# OBSERVATIONS OF SINGLE EVENT FAILURE IN POWER MOSFETS

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## *Abstract*

This first compendium of single event test data for power MOSFETs provides failure thresholds from burnout or gate rupture for over 100 devices of eight manufacturers. Ordering the data has also provided some useful insights.

## *I. Introduction*

Power transistor single event effects (SEE) test data obtained by The Aerospace Corporation, The Boeing Company, Jet Propulsion Laboratory, NWSC(Crane,IN), Rockwell International , and others have been organized into one compendium here. The intent is to present a nearly comprehensive set of MOSFET data through May, 1994. It is believed, *however,* that some other data may be available that has not been published or brought to our attention. Contributors who desire inclusion in this compendium should contact Don Nichols.

This data set includes both single event burnout (SEB) and single event gate rupture or damage (SEGR or SEGD) of MOSFET power devices. There is no hard line of separation between power devices and lower power devices, nor is there a demonstrated immunity of the latter to SEE. There is some data (not shown) for SEB of npn bipolar devices but none (as yet) of burnout of pnp bipolar devices. The bipolar data is still very limited and much of it was taken by Titus et al (1) who have refrained from identifying manufacturers. Thus the category of bipolar power transistors is still very rudimentary.

The purpose of the present work is to:

(1) provide design engineers with operating voltage limits (max $V_{DS}$ for a specified $V_{GS}$) of tested devices.

(2) identify unspecified process variables relevant to SEE response

(3) identify those parameters characterizing SEE response

(4) present trends that permit extrapolation from the existing data set,

## *II. Testing Approaches*

There are several possible testing approaches that have been considered, but two are of fundamental importance. One approach attempts to measure the SEB/SEGR cross section vs $V_{DS}$ of a device for a given test ion (or equivalently a given LET) for a fixed gate source voltage ($V_{GS}$) and temperature. This type of cross section should not be confused with the LET-dependent cross sections tabulated for soft errors in ICs. The transistor cross section equals zero at lower $V_{DS}$ and rises very rapidly only at its threshold $V_{DS}$ (almost like a step function); then tends to level off at somewhat higher $V_{DS}$. So far, no experiment has yet extended the data far beyond threshold, Then, to obtain SEE rates for a specified environment, one must perform the same experiment for several other ions to establish the LET threshold and cross sections for a few different ions (LETs) above threshold. This approach requires a large sample size and still does not provide an adequate basis for calculating the device upset rate. All of the preceding cross sections must also be repeated for angles of beam incidence greater than zero.

The second approach seeks simply to identify the threshold voltage $V_{DS}(th)$ for failure for a given ion (usually Ni/Fe or Br/Kr), $V_{GS}$ and temperature. The selected ion should represent a realistic worst case for the environment. The latter approach indicates a voltage operating limit to the designer who can apply a derating factor, but it also offers

" little chance, to estimate the failure probability if one operates above threshold.

The data tabulated here in one extended table presents threshold $V_{DS}$ for several groups of ions at a few selected gate source voltages $V_{GS}$, following the second (recommended) approach.

A nearly standard technique* for measuring the threshold drain-source voltage $V_{DS}$ consists of the following steps:

(1) Prior to any irradiation, measure the drain source current at rated BV for $V_{GS}=0$, or alternatively measure the actual breakdown $V_{DS}$ for the same conditions. One should also measure the gate-source current at maximum rated gate voltage (usually 20 V) for $V_{DS}=0$. These measurements establish the normal operating currents.

(2) Choose a single gate voltage $V_{GS}$ (start with the least susceptible zero voltage) and hold it constant for each subsequent irradiation step, for successively larger $V_{DS}$. At the end of each irradiation step of 105 ions/cm$^2$, change the bias conditions to those used in step (1) to determine the two currents $I_{GSS}$ and $I_{DSS}$.

(3) Failure is either (1) SEGR as evidenced by a large permanent increase in gate current ranging between a fraction of a milliamp up to the circuit limit (say, 10 amps) or (2) SEB (burnout) evidenced by a short across source. and drain as well as a gate short.

(4) Delayed Failures-- On several occasions JPL and other test organizations have seen delayed types of SEGR. On some occasions, the gate currents increased to -1 mA during irradiation and then increased again to the circuit limit during post-beam tests where, as always, $V_{GS}$ was reset to 20V. " Another type of SEGR failure occurs when the drain-source voltage is incremented for the next test,

## III. Supporting Studies

Several collateral tests have been performed by now. Nichols et al (2), Fischer (3) and Tastet (4) have demonstrated that higher grazing angles of ion incidence have less effect on SEB and SEGR than normally incident irradiation. Hence the complications involved in calculating SEE rates by dealing with an effective LET vs incident ion angle are simplified. (In actuality, there is no known formal method for calculating rates under these conditions for a specified environment. Since the calculation is relatively easy when compared to those for incident ions on other microcircuits, it is expected that such a rate calculation method will be developed soon.)

High temperature tests have been performed (2,5,6) showing that SEB is greatly reduced at higher temperatures due to phonon interference with the avalanche burnout mechanism. In contrast, high temperatures tend to promote SEGR to a varying degree.

Nichols and Waskiewicz have noted that most transistors that are supposed to differ only by die size (e.g. by having a different number of the same size transistor elements or cells) have similar breakdown voltages as expected. However, there are a few occasions when such devices yield widely different SEE results. Waskiewicz notes that the dielectric oxide breakdown voltage (an uncontrolled parameter) may be responsible for wafer-to-wafer and device-to-device variability to SEE.

Oberg has demonstrated that the failure threshold voltages increase with device rated breakdown voltage as expected, but not at a proportionate rate. The threshold voltage as a percentage of breakdown voltage BV tends to decrease as BV increases.

## *IV. Organization and Scope of Data*

This paper presents SEB and SEGR data for MOSFETS in Table 1 for all known data taken up to May, 1994. Eight manufacturers are represented, with especially extensive data for International Rectifier (INR) and Harris (HAR). Most data are for commercial parts; but Harris, Ixys and INR have developed devices which are resistant to total dose. These rad hard devices often turn out to be less susceptible to burnout as well, but some hardening techniques (such as oxide thinning) may cause the devices to be more susceptible to SEGR.

The data have been provided directly by testers or taken from published records of tests performed by many organizations. Most data is taken at ambient temperature; data taken at higher temperatures is noted in the "Remarks" column. One advantage of this type of data compilation is to point out and exclude inconsistent data. One example is the data set taken in 1987 that used low energy ions at the University of Washington tandem Van de Graaff. More recent tests at that facility, by Boeing, with the "Booster" accelerator, utilized higher energy ions and are therefore consistent with data taken at other accelerators. As can be seen, the remaining test results demonstrate a strong correlation between higher-LET incident ions and a lower acceptable drain-source voltage threshold. There is also a strong correlation between higher off gate-source voltage $V_{GS}$ and lower $V_{DS}$ thresholds.

The data are grouped in rows by device manufacturer with the smallest manufacturer data groups listed first. Within each manufacturing group, devices with the lowest breakdown voltage are listed first-- first n-channel and then p-channel. Devices that are very similar, or the same devices tested with different conditions (e.g. $V_{GS}$) are grouped in touching,

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*At present, no standard test approach has been described. The second approach outlined here is recommended when a large number of device types must be evaluated for a proposed system.

adjacent rows. The columns list manufacturers, device number(s), channel type, and test sample size. It is observed that samples are never large enough to provide valid statistics, nor a characterization of maverick behavior that is occasionally noted. Most data, however, are fairly repeatable. Subsequent columns list the rated breakdown voltage (BV) and gate-source voltage $V_{GS}$.

The next five columns group the ions. The first column is for low-LET ions having LETs less than that of the dominant Ni/Fe/Co/Cu group included in column two. This first group is useful in judging the adequacy of postulated theories (See for example, ref. 3). It is now often accepted that a characterization with a single ion of the second group may be all that is needed for project requirements. This view is supported by two facts: (1) those heavier ions having a higher LET have fluxes in outer space two or three orders of magnitude smaller than that of the Ni/Fe group, and (2) there is no need to account for enhanced effects from grazing-angle collisions having a high "effective" (angle-dependent) LET. The third group in the table includes Br and Kr (LET=37 MeV/mg/cm$^2$), traditional high LET ions at the. Brookhaven Van De Graaff (BNL) and U. C. Berkeley 88-inch cyclotron (88), respectively. The fourth group includes the highest LET ions easily available at the aforementioned facilities. The fifth column includes data from very high energy (10- 100 MeV/amu) facilities: the Berkeley Bevalac (now defunct) and GANIL (France). It is this last group of ions that present some inconsistencies with the lower energy LET characterizations, for reasons that have not yet been fully explained.

The remaining set of columns provide the failure mode, the test group, test date, ion facility and "Remarks." It is useful to know that INR uses 7000 and 8000 numbers to specify n-channel devices with 100 Krad and 1 Mrad total dose tolerance, respectively; 9000 numbers for p-channel devices with 100 Krad tolerance. The first INK mfr number (on the left) relates to the breakdown voltage; the second number is related to the dic size-- the larger this number, the larger the dic size and (usually) the larger number of individual cells. INK's letter "H" in the third place from the left of the prefix means that the devices arc especially designed to bc radiation resistant to total dose. It turns out that such devices are also very resistant to single event effects as well. The fourth letter of INR (which may be "}1") and third letter of' HAR devices is a package designation not expected to affect SEB/SEGR data. Harris denotes rad hard tolerance with a suffix after the device number; R= 100 Krad and H= 1 Mrad.

## *V. Future Directions*

The large body of test data have led to generation of global models of SEB and SEGR. Wc know such models are not the whole story, for burnout data often show meltdown located at physical stress points, such as the edges of metal overlayers. We also note again that f~eld-dependent irradiation models arc not sufficient to explain the delayed failures caused by bias changes following irradiation.

The SEB model first mentioned by Waskiewicz (5) and Hohl (7, 8) has been polished and extended by Wrobel (9). This model seemed sufficient, but it has been challenged, at least in part, by Ku boyama (1 O) with an experimentally-based numerical analysis. Hence the picture of SEB cannot be considered a closed subject.

The model for SEGR has yet to be produced. The most recent attack on the problem was provided by the group at the University of Arizona (1 1,12) who attempt to match a numerical analysis of the semiconductor region to properties of the gate oxide. Their computerized approach, using a n-channel cylindrical (r,z) transistor cell, describes a normally incident ion track along the z-axis whose holes migrate to the oxide-semiconductor interface. The model assumes that the holes are not trapped at the interface, but that they pile up there before drifting transversely to the grounded body. The charge buildup at the interface is thus a sensitive function of the hole mobility and the RC time constant of the interracial storage capacitor. The model shows *the* expected variation in voltages and currents; it also demonstrates that the maximum tirnc-dependent fields across the oxide are indeed sufficient to exceed the critical field characterizing oxide breakdown.

Some limitations of the above semiconductor model were amplified later (ref. 12) in order to explain the effect of grazing angle irradiation and higher temperatures on SEGR. Increased SEGR susceptibility at higher temperature is attributed to (1 ) increased concentration of holes at the interface due to decreased radial diffusion of deposited holes from the center of the ion's filament (track). and (2) a decrease of hoic mobility.

The reduced chance of SEGR at higher angles, according to numerical simulations indicated by ref. (12), comes from the fact that the holes deposited in the oblique track arc still driven vertically to the oxide-semiconductor interface. Because the hole charge is now spread over a wider area at the interface, a lower electric field is generated across the oxide.

Although neither description (of SEGR and SEB) can be considered complete, it seems clear that the greatest deficiency lies in our understanding of the oxide. Is there really a wcil-defined critical field and if so, what mechanism causes the abrupt collapse (short-circuiting) of the oxide? How long must the critical field last in the oxide before breakdown occurs? What controlled and uncontrolled oxide fabrication parameters affect oxide breakdown? Is there a first-stage incipient breakdown induced by heavy ions that is triggered by a later change. to higher applied bias? What role do mechanical stresses, impurities, structures and surfaces play? Can we find an oxide process resistant to SEGR and to total ionizing dose?

Some possibilities for further numerical analysis still remain. 1s a fully 3-dimensional code required to explain why a change in bias across the oxide is observed to be more influential than an equal change in bias across the drain-source? Can we develop a 3-D code adequate to predict the performance of novel devices? Do possible interface traps play a significant role in SEGR models and their temperature dependence?

## *VI. Conclusion*

This first compendium of SEE (SEB and SEGR) effects in power MOSFETs given here will be useful for designers of satellite and space systems. Someextrapolations may be warranted, and some cautionary observations are also provided. Testing with only one ion may be acceptable for some system requirements.

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## 4 Power MOSFET Data

Compilation of Single Event Data for Power MOSFETs-- Threshold Voltages (Vds) for Normally Incident Ions for Burnout (SEB) and Gate Rupture (SEGR)

| | | | | | | | The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mfr | Mfr Number | Generic Nc | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET=27 | Br or Kr LET-38 | High Z Ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
| Ixys | 20N60 | | n | | 5 0 0 | 5 | | 280 | | | | SEB | B WP 01 | “11/93 | 88 | Oberg Ambient . 25 deg C . |
| Ixys | 20N60 | | n | | 500 | 5 | | 300 | | | | SEB | B WP-01 | -11/93 | 88 | Oberg Temp=100 deg C |
| Ixys | 10 FA100 | | n | 3 | 1000 | 5 | | 450 | | | | SEB/SEGR | B WP-01 | 6/93 | 88 | W Will DC SC9019 Ambient = 45 deg C |
| Ixys | 10N100 | | n | | 1000 | 5 | | 450 | | | | SEGR | B WP-01 | 6/93 | 88 | W Will DC SC9019 Temp . 100 deg C |
| APT | APT40M42 | | n | 3 | 400 | 12 | | 200/225 | | | | SEB | HON WP-2 | 2/93 | BNL | DC9302 |
| | continued | | | | | +/-12 (dynamic) | | | 200/225 | | | SEB | | | | |
| APT | 1001R1AN | | n | >2 | 1000 | 5 | | 400 | | | | SEB/SEGR | B WP-01 | 4/93 | 88 | DC 9126 W Will See next entry |
| APT | 100 IR1AN | | n | >2 | 1000 | 5 | | 450 | | | | SEB/SEGR | B WP-01 | 4/93 | 88 | DC 9126 W Will 100 deg C implies SEB |
| GEC | IRF150 | 2N6764 | n | 2 | 100 | 10 | >95(Ne),70(Ar) | 70(Cu) | | | | SEB | R/A | 1990 | 88 | |
| GEC | IRF250 | 2N6766 | n | 1 | 200 | 10 | 180(N), 170(Ne), <80( Ar) | | | | | SEB | R/A | 1990 | 88 | |
| UTR | IRFF320 | 2N6792 | n | | 300 | 2? | | <260(Cu) | | | | SEB | R | 1990 | 88 | Compare to INR device |
| SIL | | 2N6660 | n | | 60 | 10 | 27 | | | | | SEB | A | “6/88 | 88 | Koga |
| SIL | | 2N6660 | n | 1 | 60 | 10 | 60( N),50(Ne),40(Ar) | 22(Cu) | | | | SEB | R/A | 1990 | 88 | |
| SIL | | 2N6660 | n | | 60 | 5 | | 40( N,) | | | | SEB | P | “7/93 | BNL | Revised fab last 2 yrs DC9230 Bob Ferndon |
| SIL | IRFF130 | ,2 N6796 | n | 2 | 100 | 10 | 100(N),100(Ne),70(Ar), | 50(Cu) | | | | SEB | R/A | 1990 | 88 | Compare to INR device |
| SIL | IRF150 | 2N6764 | n | 1 | 100 | 10 | 80(Ne),<50(Ar) | 40(Cu) | | | | SEB | R/A | 1990 | 88 | |
| SIL | IRF250 | 2N6766 | n | 2 | 200 | 10 | 160(N), 60(Ar) | | | | | SEB | R/A | 1990 | 88 | |
| SIL | IRFF230 | 2N6798 | n | | 200 | 12 | | 180” | | | | SEGR | 9 WP-01 | 10/93” | UW | Oberg 100 deg C Worst case for SEGR |
| SIL | IRF350 | 2N6768 | n | | 400 | 10 | | <120(Cu) | | | | SEB | R | 1990 | 88 | |
| SIL | 4 3 0 family | 2N6802 | n | | 500 | 5 | | 300 | | | | SEB | B WPO1 | “4193 | 88 | Ambient=45 deg C |
| | (continued) | | | | | 12 | | 300 | | | | SEB/SEGR | B WP-01 | “10/93 | UW | Temp=100 deg C |

Manufacturers APT= Advanced Power Technology, GE C=Gen Electric, HAR= Harris, INR= Int'l Rectifier, Ixys= Ixys Corp RCA. RCA, S1! Siliconix, UTR- Unitrode

Testers A-Aerospace (R Koga & W Crain), B= Boeing (D Oberg, J L Wert & W Will), C-Crane NWSC (J Titus), HON-Honeywell (J Pollock, MDSSC,Houston, 713-283-1934,, J JPL (D Nichols, 818 354 5787).

JH- John Hopkins APL (J Kinnison), R=Rockwell (A Waskiewicz), S-Sandia (T Fischer), MM AS- Martin Marietta Astrospace (James Coleman, Valley Forge,PA), ESA (Len Adams)

Facilities 88- 88-in cyclotron (Berkeley), Bev= Berkeley Bevalac, BNL= Brookhaven Nat'l Lab Van de Graaff, GANIL-French National High Energy cyclotron, UW= U of Wash , Van de G (low & medium energy modes)

## 4-Power MOSFET Data

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic No | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET=27 | Br or Kr LET=38 | High Z Ions | High Energy Ions | Failure | Test Org | Dale | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RCA | 19N10 |  | n |  | ,100 | ? |  |  |  |  |  | SEB | R | 1990 | Cf 252 data exists |  |
| RCA | IRF150 | ‘2 N6764 | n |  | 100 | 10 | 100( N),100(Ne),50(Ar),<50(Cu) |  |  |  |  | SEB | R | 1990 | 88 |  |
| RCA | 12P10 |  | p | 1 | 100 | 10 |  | Hard(Cu) |  |  |  | N/A | R/A | 1990 | 88 | DC8445 |
| RCA | IRF9130 | ‘2 N6798 | p | 1 | 100 | 10 |  | Hard (Cu) |  |  |  | N/A | PIA | 1990 | 88 |  |
| RCA | 30N15 |  | n |  | ?50 | ? |  |  |  |  |  | SEB | R | 1990 | Cf 252 data exists |  |
| RCA | RFM12N18 |  | n |  | 180 | o | 100 | 90 | 65 |  |  | SEB | A | "5/88 | 88 | Koga |
| QCA | IRF230 | 2N6758 | n |  | 200 | 1 o |  | 105 |  |  |  | SEB | A | "6/88 | 88 | Koga |
| RCA | IRF230 | 2N6758 | n |  | 200 | '27 |  | <100(Cu) |  |  |  | SEB | Q | 1990 | 88 |  |
| RCA | IRFF230 | 2N6798 | n |  | 200 | 2? |  | <90(Cu) |  |  |  | SEB | R | 1990 | 88 |  |
| RCA | IRF250 | 2N6766 | n | 1 | 200 | 10 | 180(N),120(Ar), | 80(Cu) |  |  |  | SEB | R/A | 1990 | 88 |  |
| RCA | 25N20 |  | n | 1 | 200 | 10 | "200(N), 200(Ne), 180! Ar),<70(Cu) |  |  |  |  | SEB | R/A | 1990 | 88 |  |
| INR | IRFM054 |  | n |  | 60 | 5 |  | No failure at 60" |  |  |  | N/A | B WP-01 | 4/93" | 88m | DC 9212 W Will |
| INR | IRHM7054 |  | n |  | 60 | 0 |  | 60(Ni) |  |  |  | N/A | R WP 04 | "7/93" | BNL | DC9242 Bob Ferndon 7/1 3/93 |
|  | continued |  |  |  |  | 5 |  | 60(Ni) |  |  |  | N/A | R WP-04 | "7/93- | BNL | DC9242 Bob Ferndon 7/1 3/93 |
| INR | IRF110 | 2N6782 | n |  | 100 | 0 |  | 70/80(Ni) | 50/70(Br) |  |  | SEB | ESA | "1/94 | BNL | 9039B, Harwell Rept AEA RS 1348 |
| INR | IRFF110 | 2N6782 | n | 1 | 100 | 10 | 100(N),100(Ne),90(Ar) | 60(Cu) |  |  |  | SEB | R/A | 1990 | 88 |  |
| INR | IRF120 | 2N6788 | n |  | 100 | "o |  | Hard(Ni) | 80/90(Br) |  |  | SEB | ESA | "1/94 | BNL | 9228G, Harwell Rept AEA RS 1348 |
| INR | IRF120 |  | n |  | 100 | 2? | 95(Ar) | <55(Cu) |  |  |  | SEB | R | R 1990 | 88 |  |
| INR | IRF120 | 2N6788 | n |  | 100 | 5 |  | 90 |  |  |  | SEB | B | "12/92 | UW | Oberg 23 deg C Note failure mode vs temp |
|  | continued |  |  |  |  | 5 |  | 80 |  |  |  | SEGR | B | "12/92 | UN | Oberg 80 deg c |
| INR | IRFF120 | 2N6788 | n |  | 100 | 2? |  | <60(Cu) |  |  |  | SEB | R | 1990 | 88 |  |
| INR | IRH130 |  | n |  | 100 | 0 |  |  | Hard @ 100(Br) | 501 60(I) |  | ? | C | unknown | BNL |  |
|  | continued |  |  |  |  | 10 |  |  | Hard @ 100(Br) |  |  | N/A | C | unknown | BNL |  |
| INR | IRHF130 |  | n |  | 100 | o |  |  | Hard @ 100(Br) |  |  | N/A | J | 1991 | BNL |  |
|  | continued |  |  |  |  | 75 |  |  | <100(Br) |  |  | SEGR | J | 1991 | BNL |  |
|  | continued |  |  |  |  | 15 |  |  | <100(Br) |  |  | SEGR | J | 1991 | BNL |  |

# 4-Power MOSFET Data

## The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic No | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET.27 | Br or Kr LET=38 | High Z ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | IRF130 | 2N6756 | n | 3 | 100 | 10 | 100(N),100(Ne),90(Ar) | 60(Cu) | | | | SEB | R/A | 7990 | 88 | |
| INR | IRF130 | 2N6796 | n | | 100 | 0 | | 70/80(Ni) | 60/70(Br) | | | SEB | EsA | "1/94 | BNL | 8915A, Harwell Rept AEA RS 1348 |
| INR | IRF130 | 2N6796 | n | | 100 | 0 | | 85 | | | | SEB | A | 6/87 | 88 | Koga |
| INR | IRF130 | 2N6796 | n | | 100 | 5 | | Hard | | | | N/A | B WP-01 | 3/93 | 88 | Oberg DC9236 |
| INR | IRFF130 | 2N6796 | n | 5 | 100 | 10 | 100(N),100(Ne),90(Ar) | 60(Cu) | | | | SEB | R/A | 1990 | 88 | Compare to S!L part |
| INR | IRFF130 | 2N6796 | n | | 100 | o | | | 82(Br) | | | SEB | s | 1990 | BNL | 220 MeV Br has range=28 microns |
| | continued | | | | | 10 | | | 105(Br) | 58(Au) | | SEGR | S | | BNL | 330 MeV Au has range=31 microns |
| INR | IRF140 | | n | | 100 | o | | Hard(Ni) | 70/80(Br) | | | SEB | ESA | "1/94 | BNL | 9203E, Harwell Rept AEA RS-1348 |
| INR | IRF150 | 2N6764 | n | | 100 | 0 | | 90/100(Ni) | 70/80(Br) | | | SEB | E 5A | "1/94 | BNL | 9228G, Harwell Rept AEA RS 1348 |
| INR | IRF150 | 2N6764 | " | 3 | 100 | 10 | 100(Ne),70(Ar), | 50(Cu) | | | 40/60(12 GeV La Bev ) | SEB | R/A &J | 1990 | 88 | JPL Bevalac ion LET=30 6/88 |
| INR | IRF150 | 2N6764 | n | | 100 | o | 105 | 75 | 75 | | | SEB | A | "5/92 | 88 | Koga |
| INR | IRF150 | 2N6764 | n | 3 each | 100 | off | 1001208 MeV Cl) | 70(Ni) | 65(Br) | 55(I) | 50(! to 4 GeV Xe GANIL) | SEE | CNES | 11/90 | BNL | 3 GANIL ions Tastet, RADECS91 |
| INR | IRF150 | 2N6764 | n | | 100 | 0 | 100(208 MeV Cl) | >80(Fe) | | | 80/100(>1 GeV Fe) Bev | SEB | J | 6/88 | BNL | Two Fe at Bevalac, each LET<6 |
| INR | IRH150 | | n | | 100 | 0 | | 100(Fe) 100(Cu) | 100(Kr) | | 60/100 (12GeV) La Bev | SEB | J & R | 1990 | 88 | JPL at Bevalac-June 1988 |
| | continued | | n | | 100 | 10 | | 100(Cu) | 90/100(Kr) | | | ? | R | 1990 | 88 | Waskiewicz & Groninger, DNA Rept 2/90 |
| INR | IRHF7110 | | n | | 100 | 2 | | Hard a, 100(Ni) | Hard a! 100(Br) | | | N/A | R | 7/92 | BNL | 90 deg C |
| | continued | | | | | 15 | | Hard at 1OO(NI) | 70(Br) | | | SEGR | R | 7/92 | EYVL | 90 deg c |
| INR | IRHF7130 | | n | | 100 | 2 | | Hard at 1OO(NI) | Fail at 100(Br) | | | SEGR | R | 7/92 | BNL | 90 deg c |
| | continued | | | | | 15 | | Hard at 100( Ni) | 60(Br) | | | SEGR | R | 7/92 | BNL | 90 deg C |
| INR | IRHM7130 | | n | | 100 | 5 | | 80 | | | | SEGR | 9 WPO1 | 1/93" | UW | 100 deg C DC 9112 |
| INR | IRH7150 | | n | 6 | 100 | 0 | | | Br Only one o! 6 fails, with 60/70 VDS | | | SEB | J | 91/92 | BNL | A maverick |
| | continued | | | 4 | | 15 | | | 60/80(Br) | | | SEGR | J | 91/92 | BNI | Data @100 deg C exists for Vgs-15 only |
| INR | IRH7150 | | n | 2/3 ea | 100 | off | | 100(Ni) | | | >>80(Xe) GA NIL | N/A | CNES | 11/90 | GANIL | 3 GANIL ions Tastet, RADECS91 |
| INR | IRH7150 | | n | | 100 | 0 | | | Hard @ 100(Br) | .1 O()(I) | | ? | c | unknown | BNL | |
| INR | IRH7150 | | n | | 100 | 0 | | | Hard @ 100 (Kr) | >100(Xe) | | N/A | A | "5/92 | 88 | Koga reports no SEB up to 150V |
| INR | IRFG6110 | | n&p CMOS | | 100 | 2 | | 85(Fe)--p ch only | | | | SEB onl | MM AS WP2 | "5/93" | BNL | DC 9118 No SEGR No SEB p-ch devices |
| INR | 9120 family | 2N6845 | p | | 100 | 2 | | Hard @ 100(Ni) | Hard @ 100(Br) | | | N/A | R WP 4 | 8/92 | BNL | DC9218, 90 deg C |
| | continued | | | | | 15 | | Hard @ 100(Ni) | 60(Br) | | | SEGR | R WP-4 | 8/92 | BNI | DC9218 90 deg C |
| INR | IRFF9122 | | p | 1 | 100 | 10 | | Hard(Cu) | | | | N/A | R/A | 1990 | 88 | DC8511 |

## 4-Power MOSFET Data

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfi | Mfr Number | Generic Nc | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET.27 | Br or Kr LET=38 | High Z ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | 9 1 3 0 family | 2N6804 | p |  | 100 | 2 |  | Hard @ 1OO(NI) | Hard @ 100(Br) |  |  | N/A | R WP-4 | 8/92 | BNL | DC9141 90 deg c |
|  | continued |  |  |  |  | 15 |  | Hard @ 100(Ni) | 50(Br) |  |  | SEGR | R WP-4 | 8/92 | BNL | DC914 1 90 (leg C |
| INR | IRHF9130 |  | o | 5 | 100 | 0 |  | Hard @ 100(Ni) |  |  |  | N/A | R | 4/93 | BNL | 90 deg C First INR hardened p channel |
|  | continued |  |  | 5 |  | 5 |  | Hard @ 100(Ni) |  |  |  | N/A | R | 4/93 | BNL | 90 deg C |
| INR | IRFF9130 | 2N6849 | D | 2 | 100 | 10 |  | Hard (Cu) |  |  |  | N/A | R/A | 1990 | 88 | DC8533, 8547 |
| INR | IRFF9130 | 2N6849 | p |  | 100 | 0 |  |  | Hard @ 100(Br) |  |  | N/A | s | 1987 | BNL |  |
|  | continued |  |  |  |  | 0 to 35 |  |  |  | pass @ 0(Au) |  | SEGR | s | 1987 | BNL |  |
|  | continued |  |  |  |  | 36 |  |  |  | Fail @ 0(Au) |  | SEGR | s | 1987 | BNL |  |
| INR | IRF9130 |  | p | 2 | 100 | 10 |  |  | Hard(Cu) |  |  | N/A | R/A | 1990 | 88 | DC8406, 8545 |
| INR | continued |  |  |  |  | 10 |  |  | Hard @ 1OO(%) |  |  | N/A | s | unknown | BNL |  |
| INR | IRF9140 |  | p | 3&2 | 100 | 0 |  | 60/70(Fe) | 70/80(Br) |  |  | SEGR |  | 91/92 | BNL/88in | Anomalous comparison Vds of Br and Ar |
|  | continued |  |  | 3&3 |  | 15 | Hard(Ar) |  | 40/60(Kr) |  |  | SEGR |  | 91/92 | BNL/88in |  |
| INR | IRF9150 |  | p | 5 | 100 | 0 |  | Hard @ 1OO(NI) |  |  |  | N/A | R | 12/92 | BNL | 90 deg C |
|  |  |  |  | 5 | 100 | 5 |  | Hard @ 100(Ni) |  |  |  | N/A | R | 12/92 | BNL | 90 deg c |
| INR | IRH9150 |  | 0 |  | 1 0 0 | 0 s 5 |  | Hard @ 100(N, ) |  |  |  | N/A | Q | 8/93 | BNL | D C A9330 Bob Ferndon |
| INR | IRF21O | 2N6784 | n |  | 200 | 0 |  | 140/150(Ni) | ? 00/120(5,) |  |  | SEB | ESA | "1/94 | BNL | 92 28G, Harwell Rep! AEA RS-1348 |
| INR | IRF210 | 2N6784 | n |  | 200 | off |  | <130(Cu) |  |  |  | SEB | R | 1990 | 88 |  |
| INR | IRF220 |  | n |  | 200 | 5 |  | 145(Co) |  |  |  | SEB | B WP-01 | "6/93 | 88in | Am bient=45 deg C DC 921 8G W Will |
|  | continued |  |  |  |  | 5 |  | 150(Co) |  |  |  | SEB | B WP-01 | "6/93 | 88in | 100 deg C W Will |
| INR | IRFF220 | 2N6790 | n |  | 200 | 5 |  | 145(Ni) |  |  |  | SEB | R WP-04 | "7/93 | BNL | DC 9040 Bob Ferndon |
| INR | IRF230 | 2N6798 | n |  | 200 | 0 |  | 160/170(Ni) | <140(Br) |  |  | SEB | ESA | '1/94 | BNL | 9228G, Harwell Rept A E A RS 1348 |
| INR | IRFF230 | 2N6798 | n |  | 200 | 2? |  | <120(Cu) |  |  |  | SEB | R | 1990 | 88 |  |
| INR | IRFF230 | 2N6798 | n |  | 200 | 0 & 5 |  | 135(Ni) |  |  |  | SEB | R | "7/93 | BNL | DC 9146 Bob Ferndon |
| INR | IHFF230 | 2N6798 | n |  | 200 | 0 |  |  | 169(Br) | 107(Au) |  | SEB(Br)/SEGR (Au) | S | unknown | BNL |  |
| INR | IRFF230 | 2N6798 | n |  | 200 | 0 |  | 140 |  |  |  | SEB | B WP-01 | 10/93" | UW | DC 9217 Oberg 22 deg C |
| INR | IRFF230 | 2N6798 | " |  | 200 | 5 |  | 120 |  |  |  | SE B/SEGR | B WP-01 | 1 0/93" | UW | Oberg 80 deg c |
| INR | IRF240 |  |  |  | 200 | 0 |  | 140/150(Ni) | 120/130(Br) |  |  | SEB | ESA | "1/94 | BNL | 9228G, Harwell Rept A E A RS 1348 |

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic No | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe, Ni,Co LET.27 | Br or Kr LET.38 | High Z Ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | IRF250 | 2N6766 | 'n |  | "200 | o |  | "120/ 140( N,) | <120(Br) |  |  | SEB | ESA | '1/94 | BNL | 9228G, Harwell Rept AEA- RS-1348 |
| INR | IRF250 | 2N6766 | n |  | 200 | 0 |  | 150 | 135 |  |  | SEB | A | "9/89 | 88 | Koga |
| INR | IRF250 | 2N6766 | 'n |  | '200 | 0? |  | 140( Fe),120(Cu) 100(Kr) |  |  | 80( La1),80(La2) | SEB | A & B | 1988 | 88/Bev | Oberg & Kolasinski |
|  | continued |  |  | 2 | ' | 10 | 190( N),200(Ne),120(Ar),90(Cu), |  | 100(Ni),85(Br)--150(Cf-252) |  |  | SEB | R/A | 1990/1 992 | 88/BNL | Waskiewicz |
|  | continued |  |  | 3 each |  | off | 200( Cl-2) | 135(Ni) | 112(Br) | '107(I) | 100( Xe)- GANIL | SEB | CNES | 11/90 | BNL | 3 GANIL ions Tastet, RAE) ECS91 |
| INR | IRF250 | '2 N7225 | n |  | '200 | 5 |  | 150 |  |  |  | SEB | 9 WP-01 | 11/93 | 88 | Temp= 25 deg C |
|  |  |  |  |  |  | 5 |  | 160 |  |  |  | SEB | B WP.01 | 11/93 | 88 | Temp. 100 deg C |
| INR | IRH7230 |  | n | 5 | 200 | 'o |  | Hard a! 200 V(Ni) |  |  |  | N/A | R | 12{92 | BNL | DC 9042 90 deg C |
|  | copntinued |  |  | '5 |  | 5 |  | Hard at 200 V(Ni) |  |  |  | N/A | R | 1 2/92 | BNL | DC 9042 90 deg C |
| INR | IRHF7230 | 2N7262 | n |  | 200 | 2 |  | Hard al 200V(Ni 160(Br) |  |  |  | SEGR | R | 7/92 | BNL | IR 7xxx =Rad tolerant 90 deg C |
|  | continued |  |  | '5 |  | '15 |  | 1 fad at 200 V(Ni) | 90(Br) |  |  | SEGR | R | 7/92 | BNL | 1 of 5 fail-- Ni 90 deg C |
| INR | IRH7250 |  | n | 4 | 200 | 0 |  |  | Hard @ 200(Br) |  |  | N/A | J | 91/92 | BNL |  |
|  | continued |  |  | 3 . 2 , 4 |  | 15 | 180/200(Ar) | 160/200( Fe) | 120/140( B,) |  |  | SEGR | J | 91/92 | BNL | Data @ 100 deg C exists for Br Vgs=15 only |
|  | continued |  |  | 2 |  | "20 |  |  | 80(Br) |  |  | SEGR | J | 91/92 | BNL |  |
| INR | IRH7250 |  | n | 2/3 ea | '200 | off |  | 200(Ni) |  |  | 200(Xe) GANIL | N/A | CNES | 1 1/90 | GANIL | 3 GANIL tons Tastet, RADECS91 |
| INR | IRH7250 |  | n |  | 200 | 0 |  | 180(Ni) |  |  |  | SEGR | R | 8/93 | BNL | T=90 deg C. DC A9316 Ferndon 818-586-2607 |
|  | continued |  |  |  |  | '5 |  | 120(Ni) |  |  |  | SEGR | R | 8/93 | BNL | T=90 deg C DC A9316 Ferndon 818.5862607 ! |
| INR | IRHM7250 |  | n |  | 200 | '5 |  | No failure @ zoo |  |  |  | N/A | B WP-01 | 1/94 | 88in | Oberg 100 deg C |
|  |  |  |  |  |  | "12 |  | 170 |  |  |  | SEGR | B WP-01 | .1 /94 | 88in | Oberg 100 deg C |
| INR | IRHM8250 |  | n | '4 | "200 | 'o |  | 140 |  |  |  | SEGR | B WP-01 | 1/93" | UW | Oberg 100 deg C |
|  | continued |  |  |  | 200 | 5 |  | 110 |  |  |  | SEGR | B WP-01 | 1/93 | Lw | Oberg 100 deg C |
| INR | 9230 family | 2N6851 | p |  | 200 | 5 |  | 160 |  |  |  | ? | B WP 01 | "1993 | UW? | SSF Table |
| INR | 9230 family | 2N6851 | p |  | 200 | '5 |  | fails at 200 |  |  |  | SEGR | B WP-01 | "11/93 | 88 | Oberg Temp .80 deg C |
| INR | IRF9230 |  | p |  | 200 | 10 |  |  | Hard @ 200(Br) |  |  | N/A | s | unknown | BNL |  |
| INR | IRFF9230 | 2N6851 | p |  | 200 | 0 |  |  | Hard @ 200(Br) |  |  | N/A | s | 1987 | BNL |  |
|  | continued |  |  |  |  | o to 35 |  |  |  | Pass al O (Au) |  | SEGR | s | 1987 | BNL |  |
|  | continued |  |  |  |  | 36 |  |  |  | Fail at 0 (Au) |  | SEGR | S | 1987 | BNL |  |
| INR | IRFF9230 | 2N6851 | p |  | 2000 | & 5 |  | Hard(Ni) |  |  |  | None | R | "8/16/93 | BNL | DC A9330 Redesigned Bob Ferndon |
| INR | IRFF9230 | 2N6851 | p |  | 200 | 10 |  | Hard(Cu) |  |  |  | None | R/A | 1990 | 88 | DC8607 |
| INR | IRF9240 | 2N7237 | P | 2&2 | 200 | 0 |  | 80/100(Fe) | 80/100(Br) |  |  | SEGR | J | 91/92 | BNL | Same Vds range for Br at 125 deg C |
|  | continued |  |  | 3,1,3 |  | 15 | Hard(Ar) | 100/120(Fe) | 80/100(Kr) |  |  | SEGR | J | 91/92 | BNL &88in | Fe datum @ Vgs= 0(above) is anomalous |
|  | IRF9240 |  |  |  |  | 5 |  | <200(Co) |  |  |  | SEGR | B WP 01 | 8/93 | ? | W Will 100 deg C Temp dependence is SEGR |
|  | continued |  |  |  |  | 5 |  | No failure |  |  |  | N/A | B WP 01 | 11/93 | 88in | Oberg Ambient Compare preceding |

4·Power MOSFET W — - - - - - -

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic Nc | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe, Ni, Co LET=27 | Br or Kr LET=38 | High Z Ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | IRH254 |  | n |  | 250 | 27 |  |  | Hard(Cu) >225( Kr) |  |  | 7 | R | 1990 | 88 |  |
|  | continued |  | n |  | 250 | 10 | Hard(Ar) |  | Hard(Cu) 225/250 (Kr) |  |  | ? | R | 1 ,9% | 88 |  |
| INR | ? | 2N6780 | n |  | 400 | 0 |  |  | 200/240(Br) |  |  | SEB | ESA | "1/94 | BNL | Commercial, Harwell Rept AEA RS 1348 |
| INR | IRF31O | 2N6786 | n |  | 400 | 0 |  | 260/270(Ni) | 250/260(Br) |  |  | SEB | ESA | "1/94 | BNL | 9228G, Harwell Rept AEA RS- 1348 |
| INR | IRFF320 | 2N6792 | n |  | 400 | 2? |  |  | <260(Cu) |  |  | SEB | R | 1990 | 88 | Compare UTR device |
| INR | IRF330 | 2N6800 | n |  | 400 | 0 |  | 240/260(Ni) | 200/240(90 |  |  | SEB | ESA | -1/94 | BNL | 9228G, Harwell Rept AEA RS-1348 |
| INR | IRFF330 | 2N6800 | n |  | 400 | 2 |  | <235 (Cu) | 235(Br) |  |  | SEB | P | 7/92 | BNl | 90 dey C |
|  | continued |  |  |  |  | 15 |  |  | 235(Br) |  |  | SEB | R | 7/92 | BNL | 90 deg C |
| INR | IRFF330 | 2N6800 | n |  | 400 | 5 |  | 240(LET=28) |  |  |  | SEB | B WPO1 | 12/92 | UW | 100 deg C DC E9115 |
| INR | IRF340 |  | n |  | 400 | 0 |  | 250/260(Ni) | 240/280(Br) |  |  | SEB | ESA | "1/94 | BNL | 9228G, Harwell Rept AEA RS-1348 |
| INR | IRF340 |  | n |  | 400 | 2? |  | 245 |  |  |  | SEB | MM-AS wP2 | "8/93 | BNL? | DC 8924,9031,9110 Dr T Rao Sahib |
| INR | IRF350 | 2N6768 | n |  | 400 | ? |  |  |  |  | 130( LET=32) | SEB | CNES | 1 992 | GANIL | Dufour et al 92IEEE Workshop |
| INR | IRF350 | 2N6768 | n |  | 400 | 5 |  | 260 |  |  |  | SEB | B WP-01 | "6/93 | 88in | Oberg Vth=280 at 100 deg C |
| INR | IRF350 | 2N6768 | n |  | 400 | 0 |  | 260/2 80(Ni) | 200/240(Br) |  |  | SEB | ESA | -1/94 | BNL | 9228G, Harwell Rept AEA RS 1348 |
| INR | IRH7360 |  | n |  | 400 | 7 | Hard @ 400 |  |  |  |  | N/A | INR | 1/93 | BNL | IR 7xxx Rad tolerant |
| INR | IRHM7360 |  | n | 6(Ni) | 400 | 0 to 2 |  | 175/200(Ni) | 220(Br) |  |  | SEGR | R | 7/92&4/93 | BNL | 90 deg C |
|  | continued |  |  | 5(Ni) |  | 5 |  | 175/200(Ni) |  |  |  | SEGR | R | 12/92&4/93 | BNL | 90 deg C |
|  | continued |  |  | 5(Ni) |  | 7 |  | 175/200(Ni) |  |  |  | SEGR | R | 4/93 | BNL | 90 deg c |
|  | continued |  |  |  |  | 15 |  | No data | 125(Br) |  |  | SEGR | R | 7/92 | BNL | 90 deg C |
| INR | IRF360 |  | n | 4 | 400 | ?2 |  | 225/250 |  |  |  | SEGR | HON WP 2 | 2/93 | BNL | DC9238G |
|  | continued |  |  |  |  | 12 |  |  | <250 |  |  | SEB |  |  |  |  |
|  | continued |  |  |  |  | +/-12 (dynamic) |  | >300 | .250 |  |  | SEB |  |  |  |  |
| INR | IRF360 |  | n | 5&4 | 400 | 0 |  | 220/230(Ni) | 225/250( Br) |  |  | SEB | R | 9 &12/92 | BNL | DC9143 B, 90 deg C N, @ room T |
|  | continued |  |  | 5&1 |  | 5 |  | 220/250(Ni) | 225/250(Br) |  |  | SEB |  |  |  |  |
| INR | IR 420 | 2N6794 | n |  | 500 | 5 |  | 300 at high T |  |  |  | SEB | B WP-01 | 11/93 | 88 | Oberg D atum at 1 00 deg C only |

## 4-Power MOSFET Data

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic Nc | Channel, | Sample, | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET=27 | Br or Kr LET=38 | High Z Ions | High Energy Ions | Failure | Test Org | Dale | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INR | IRF430 | 2N6802 | n | | 500 | ‘o | | 300/350(Ni) | 320(Br) | | | SEB | ESA | .1 /94 | BNL | 9228G, Harwell Rept AEA-RS- 1348 |
| INR | IRF430 | 2N6762 | n | | ,500 | “7 | | | <310(Cu) | | | SEB | R | 1990 | 88 | |
| INR | IRFF430 | ‘2 N6802 | n | | ,500 | ? | | | | 500( Au) | | | JH | | BNL | Au has inadequate range =27 mic |
| INR | IRFF430 | ‘2 N6802 | “n | | 500 | ? | | | | 275( LET=100) | | SEB | JH | | BNL | J Kinnison |
| INR | IRFF430 | ‘2 N6802 | n | | 500 | ‘5 | | 325 | | | | SEB | B WP-01 | “4/93 | 88in | Oberg ambient .45 deg C > |
| | (con tinued) | | | | “ | 1 2 | | 325 | | | | SEB | B WP-01 | “10/93 | UW | Oberg Temp= 100 deg C |
| INR | IRF440 | | n | | ’ 500 | “ o | | 300/350(Ni) | 250/300(Br) | | | SEB | ESA | "1/94 | BNL | 9228G, Harwell Rept AEA- RS-1 348 |
| INR | IRF440 | | n | | 500 | 5 | | 300 | | | | SEB | B WP-01 | 6/93 | 88 | Oberg ambient .45 deg C |
| INR | IRF440 | | n | | 500 | “12 | | 325 | | | | SEB | B WP-01 | 6/93 | 88 | Oberg Temp =100 deg C |
| INR | | 2N6820?? | n | | ‘? | 5 | | “350 | | | | SEGR | B WP-01 | 6/93 | UW? | W Will DC 9225 |
| INR | IRFM450 | 2N7227 | n | | 500 | “ o | 370(LET=15) | 350(LET=30) | 320 (LET=40) | | | SEB | A | "9/93 | 88 | Koga has cross sections for each LE |
| INR | IRFM450 | 2N7227 | n | | 500 | ? | 350( Cl) | 300(Ni) | 275(Br) | 250(1) | | SEB | CNES | 1 1/90 | BNL | |
| INR | IQF450 | 2N6770 | n | | 500 | 0 | | 300/350(Ni) | 300 (Br) | | | SEB | ESA | .1 /94 | BNL | 9228G, Harwell Rept AEA RS 1348 |
| INR | IRF450 | 2N6770 | n | 5 &1 | 500 | “o | | 290/300( N,) | 275/300(Br) | | | SEB | R | 9 & 12/92 | BNL | Br @ 90 deg C., Ni @ room T |
| | continued | | | 5 &3 | | 5 | | 290/300(Ni) | 275/300(Br) | | | SEB | R | 9 & 12/92 | BNL | Br @ 90 deg C ; Ni @ room T |
| INR | IRF450 | 2N6770 | n | | ,500 | ? | | | | | 250 ( LET=23) | SEB | CNES | 1992 | GANIL | Dufour et al 92IEEE Workshop |
| INR | IRH450 | | n | 2/4 ea | “500 | off | | | 350(Br) | 325(!) | 250( Xe)-GANIL | SEB | CNES | 11/90 | BNL | 3 GANIL Ions Tastet RADECS91 |
| INR | IRH7450 | | n | | 500 | ? | | | 310 (Br) | | | SEB | CNES | 1990 | ? | |
| INR | IRH7450 | 2N6770 | n | 5&5 | 500 | “o to 2 | | 300/325(Ni) | 250/275(Br) | <120(1) | | SEGR | R & C(!only) | 7,9,12/92 | BNL | R 90 deg C Epi=40-50 mic for high V parts |
| | continued | | | 5&4 | | 5 | | 275/300(Ni) | 225/250(Br) | | | SEGR | R | 9 & 12/92 | BNL | 90 deg C |
| | continued | | | | | 15 | | “No data | 155(Br) | | | SEGR | R | ‘7/92 | BNL | 90 deg C |
| INR | IRHM7450 | | n | | 500 | ‘5 | | 300 | | | | SEGR | B WP-01 | "1/93 | UW | Oberg Temp= 100 deg C |
| INR | IRGAC50U | IGBT | n | 2(Ni) | 600 | 0 | | 340/350(Ni) | | | | SEB | R | 12/92 | BNL | room T |
| | continued | IGBT | | 2(Ni) | ’600 | 5 | | 340/350(Ni) | | | | SEB | R | 12/92 | BNL | room T |
| INR | IRGAC50U | IGBT | n | | 600 | 5 | | 380(Co) | | | | SEB | B WP-01 | 6/93 | 88 | DC 9300 W Will Temp .25 deg C |
| INR | IRFAG30 | | n | | ‘1000 | 5 | | 400 | | | | SEGR/SEB | B WP-01 | 6/93 | 88 | DC 9227, W Will Temp .45 deg C |
| INR | IRFAG30 | | n | | 1000 | 5 | | 450 | | | | SEGR/SEB | B WP-01 | 6/93 | 88 | DC 9227 W Will Temp . 100 deg C |

## 4-Power MOSFET Data

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic | N< Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co LET=27 | Br or Kr LET=38 | High Z 'ens | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HAR | IRF130 | 2N6796 | n | | 100 | 5 | | 40(Co) | | | | SEB | B WP-0 I | 4/93 | 88in | M9226 Oberg Same result at 45 & 100 deg C |
| HAR | FRM130 | 2N7271 | n | | 100 | 5 | | 100 | | | | None | Harris | -? 993" | BNL? | SSF Table |
| HAR | 1 3 0 family | 2N6756 | n | | 100 | 5 | | 41 | | | | ? | Harris | .,1993 - | BNL? | SSF Table |
| HAR | FRM140D1 | 2N7283 | n | 2 | 100 | 0 | | | . 70/80 (Br) | | | SEGR | J | 91/92 | BNL | Data @100 deg C exists for Vgs=0 & 15 |
| | continued | | | 3" | | 15 | | | 20/40(Kr) | | | SEGR | J | 91/92 | 88-in | *HAR says these are not latest technology |
| HAR | FRM140 | 2N7283 | n | | 100 | 5 | | 98 | | | | ? | Harris | "1993" | BNL? | SSF Table |
| HAR | FRK150R | 2N7291 | n | 5 | 100 | 0 | | 80/100(Ni) | | | | SEGR | R WP-4 | 12/92 | BNL | 90 deg C |
| | continued | | | 4 | | 5 | | 80/100(Ni) | | | | SEGR | R W P 4 | 12/92 | BNL | 90 deg c |
| HAR | FRK150 | 2N7291 | n | | 100 | 5 | | 97 | | | | ? | Ha, ris | "1993- | BNL? | SSF Table |
| HAR | F RK 1600 | 2N7299 | n | 2 | 100 | 0 | | | 70/80(Br) | | | SEGR | J | 91/92 | BNL | |
| HAR | FRK160 | 2N7299 | n | | 100 | 5 | | No failure at 100 | | | | N/A | Harris | "1993" | BNL? | SSF Table |
| HAR | 9 i1 o family | RFL1P10 | D | | 100 | </=10 | | | Hard @ 100 | | | N/A | R | '1992 | BNL | |
| | | | | | | | | | | | | | | | | for device coded data |
| HAR | 9130 family | 2N6849 | p | | 100 | 5 | | No failure at100 | | | | N/A | B WP 01 | -3/93 | 88in | Oberg Rm Temp |
| HAR | FRM9140R | | p | 4 | 100 | 0 | | | 60/70(Br) | | | SEGR | J | 91/92 | BNL | |
| | continued | | | 3&3 | | 15 | 90/100(Ar) | | 30/40(Br) | | | SEGR | J | 91/91 | BNL | I of 3 SEGR for A, |
| HAR | FRK9150R | 2N7322 | p | 5 & 5 | 100 | 0 | | Hard @ 1OO(NI) | 60/70(Br) | | | SEGR | R WP-4 | 12/92 | BNL | DC928x 90 deg C> |
| | continued | | | 5 & 5 | | 5 | | Hard @ 100(Ni) | 50/60 (Br) | | | SEGR | | | | 90 deg c |
| HAR | IRF9150 | | p | | 100 | -o | | | Hard @ 100V | | | N/A | R | 1992 | BNL | DC901O |
| | continued | | | | | 10 | | | Fail @ 100 | | | SEGR | | | | |
| HAR | FRK9160 | | p | 3 | 100 | 0 | | | 60/70(Br) | | | SEGR | J | 91/92 | BNL | |
| HAR | FRK9160R | 2N7328 | p | 5 | too | o | | 80/90(Ni) | | | | SEGR | R | 12/92 | BNL | 90 deg C Compare FRK9150R |
| | continued | | | 3 | | 5 | | 70/80(Ni) | | | | SEGR | R | 12/92 | BNL | 90 deg C Compare FRK9150R |
| HAR | FRM230R | 2N7274 | n | 2 | 200 | 0 | | 160/180(Ni) | | | | SEGR | R | 12/92 | BNL | 90 deg C Compare FRK250R |
| | continued | | | 2 | | 5 | | 160/180(Ni) | | | | SEGR | R | 12/92 | BNL | 90 deg C Compare F RK250R |
| HAR | FRM230 | 2N7274 | n | | 200 | 5 | | 166 | | | | ? | Harris | "1993" | BNL? | SSF Table |
| HAR | FRK230R | | n | | 200 | 0 | | 140(Ni) | | | | | R- WP-04 | | BNL | Temp - ? |
| | continued | | | | | 5 | | 120(Ni) | | | | | R WP 04 | | BNL | T emp ? |

## 4 Power MOSFET Data

|  |  |  |  |  |  |  | The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mfr | Mfr Number | Generic Nc | Channel | Sample | BVds | Vgs(off) | Low Z Ions | Fe,Ni,Co,LET=27 | Br or Kr LET=38 | High Z Ions | High Energy Ions | Failure | Test Org | Date | Location | Remarks |
| HAR | 2 3 0 family | 2N6758 | n |  | 200 | 5 |  | 64 |  |  |  | ? | Harris | "1993" | BNL? | SSF Table |
| HAR | 2 3 0 family | 2N6798 | n |  | 200 | 5 |  | 70 |  |  |  | 7 | Harris | "1993" | BNL? | SSF Table |
| HAR | 2 3 0 family | 2N6798 | n |  | 200 | 5 |  | 70 |  |  |  | SEB/SEGR | B WP-01 | 3/93 | 88in | W Will DC M9227 T= 45 deg C |
|  | continued |  |  |  |  | "5 |  | 80 |  |  |  | SEB/SEGR | B WP-01 | j/93 | 88in | W Will DC M9227 T. 100 deg C |
| HAR | FRM240D1 | 2N7285 | n | 2.s2 | 200 | 0 |  | 60/t 00(Fe) | "80/100(Br) |  |  | SEGR | J | 91/92 | BNL | 100 deg C data has Vds(th) 60/80(Br) |
|  | continued |  |  | 1 • |  | 15 | 180/2oo(AT) |  |  |  |  | SEB | J | 91/92 | 88-in | 100 deg C data has no SEB "Not latest |
| HAR | FRK250R | 2N7293 | n | 4&3 | 200 | 0 |  | 140/160(Ni) | 80/100(Br) |  |  | SEGR | R WP.4 | 1 & 9/92 | BNL | 90 deg C Compare FRK230R |
|  | continued |  |  | 4&1 |  | 5 |  | 120/140(Ni) | 80/100(Br) |  |  | SEGR |  |  |  | 90 deg C |
| HAR | IRF9230 |  | P |  | 200 | 1 |  |  |  | 80/90(1) |  | ? | c | unknown | BNL |  |
| HAR | FRM9240R | 2N7318 | P | 583 | 200 | 0 |  | Hard @ 200( Fe) | 80/100(Br) |  |  | SEGR | J | 91 /92 | BNL | At 8 5 deg C , Vds(Fe)=120/180 @ Vgs=0 |
|  | continued |  |  |  |  | 15 | 60/80(Ar) | 100/120( Fe) | 50(Br) |  |  | SEGR | J | 91/92 | BNL/88-in | Hard @ 200 for Ne |
| HAR | FRM9250 |  | p | 3 | 200 | 0 |  | Hard @ 200(Ni) |  |  |  | N/A | J | 12/93 | BNL | 1 of 3 older version failed at Vds=200/Vgs= O |
|  | continued |  |  | 3 |  | 15 |  | Hard @ 200 (Ni) |  |  |  | N/A | J | 12/93 | BNL | Older version not tested at Vds=15 |
| HAR | FRL234R |  | n | 5 | 250 | 0 |  | 175/200 (Ni) |  |  |  | SEGR | R | 3/93 | BNL | 90 deg C DC 9312 |
| HAR | FRM234 |  | n |  | 250 | 5 |  | 238( Pass) |  |  |  | ? | Harris | "1993" | BNL? | SSF Table |
| HAR | FRK264D | 2N7303 |  |  | 250 | 5 |  | 160 |  |  |  | SEGR | 9 WP-01 | 1 1/93 | UW&88 | Room temp & 100 deg C |
| HAR | IRHM7360 |  | n | 2 & 4 | 4 0 0 | 0 |  | 225/250(Ni) | 175/200(Br) |  |  | SEGR | R | 9/92 | BNL | 90 deg C |
|  | continued |  |  | 2 & 3 |  | 5 |  | 175/200 (Ni) | 200/225(Br) |  |  | SEGR |  |  |  | 90 deg C |
| HAR |  | 2N6800 | n |  | 400 | 5 |  | 130 |  |  |  | SEB | B WP-01 | 1/93 | UW | DC8830 Temp = 28 deg C |
|  |  | continued | n |  |  | 5 |  | 130 |  |  |  | SEB | B WPO, | 1/93 | UW | Temp . 100 deg C See preceding |
| HAR | 4 2 0 family | 2N6794 | n |  | 500 | 0 |  | 220 |  |  |  | SEB | B WPO1 | -12/92 | UW | Oberg Temp= 22 deg C |
|  | continued |  |  |  |  | 5 |  | 25o |  |  |  | SEB | B WP-01 | "12/92 | UW | Oberg Temp= 80 deg C |
| HAR | 4 3 o family | 2N6802 | n |  | 500 | 0 |  | 250 |  |  |  | SEB & SEGR | B WP 01 | "12/92 | UW | Oberg 100 deg C |
| HAR | 430 family | 2N6762 | n |  | 500 | 5 |  | 280 |  |  |  | ? | Harris | "1993 | BNL? | SSF Table |
| HAR | IR450 |  | {1 |  | 500 | 0 |  |  |  |  |  | SEB | A | "9/93 | 88in | Koga |

# 4 Power MOSFET Data

The Pass/Fail Vds Voltages for Indicated Beams of Columns H through L

| Mfr | Mfr Number | Generic | Nc Channel | Sample | BVds | Vgs(off) | Low Z fens | Fe,Ni,Co LET=27 | Br or Kr LET=38 | High Z Ions | High Energy ions | Failure | Test Org | Date | Location | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HAR | FRL430D | | n | | 500 | 0 | | >400 | | | | SEB | HON WP-2 | 2/93 | BNL | |
| | continued | | | | | Dynamic? | | | >400 | | | SEB | | | | |
| | continued | | | | | 0 | | | <400 | | | Unk. | | | | |
| | continued | | | | | 5 | | | <250 | | | Unk | | | | |
| HAR | FRM450R | | n | 5&4 | 500 | 0 | | 275/300( Ni) | 175/200(Br) | | | SEGR | R | 9/92&3/93 | BNL | 90 deg C Ni DC9232 |
| | continued | | | 5&1 | | 5 | | 200/225 (Ni) | 100/125 (Br) | | | SEGR | R | 9/92&3/93 | BNL | 90 deg C Ni: DC9232 |
| HAR | EN460 | | n | | 500 | 0 | | | 300(Br) | | | SEGR | R | 1992 | BNL | Deleted from WP.04 design |
| HAR | TA6768 | | n | 1 | 500 | 0 | <320(Cl) | | | <320(I) | | Gate leakage | C | 1989 | BNL | Early parts; ambiguous data LET(Cl)=12 |
| HAR | TA9768 | | n | | 500 | 0 | <320(Cl) | | | <320(I) | | Gate leakage | C | 1989 | BNL | Early parts; ambiguous data LET(Cl) .12 |
| HAR | TA9783 | IGBT | n | 2 | 600 | 5 | | 325/350(Ni) | | | | SEGR | R | 12/92 | BNL | room T |