Compendium of Single Event Failures in Power MOSFETs[1]

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Abstract

This compendium of SEGR and SEB data organizes results from several laboratories comparing failure thresholds for several different manufacturers and technologies. The results of this compendium are aimed at the designer to show the possible variations between manufacturers and processes. The compendium incorporates previously published data with the most recent data obtained from various sources.

I. Introduction

Over the past several years, an enormous amount of work has been done to quantify and understand the effects of single ion strikes on power MOSFETs [1,2,3,4]. Most of the data in this compendium summarizing single event gate rupture (SEGR) and burnout (SEB) have been contributed by the following laboratories designated by the abbreviations in parentheses: Jet Propulsion Laboratory (JPL); the Boeing Company (BREL); Naval Surface Warfare Center (NSWC); Rockwell International, now part of Boeing, (Rock); the Aerospace Corporation (Aero); and Honeywell Space Systems Group (HON). Additional data have been contributed by the French Space Agency (CNES), Harris and International Rectifier Corporations (HAR and INR), European Space Agency (ESA), Johns-Hopkins (JH) and the University of Arizona (UA). Other contributors who would like to have their data included in future compendia should contact Jim Coss at JPL.

This compendium presents both tabular and graphical data sets showing the failure and/or passing drain-source voltages (V_{ds}) for either single event gate rupture (SEGR) or single event burnout (SEB) of power MOSFET devices only. As evident from the data, n-channel devices are generally more susceptible to either phenomena than p-channel devices. A major difference is the effect of temperature. Higher temperatures tend to exacerbate SEGR, but improves SEB susceptibility. Other recent work has also shown that power MOSFETs can be damaged by proton or neutron strikes [5]. This data is included in the tables, but without graphical presentation.

There has also been some testing done to determine the prevalence of SEB in bipolar power transistors. Obviously, because bipolar devices do not have a gate, SEGR cannot occur. Although SEB has been seen in a few npn-bipolar power transistors, there have been no reported instances in pnp-bipolar transistors. Because there is such limited data for bipolar power transistors, these data are not presented here.

The main purpose of this work is to give designers an appreciation for the great variation in V_{ds} failure voltage for different manufacturers, and in many cases for different processes from the same manufacturer. Some semiconductor manufacturers, mainly International Rectifier and Harris, have made numerous process changes to enhance device resistance to total dose and/or single event effects. The data presented here has been gathered by various test groups over a ten-year span, which accounts for some of the high

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variability in failure thresholds.

II. General Testing Techniques

Testing techniques for SEGR and SEB have changed little over the years. Although the Japanese have a non-destructive method for characterizing the critical charge required for burnout [6,7], which might also be extended to SEGR, it has not been widely accepted by U.S. experimenters.

In general there are only two test methods in wide use, both of which are destructive, which makes doing thorough evaluations difficult and costly. The first technique establishes a V_{ds} failure threshold by irradiating a device with several different ions, with different LETs (with fixed temperature and V_{gs} operating conditions) to create a "classic" cross section vs. LET curve. This requires a large number samples because of the destructive nature of the test, i.e., each data point destroys a test sample.

The second technique establishes the V_{ds} failure threshold under fixed V_{gs} and temperature conditions using a given ion group, typically either Fe/Ni/Co, or Kr/Br, dependent on worst-case requirements. In this technique, V_{gs} and temperature are held constant and V_{ds} incrementally increased until failure, or rated BV_{ds}, is reached. Vgs is then raised and experiment repeated until either rated V_{ds} or V_{gs} is reached. Knowing the voltage failure threshold allows the designer to apply reasonable derating guidelines. In addition to destruction of samples, this technique also requires a large sample size because the total dose accumulation from repeated irradiations may skew the failure thresholds.

III. Organization and Scope of Data

Some early data has been expunged from the compendium because the data was incomplete (no ion species or test facility defined, etc.). Previous testing has provided a great deal of data in the LET range of 27 to 38, with lesser amounts of data at higher and lower LETs. Additional data using V_{gs} and V_{ds} values in excess of rated values are also included in the tables, but not in the graphs. Although this type of data has been used to theoretically predict failure thresholds [8], it was felt that limiting the graphical data to manufacturer's specifications was of more interest to the design community. A second reason for not including this data in the graphs is the paucity of available data.

The tables have also been rearranged from previous versions and the latest data additions highlighted in bold print for emphasis. The n- and p-channel data have been separated into different tables (Tables 1 and 2) for ease of analysis, and failure thresholds from the same test have been made separate line items. Previously, the devices were arranged by BV_{ds} under a given manufacturer, regardless of channel type or test V_{gs}. The n- and p-channel are now arranged in sections of increasing BV_{ds}, then alphabetically by manufacturer and increasing V_{gs}. The V_{gs} separation is because of the importance of V_{gs} in determining V_{ds} failure thresholds.

Because the BV_{ds} range is so wide (60 – 1000V) a plot of absolute failure thresholds would require presentation on a semi-logarithmic scale. This tends to crowd the data points, making data interpretation difficult. To alleviate this problem, the absolute failure threshold is normalized to the rated BV_{ds}. Figures 1 -5 show the normalized failure voltage as a function of applied V_{gs} at 0, 5, 10, 15 and 20 V, which show the V_{gs} dependence more clearly. Because the p-channel data devices was so sparse, there are only graphs for Vgs = 0 and 15 V (Figures 6 and 7).

The bulk of the data has been collected over the LET ranges of 27 to 38 because this is considered to be a credible worst case for cosmic rays. Studies have shown that, as opposed to single event latchup, the cosine law does not hold for SEGR, i.e., normal incidence is worst case.

However, even with normal incidence irradiation some concerns have been raised that ion ranges specified for testing (usually 35-40 μm) by various programs, such as Space Station, may be insufficient for accurate determination of failure thresholds in higher voltage rating devices (400-1000 V). Although these device classes have typically shown failure with these shorter range ions at approximately 50 to 80% of rated V_{ds}, questions have been raised as to whether the failure thresholds may be even lower with longer range ions. This is due to the device and oxide thicknesses required to hold off the higher voltages.

IV. Conclusions

This compendium presents the most up to date information on SEGR/SEB testing of power MOSFETs that we are aware of, and provides designers with a useful database for selection of spacecraft and satellite parts. Although extrapolations from data using lower LET ions may be useful, care must be taken because of the extreme non-linearity of failure as a function of LET, applied V_{gs} and V_{ds}, and temperature.

V. Acknowledgements

The authors wish to acknowledge the original and pioneering efforts of the late Don Nichols who published the first version of this compendium in 1994, and pioneered SEGR testing at JPL. Much of the data in this compendium was by Don, and his leadership in this, and other SEE testing, will be sorely missed.

Other acknowledgements are due to Michael O'Connor of the Radiation Effects Test Group and A.S. "Sid" Johnson of the Failure Analysis Group for test support, Harris and International Rectifier Corporations for sharing their data, and the staffs of Brookhaven National Laboratories and Texas A&M radiation facilities.

VI. References

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(8) J.L. Titus and C.F. Wheatley, "Experimental Studies of Single-Event Gate Rupture and Burnout in Vertical Power MOSFETs"; IEEE Trans. Nuc. Sci., Vol. 43, No. 2, pg. 533 (Apr 1996).

TABLE 1 - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams																
BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
Rated Vds < 100 V																
60	INR	IRHM7054		n		0		60(Ni)				none	Rock	7/93	BNL	D/C 9242. R. Ferdon. WP-04
60	INR	IRFM054		n		5		60				none	BREL	4/93	UCB	D/C 9212. W. Will. WP-01
60	INR	IRHM7054		n		5		60(Ni)				none	Rock	7/93	BNL	D/C 9242. R. Ferdon. WP-04
60	INR	IRHM7054		n	4	12			55(Br)	<35(I)		SEGR	NWSC	4/95	BNL	Titus, Rept #SEGR-003 (T = 25° C only)
60	INR	IRHM7054		n		20			46(Br)			SEGR	NWSC	4/95	BNL	Titus, Rept #SEGR-003 (T = 25° C only)
60	SIL		2N6660	n		5		40(Ni)				SEB	Rock/ Aero	7/93	BNL	Revised fab last 2 yrs. DC9230. Rob Ferdon
60	SIL		2N6660	n	1	10	60(N) 50(Ne) 40(Ar)	22(Cu)				SEB	Rock/ Aero	1990	UCB	
80	SIL	VN88AF		n	1	0					60/70(Ne)	SEB	JPL	11/95	TAM	Nichols LET(Xe) = 44.
80	SIL	VN88AF		n	1	10					60/65(Ne)	SEB	JPL	11/95	TAM	Nichols LET(Xe) = 44.
Rated Vds = 100 V																
100	GEC	IRF150	2N6764	n	2	10	>95(Ne) 70(Ar)	70(Cu)				SEB	Rock/ Aero	1990	UCB	
100	HAR	FRK150		n	3	0		80/100(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
100	HAR	FRK150		n	2	0		100(Ni)				none	Rock	12/92	BNL	T = 90° C
100	HAR	FRK150R	2N7291	n	5	0		80/100(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C.
100	HAR	FRK160		n	2	0			70/80(Br)			SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRK160D	2N7299	n	2	0			70/80(Br)			SEGR	JPL	91/92	BNL	
100	HAR	FRL130D1		n	1	0				50/52.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	HAR	FRM140		n	1	0		80/90(Fe)				SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRM140		n	2	0			70/80(Br)			SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRM140		n	2	0			60/80(Br)			SEGR	JPL	12/91	BNL	T = 100° C
100	HAR	FRM140D1	2N7283	n	2	0			70/80(Br)			SEGR	JPL	91/92	BNL	Data @ T = 100° C exists for Vgs = 0 & 15 V.
100	HAR	IRF150	2N6764	n	2	0					40/50(Xe)	SEB	JPL	11/95	TAM	Nichols. LET(Xe) = 44.
100	HAR	130 family	2N6756	n		5		41(Ni?)					HAR	1993	BNL?	SSF Table
100	HAR	FRK150		n	4	5		80/100(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
100	HAR	FRK150	2N7291	n		5		97(Ni?)					HAR	1993	BNL?	SSF Table
100	HAR	FRK150R	2N7291	n	4	5		80/100(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C.
100	HAR	FRK160	2N7299	n		5		100(Ni?)				none	HAR	1993	BNL?	SSF Table
100	HAR	FRL130D1		n	1	5				37.5/40(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	HAR	FRM130	2N7271	n		5		100(Ni?)				none	HAR	1993	BNL?	SSF Table
100	HAR	FRM140	2N7283	n		5		98(Ni?)					HAR	1993	BNL?	SSF Table
100	HAR	IRF130	2N6796	n		5		40(Co)				SEB	BREL	4/93	UCB	WP-01. D/C M9226. Same results @ 45 & 100° C.
100	HAR	FRL130D1		n	1	10				25/27.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	HAR		2N6764	n	1	10					45/50(Xe)	SEGR	JPL	11/95	TAM	Nichols. Note change in failure mode vs Vgs.
100	HAR	FRL130D1		n	1	15				17.5/20(I)		SEGR	JPL	6/97	BNL	Selva/Swift

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) | V|	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
100	HAR	FRM140D1	2N7283	n	3*	15			20/40(Kr)			SEGR	JPL	91/92	UCB	*Harris says these are their latest technology.
100	HAR	FRL130D1		n	1	20				12.5/15(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	HAR	FSL130		n	11	20		100(Ni)				none	NSWC	7/93	BNL	T = 25°C
100	HAR	IRF140		n	5	25			50?(Br)			SEGR	UA	1994	IPN	Mouret, 94IEEE TNS. RT and angle data exist.
100	HAR	FSL110		n	2	35		100(Ni)				none	NSWC	2/95	BNL	T = 25°C
100	HAR	FSL110		n	2	40		100(Ni)				none	NSWC	2/95	BNL	T = 25°C
100	HAR	FSF150R		n		<20			100(Br)	100(I)		SEGR	NWSC	1995	BNL	Titus, 95IEEE TNS. FSF = "SEE Hard"
100	HAR		2N6782	n	13	0&5		40/45(Ni)				SEB	HON	11/93	BNL	D/G 9352. Same response @ RT and 90° C. Lintz.
100	INR	2N7261SH	130	n	5	0		100				none	BREL	7/97	88"	
100	INR	IRF110	2N7682	n		0		70/80(Ni)	50/70(Br)			SEGR	ESA	1/94	BNL	D/C 9039B. Harwell Rept. AEA-RS-1348
100	INR	IRF120	2N6788	n		0		100(Ni)	80/90(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
100	INR	IRF130	2N6796	n		0		70/80(Ni)	60/70(Br)			SEB	ESA	1/94	BNL	D/C 8915A. Harwell Rept. AEA-RS-1348
100	INR	IRF130	2N6796	n		0		85(Cu?)				SEB	Aero	6/87	UCB	Koga
100	INR	IRF140		n		0		100(Ni)	70/80(Br)			SEB	ESA	1/94	BNL	D/C 9203E. Harwell Rept. AEA-RS-1348
100	INR	IRF150	2N6764	n		0		90/100(Ni)	70/80(Br)			SEB	ESA	1/94	BNL	D/C 9228E. Harwell Rept. AEA-RS-1348
100	INR	IRF150	2N6764	n		0	105	75(Cu?)	75			SEB	Aero	5/92	UCB	Koga
100	INR	IRFF130	2N6796	n		0			82(Br)			SEB	SNL	1990	BNL	200 MeV Br Range = 28μ
100	INR	IRH130		n		0			100(Br)	50/60(I)		?	NWSC		BNL	
100	INR	IRH7150		n	6	0			1 failure @ 60/70(Br)			SEB	JPL	91/92	BNL	One maverick.
100	INR	IRH7150		n		0			100(Kr)			none	Aero	5/92	UCB	Koga reports no SEB up to 150 V.
100	INR	IRHF130		n		0			100(Br)			none	JPL	1991	BNL	
100	INR		2N6782	n	1	0				65/70(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR		2N6782	n	4	0				58/59(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR	IRFG6110		n & p		2		85(Fe) p-chan only				SEB	MM	5/93	BNL?	D/C 9118. WP-02. No SEGR, no SEB in n-channel devices.
100	INR	IRHF7110		n		2		100(Ni)	100(Br)			none	Rock	7/92	BNL	T = 90° C.
100	INR	IRHF7130	2N7261	n		2		100(Ni)	<100(Br)			SEGR	Rock	7/92	BNL	T = 90° C.
100	INR	IRF120	2N6788	n		5		90				SEB	BREL	12/92	UW	Oberg. T = 23° C. Note failure mode versus temperature
100	INR	IRF120	2N6788	n		5		80				SEGR	BREL	12/92	UW	Oberg. T = 80° C.
100	INR	IRF130	2N6796	n		5		100(Cu?)				none	BREL	3/93	UCB	D/C 9236. Oberg. WP-01
100	INR	IRHM7130		n		5		80				SEGR	SEGR	1/93	UW	D/C 9112. WP-01. T = 100° C.
100	INR		2N6782	n	3	5				55/60(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR	IRHF130		n		7.5			<100(Br)			SEGR	JPL	1991	BNL	
100	INR	1RFF110	2N7682	n		10	100(N) 100(Ne) 90(Ar)	60(Cu)				SEGR	Rock/ Aero	1990	UCB	

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) |V|	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
100	INR	IRF130	2N6756	n	3	10	100(N) 100(Ne) 90(Ar)	60(Cu)				SEB	Rock/ Aero	1990	UCB	
100	INR	IRF150	2N6764	n	3	10	100(Ne) 70(Ar)	50(Cu)			40/60 (La)	SEB	Rock/ Aero/ JPL	1990	UCB	JPL used 12 GeV La Bevalac ion, LET = 30. 6/88
100	INR	IRFF130	2N6796	n	5	10	100(N) 100(Ne) 90(Ar)	60(Cu)				SEB	Rock/ Aero	1990	UCB	Compare to SIL part.
100	INR	IRH130		n		10			100(Br)			none	NWSC		BNL	
100	INR	IRH150	2N6764	n		10		100(Cu) 100(Fe)	100(Kr)		60/100 (La)	SEB	JPL/ Rock	1990	UCB	JPL, 12 GeV @ Bevalac, 6/88
100	INR		2N6782	n	1	10				40(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR	IRHF7110		n	4	12			85(Br)	41(I)		SEGR	NWSC	4/95	BNL	Titus, Rept #SEGR-003 (T = 25° C only)
100	INR	IRH7150		n	4	15			60/70(Br)			SEGR	JPL	91/92	BNL	Data @ T = 100° C exists for Vgs = 15 V only.
100	INR	IRHF130		n		15			<100(Br)			SEGR	JPL	1991	BNL	
100	INR	IRHF7110		n		15		100(Ni)	70(Br)			SEGR	Rock	7/92	BNL	T = 90° C.
100	INR	IRHF7130	2N7261	n		15		100(Ni)	60(Br)			SEGR	Rock	7/92	BNL	T = 90° C.
100	INR		2N6782	n	1	15				30/32.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR	IRHF7110		n		20			63(Br)	29(I)		SEGR	NWSC	4/95	BNL	Titus, Rept #SEGR-003 (T = 25° C only)
100	INR		2N6782	n	1	20				22.5/25(I)		SEGR	JPL	6/97	BNL	Selva/Swift
100	INR	IRH7150		n	2/3	0?		100(Ni)			>80(Xe)	none	CNES	11/90	GANIL	Used 3 GANIL ions. Tastet, RADECS91
100	INR	IRF150	2N6764	n	3	0?0	100(Cl)	70(Ni)	65(Br)	55(I)	50(Fe)	SEB	CNES	11/90	BNL	Used 1-4 GeV GANIL ions. Tastet, RADECS91
100	INR	IRF120	2N6788	n		2?	95(Ar)	<55(Cu)				SEB	Rock	1990	UCB	
100	INR	IRFF120	2N6788	n	1	2?		<60(Cu)				SEB	Rock	1990	UCB	
100	INR	IRH150	2N6764	n				100(Cu)	90/100(Kr)				Rock	1990	UCB	Waskiewicz & Groniger, DNA Rept 2/90
100	PHL	ECG2392		n	1	0					60 (Xe)	SEGR SEB	JPL	11/94	TAM	Nichols. Igs & Ids mA. At LET = 80, >50mA
100	RCA	IRF150	2N6764	n		10	100(N) 100(Ne) 50(Ar)	<50(Cu)				SEB	Rock	1990	UCB	
100	SIL	IRFF130	2N6796	n		5		50(Co)				SEB	BREL	7/95	UCB	
100	SIL	IRF150	2N6764	n	1	10	80(Ne) <50(Ar)	40(Cu)				SEB	Rock/ Aero	1990	UCB	
100	SIL	IRFF130	2N6796	n	2	10	100(N) 100(Ne) 70(Ar)	50(Cu)				SEB	Rock/ Aero	1990	UCB	
Rated 100 V <Vds < 200 V																
180	RCA	RFM12N18		n		0	100	90	65			SEB	Aero	5/88	UCB	Koga
Rated Vds = 200 V																

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
200	APT	20M45BNFR		n	5	0		115/120(Co)				SEB	BREL	3/97	UCB	
200	GEC	IRF250	2N6766	n	1	10	180(N) 170(Ne) <80(Ar)					SEB	Rock/ Aero	1990	UCB	
200	HAR	FRK250		n	3	0			80/100(Br)			SEGR	Rock	9/92	BNL	WP-04. T = 90° C
200	HAR	FRK250		n	2	0		140160(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C
200	HAR	FRK250		n	2	0		160/180(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C
200	HAR	FRL230D1		n	1	0				60/62.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	0			90/95(Br)			SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRM230		n	1	0		180/200(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
200	HAR	FRM230R		n	1	0		150/170(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
200	HAR	FRM240		n	2	0		60/100(Fe)				SEGR	JPL	12/91	BNL	T = 25° C
200	HAR	FRM240		n	2	0			80/100(Br)			SEGR	JPL	12/91	BNL	T = 25° C
200	HAR	FRM240		n	1	0			60/80(Br)			SEGR	JPL	6/92	BNL	T = 25° C
200	HAR	FRM240D1	2N7285	n	2 & 2	0		60/100(Fe)	80/100(Br)			SEGR	JPL	91/92	BNL	T = 100° C data has Vds(th) = 60/80 with Br.
200	HAR	230 family	2N6758	n		5		64					HAR	1993	BNL?	SSF Table
200	HAR	230 family	2N6758	n		5		70					HAR	1993	BNL?	SSF Table
200	HAR	230 family	2N6758	n		5		70				SEB SEGR	BREL	3/93	UCB	WP-01. D/C M9226. T = 45° C.
200	HAR	230 family	2N6758	n		5		80				SEB SEGR	BREL	3/93	UCB	WP-01. D/C M9226. T = 100° C.
200	HAR	FRK250		n	1	5			80/100(Br)			SEGR	Rock	9/92	BNL	WP-04. T = 90° C
200	HAR	FRK250		n	3	5		140160(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C
200	HAR	FRK250		n	1	5		120/140(Ni)				SEGR	Rock	12/92	BNL	WP-04. T = 90° C
200	HAR	FRK250R	2N7293	n	2	5			90(Kr)			SEGR	NASDA	2&3/95	JAERI?	D/C 9249. T = 80° C. Shinosaki.
200	HAR	FRL230D1		n	1	5				47.5/50(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	5			90/95(Br)			SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230R		n		5			100(Kr)			SEGR	NASDA	2&3/95	JAERI?	D/C 9327. T = 25 & 80° C. Shinosaki
200	HAR	FRM230		n	1	5		180/200(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
200	HAR	FRM230	2N7274	n		5		166(Ni?)					HAR	1993	BNL?	SSF Table
200	HAR	FRM230R		n	1	5		160/180(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
200	HAR	FRL230D1		n	1	10				30/32.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	10			90/95(Br)			SEGR / SEB	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	10			70(Br)			SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	15				22.5/25(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRM240D1	2N7285	n	1*	15	180/200(Ar)					SEB	JPL	91/92	UCB	*Not latest technology. T = 100° C data has no SEB.

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
200	HAR	FRL230D1		n	1	20				17.5/20(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FRL230D1		n	1	20			30/32.5(Br)			SEGR	JPL	6/97	BNL	Selva/Swift
200	HAR	FSL230		n	3	22		200(Ni)				none	NSWC	7/93	BNL	T = 25°C
200	INR	2N6798		n	3	0					170-p	SEB	BREL	1995	HCL	148 MeV protons
200	INR	2N7262SG	230	n	10	0		136	155			SEGR	BREL	7/97	88"	
200	INR	2N7269SG	250	n	10	0		145	150			SEGR	BREL	9/97	88"	
200	INR	2N7269SG	250	n	10	0		157	180			SEGR	BREL	9/97	88"	
200	INR	IRF210	2N6784	n		0		140/150(Ni)	100/120(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
200	INR	IRF230	2N6798	n		0		160/170(Ni)	<140(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
200	INR	IRF240		n		0		140/150(Ni)	120/130(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
200	INR	IRF250	2N6766	n		0		120/140(Ni)	<120(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
200	INR	IRF250		n	6	0					200-n	SEB	BREL	1995	WNR	Cosmic ray neutrons
200	INR	IRFF230	2N6798	n		0		135(Ni)				SEB	Rock	7/93	BNL	D/C 9146. R. Ferdon
200	INR	IRFF230	2N6798	n		0		140				SEB	BREL	10/93	UW	D/C 9217. T = 22° C. WP-01. Oberg.
200	INR	IRH7230		n	5	0		200(Ni)				none	Rock	12/92	BNL	D/C 9042. T = 90°C.
200	INR	IRH7250		n	4	0			200(Br)			none	JPL	91/92	BNL	
200	INR	IRH7250		n		0		180(Ni)				SEGR	Rock	8/93	BNL	D/C A9316. WP-04. R. Ferdon.
200	INR	IRHM8250		n	4	0		140				SEGR	BREL	1/93	UW	WP-01. T = 100° C. Oberg
200	INR		2N6790	n	1	0				105/110(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	INR	IR7250		n	18	2			125(Br)	50(Au)		SEGR	NWSC	8/95	BNL	Titus
200	INR	IRHF7230	2N7262	n		2		200(Ni)	160(Br)			SEGR	Rock	7/92	BNL	IR7xxx = Rad tolerant. T = 90° C.
200	INR	IRF220		n		5		145(Co)				SEB	BREL	6/93	UCB	D/C 9218G. T = 45° C. WP-01. W.Will.
200	INR	IRF220		n		5		150(Co)				SEB	BREL	6/93	UCB	T =100° C. WP-01. W. Will
200	INR	IRF250	2N7225	n		5		150(Co?)				SEB	BREL	11/93	UCB	WP-01. T = 25° C.
200	INR	IRF250	2N7225	n		5		160(Co?)				SEB	BREL	11/93	UCB	WP-01. T = 100° C.
200	INR	IRFF220	2N6790	n		5		145(Ni)				SEB	Rock	7/93	BNL	D/C 9040. WP-04. R. Ferdon
200	INR	IRFF230	2N6798	n		5		135(Ni)				SEB	Rock	7/93	BNL	D/C 9146. R. Ferdon
200	INR	IRFF230	2N6798	n		5		120				SEB SEGR	BREL	10/93	UW	T = 80° C. WP-01. Oberg.
200	INR	IRFF230	2N6798	n	2	5			120(Kr)			SEB	NASDA	3/95	JAERI?	D/C 9313. T = 25 & 80° C. Shinosaki.
200	INR	IRFM250	2N7225	n	2	5			130(Kr)			SEB	NASDA	3/95	JAERI?	D/C 9120. T = 80° C. Shinosaki. Need RT data>
200	INR	IRH7230		n	5	5		200(Ni)				none	Rock	12/92	BNL	D/C 9042. T = 90°C.
200	INR	IRH7250		n		5		120?(Ni)				SEGR	Rock	8/93	BNL	D/C A9316. WP-04. R. Ferdon.
200	INR	IRHM7250	2N7269	n		5		200				none	BREL	1/94	UCB	WP-01. T = 100° C. Oberg
200	INR	IRHM8250		n		5		110				SEGR	BREL	1/93	UW	WP-01. T = 100° C. Oberg
200	INR		2N6790	n	1	5				90/95(I)		SEGR	JPL	6/97	BNL	Selva/Swift

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) |V|	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
200	INR	IRF250	2N6766	n	2	10	190(N) 200(Ne) 120(Ar)	100(Ni) 90(Cu)	85(Br)			SEB	Rock/ Aero	90/92	UCB BNL	Waskiewicz
200	INR		2N6790	n	1	10				65(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	INR		2N6790	n	2	10				70/75(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	INR	IRHM7250	2N7269	n		12		170				SEGR	BREL	1/94	UCB	WP-01. T = 100° C. Oberg
200	INR	IR7250		n		15			75(Br)	25(Au)		SEGR	NWSC	8/95	BNL	Titus
200	INR	IRH7250		n	3,2,4	15	180/200(Ar)	160/200(Fe)	120/140(Br)			SEGR	JPL	91/92	BNL	Data @ T = 100° C exists for Vgs = 15 V only.
200	INR	IRHF7230	2N7262	n	5	15		*200(Ni)	90(Br)			SEGR	Rock	7/92	BNL	*1 OF 5 Failed @ 200 V with Ni.
200	INR	IRH7250		n	2	20			80(Br)			SEGR	JPL	91/92	BNL	
200	INR		2N6790	n	3	20				35/37.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
200	INR	IRF210	2N6784	n				<130(Cu)				SEB	Rock	1990	UCB	
200	IXY	IXFH50N20		n	5	0		50	55			SEB	BREL	3/97	88"	
200	RCA	25N20		n	1	10	200(N) 200(Ne) 180(Ar)	<70(Cu)				SEB	Rock/ Aero	1990	UCB	
200	RCA	IRF250	2N6766	n	1	10	180(N) 120(Ar)	80(Cu)				SEB	Rock/ Aero	1990	UCB	
200	RCA	IRF230	2N6758	n		2?		<100(Cu)				SEB	Rock	1990	UCB	
200	RCA	IRFF230	2N6798	n		2?		<90(Cu)				SEB	Rock	1990	UCB	
200	SIL	2N6790	220	n	5	0		80	90			SEB	BREL	7/97	88"	
200	SIL	9230 family	2N6851	n		5		200(Co)				none	BREL	7/95	UCB	Oberg. T ~100°C. (looking for SEGR)
200	SIL	IRF250	2N6766	n	2	10	160(N) 60(Ar)					SEB	Rock/ Aero	1990	UCB	
200	SIL	IRFF230	2N6798	n		12		180				SEGR	BREL	10/93	UW	Oberg. T = 100°C. Worst case for SEGR. SSF WP-01
	Rated Vds = 250 V															
250	HAR	FRL234		n	1	0		175/200(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
250	HAR	FRL234		n	4	0		200/225(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
250	HAR	FRL234		n	1	0		175/200(Ni)				SEGR	Rock	6/93	BNL	T = 90° C
250	HAR	FRL234		n	4	0		200/225(Ni)				SEGR	Rock	6/93	BNL	T = 90° C
250	HAR	FRL234R		n	5	0		175/200(Ni)				SEGR	Rock	3/93	BNL	D/C 9312. T = 90° C.
250	HAR	FSF254R		n		0			250(Br)	170(I)		SEGR	NWSC	1995	BNL	Titus, 95IEEE TNS, pg 1933. FSF = "SEE Hard"
275	HAR	TA17463RH		n	6	0	210(Ne) 175(Ar)		75(Kr)			SEB	JPL	3&6/90	UCB	Higher thresholds @ T = 100° C. Nichols.
250	HAR	TA17663		n	6	0	250(Ne) 250(Ar)		245(Kr)			SEB	JPL	3&6/90	UCB	Hard @ T = 100° C. Nichols.
250	HAR	FRF254R	2N7296	n	2	5			100(Kr)			SEGR	NASDA	2&3/95	JAERI?	D/C 9041,T = 80° C. Shinosaki.
250	HAR	FRK264D	2N7303	n		5		160				SEGR	BREL	11/93	UW UCB	WP-01. Tested @ RT & 100° C.
250	HAR	FRK264R	2N7303	n	2	5			75(Kr)			SEGR	NASDA	2&3/95	JAERI?	D/C 9328. T = 80° C. Shinosaki

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams																
BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) | V|	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
250	HAR	FRL234		n	5	5		175/200(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
250	HAR	FRL234		n	1	5		150/175(Ni)				SEGR	Rock	6/93	BNL	T = 90° C
250	HAR	FRL234		n	3	5		175/200(Ni)				SEGR	Rock	6/93	BNL	T = 90° C
250	HAR	FRL234		n	5	5		200/225(Ni)				SEGR	Rock	6/93	BNL	T = 90° C
250	HAR	FRM234		n		5		238					HAR	1993	BNL?	SSF Table
250	HAR	FSL234		n		5		250(Co)					BREL	3/95	UCB	Oberg
250	HAR	FSL254		n		5		250(Co)					BREL	3/95	UCB	Oberg
250	HAR	FSF254R		n		15						SEGR	NWSC	1995	BNL	Titus, 95IEEE TNS, pg 1933. FSF = "SEE Hard"
250	HAR	FSL234		n	5	20		250(Ni)				none	NSWC	7/93	BNL	T = 25°C
250	INR	IRH7264SE	2N7434	n	3	0		250(Cu)				SEGR	INR/ NSWC	2/98	BNL	
250	INR	IRH7264SE	264	n	5	0		250				SEB	BREL	3/97	UCB	
250	INR	IRH7264SE	264	n	5	0		250	NA			Pass	BREL	3/97	88"	
250	INR	IRH7264SE	2N7434	n	3	5		250(Cu)				SEGR	INR/ NSWC	2/98	BNL	
250	INR	IRH254		n		10		200(Cu)	225/250(Kr)			none	Rock	1990	UCB	
250	INR	IRH7264SE	2N7434	n	3	10		250(Cu)	250(Br)			SEGR	INR/ NSWC	2/98	BNL	
250	INR	IRH7264SE	2N7434	n	3	15		250(Cu)	225/240(Br)			SEGR	INR/ NSWC	2/98	BNL	
250	INR	IRH7264SE	2N7434	n	3	20		250(Cu)	250(Br)			SEGR	INR/ NSWC	2/98	BNL	
250	INR	IRH7264SE	2N7434	n	3	25		250(Cu)				SEGR	INR/ NSWC	2/98	BNL	At V_{GS} = 30 V, 2 devices passed, 1 failed with Cu.
250	INR	IRH254		n		2?		200(Cu)	>225(Kr)			none	Rock	1990	UCB	
250	IXY	IXFM40N25RH		n	6	0	200(Ne) 140(Ar)		55(Kr)			SEB	JPL	3 & 6/90	UCB	Higher thresholds @ T = 100° C. Nichols.
Rated Vds = 300 V																
300	APT	30M85BNFR		n	5	0		200/210				SEB	BREL	3/97	UCB	
300	IXY	IXTM35N30		n	4	0	225(Ne) 160(Ar)		67(Kr)			SEB	JPL	6/90	UCB	Higher thresholds @ T = 100° C. Nichols.
300	UTR	IRFF320	2N6792	n		2?		<260(Cu)				SEB	Rock	1990	UCB	Compare to INR device
Rated Vds = 400 V																
400	APT	APT40M42		n	3	12		200/225				SEB	HON	2/93	BNL	D/C 9302. SSF WP-02

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) | V|	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
400	HAR	FRL430		n	1	0				72.5/75(I)		SEGR	JPL	6/97	BNL	Selva/Swift
400	HAR	IRHM7360		n	2 & 4	0		225/250(Ni)	175/200(Br)			SEGR	Rock	9/92	BNL	T = 90° C.
400	HAR		2N6800	n		5		130				SEB	BREL	1/93	UW	WP-01. D/C 8830. T = 28° C.
400	HAR		2N6800	n		5		130				SEB	BREL	1/93	UW	WP-01. T = 100° C. See preceding.
400	HAR	FRL430		n	1	10				47.5/50(I)		SEGR	JPL	6/97	BNL	Selva/Swift
400	HAR	FRL430		n	1	20				25/27.5(I)		SEGR	JPL	6/97	BNL	Selva/Swift
400	INR	IRF310	2N6786	n		0		260/270(Ni)	250/260(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
400	INR	IRF330	2N6800	n		0		240/260(Ni)	200/240(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
400	INR	IRF340		n		0		250/260(Ni)	240/280(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
400	INR	IRF350	2N6768	n		0		260/280(Ni)	200/240(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
400	INR	IRF360		n	5 & 4	0		220/230(Ni)	225/250(Br)			SEB	Rock	9/92 12/92	BNL	D/C 9143. Br @ T = 90° C; Ni @ RT
400	INR	IRF360		n	6	0					290-n	SEB	BREL	1995	WNR	Cosmic ray neutrons
400	INR	IRF360		n	3	0					350-n	SEB	BREL	1996	14 MeV	14 MeV neutrons
400	INR	IRH7264SE	2N7391	n	3	0		325/350(Cu)	400(Br)			SEGR	INR/ NSWC	2/98	BNL	Different D/Cs?
400	INR		2N6780	n		0			200/240(Br)			SEB	ESA	1/94	BNL	Commercial, Harwell Rept. AEA-RS-1348
400	INR	IRFF330	2N6800	n		2		<235(Cu)	235(Br)			SEB	Rock	7/92	BNL	T = 90° C.
400	INR	IRF340		n		5		260				SEB	BREL	5/94	UCB	T =45 & 100° C tests. Oberg.
400	INR	IRF350	2N6768	n		5		260				SEB	BREL	6/93	UCB	WP-01. Vth = 280 @ T = 100° C. Oberg.
400	INR	IRF350	2N6768	n		5		240(Co)				SEB	BREL	5/94		WP-01. RT & 100° C tests. Oberg
400	INR	IRFF330	2N6800	n		5		240(Co)				SEB	BREL	12/92	UW	D/C E9115. WP-01 T = 100° C.
400	INR	IRFF330	2N6800	n		5		240(Co)				SEB	BREL	3/95		WP-01. RT & 100° C tests. Oberg
400	INR	IRH7264SE	2N7391	n	3	5		400(Cu)	400(Br)			SEGR	INR/ NSWC	2/98	BNL	
400	INR	IRHM7360		n	5	5		175/200(Ni)				SEGR	Rock	12/92 4/93	BNL	T = 90° C.
400	INR		2N6786	n	1	5				150(I)		SEGR	JPL	6/97	BNL	Selva/Swift
400	INR	IRHM7360		n	5	7		175/200(Ni)				SEGR	Rock	4/93	BNL	T = 90° C.
400	INR	IRH7264SE	2N7391	n	3	10		400(Cu)	400(Br)			SEGR	INR/ NSWC	2/98	BNL	
400	INR		2N6786	n	1	10				110/115(I)		SEGR	JPL	6/97	BNL	Selva/Swift
400	INR	IRF360		n	4	12		225/250				SEGR	HON	2/93	BNL	D/C 9238G. Lintz
400	INR	IRFF330	2N6800	n		15			235(Br)			SEB	Rock	7/92	BNL	T = 90° C.
400	INR	IRH7264SE	2N7391	n	3	15		400(Cu)	275/300(Br)			SEGR	INR/ NSWC	2/98	BNL	At V_{GS} = 20 V, 2 devices passed, 1 failed with Cu.
400	INR	IRHM7360		n		15			125(Br)			SEGR	Rock	7/92	BNL	T = 90° C.

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
400	INR		2N6786	n	1	20				40/45(1)		SEGR	JPL	6/97	BNL	Selva/Swift
400	INR	IRHM7360		n	6	0 to 2		175/200(Ni)	220(Br)			SEGR	Rock	7/92 4/93	BNL	T = 90° C.
400	INR	IRF340		n		2?		245				SEB	MM	8/93	BNL?	WP-02. D/Cs 8924, 9031, 9110. T. Rao-Sahib
400	INR	IRFF320	2N6792	n		2?		<260(Cu)				SEB	Rock	1990		Compare UTR device.
400	INR	IRF350	2N6768	n						130		SEB	CNES	1992	GANIL	Dufour, et. al., 92IEEE Workshop Record.
400	INR	IRH7360		n			400					none	INR	1/93	BNL	IR7xxx = Rad tolerant.
400	SIL	IRF350	2N6768	n		10		<120(Cu)				SEB	Rock	1990	UCB	
Rated 400V < Vds < 500 V																
450	IXY	IXTM21N45		n	5	0	316(Ne) 214(Ar)		144(Kr)			SEB	JPL	3 & 6/90	UCB	Higher thresholds @ T = 100° C. Nichols.
450	IXY	IXTM21N45RH		n	3		300(Ne) 270(Ar)		140(Kr)			SEB	JPL	3 & 6/90	UCB	Higher thresholds @ T = 100° C. Nichols.
Rated Vds = 500 V																
500	HAR	420 family	2N6794	n		0		220				SEB	BREL	12/92	UW	WP-01. T = 22° C. Oberg.
500	HAR	430 family	2N6802	n		0		250				SEB SEGR	BREL	12/92	UW	WP-01. T = 100° C. Oberg.
500	HAR	EN469		n		0			300(Br)			SEGR	Rock	1992	BNL	Deleted from wp-04 design.
500	HAR	FRL430D		n		0		>400				SEB	HON	2/93	BNL	WP-02
500	HAR	FRL430D		n		0			>400			SEB	HON	2/93	BNL	WP-02
500	HAR	FRL430D		n	4	0		>400(Ni)	<250(Br)			SEGR	HON	2/93	BNL	D/C 9138. Lintz.
500	HAR	FRL430D1	430	n	5	0		240(Co)				SEGR	BREL	3/95	UCB	
500	HAR	FRL430D1	430	n	5	0		240/275(Co)				SEGR	BREL	3/97	UCB	
500	HAR	FRM450		n	2	0		275/300(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
500	HAR	FRM450		n	3	0		300/325(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
500	HAR	FRM450		N	4	0			175/200(Br)			SEGR	Rock	9/92	BNL	T = 90° C
500	HAR	FRM450R		n	5 & 1	0		200/225(Ni)	100/125(Br)			SEGR	Rock	9/92 3/93	BNL	D/C/9232. T = 90° C.
500	HAR	IR450		n		0						SEB	Aero	9/93	UCB	Koga
500	HAR	TA17465		n	2	0	410(N) 380(Ne)		250(Kr)			SEB	JPL	3&6/90	UCB	RT. Nichols.
500	HAR	TA17665RH		n	6	0			494(Kr)			SEB	JPL	3&6/90	UCB	RT. On 6/90 a maverick failed @ 323 V with Kr.
500	HAR	420 family	2N6794	n		5		250				SEB	BREL	12/92	UW	WP-01. T = 80° C. Oberg.
500	HAR	430 family	2N6762	n		5		280					HAR	1993	BNL?	SSF Table
500	HAR	FRL430D		n		5			<250			SEB	HON	2/93	BNL	WP-02
500	HAR	FRM450		n	5	5		200/225(Ni)				SEGR	Rock	4/93	BNL	T = 90° C
500	HAR	FRM450		N	1	5			100/125(Br)			SEGR	Rock	9/92	BNL	T = 90° C
500	HAR	FRM450R		n	5& 4	5		275/300(Ni)	175/200(Br)			SEGR	Rock	9/92 3/93	BNL	D/C/9232. T = 90° C.

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
500	HAR	FSF450		n	1	5		500(Ni)				none	NSWC	4/95	BNL	T = 25°C
500	HAR	IRF440		n	5	15			246(Br)			SEGR	UA	1993	IPN	Mouret, 94IEEE TNS, RT Angle data exists.
500	HAR	FSF450		n	6	20		450(Ni)				none	NSWC	9/97	BNL	T = 25°C
500	HAR	FSL430		n	5	20		500(Ni)				none	NSWC	7/93	BNL	T = 25°C
500	HAR	FRL430D		n		Dyn?			>400			SEB	HON	2/93	BNL	WP-02
500	INR	2N6802	430	n	10	0		305/310(Co)				SEB	BREL	1/98	UCB	D/C 9715
500	INR	2N6802	430	n	10	0		317/320(Co)				SEB	BREL	8/95	UCB	D/C 9429
500	INR	IR7450		n	18	0			385(Br)			SEGR	NWSC	8/95	BNL	Titus Rept "SEGR-002". T = 25° C only.
500	INR	IRF430	2N6802	n		0		300/350(Ni)	320(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
500	INR	IRF440		n		0		300/350(Ni)	250/300(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
500	INR	IRF450	2N6770	n		0		300/350(Ni)	300(Br)			SEB	ESA	1/94	BNL	D/C 9228G. Harwell Rept. AEA-RS-1348
500	INR	IRF450	2N6770	n	5 & 1	0		290/300(Ni)	275/300(Br)			SEB	Rock	9/92 12/92	BNL	Br @T = 90° C; Ni @ RT
500	INR	IRF460		n	6	0					325-n	SEB	BREL	1995	WNR	Cosmic ray neutrons
500	INR	IRFE430		n	2	0		300/350(Ni)				SEB	HON	8/94	BNL	Also survived 450 V Vds peak @ 37kHz. Lintz.
500	INR	IRFM450	2N7227	n		0	370	350	320			SEB	Aero	9/93	UCB	Koga has cross sections for each LET.
500	INR	IRH7450SE		n	3	0		500(Cu)	350/375(Br)			SEGR	INR/ NSWC	2/98	BNL	
500	INR	IR420	2N6794	n		5		300				SEB	BREL	11/93	UCB	WP-01. T = 100° C data only. Oberg
500	INR	IRF440		n		5		300				SEB	BREL	6/93	UCB	WP-01. Ambient = 45° C. Oberg.
500	INR	IRF450	2N6770	n	5 & 3	5		290/300(Ni)	275/300(Br)			SEB	Rock	9/92 12/92	BNL	Br @T = 90° C; Ni @ RT
500	INR	IRFF430	2N6802	n		5		316(Co)				SEB	BREL	7/95	UCB	WP-01. Ambient and 100° C. Oberg
500	INR	IRFF430	2N6802	n		5		300				SEB	BREL	4/93	UCB	WP-01. Ambient = 45° C. Oberg
500	INR	IRH7450		n	5 & 4	5		275/300(Ni)	225/250(Br)			SEGR	Rock	9/92 12/92	BNL	T = 90° C.
500	INR	IRH7450SE		n	10	5		373(Co)				SEB	BREL	7/95	UCB	Ambient & 100° C. Oberg.
500	INR	IRH7450SE		n	23+	5	>400(Ne) 360(Ar)	350(Cu)	350(Kr)			SEB	Aero	4/96	UCB	Also Vds (threshold) vs Vgs for SEGR (Kr). Koga.
500	INR	IRH7450SE		n	3	5		500(Cu)	500(Br)			SEGR	INR/ NSWC	2/98	BNL	
500	INR	IRHM7450		n		5		300				SEGR	BREL	1/93	UW	WP-01. T = 100° C. Oberg.
500	INR	IRH7450SE		n	3	10		500(Cu)	500(Br)			SEGR	INR/ NSWC	2/98	BNL	
500	INR	IRF440		n		12		325				SEB	BREL	6/93	UCB	WP-01. T = 100° C. Oberg.
500	INR	IRF440		n		12		300(Co)				SEB	BREL	5/94	UCB	WP-01. Ambient and 100° C. Oberg.
500	INR	IRFF430	2N6802	n		12		325				SEB	BREL	10/93	UW	WP-01. T = 100° C. Oberg

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams																	
BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
500	INR	IR7450		n		15			400(Br)			SEGR	NWSC	8/95	BNL	Titus Rept "SEGR-002". T = 25° C only.
500	INR	IRH7450		n		15			155(Br)			SEGR	Rock	7/92	BNL	T = 90° C.
500	INR	IRH7450SE		n	3	15		500(Cu)	500(Br)			SEGR	INR/ NSWC	2/98	BNL	
500	INR	IRF440		n	4	20			220?(Br)			SEGR	UA	1994	IPN	Mouret, 94IEEE TNS. RT and angle data exist.
500	INR	IRH7450SE		n	3	20		500(Cu)	500(Br)			SEGR	INR/ NSWC	2/98	BNL	
500	INR	IRH7450		n	5 & 5	0 to 2		300/325(Ni)	250/275(Br)	<120(I)		SEGR	Rock/ NWSC	7, 9 & 12/92	BNL	T = 90° C. Epi = 40-50μ for high voltage parts.
500	INR	IRF420		n	9	0-10		340/380(Ni)				SEB	HON	8/95	BNL	D/C 9517. 125 kHz, 3.2 μs OFF. Lintz
500	INR	IRF430	2N6802	n				<310(Cu)				SEB	Rock	1990	UCB	
500	INR	IRF450	2N6770	n							250	SEB	CNES	1992	GANIL	Dufour, et. al., 92IEEE Workshop Record.
500	IXY	2N50		n	6	0					350-n	SEB	BREL	1995	WNR	Cosmic ray neutrons
500	IXY	20N60		n		5		280				SEB	BREL	11/93	UCB	Oberg. T = 25°C. SSF WP-01
500	IXY	20N60		n		5		300				SEB	BREL	11/93	UCB	Oberg. T = 100°C. SSF WP-01
500	MOT	MTW20N50E		n	4	0					400-n	SEB	BREL	1996	WNR	Cosmic ray neutrons
500	MOT	IRF440		n	3	30			240?(Br)			SEGR	UA	1994	IPN	Mouret, IEEE94. Room temp. Angle data exists.
500	SIL	420 family	2N6794	n		5		300(Co)				SEB	BREL	3/95	UCB	Oberg. Ambient & 100°C
500	SIL	430 family	2N6802	n	10	5		317(Co)				SEB	BREL	7/95	UCB	Oberg. Ambient & 100°C. SSF WP-01
500	SIL	430 family	2N6802	n		5		300				SEB	BREL	4/93	UCB	Ambient = 45°C. SSF WP-01
500	SIL	430 family	2N6802	n		12		300				SEB SEGR	BREL	10/93	UW	T = 100°C. SSF WP-01
500	STX	0350N5		n	6	0					350-n	SEB	BREL	1995	WNR	Cosmic ray neutrons
Rated Vds = 600 V																
600	HAR	TA9783	IGBT	n	2	5		325/350(Ni)				SEGR	Rock	12/92	BNL	RT
600	INR	IRGAC50U	IGBT	n	2	0		340/350(Ni)				SEB	Rock	12/92	BNL	RT
600	INR	IRGAC50U	IGBT	n	2	5		340/350(Ni)				SEB	Rock	12/92	BNL	RT
600	INR	IRGAC50U	IGBT	n		5		380(Co)				SEB	BREL	6/93	UCB	D/C 9308. T = 25° C. WP-01. W. Will
Rated Vds = 800 V																
800	APT	802R4AN		n	5	0		410/420(Co)				SEB	BREL	3/97	UCB	
Rated Vds = 1000 V																
1000	APT	1002RBN		n	3	0					650-n	SEB	BREL	1996	WNR	Cosmic ray neutrons
1000	APT	1002RBN		n	3	0					800-n	SEB	BREL	1996	14 MeV	14 MeV neutrons
1000	APT	1001R1AN		n	>2	5		400				SEGR SEB	BREL	4/93	UCB	D/C 9126. W. Will.
1000	APT	1001R1AN		n	>2	5		450				SEGR SEB	BREL	4/93	UCB	D/C 9126. T = 100°C - implies SEB. W. Will.

TABLE 1 (cont.) - Failure (or Pass/Fail) N-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [V]	Low Z Ions	Cu = 16: Fe, Ni, Co LET = 27:	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
1000	INR	IRFPG50		n	5	0					650-n	SEB	BREL	1996	WNR	Cosmic ray neutrons
1000	INR	IRFPG50		n	2	0					800-n	SEB	BREL	1996	14 MeV	14 MeV neutrons
1000	INR	IRFAG30		n		5		400				SEGR SEB	BREL	6/93	UCB	D/C 9227. T = 45° C. WP-01.
1000	INR	IRFAG30		n		5		450				SEGR SEB	BREL	6/93	UCB	D/C 9227. T = 100° C. WP-01.
1000	IXY	10N100		n	3	5		450				SEGR SEB	BREL	6/93	UCB	D/C SC9019. T = 45°C. SSF WP-01 W. Will
1000	IXY	10N100		n		5		450				SEGR	BREL	6/93	UCB	D/C SC9019. T = 100°C. SSF WP-01 W. Will
	Rated Vds >1000 V															
1200	HAR	20N120E2		IGBT	4	n/a					850-n	SEB	BREL	1996	WNR	Cosmic ray neutrons

Legend:

Manufacturers: APT = Advanced Power Technology; GEC = General Electric Company; HAR = Harris; INR = International Rectifier; IXY = Ixys Corp.; MOT = Motorola; PHL = Phillips; RCA = Radio Corporation of America; SIL = Siliconix; UTR = Unitrode.

* High energy beams also includes other particles, p stands for protons and n for neutrons

BNL - Tandem Van de Graaff, Brookhaven National Laboratories, Long Island, NY

GANIL - GANIL Accelerator, France

HCL - Harvard Cyclotron Laboratory, Boston, MA

IPN - Insitute Physique Nuclaire, University of Orsey, France

JAERI - Japanese Atomic Energy Research Institute, Japan

TAM - Texas A&M University Cyclotron Institute, College Station, TX

UCB - 88-inch cyclotron, University of California, Berkeley, CA

UW - University of Washington cyclotron, Seattle, WA

WNR - Los Alamos National Laboratories, NM

Aero = Aerospace Corp., El Segundo, CA

BREL = Boeing Radiation Effects Laboratory, Seattle, WA

CNES = Centre National d'etudes Spatiales, Toulouse, France

ESA = European Space Agency, Noordwijk, Netherlands

HON = Honeywell Space Systems, Clearwater, FL

JPL = Jet Propulsion Laboratory, Pasadena, CA

MM = Martin Marietta Aerospace, Valley Forge, PA

NASDA = National Space Development Agency of Japan, Tokyo, Japan

NSWC = Naval Surface Warfare Center, Crane, IN

Rock = Rockwell Corp. (now Boeing), Anaheim, CA

SNL = Sandia National Laboratories, Albuquerque, NM

UA = University of Arizona, Tuscon, AZ

TABLE 2 - Failure (or Pass/Fail) P-Channel Device Vds Voltages for the Indicated Ion Beams																
BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [+V]	Low Z Ions	Fe, Ni, Co LET = 27	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
Rated Vds = 100 V																
100	HAR	FRK9150R		p	5	0		100(Ni)				none	Rock	12/92	BNL	WP-04. D/C 928x. T = 90° C
100	HAR	FRK9150R		p	4	0			60/70(Br)				Rock	9/92	BNL	WP-04. D/C 928x. T = 90° C
100	HAR	FRK9160		p	3	0			60/70)Br)			SEGR	JPL	91/92	BNL	
100	HAR	FRK9160		p	1	0		80/90(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
100	HAR	FRK9160		p	3	0		90/100(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
100	HAR	FRK9160		p	1	0		100(Ni)				none	Rock	12/92	BNL	T = 90° C
100	HAR	FRK9160		p	3	0			60/70(Br)			SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRK9160R	2N7328	p	5	0		80/90(Ni)				SEGR	Rock	12/92	BNL	T = 90° C.
100	HAR	FRM9140		p	4	0			70(Br)			SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRM9140R		p	4	0			60/70(Br)			SEGR	JPL	12/92	BNL	T = 90° C.
100	HAR	IRF9150		p		0			100			N/A	Rock	1992	BNL	D/C 9010
100	HAR	9130 family	2N6849	p		5		100				N/A	BREL	3/93	BNL	WP-01. RT data. Oberg
100	HAR	FRK9150R		p	5	5		100(Ni)				none	Rock	12/92	BNL	T = 90° C
100	HAR	FRK9150R		p	4	5			50/60(Br)				Rock	9/92	BNL	T = 90° C
100	HAR	FRK9160		p	1	5		90/100(Ni)				SEGR	Rock	12/92	BNL	T = 90° C
100	HAR	FRK9160R	2N7328	p	3	5		70/80(Ni)				SEGR	Rock	12/92	BNL	T = 90° C.
100	HAR	9110 family	RKL1P10	p		10			100			N/A	Rock	1992	UCB	
100	HAR	FRM9140		p	3	15			40(Br)			SEGR	JPL	12/91	BNL	T = 25° C
100	HAR	FRM9140R		p	3 & 3	15	90/100(Ar)		30/40(Br)			SEGR	JPL	12/92	BNL	1 of 3 SEGR with Ar.
100	INR	IRF9140		p	3&2	0		60/70(Fe)	70/80(Br)			SEGR	JPL	91/92	BNL UCB	Anomalous comparison Vds OF Br and Ar.
100	INR	IRF9150		p	5	0		100(Ni)				N/A	Rock	12/92	BNL	T = 90° C.
100	INR	IRFF9130	2N6849	p		0			100(Br)			N/A	SNL	1987	BNL	
100	INR	IRH9150		p		0		100(Ni)				N/A	Rock	12/92	BNL	D/C A9330. R. Ferdon
100	INR	IRHF9130		p	5	0		100(Ni)				N/A	Rock	4/93	BNL	T = 90° C. First INR hardened p-channel
100	INR	9120 family	2N6845	p		2		100(Ni)	100(Br)			N/A	Rock	8/92	BNL	D/C 9218. T = 90° C. WP-04
100	INR	9130 family	2N6804	p		2		100(Ni)	100(Br)			N/A	Rock	8/92	BNL	D/C 9141. T = 90° C. WP-04
100	INR	IRF9150		p	5	5		100(Ni)				N/A	Rock	12/92	BNL	T = 90° C.
100	INR	IRH9150		p		5		100(Ni)				N/A	Rock	12/92	BNL	D/C A9330. R. Ferdon
100	INR	IRHF9130		p	5	5		100(Ni)				N/A	Rock	4/93	BNL	T = 90° C.
100	INR	IRF9130		p	2	10		100(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8406 and 8545
100	INR	IRF9130		p		10			100(Br)			N/A	SNL		BNL	
100	INR	IRFF9122		p	1	10		100(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8511
100	INR	IRFF9130	2N6849	p	2	10		100(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8533
100	INR	9120 family	2N6845	p		15		100(Ni)	60(Br)			SEGR	Rock	8/92	BNL	D/C 9218. T = 90° C. WP-04

TABLE 2 (cont.) - Failure (or Pass/Fail) P-Channel Device Vds Voltages for the Indicated Ion Beams

BVds	Mfr.	Mfr. No.	Gen. No.	Chan. Type	Samp.	Vgs (off) [+V]	Low Z Ions	Fe, Ni, Co LET = 27	Br, Kr LET = 38	Hi Z Ions	Hi-Energy Beams*	Fail mode	Test Org.	Date	Test Fac.	Remarks
100	INR	9130 family	2N6804	p		15		100(Ni)	50(Br)			SEGR	Rock	8/92	BNL	D/C 9141. T = 90° C. WP-04
100	INR	IRF9140		p	3&3	15	100(Ar)		40/60(Br)			SEGR	JPL	91/92	BNL UCB	
100	RCA	12P10		p	1	10		100(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8445
100	RCA	IRF9130	2N6798	p	1	10		Hard(Cu)				N/A	Rock/ Aero	1990	UCB	
100	RCA	IRF9140		p	1	10		100(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8547
	Rated Vds = 200 V															
200	HAR	FRM9240R	2N7318	p	2	0		200(Fe)				none	JPL	12/91	BNL	T = 25° C
200	HAR	FRM9240R	2N7318	p	3	0		200(Fe)				none	JPL	6/92	BNL	T = 25° C
200	HAR	FRM9240R	2N7318	p	2	0		120/180(Fe)				SEGR	JPL	2/92	UCB	T = 85° C
200	HAR	FRM9240R	2N7318	p	3	0			80/100(Br)			SEGR	JPL	12/91	BNL	T = 25° C
200	HAR	FRM9250		p	4	0				160/180(Xe)		SEGR	Aero		UCB	No SEB @ LET = 40 for Vds = 200. Koga.
200	HAR	FRM9250		p	3	0		200(Ni)				N/A	JPL	12/93	BNL	1 of 3 older version failed @ Vds = 200 and Vgs = 0.
200	HAR	IRF9230		p		1				80/90(I)			NSWC		BNL	
200	HAR	FRM9240R	2N7318	p	3	15	200(Ne) 60/80(Ar)					SEGR	JPL	12/92	BNL UCB	
200	HAR	FRM9240R	2N7318	p	3	15		100/120(Fe)				SEGR	JPL	12/91	BNL	T = 25° C
200	HAR	FRM9240R	2N7318	p	3	15			50(Br)			SEGR	JPL	12/91	BNL	T = 25° C
200	HAR	FRM9250		p	3	15		200(Ni)				N/A	JPL	12/93	BNL	Older version not tested @ VGS = 15.
200	INR	IRF9240	2N7237	p	2 & 2	0		80/100(Fe)	80/100(Br)			SEGR	JPL	91/92	BNL	Same Vds range for Br @ T = 125° C.
200	INR	IRFF9230	2N6851	p		0		200(Ni)				N/A	Rock	8/93	BNL	D/C A9330. Redesigned. R. Ferdon
200	INR	IRF9240	2N7237	p		5		<200(Co)				SEGR	BREL	8/93		WP-01. T = 100° C. W. Will. Temp. dependence
200	INR	IRF9240	2N7237	p		5		200				N/A	BREL	11/93	UCB	WP-01. Ambient. Oberg. Compare preceding.
200	INR	IRFF9230	2N6851	p		5		200(Ni)				N/A	Rock	8/93	BNL	D/C A9330. Redesigned. R. Ferdon
200	INR	IRF9230		p		10			200(Br)			N/A	SNL		BNL	
200	INR	IRFF9230	2N6851	p		10		200(Cu)				N/A	Rock/ Aero	1990	UCB	D/C 8607
200	INR	9230 family	2N6851	p		12		200(Co)				SEGR	BREL	5/94	UCB	WP-01. T = 100° C. Oberg
200	INR	IRF9240	2N7237	p	3,1,3	15	200(Ar)	100/120(Fe)	80/100(Kr)			SEGR	JPL	91/92	BNL UCB	Fe data above Vgs = 0 is anomalous.

Legend:

Manufacturers: HAR = Harris; INR = International Rectifier; RCA = Radio Corp. of America

BNL - Tandem Van de Graaff, Brookhaven National Laboratories, Long Island, NY

UCB - 88-inch cyclotron at University of California, Berkeley, CA

Aero = Aerospace Corp., El Segundo, CA

BREL = Boeing Radiation Effects Laboratory, Seattle, WA

JPL = Jet Propulsion Laboratory, Pasadena, CA

NSWC = Naval Surface Warfare Center, Crane, IN

Rock = Rockwell Corp. (now Boeing), Anaheim, CA

SNL = Sandia National Laboratories, Albuquerque, NM

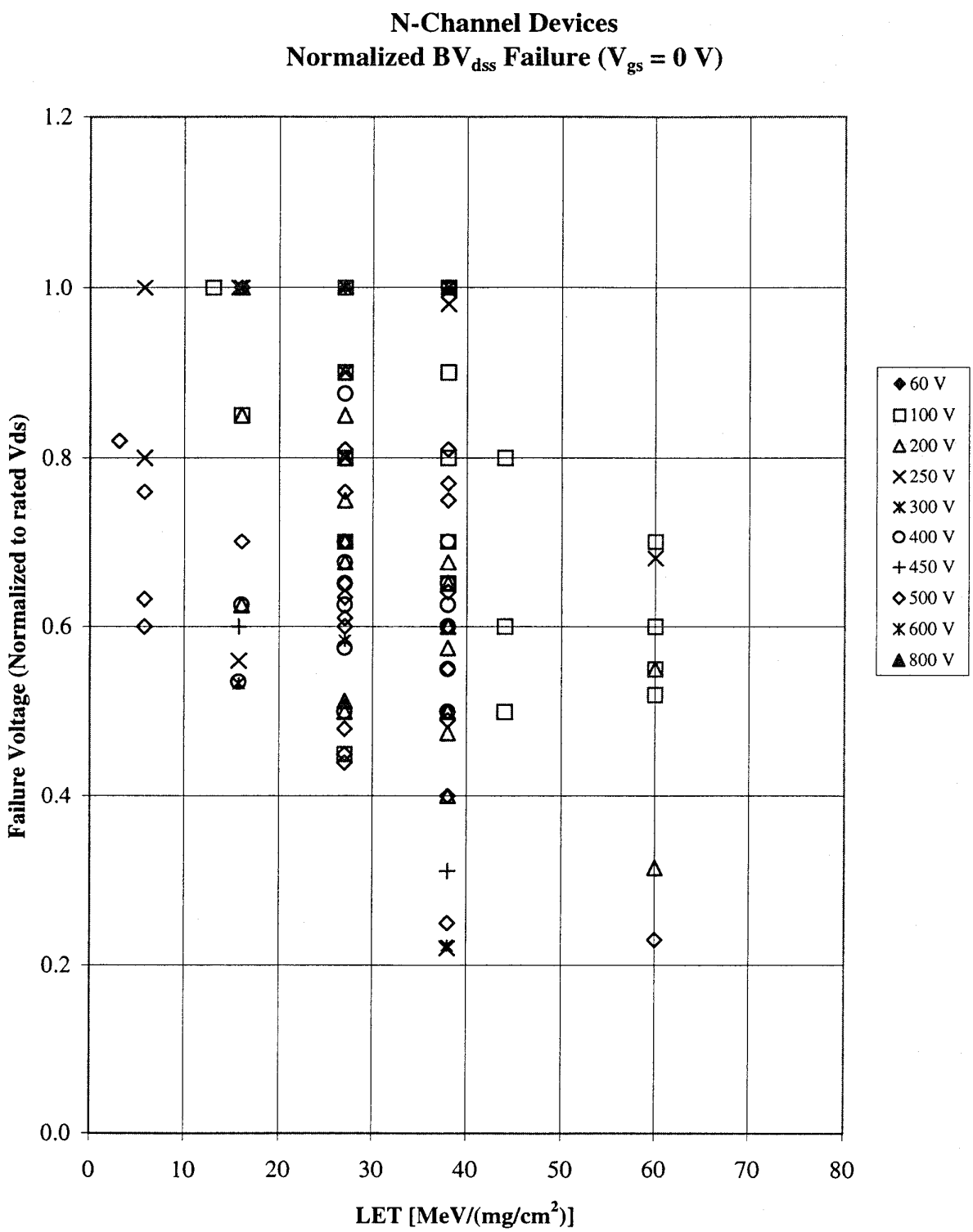
N-Channel Devices
Normalized BVdss Failure (Vgs = 0 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
60 V
100 V
200 V
250 V
300 V
400 V
450 V
500 V
600 V
800 V

Figure 1

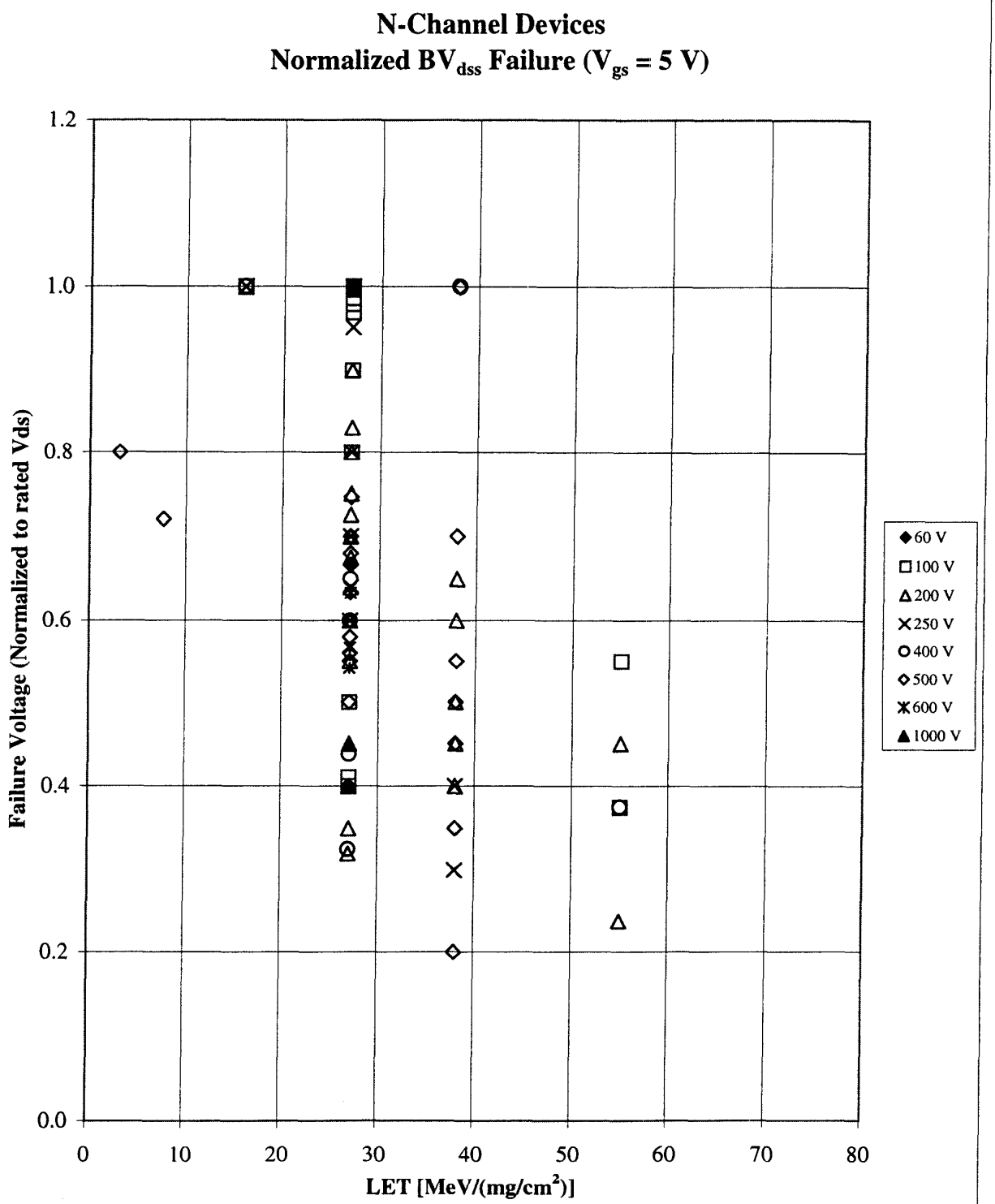
N-Channel Devices
Normalized BVdss Failure (Vgs = 5 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
60 V
100 V
200 V
250 V
400 V
500 V
600 V
1000 V

Figure 2

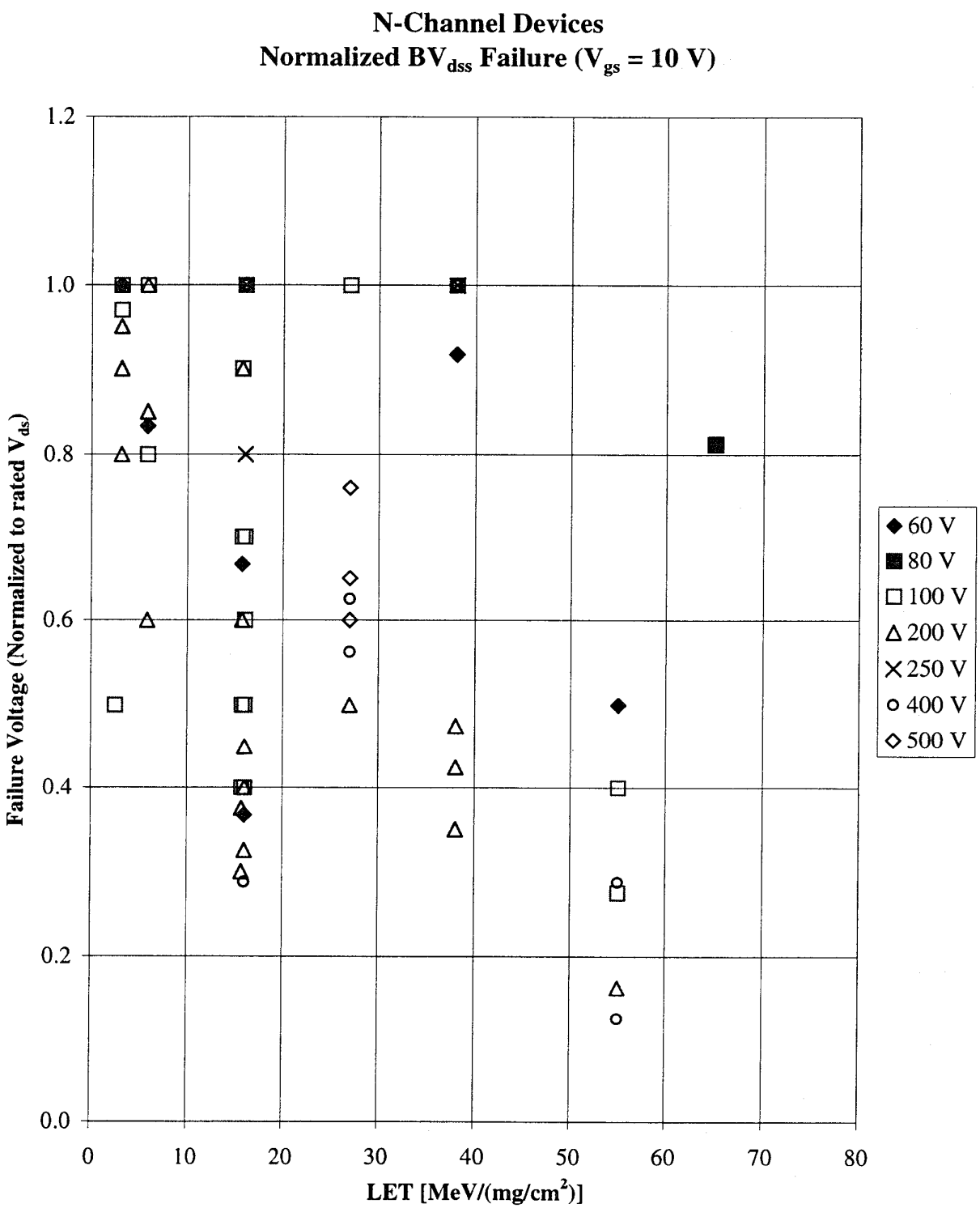
N-Channel Devices
Normalized BVdss Failure (Vgs = 10 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
60 V
80 V
100 V
200 V
250 V
400 V
500 V

Figure 3

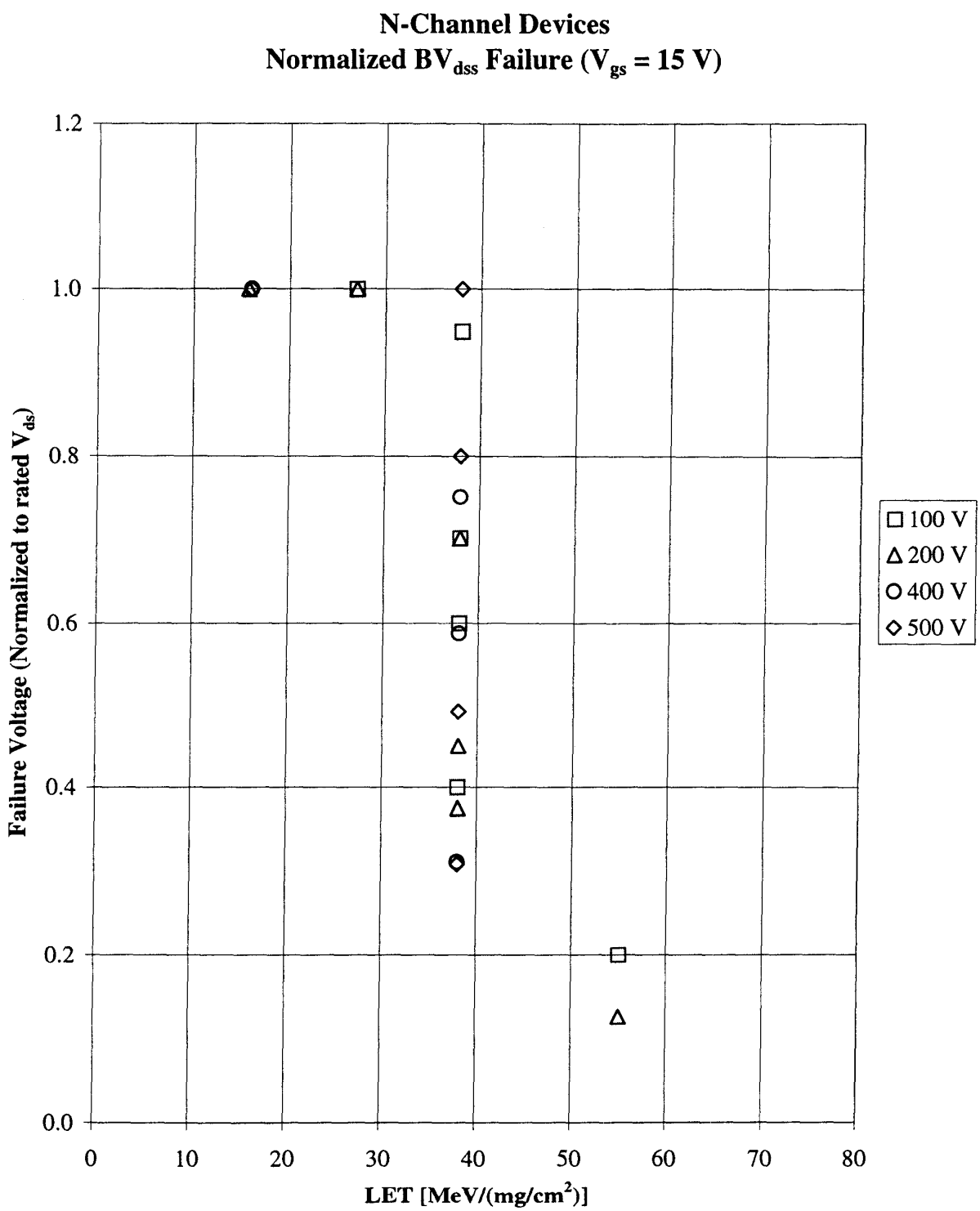
N-Channel Devices
Normalized BVdss Failure (Vgs = 15 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
100 V
200 V
400 V
500 V

Figure 4

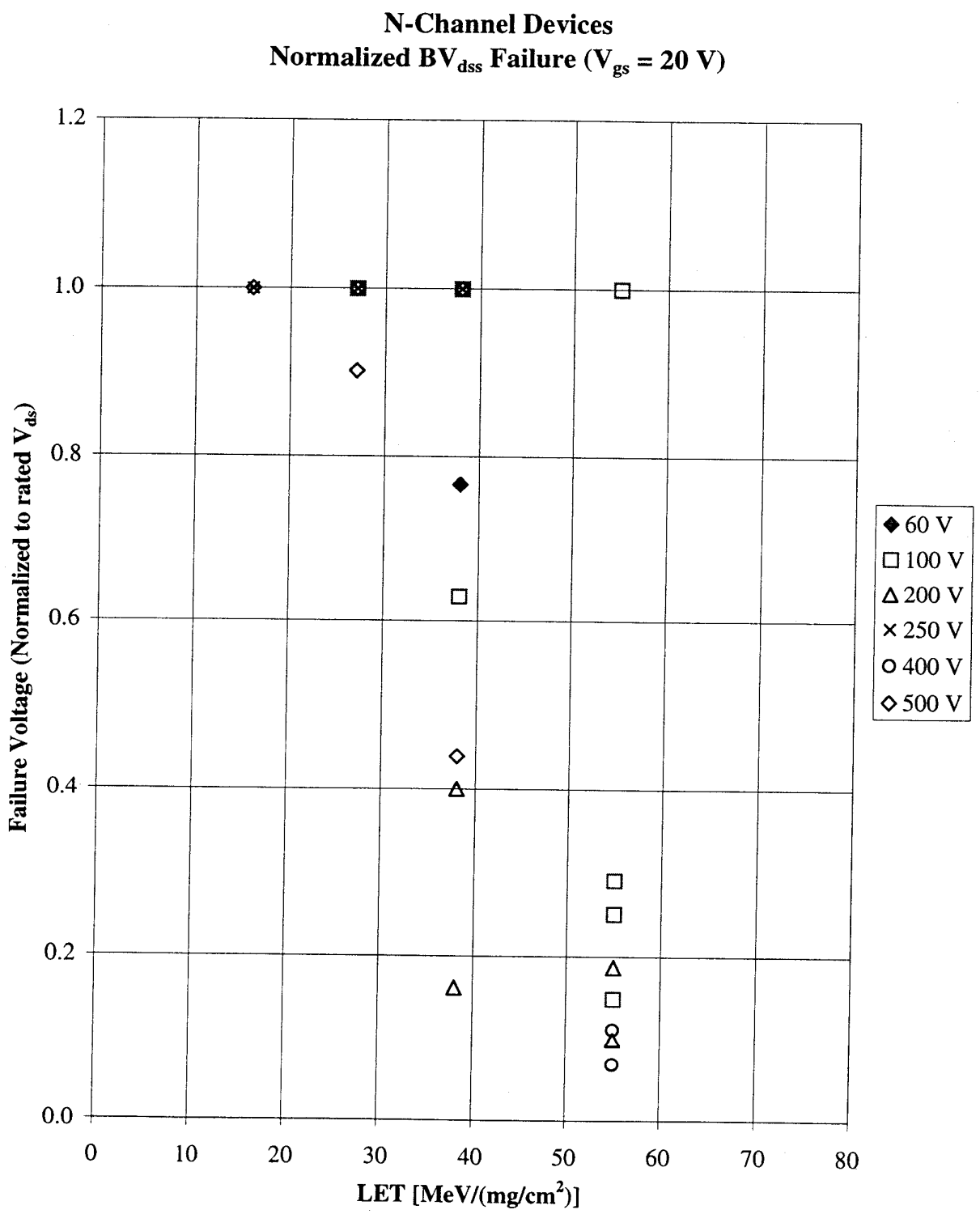
N-Channel Devices
Normalized BVdss Failure (Vgs = 20 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
60 V
100 V
200 V
250 V
400 V
500 V

Figure 5

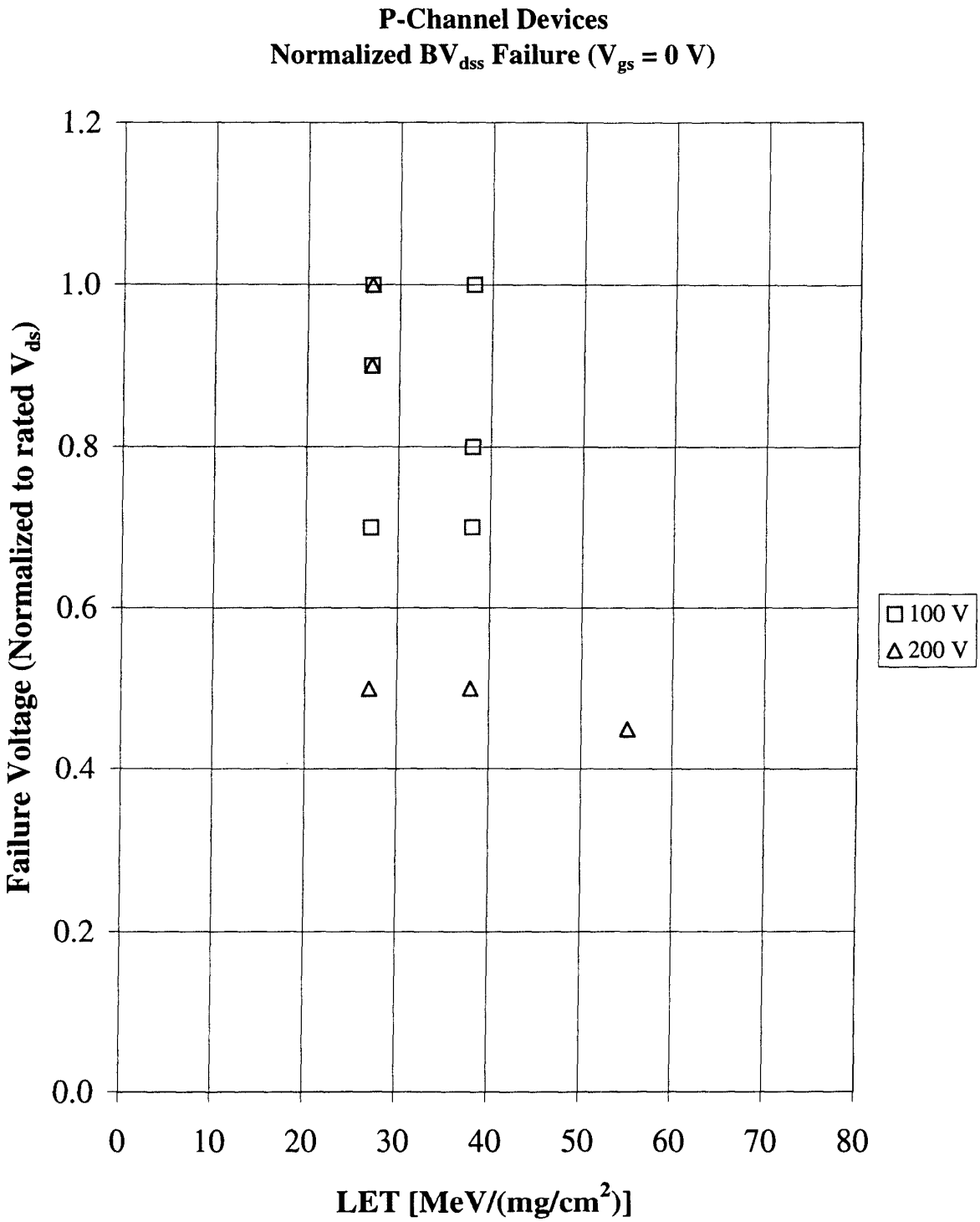
P-Channel Devices
Normalized BVdss Failure (Vgs = 0 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
100 V
200 V

Figure 6

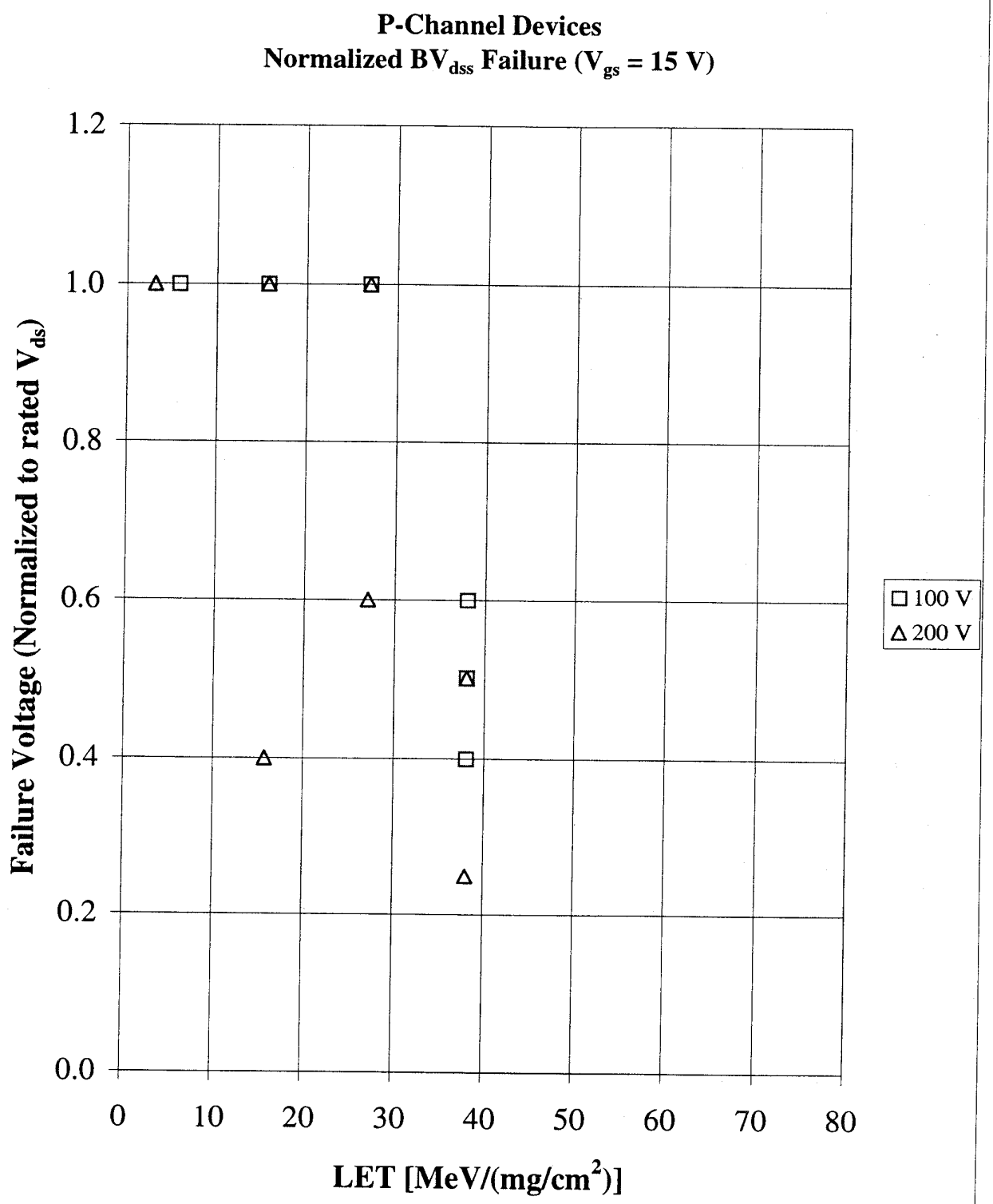
P-Channel Devices
Normalized BVdss Failure (Vgs = 15 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
100 V
200 V

Figure 7