# 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 | IRFF110 | 2N7682 | n | | 10 | 100(N) 100(Ne) 90(Ar) | 60(Cu) | | | | SEGR | Rock/ Aero | 1990 | UCB | |

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| 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<br>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/<br>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<br>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<br>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)<br>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/<br>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/<br>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

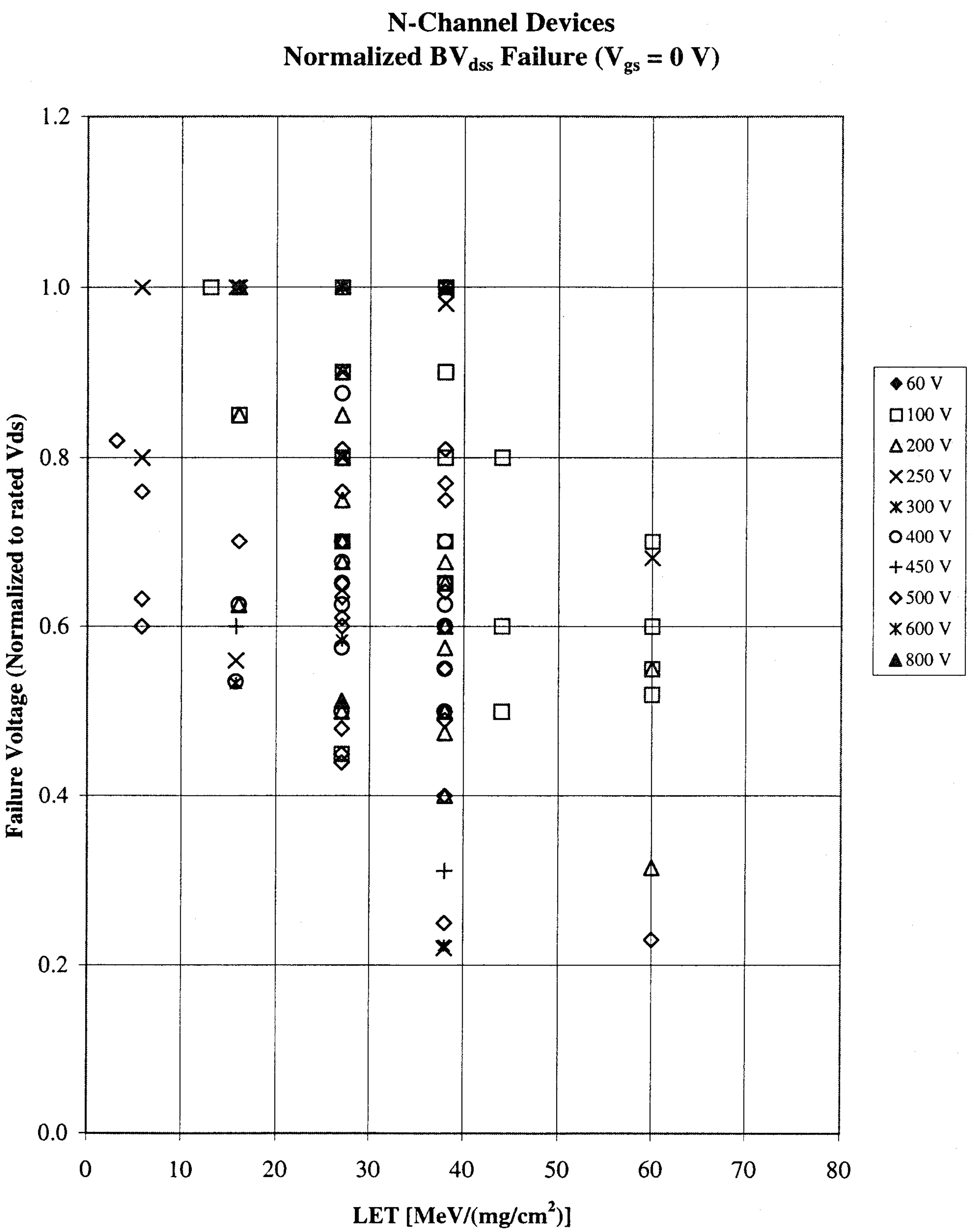
BREL = Boeing Radiation Effects Laboratory, Seattle, WA

JPL = Jet Propulsion Laboratory, Pasadena, CA

NSWC = Naval Surface Warfare Center, Crane, IN

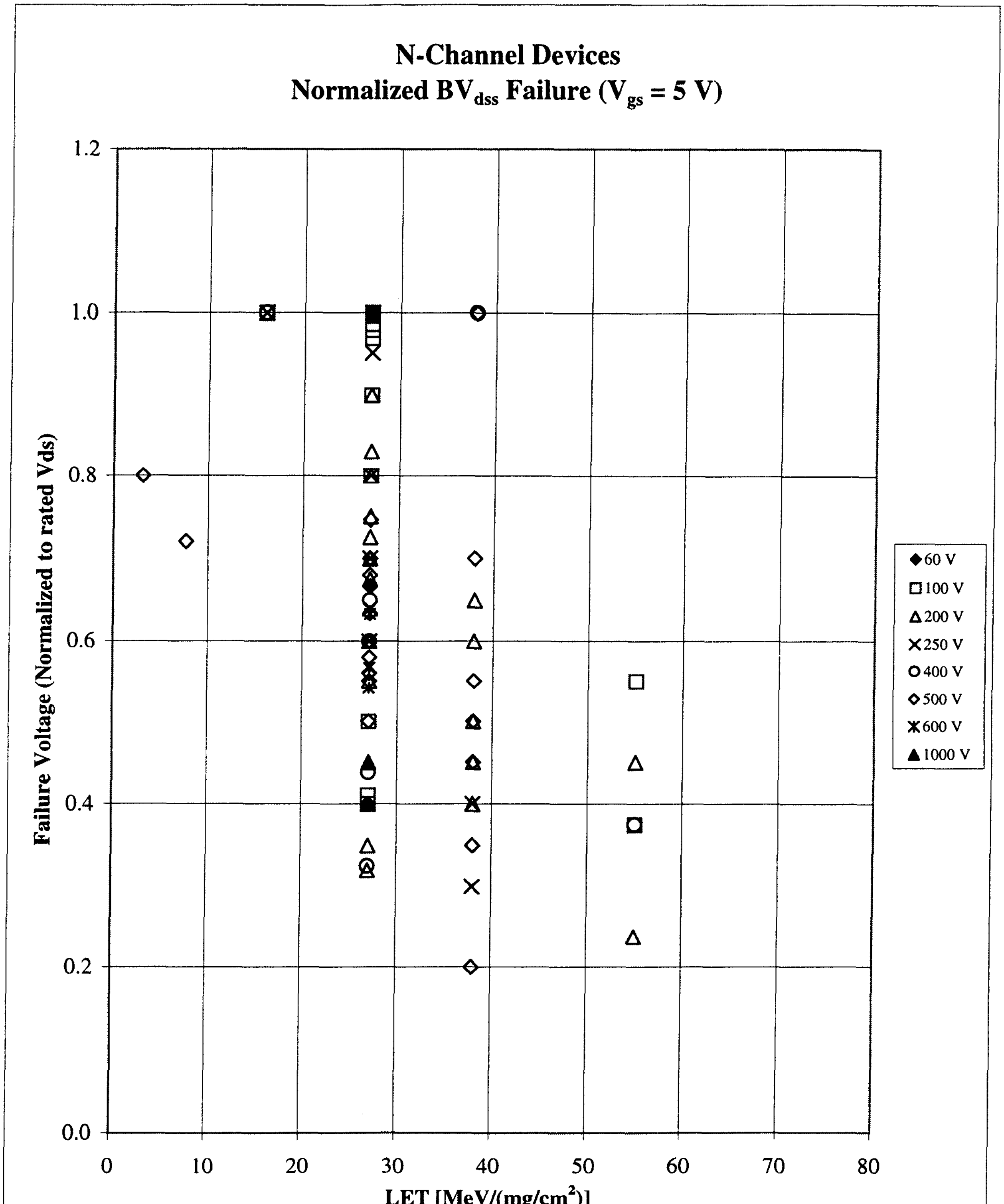
Rock = Rockwell Corp. (now Boeing), Anaheim, CA

SNL = Sandia National Laboratories, Albuquerque, NM



N-Channel Devices
Normalized $BV_{dss}$ Failure ($V_{gs}$ = 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/cm$^2$)]
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 $BV_{dss}$ Failure ($V_{gs}$ = 5 V)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
Failure Voltage (Normalized to rated Vds)
LET [MeV/(mg/cm$^2$)]
60 V
100 V
200 V
250 V
400 V
500 V
600 V
1000 V
Figure 2

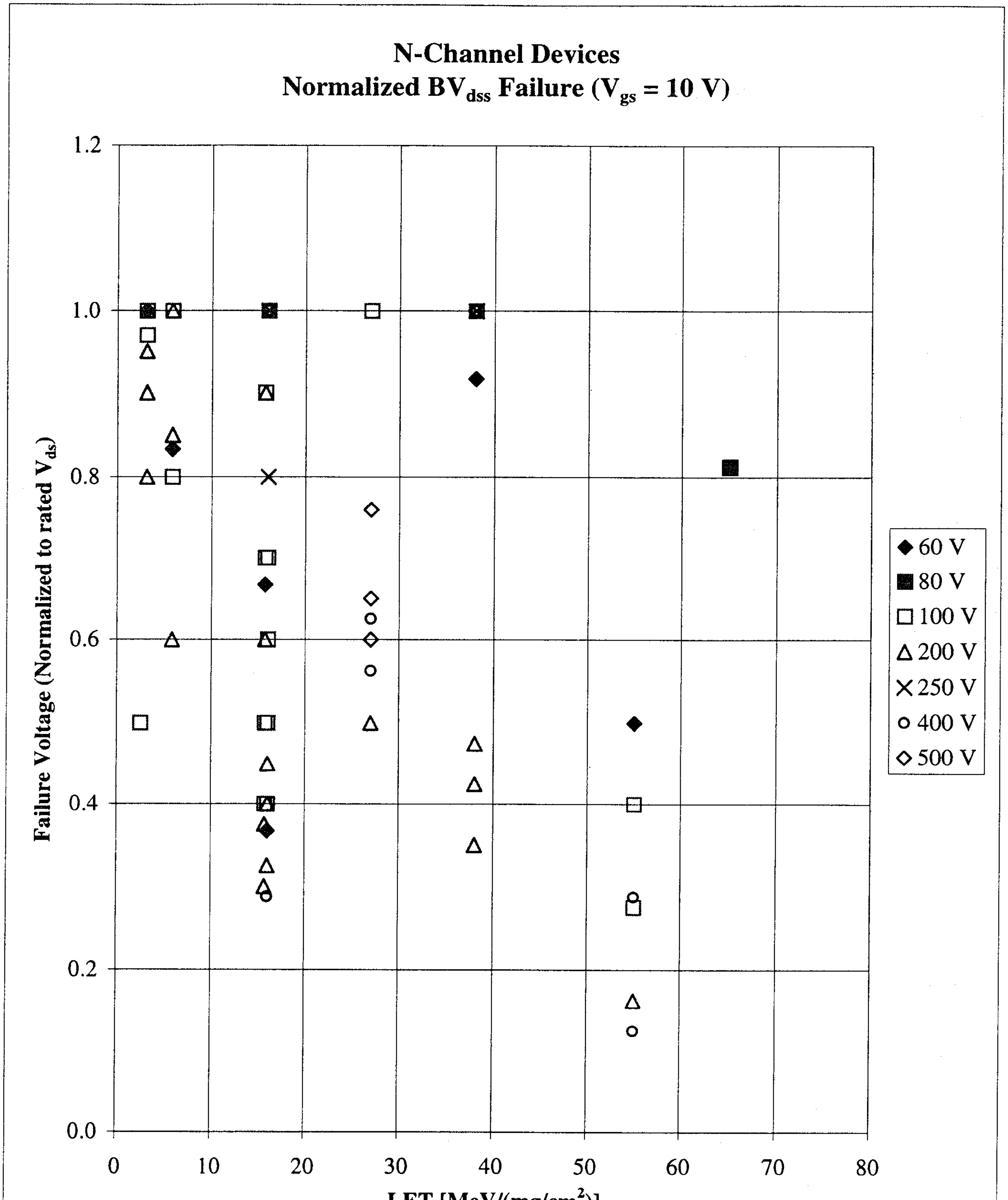

N-Channel Devices
Normalized $BV_{dss}$ Failure ($V_{gs}$ = 10 V)
Failure Voltage (Normalized to rated $V_{ds}$)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm$^2$)]
60 V
80 V
100 V
200 V
250 V
400 V
500 V

Figure 3

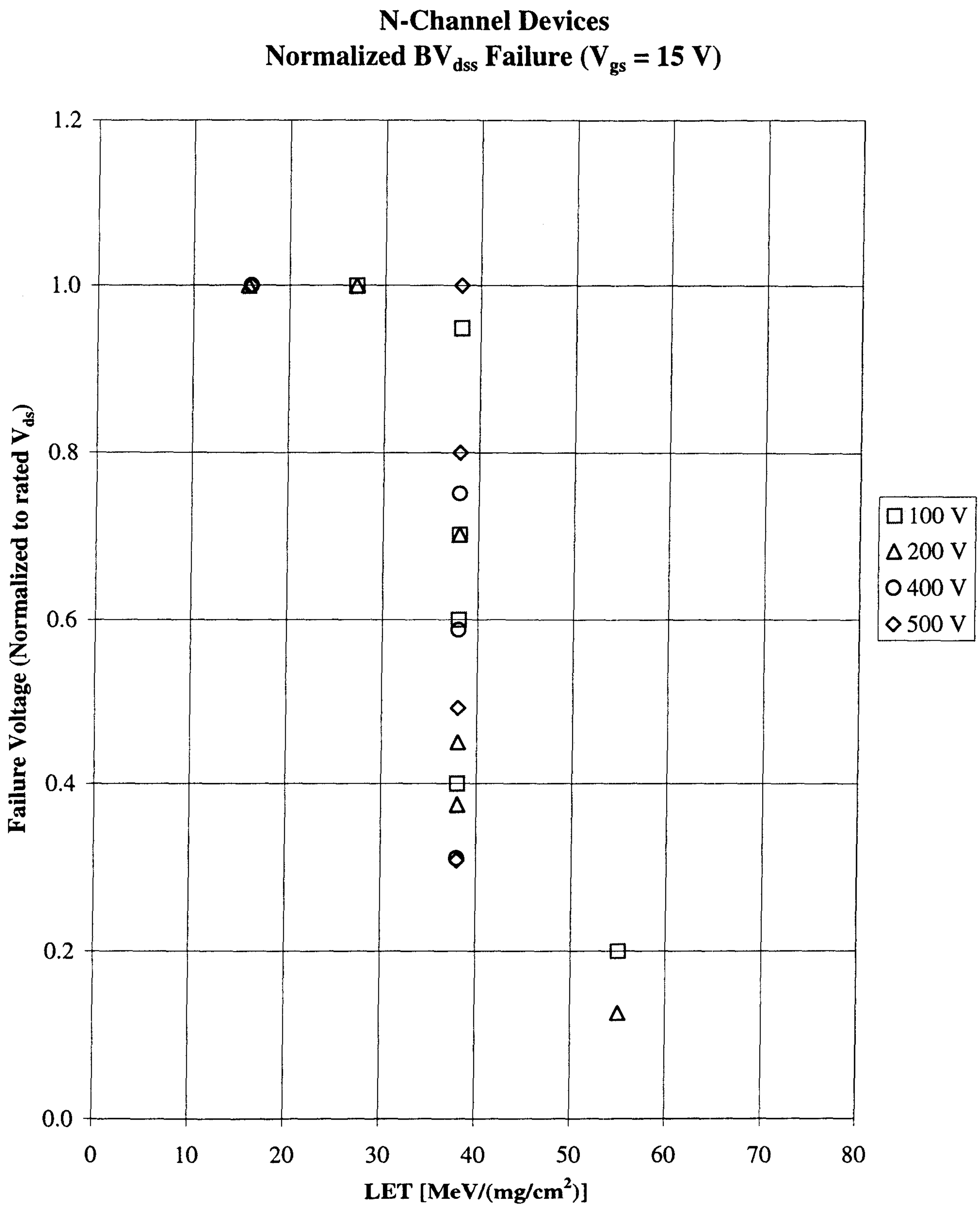
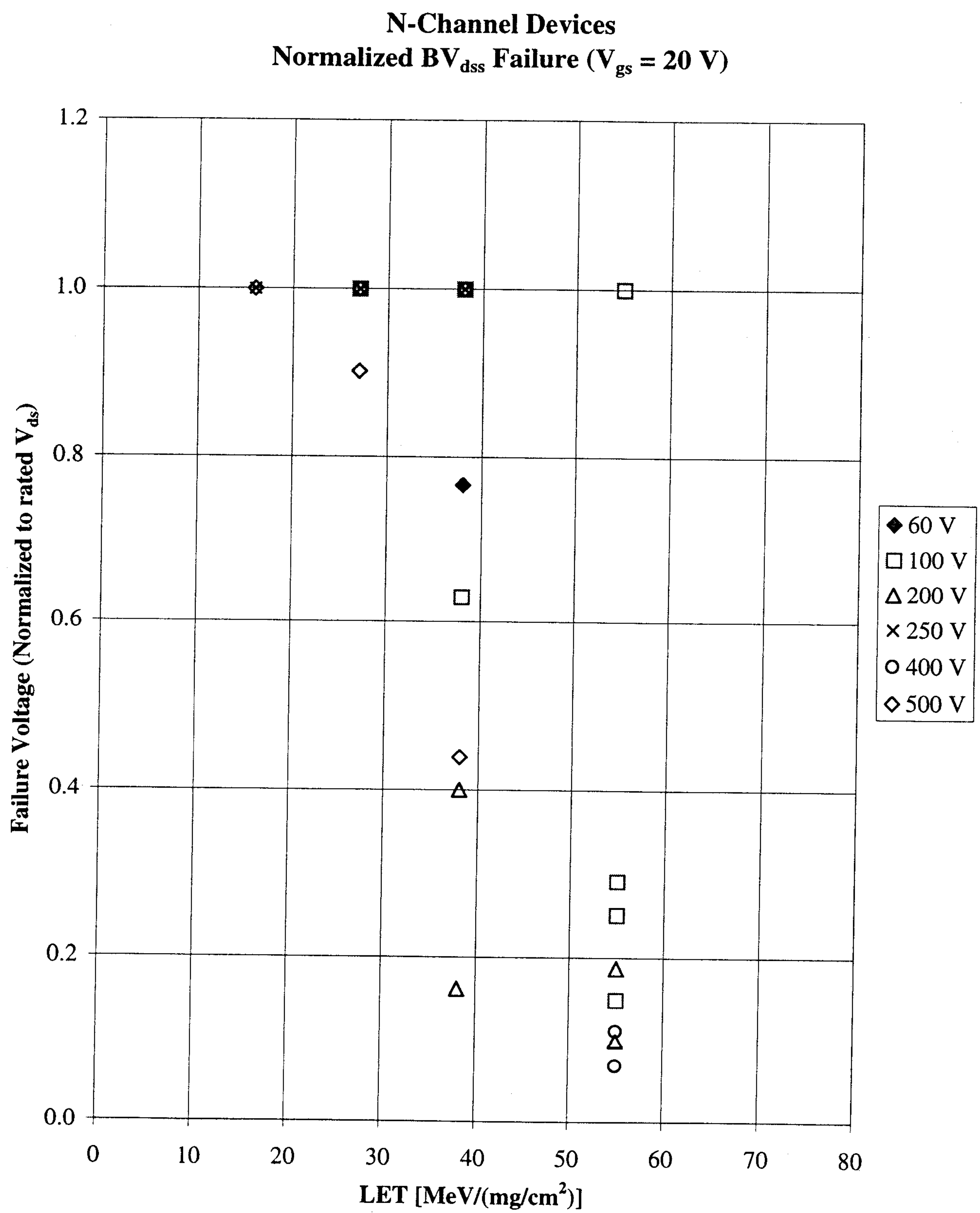
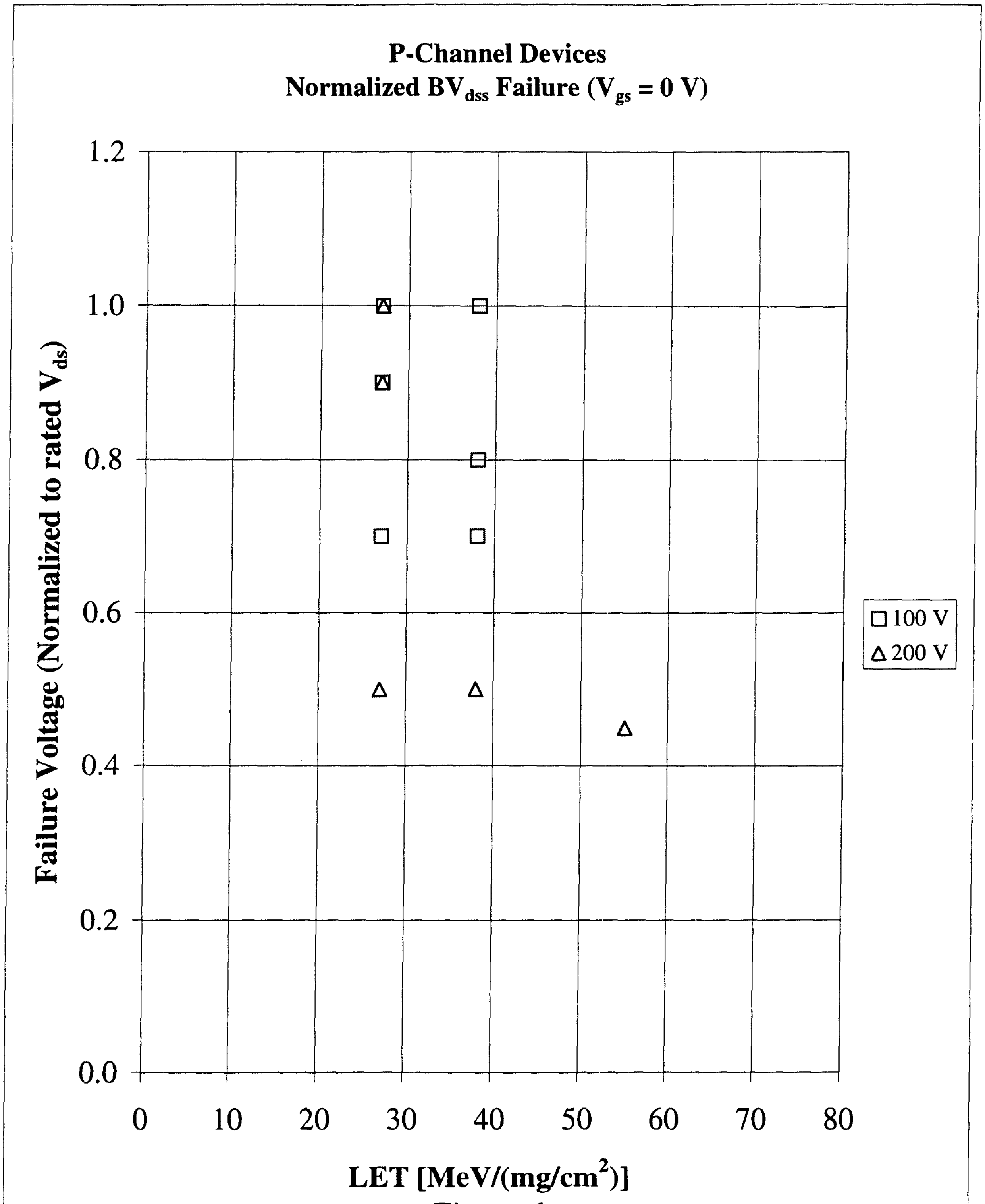

N-Channel Devices
Normalized $BV_{dss}$ Failure ($V_{gs}$ = 15 V)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Failure Voltage (Normalized to rated $V_{ds}$)
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm$^2$)]
100 V
200 V
400 V
500 V

Figure 4


N-Channel Devices
Normalized $BV_{dss}$ Failure ($V_{gs}$ = 20 V)
Failure Voltage (Normalized to rated $V_{ds}$)
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/cm$^2$)]
60 V
100 V
200 V
250 V
400 V
500 V
Figure 5


P-Channel Devices
Normalized BV$_{dss}$ Failure (V$_{gs}$ = 0 V)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
Failure Voltage (Normalized to rated V$_{ds}$)
LET [MeV/(mg/cm$^2$)]
100 V
200 V
Figure 6

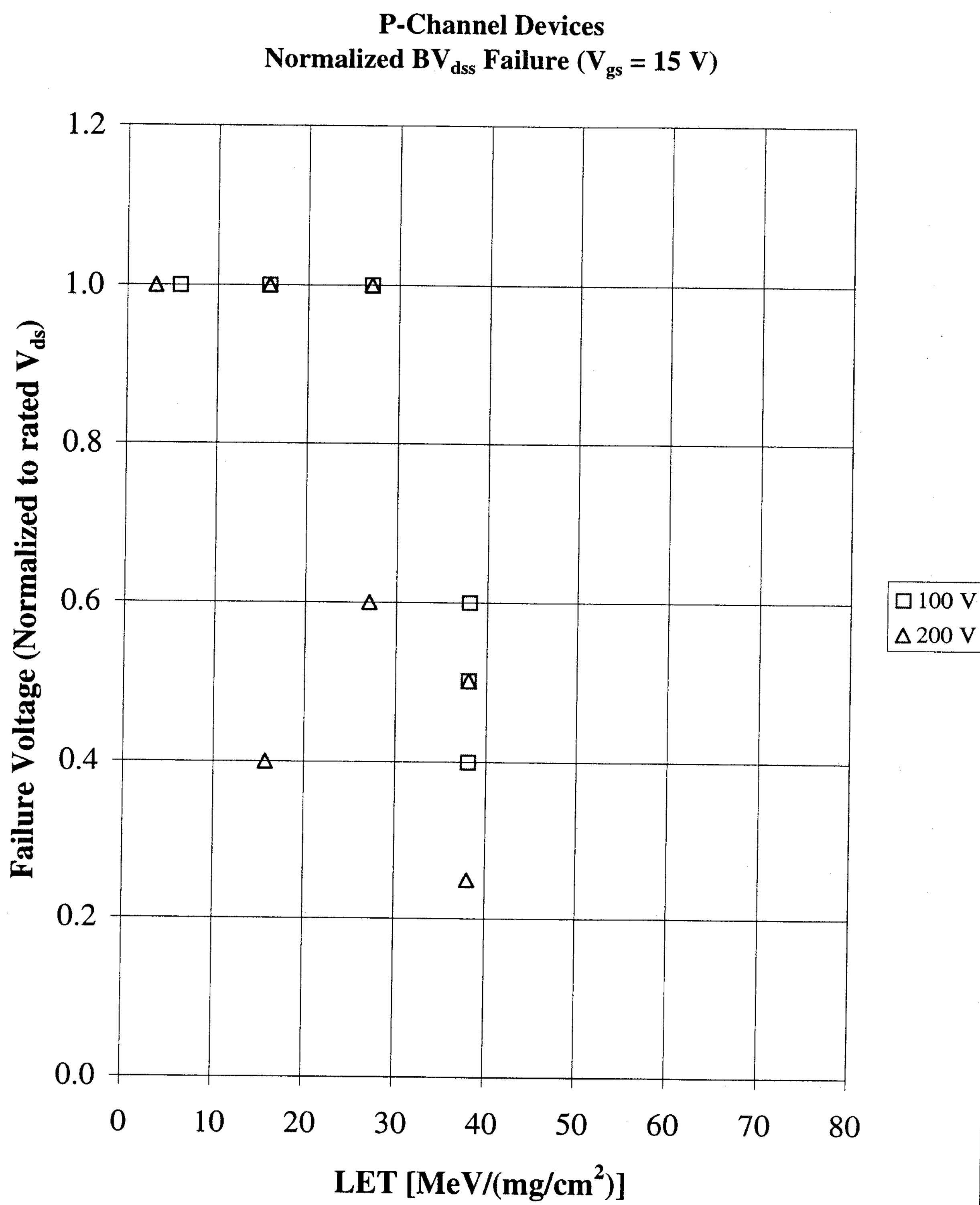

P-Channel Devices
Normalized BVdss Failure (Vgs = 15 V)
Failure Voltage (Normalized to rated Vds)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
LET [MeV/(mg/cm2)]
100 V
200 V

Figure 7