The major recommendations were:

1) The addition of input threshold voltage tests as a precursor to device failure. Previous studies have shown that there is often a close correlation between degradation in input threshold voltage and total dose functional failure (Ref. 8). This provides a useful screen for "soft" lots which might functionally fail at total dose levels precariously close to the test level. Many device types require some type of input threshold voltage measurement as part of normal Group A tests. This was not the case for the 16K RAMs and a recommendation was made to add these additional tests. This recommendation was incorporated into the latest draft.

2) A recommendation was made to restate the use of the term, "Post-irradiation electrical characteristics". The definition of this term is presently being reviewed.

3) A concern about "imprinting" errors was raised for those devices allowed to power-up in a random state for total dose exposures. However, this concern is not as serious for devices irradiated to a single level such as is the intent for the devices included in /291 (either 100 krads for R or 1 Mrad for H devices).

3.3 PERIODIC RHA QCI PROPOSAL

The present RHA Mil Spec requirements mandate that all RHA devices be qualified and quality conformance inspection be performed for each lot regardless of the technical necessity. This is a particularly acute problem for certain devices with very low RHA requirements; i.e., devices with designed or intrinsic hardness to levels much higher than M- or D-levels (3000 and 1×10^4 rads, 2×10^{12} n/cm^2). The rejection of the concept of using existing radiation data for RHA qualification for this situation requires that standardized radiation characterization testing be performed regardless of their hardness margin. A significant cost savings would be achieved if an alternative method to testing every lot for assuring the hardness of these lots.

A proposal was made for an alternative approach which would minimize these costly repetitive tests with only a small increase in risk in accepting "bad" parts. The basic approach that we propose is to require that RHA Qualification testing be performed for RHA QPL listing as is currently required, but with the additional provision that if the parts satisfy a specific hardness margin above the basic requirements, then RHA QCI testing requirements could be relaxed. The margin would be selected such that it would be highly unlikely that these parts would ever fail QCI testing. Annual "requalification" testing only would be required to monitor major shifts in hardness. This approach, especially for widely used devices, would substantially reduce the cost impact of RHA requirements and result in even further cost savings by increasing the utilization and thus availability of RHA devices. The required hardness margin for this "special" Qual was demonstrated in Ref. 2 using the large store of radiation effects data which currently exists for many mature devices and an analysis approach based on projections of long-term parts hardness variations. This approach avoids many of the original objections to the proposed qualification waiver for these devices.

3.4 INITIAL RECOMMENDATIONS FOR RHA GUIDELINES

3.4.1 General

The format for incorporating Radiation Hardness Assurance (RHA) into Military Device Specifications will be in the form of:

(1) New RHA detail specifications (such as the /291).
(2) RHA amendments to existing Detail Specifications.
(3) RHA supplements to current amendments.
(4) RHA standard military drawings.

Separate end-point parameter limits for neutrons and total dose must be specified, where applicable, in each detail specification. This approach is required because of the complexities involved in post-irradiation total dose effects and because the facilities for neutron and total dose exposure are usually located in widely separated areas. This concern is not an issue for all device types, e.g., MOS devices are relatively unaffected at M, D, R, and H neutron levels (2×10^{12} n/cm^2) because they are majority carrier devices.

3.4.2 Post-Irradiation End-Point Limits

The following is a summary of the key issues which need to be considered in determining the "best" values for post-irradiation end-point limits:

(1) Include key Group A parameters <u>and</u> functional tests.

(2) Use existing or new RHA characterization data to determine parameter sensitivity of representative parts. As a minimum, include key parameters in Electrical Characteristics tables.

(3) Use standard Mil-Spec parameter designations and include M, D, R, and H levels for characterization tests.

(4) Characterize parts to failure.

(5) Use appropriate analysis to determine optimum end-point limits reflecting expected lot-to-lot and vendor-to-vendor variations.

(6) Use standard RHA format for tables.

(7) Use Mil Standard test methods.

3.4.3 Post-Irradiation Electrical Characteristics

The post-irradiation electrical characteristics are information for a potential user of RHA parts. We recommend extensions to the current tables of electrical characteristics (Tables 1.4-1.5 in Semiconductors and Table 1 in Microcircuits) to provide this information. These characteristics are necessary for the part user and are parameter values based on electrical post-irradiation end-point limits and, possibly, on the radiation characterization tests performed to obtain these end-points.. For RHA parts, the main feature of the recommended addition to these tables is the combined neutron and total dose performance limits reflecting Group E/D test limits. The recommended format is to add these combined values as Table 1.4.1 or 1.5.1 for Semiconductors and Table 1A for Microcircuits. Since this information applies <u>only</u> to the part user, these tables would be totally optional for the preparation of the RHA specification.

The method recommended for combining end-points is to use one of the following two methods:

(1) Combine deltas as prescribed in Section 2; apply these results to the pre-irradiation characteristic values.

(2) Use total dose end-point for M, D, R, and H levels; apply delta limit for Subgroup 1 (neutrons) for combined M, D, R, and H characteristics.

3.4.4 Overtesting for RHA Devices

The issue of requiring RHA qualification and/or QCI testing at levels above those specified as the general requirements is presently the subject of much debate. While overtesting is used extensively in systems' nuclear survivability programs, the major participants in the Mil Spec system are philosophically opposed to "custom" testing. A specific proposal has been outlined in Section 3.3 which provides for relaxed RHA testing for QCI where a device type is qualified to overtest levels. This proposal has not been accepted as of the date of this report.

3.4.5 Radiation Databanks

Previous attempts to utilize existing radiation characterization data for RHA device development were nonproductive due to a variety of problems, many of which were due to format and nomenclature problems. Most of the data in these databanks were from tests performed in support of specific programs or applications. As expected, many of the parameters and test levels differed from test to test. Limited success can be achieved using interpolation and extrapolation methods to develop a standard database, but significant errors can be introduced using such methods (Ref. 7).

The following specific recommendations are proposed to maximize the utility of radiation databanks:

1. Establish standard data format based on Mil Spec parameters and nomenclature. Draft RHA specifications provide a standardized format.

2. Establish basic data matrix for each device type in these databanks such that missing data could be easily identified and the required data defined.

3. Develop standardized electronic transfer formats.

4. Apply screen for "reasonableness" of data.

SECTION 4

SUMMARY AND RECOMMENDATIONS

4.1 SUMMARY

Radiation Hardness Assured supplements to four military device detail specifications have been prepared using radiation characterization data on the six device types included in these specifications. The four RHA specifications (M38510/101, S19500/323, S19500/350, and S19500/355) include provisions for six part types; the 741A, LM101A, LM108A, 2N3251A, 2N3868, and the 2N2920. The major revisions in these draft RHA supplements compared to previous drafts are as follows:

(1) Group E/D end-points reduced to only key parameters such as those in regular non-RHA characteristics.

(2) All reference to "QCI waiver" or "overtest" removed from these draft RHA supplements.

(3) Nominal derating of pre-irradiation end-points beyond multi-lot estimates for degraded parameters.

(4) Post-irradiation characteristics only for combined neutron and total dose. Footnote added to eliminate vendor liability.

4.2 RECOMMENDATIONS

The primary recommendations that arise from this effort are the obvious need for better radiation characterization testing standards and a definitive guideline for the preparation of RHA device specifications. The major emphasis in current test standards is directed towards the post-total dose recovery problem in MOS (and MOS-like) devices. The devices included in this study are bipolar devices which do not show significant post-irradiation recovery problems. The biggest problem for this study was the lack of standard test conditions, nomenclature, and data storage. These problems largely eliminated the use of highly structured computer data analysis programs for analyzing these data and forced a large amount of "custom" analyses. The availability of a standard guideline for characterizing RHA devices and for storing and analyzing these data would avoid many of these problems. The use of preliminary draft RHA detail specifications would provide specific data requirements for characterization testing and would greatly simplify the preparation of final RHA detail specifications.

SECTION 5

REFERENCES

1. I. Arimura, R. A. Kennerud, and O. R. Mulkey, "Hardness Assured Device Specifications", Defense Nuclear Agency Report No. DNA-TR-81-90, 15 July, 1982.

2. I. Arimura, L. Kolb, and O. R. Mulkey, "Hardness Assured Device Specifications for Moderate Radiation Requirements", Defense Nuclear Agency Report No. TR-84-220-V1, 15 November 1985

3. I. Arimura and R. Audette, "Radiation Hardness Assured Device Specifications", Final Report on NRL contract no. N00014-85-C-2077, 15 November 1987

4. MIL HDBK 280, "Neutron Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits", 10 February 1985.

5. MIL HDBK 279, "Total-Dose Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits", 25 January 1985.

6. I. Arimura and A. I. Namenson, "Hardness Assurance Statistical Methodology for Semiconductor Devices", IEEE Trans. Nucl. Sci., NS-30, No. 6, 4322 (1983).

7. A. I. Namenson, "Hardness Assurance and Overtesting", IEEE Tran. Nucl. Sci., NS-29, No. 6, 1821 (1982).

8. I. Arimura, R. A. Kennerud, and L. Kolb, "Hardness Assured Device Specification for 4K X 1 CMOS/SOS Static RAM", Defense Nuclear Agency Report No. TR-84-220-V2, 11 February 1985

APPENDIX A

SPECIFICATIONS FOR RADIATION-HARDNESS-ASSURED DEVICES---DRAFT

This appendix contains draft radiation-hardness-assured (RHA) supplements to the four military device detail specifications listed below:

(1) M38510/101F (types 01, 03, and 04)

(2) S19500/323B (type 2N3251A)

(3) S19500/350A (type 2N3868)

(4) S19500/355C (type 2N2920)

DRAFT NO.__________ DATED________

DO NOT USE FOR ACQUISITION PURPOSES

MIL-M-38510/101F
SUPPLEMENT TO
AMENDMENT 9
13 DEC 1985

MILITARY SPECIFICATION

MICROCIRCUITS, LINEAR, OPERATIONAL AMPLIFIERS
MONOLITHIC SILICON

PAGE 1

1.1 Scope. ...Add the following sentence:

"Provision for radiation hardness assurance (RHA) to four radiation levels is included for device types 01, 03, and 04."

Add the following new paragraph:

"1.2.4 Radiation hardness level. Radiation hardness levels shall be as defined in MIL-M-38510."

PAGE 3

Add the following new paragraph:

"3.4.3 Post-irradiation performance characteristics. The electrical performance characteristics for which significant changes occur following exposure to the designated radiation levels are as specified in table IA and apply at an ambient temperature of 25°C. These post-irradiation parameter values are calculated for the combined neutron and total dose defined in MIL-M-38510 for these part designations."

PAGE 7

Add to Table II, the following:

"Group E end point electrical parameters (method 5005)"	See table V	See table V

4.2: Delete "and D inspections (see 4.4.1 through 4.4.4)." and add the following, "and E inspections (see 4.4.1 through 4.4.5)."

TABLE IA. Post-irradiation electrical characteristics for RHA devices at $T_A = 25^{\circ}C$.

Characterisitics	Symbol	Conditions	RHA Lev	Limits -01 Min	-01 Max	-03 Min	-03 Max	-04 Min	-04 Max	Units
Input offset voltage	V_{IO}	$R_S = 50$	M	-10	+10	- 8.0	+ 8.0	- 9.0	+ 9.0	
			D	-25	+25	- 8.0	+ 8.0	-10	+10	
		1/	R	-30	+30	- 8.0	+ 8.0	-12	+12	mVdc
			H	-105	+105	-12.0	+12.0	-15	+15	
			M	-100	+100	-50	+50	- 4.0	+ 4.0	
Input offset current	I_{IO}	1/	D	-100	+100	-50	+50	- 5.0	+ 5.0	nAdc
			R	-100	+100	-110	+110	- 6.0	+ 6.0	
			H	-150	+150	-210	+210	- 8.0	+ 8.0	
			M	+1.0	+400	- 1.0	+200	-0.1	+70	
Input bias current	$I_{IB}(+)$	1/	D	+1.0	+500	- 1.0	+200	-0.1	+135	nAdc
			R	+1.0	+700	- 1.0	+450	-0.1	+135	
			H	+1.0	+1.2u	- 1.0	+900	-0.1	+135	
			M	+1.0	+400	- 1.0	+200	-0.1	+70	
Input bias current	$I_{IB}(-)$	1/	D	+1.0	+500	- 1.0	+200	-0.1	+135	nAdc
			R	+1.0	+700	- 1.0	+450	-0.1	+135	
			H	+1.0	+1.2u	- 1.0	+900	-0.1	+135	
Open loop voltage gain (single ended)	$A_{VS(+)}$		M							
			D			40				
			R			5				
			H							
Output short circuit current (positive out)	$I_{OS(+)}$		M							
			D							
			R							
			H							
			M							
			D							
			R							
			H							
			M							
			D							
			R							
			H							

1/ V_{IO} (ADJ) is not performed on device type 02, case 1 only, or on device type 08 for either case.

PAGE 8

Add the following new paragraph:

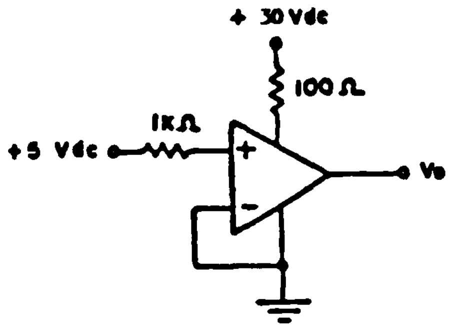
"4.4.5 <u>Group E inspection.</u> Group E inspection shall be in accordance with table V of method 5005 of MIL-STD-883 and as follows:

a. End-point electrical parameters shall be as specified in table V.

b. Radiation hardness assurance exposure method 1019 of MIL-STD-883 conditions:

(1) Total dose exposure circuit shown in Figure 8."

Device types 01, 04



Device type 03

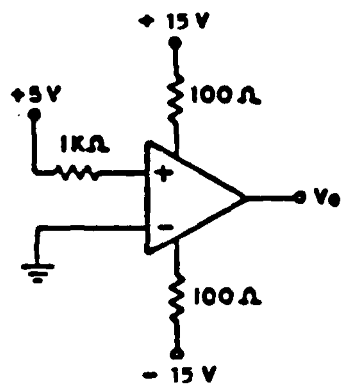


FIGURE 8 Total Dose Exposure Circuit.

TABLE V. GROUP-E END-POINT ELECTRICAL PARAMETER LIMITS
FOR RHA DEVICES. T = 25°C (all classes).

SUBGROUP RHA LEV.	MIL STD 883	TABLE III TEST NO.	TEST SYMBOL	-01 MIN	-01 MAX	-03 MIN	-03 MAX	-04 MIN	-04 MAX	UNITS
1 NEUTRON	1017									
M,D,R,H		3	V_{IO}	-5.0	+5.0	-5.0	+5.0	-3.0	+3.0	mV
		7	I_{IO}	-50	+50	-20	+20	-10	+10	nA
		11	$+I_{IB}$	+1.0	+500	+1.0	+120	-.1	+10	nA
		15	$-I_{IB}$	+1.0	+500	+1.0	+120	-.1	+10	nA
		22	$I_{OS}(+)$	-55		-55		-12		mA
		81	$A_{VS}(+)$	45		45		10		V/mV
2 TOTAL DOSE	1019									
		3	V_{IO}							mV
M				-5.0	+5.0	-10	+10	-4.0	+4.0	
D				-5.0	+5.0	-10	+10	-5.0	+5.0	
R				-20	+20	-15	+15	-6.0	+6.0	
H				-100	+100	-25	+25	-10	+10	
		7	I_{IO}							nAdc
M				-50	+50	-20	+20	-2.0	+2.0	
D				-50	+50	-20	+20	-2.0	+2.0	
R				-50	+50	-175	+175	-4.0	+4.0	
H				-100	+100	-380	+380	-5.0	+5.0	
		11	$+I_{IB}$							nAdc
M				+1.0	+200	+1	+100	-.1	+60	
D				+1.0	+300	+1	+100	-.1	+125	
R				+1.0	+500	+1	+320	-.1	+125	
H				+1.0	+1000	+1	+750	-.1	+125	

TABLE V. GROUP-E END-POINT ELECTRICAL PARAMETER LIMITS
FOR RHA DEVICES. T = 25°C (all classes) (cont.)

SUBGROUP RHA LEV.	MIL STD 883	TABLE III TEST NO.	TEST SYMBOL	-01 MIN	-01 MAX	-03 MIN	-03 MAX	-04 MIN	-04 MAX	UNITS
2 TOTAL DOSE	1019									
		15	$-I_{IB}$							nA
M				+1.0	+200	+1	+100	-.1	+60	
D				+1.0	+300	+1	+100	-.1	+125	
R				+1.0	+500	+1	+320	-.1	+125	
H				+1.0	+1000	+1	+750	-.1	+125	
		22	$I_{OS}(+)$							mA
M				-55		-55		-12		
D				-55		-55		-12		
R				-55		-55		-12		
H				-55		-55		-12		
		81	$A_{VS}(+)$							V/mV
M				45		45		20		
D				45		45		10		
R				45		45		5		
H				45		5		--		

See footnotes at end of Table I.

MILITARY SPECIFICATION

SEMICONDUCTOR DEVICE, TRANSISTOR, PNP, SILICON, SWITCHING
TYPES 2N3250A, 2N3251A
JAN, JANTX, AND JANTXV

Page 1

1.1 Scope....Add the following: "Provision for radiation hardness assurance (RHA) to four radiation levels is provided for JAN, JANTX, and JANTXV product assurance levels of type 2N3251A".

Add the following new paragraph:

"1.5 Post-irradiation characteristics for RHA devices at 25°C.*

RHA LEVEL	LIMITS	HFE1 Vce=-1.0Vdc Ic=-.1mAdc	HFE3 Vce=-1.0Vdc Ic=-10mAdc	HFE4 Vce=-1.0Vdc Ic=-50mAdc	Vce(SAT) Ib=-1.0mAdc Ic=-10mAdc
M	MIN	25	60	20	
	MAX				0.30
D	MIN	25	60	20	
	MAX				0.30
R	MIN	25	60	20	
	MAX				0.30
H	MIN	20	60	20	
	MAX				0.30

* Post-irradiation characteristics are provided for parts selection purposes and are not intended to represent "worst case" application limits.

Page 4

Add the following new paragraphs:

"3.4.1 Radiation hardness level. Radiation hardness levels shall be as defined in MIL-S-19500."

"4.2.1 Qualification for radiation hardness assurance. Qualification inspection for RHA JAN, JANTX, and JANTXV devices shall consist of the group D examinations and tests specified in Table V, and in section 4.5.3."

Page 5

Add the following new paragraph:

"4.3.5 Group D inspection. Quality conformance inspection for RHA JAN, JANTX, and JANTXV devices shall consist of group D examinations and tests specified in Table V and 4.5.3."

Add the following new paragraph:

"4.5.4 Radiation hardness assurance exposure tests. Conditions for RHA testing shall be according to MIL-STD-750. For total dose irradiation exposure, Method 1019, the device shall be irradiated with the base and emitter tied together and V_{CB} = -45 Vdc applied."

TABLE V. Group D inspection for RHA devices (all classes)

EXAMINATION OR TEST	MIL-STD-750 METHOD	MIL-STD-750 CONDITIONS	QUANTITY/REJECT NUMBER 1/ JANS	QUANTITY/REJECT NUMBER 1/ JAN TX TXV	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
Subgroup I								
Neutron Irradiation	1017	25°C	1/	1/				
Forward current transfer ratio	3076	V_{CE}=1.0Vdc I_C=0.1mAdc			h_{FE1}			
M,D,R,H2N3251A						70		
Collector-base cutoff current	3036	Bias cond.D V_{CB}=40 Vdc			I_{CBO}			
M,D,R,H2N3251A							40	nA dc
Forward current transfer ratio	3076	V_{CE}=1.0Vdc I_C= 10mAdc			h_{FE3}			
M,D,R,H2N3251A						60	300	
Forward Current transfer ratio	3076	V_{CE}=1.0Vdc I_C=50mAdc Pulsed			h_{FE4}			
M,D,R,H2N3251A						27		
Collector to Emitter voltage (Saturated)	3071	I_C=10mAdc I_B=1.0mAdc Pulsed			$V_{CE(SAT)}$			
M,D,R,H2N3251A							.30	Vdc

TABLE V. Group D inspection for RHA devices (all classes) (Continued)

EXAMINATION OR TEST	MIL-STD-750 METHOD	MIL-STD-750 CONDITIONS	QUANTITY/REJECT NUMBER 1/ JANS	QUANTITY/REJECT NUMBER 1/ JAN TX TXV	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
Subgroup II			1/	1/				
Total Dose Irradiation	1019	$25^{o}C$						
Collector-base cutoff current	3036	Bias cond.D V_{CB}=40 Vdc			I_{CBO}			
M,D2N3251A							40	nA dc
R2N3251A							50	nA dc
H2N3251A							100	nA dc
Forward current transfer ratio	3076	V_{CE}=1.0Vdc I_C=0.1mAdc			h_{FE1}			
M, D, R2N3251A						70		
H2N3251A						40		
Forward current transfer ratio	3076	V_{CE}=1.0Vdc I_C= 10mAdc			h_{FE3}			
M, D2N3251A						90	300	
R, H2N3251A						90	300	
Forward Current transfer ratio	3076	V_{CE}=1.0Vdc I_C=50mAdc Pulsed			h_{FE4}			
M,D,R,H2N3251A						27		
Collector to Emitter voltage (Saturated)	3071	I_C=10mAdc I_B=1.0mAdc Pulsed			$V_{CE(SAT)}$			
M,D,R,H2N3251A							.30	Vdc

1/ Quantity/reject numbers used are taken from MIL-S-19500

DRAFT NO. ________ DATE ________

DO NOT USE FOR ACQUISITION PURPOSES

MIL-S-19500/350A
SUPPLEMENT TO
AMENDMENT 4
10 JULY 1985

MILITARY SPECIFICATION

SEMICONDUCTOR DEVICE, TRANSISTOR, PNP, SILICON, SWITCHING
TYPES 2N3867, 2N3867S, 2N3868, AND 2N3868S
JAN, JANTX, AND JANTXV

Page 1

1.1 Scope. ...Add the following: "Provision for radiation hardness assurance (RHA) to four radiation levels is provided for JAN, JANTX, and JANTXV product assurance levels of types 2N3868 and 2N3868S".

Add the following new paragraph:

"1.5 Post-irradiation characteristics for RHA devices at $T_A = 25^\circ C$.*

JAN, JANTX, and JANTXV 2N3868 and 2N3868S

RHA LEVEL	LIMITS	HFE2 Vce=2.0Vdc Ic=1.5 Adc	HFE4 Vce=5.0Vdc Ic= 3.0Adc	Vce(SAT)2 IB=1.5 Adc Ic=150mAdc
M	MIN	18	15	1.0 Vdc
	MAX			
D	MIN	18	15	1.0
	MAX			
R	MIN	16	10	1.0
	MAX			
H	MIN	10	5	1.2
	MAX			

* Post-irradiation characteristics are provided for parts selection purposes and are not intended to represent "worst case" application limits."

Page 2

Add the following new paragraph:

"3.4.2 Radiation hardness assurance (RHA). Radiation hardness levels shall be as defined in MIL-S-19500."

Page 5

Add the following new paragraph:

"4.2.2 Qualification for radiation hardness aswsurance. Qualification inspection for RHA JAN, JANTX, and JANTXV devices shall consist of the Group D examination and tests specified in Table V and 4.5.10."

Page 5

Add the following new paragraph:

"4.3.5 Group D inspection. Quality conformance inspection for hardness assured types shall include the group D tests specified in Table V and 4.5.10."

Page 14

Add the following new paragraph:

"4.5.10 Radiation hardness assurance exposure tests. Conditions for RHA testing shall be according to MIL-STD-750. For total dose irradiation exposure, Method 1019, the device shall be irradiated with the base and emitter tied together and V_{CB} = -45 Vdc applied."

TABLE V. Group D inspection for RHA 2N3868 and 2N3868S (all classes)

EXAMINATION OR TEST	MIL-STD-750 METHOD	MIL-STD-750 CONDITIONS	QUANTITY/ REJECT NUMBER 1/ JAN TX TXV	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
Subgroup I							
Neutron Irradiation	1017	25°C	1/				
Collector-emitter cutoff current	3041	Bias cond A V_{EB}=-2.0 V V_{CE}=-60 V		I_{CEX}			
M, D, R, and H						-1.2	uA
Forward current transfer ratio	3076	V_{CE}=2.0Vdc I_C=1.5 Adc Pulsed (See 4.4.1)		h_{FE2}			
M, D, R, and H					20		
Forward Current transfer ratio	3076	V_{CE}=5.0Vdc I_C=3.0 Adc Pulsed (See 4.4.1)		h_{FE4}			
M, D, R, and H					16		
Collector to Emitter voltage (Saturated)	3071	I_C=1.5 Adc I_B=150mAdc Pulsed (See 4.4.1)		$V_{CE(SAT)1}$			
M, D, R, and H						-0.90	Vdc

1/ Quantity/reject numbers used are taken from MIL-S-19500

TABLE V. Group D inspection for RHA 2N3868 and 2N3868S (all classes) (Cont.)

EXAMINATION OR TEST	MIL-STD-750 METHOD	MIL-STD-750 CONDITIONS	QUANTITY/ REJECT NUMBER 1/ JAN, TX, TXV	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
Subgroup II			1/				
Total Dose Irradiation	1019	25° C					
Collector-emitter cutoff current	3041	Bias cond A V_{EB}=-2.0 V V_{CE}=-60 V		I_{CEX}			
M, D, and R						-1.2	uA
H						-2.0	
Forward current transfer ratio	3076	V_{CE}=2.0Vdc I_C=1.5 Adc Pulsed (See 4.4.1)		h_{FE2}			
M, D					27		
R					22		
H					10		
Forward Current transfer ratio	3076	V_{CE}=5.0Vdc I_C=3.0 Adc Pulsed (See 4.4.1)		h_{FE4}			
M, D					18		
R					12		
H					5		
Collector to Emitter voltage (Saturated)	3071	I_C=1.5 Adc I_B=150mAdc Pulsed (See 4.4.1)		$V_{CE(SAT)2}$			
M, D						0.90	Vdc
R							
H							

DRAFT NO. ________ DATE ________

DO NOT USE FOR ACQUISITION PURPOSES

MIL-S-19500/355C
SUPPLEMENT TO
AMENDMENT 1
9 NOV 1984

MILITARY SPECIFICATION

SEMICONDUCTOR DEVICE, UNITIZED DUAL-TRANSISTOR, NPN, SILICON TYPES 2N2919, 2N2919L, 2N2920, 2N2920L JAN, JANTX, JANTXV, AND JANS

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1.1 Scope. ...Add the following: "Provision for radiation hardness assurance (RHA) to four radiation levels is provided for JAN, JANTX, JANTXV and JANS product assurance levels of type 2N2920".

Add the following new paragraph:

"1.6 Post-irradiation characteristics for RHA devices at 25°C.*

JAN, JANTX, JANTXV AND JANS 2N2920

RHA LEVEL	LIMITS	HFE1 Vce= 5 Vdc Ic= 10uAdc	h_{FE-1} / h_{FE-2} Vce= 5Vdc Ic=100 uA	Vce(SAT) IB=100uAdc Ic=1.0mAdc Vdc	Icbo Vcb=45Vdc nAdc
M	MIN	30	0.8		
	MAX		1.2	0.5	6.0
D	MIN	20	0.7		
	MAX		1.4	0.5	6.0
R	MIN	12	0.6		
	MAX		1.6	0.5	15
H	MIN	12	0.5		
	MAX		2.0	0.5	25

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* Post-irradiation characteristics are provided for parts selection purposes and are not intended to represent "worst case" application limits."

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Add the following new paragraphs:

"3.4.1 Radiation hardness level. Radiation hardness levels shall be as defined in MIL-S-19500."

Add the following paragraphs:

"4.2.1 Qualification for radiation hardness assurance. Qualification inspection for RHA JAN, JANTX, JANTXV, and JANS devices shall consist of the group D examinations and tests specified in Table V, and in section 4.5.4."

"4.4.4 Group D inspection. Quality conformance inspection for RHA JAN, JANTX, JANTXV, and JANS devices shall consist of group D examinations and tests specified in Table V and 4.5.4."

"4.5.4 Radiation hardness assurance exposure tests. Conditions for RHA testing shall be according to MIL-STD-750. For total dose irradiation exposure, Method 1019, each device shall be irradiated with their base and emitters tied together and V_{CB} = 45 Vdc applied to each device."

TABLE V. Group D inspection for 2N2920 (all classes)

EXAMINATION OR TEST	MIL-STD-750 METHOD	MIL-STD-750 CONDITIONS	QUANTITY/ REJECT NUMBER 1/ JANS	QUANTITY/ REJECT NUMBER 1/ JAN TX TXV	SYMBOL	LIMITS MIN	LIMITS MAX	UNITS
Subgroup I								
Neutron Irradiation	1017	25°C						
Collector to base cutoff current	3036	Bias cond.D VCB= 45Vdc			I_{CBO1}			
M,D,R,H							4.0	nA
Forward current transfer ratio	3076	VCE= 5Vdc IC= 10uAdc			h_{FE1}			
M,D,R,H						50	600	
Collector to Emitter voltage (Saturated)	3071	IC=1.0mAdc IB=100uAdc Pulsed			$V_{CE(SAT)}$			
M,D,R,H							0.4	Vdc
Forward-current transfer ratio	3076	V_{CE}=5 Vdc I_C=100 uAdc (see 4.5.4)			h_{FE-1} / h_{FE-2}			
M,D,R,H						0.8	1.2	

* See footnotes at end of table.

TABLE V. Group D inspection for 2N2920 (all classes) (Continued)

	MIL-STD-750		QUANTITY/ REJECT NUMBER 1/			LIMITS		
EXAMINATION OR TEST	METHOD	CONDITIONS	JANS	JAN TX TXV	SYMBOL	MIN	MAX	UNITS
Subgroup II								
Total Dose Irradiation	1017	$25^{\circ}C$						
Collector to base cutoff current	3036	Bias cond.D VCB= 45Vdc			I_{CBO1}			
M, D							4.0	nA
R							10	
H							20	
Forward current transfer ratio	3076	VCE= 5Vdc IC= 10uAdc			h_{FE1}			
M						50		
D						30		
R						15		
H						15		
Forward-current transfer ratio	3076	V_{CE}=5 Vdc I_C=100 uAdc (see 4.5.4)			$\frac{h_{FE-1}}{h_{FE-2}}$			
M						0.8	1.2	
D						0.7	1.4	
R						0.6	1.6	
H						0.5	2.0	
Collector to Emitter voltage (Saturated)	3071	IC=1.0mAdc IB=100uAdc Pulsed			$V_{CE(SAT)}$			
M,D,R,H							0.4	Vdc

1/ Quantity/reject numbers used are taken from MIL-S-19500