Test Report for Heavy Ion Testing of the MSK5059RH Step Down Switching Regulator

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I. Introduction

This purpose of this test is to examine the heavy-ion induced single event effects (SEE) susceptibility of the MSK5059RH step down switching voltage regulator from M. S. Kennedy Corporation. The tests will be carried out at the Texas A&M University Cyclotron SEE Test Facility.

II. Device Description

The MSK5059RH is a radiation hardened 500 KHz switching regulator controller capable of delivering up to 4.5A of current to the load. The output voltage is adjustable down to 1.21 V. Typical applications include point of load DC/DC converters for satellite power supplies, microprocessors, FPGAs, and ASICS. Table 1 displays the part and test information. Figure 1 shows the pin configurations for the device.

Table I. Test and part information.

Generic Part Number	MSK5059RH
Package Marking	MSK 5059RHG Be0 51651 USA
Manufacturer	M. S. Kennedy Corp./Linear Tech. die
Lot Date Code (LDC)	To be determined
Quantity tested	1 to 2
Part Function	Step down switching regulator
Part Technology	BiCMOS
Package Style	Hermetically sealed flat-16
Test Equipment	Power supply, digital oscilloscope, multimeter, and computer

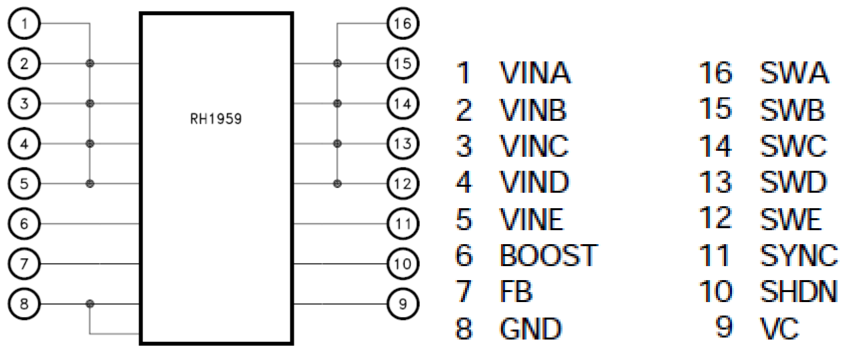

Figure 1. Pin configuration for the MSK5059RH.

III. Test Facility

Facility: Texas A&M University Cyclotron SEE Test Facility
Beam Energy: 15 MeV/amu tune
Flux: 1×10^3 to 1×10^5 particles/cm^2/s (adjust according to the number of transients observed)
Fluence: $\leq 1 \times 10^7$ ions/cm^2
Ions: Shown in Table II

Table II. Heavy-ion information.

Ion	Initial LET in air (MeV·cm^2/mg)	Range in Si (µm)
Ne	2.6	316
Ar	8.0	229
Kr	26.6	170
Xe	53.9	156

IV. Test Methods

Figure 2 shows the circuit diagram schematics for the application circuit. The output voltage (V_{out}) is fixed at 3.3 V. We added two additional capacitors (100 µF and 0.1 µF) in parallel at the output, externally to the board, to improve output stability. Nevertheless, we observed oscillation noise at the output, which consists of two components: one with frequency on the scale of the regulator switching frequency (500 kHz), and the other with a much higher frequency element (~ 14 MHz). The high frequency component may be caused by the load transient frequency. The magnitude of the oscillation of the more significant low frequency component was approximately 0.5 V peak-to-peak. Circuit layout considerations, such as creating a ground plane and/or placing the output capacitors closer to the device leads, may decrease the magnitude of the output noise and improve stability. Figure 3 shows a schematic of the test setup. The oscilloscope is connected to the device output to monitor SETs.

Figure 4 shows a photograph of the setup inside of the irradiation chamber at TAMU. We note that we clipped on a rectangular copper plate as an additional heat sinking element.

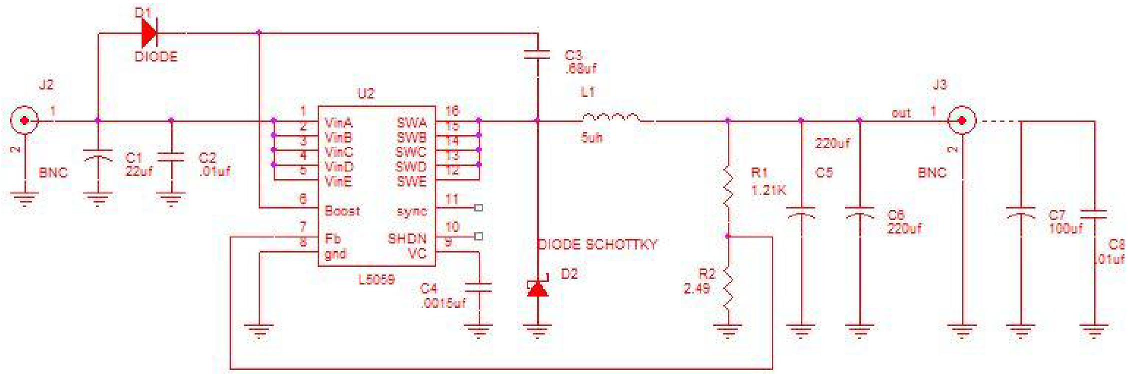

Figure 2. Application circuit diagram.

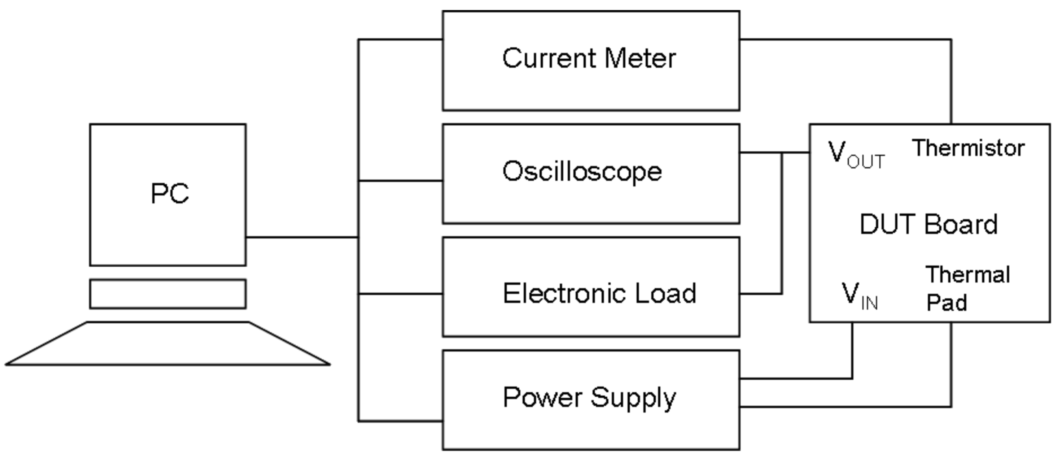

Figure 3. Block diagram of the testing setup.

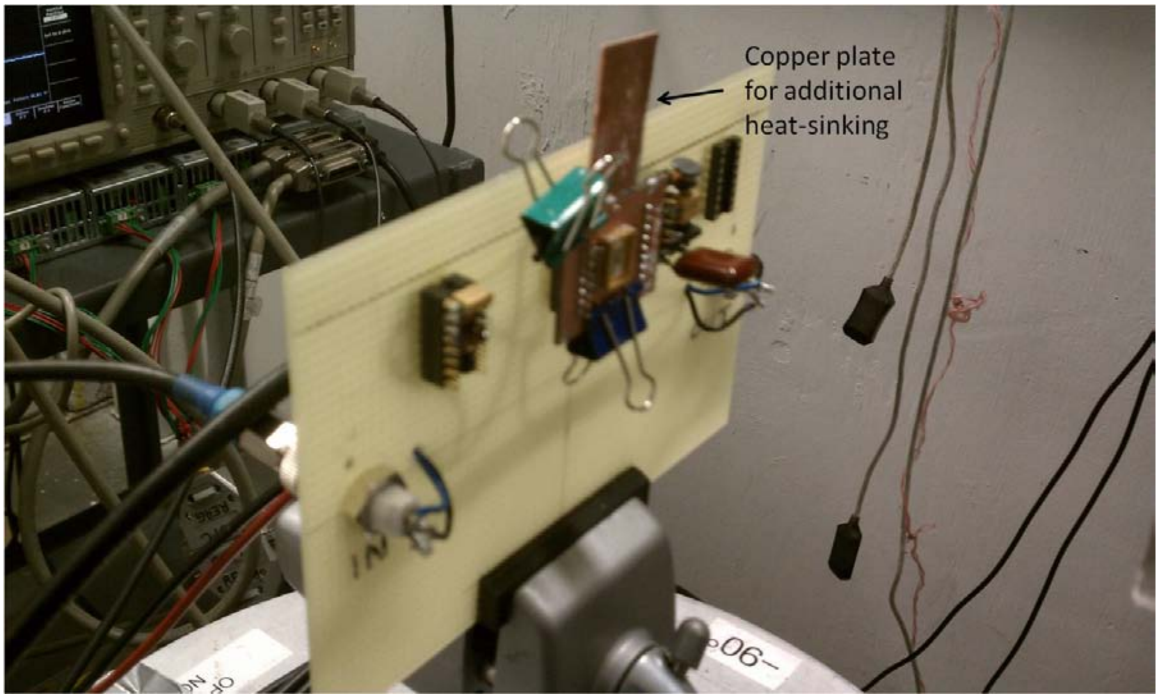

Figure 4. Photograph of the test setup inside of the irradiation chamber.

Test Conditions

Test Temperature:	Room temperature to 100^{o}C
Operating Frequency:	DC
Power Supply:	V_{in} = 7 V
Output Load:	I_{out} = 100 mA, 0.5 mA, 1 A, and 1.5 A
Output Voltage:	V_{out} = 3.3 V
Angles of Incidence:	0^{o} (normal), 60^{o}, and 90^{o}
Parameters:	1) Input supply voltage 2) Feedback voltage 3) Output current 4) Output voltage
Beam Hours:	**8**

V. Test Results

We observed perturbations to the output that were caused by increased fluctuations of the output oscillation noise. Figure 5 shows an example of such an event. Although we would not classify these events in the classical sense as a single event transient (SET), heavy-ion irradiation clearly magnifies the magnitude of the output oscillation noise. We found that in the more significant cases, the magnitudes of the oscillations were magnified to$\geq$ 0.9 V. Therefore, the heavy-ion irradiation caused an increase of more than 0.4 V in the magnitude of the output oscillation, taking into account the pre-irradiation magnitude of ~ 0.5 V. Figure 6 shows the cross-section of these events, with the device operating at V_{in} = 7 V and I_{out} = 1 A.

We observed a rapid decrease in the cross-section at a linear energy transfer (LET) value of 29.4 MeV·cm^2/mg, as shown in Figure 6. Then the cross-section continues to increase with increasing LET. This may be caused by the variability of these oscillation events and/or parts. It may also indicate a high sensitivity at low LET values. We will need additional tests at the lower LET regions to further investigate this behavior.

We also observed a dropout event at an effective LET of 124 MeV·cm^2/mg for one device. The device was operating with V_{in} = 7 V and I_{out} = 1.5 A. Figure 7 shows the input supply current vs. time. The current drops from the nominal operation level of ~ 1.15 A to ~ 0.75 A after 100s of run time, then dropping steeply to ~ 0.006 A. We did not observe similar events for another device, with the same operation conditions and effective LET value. We also did not observe such an event for the same device at an earlier run with similar conditions. We suspect that device over-heating, caused by the high output load, may have triggered the dropout.

The detailed information for each irradiation run is shown in Table III in the appendix.

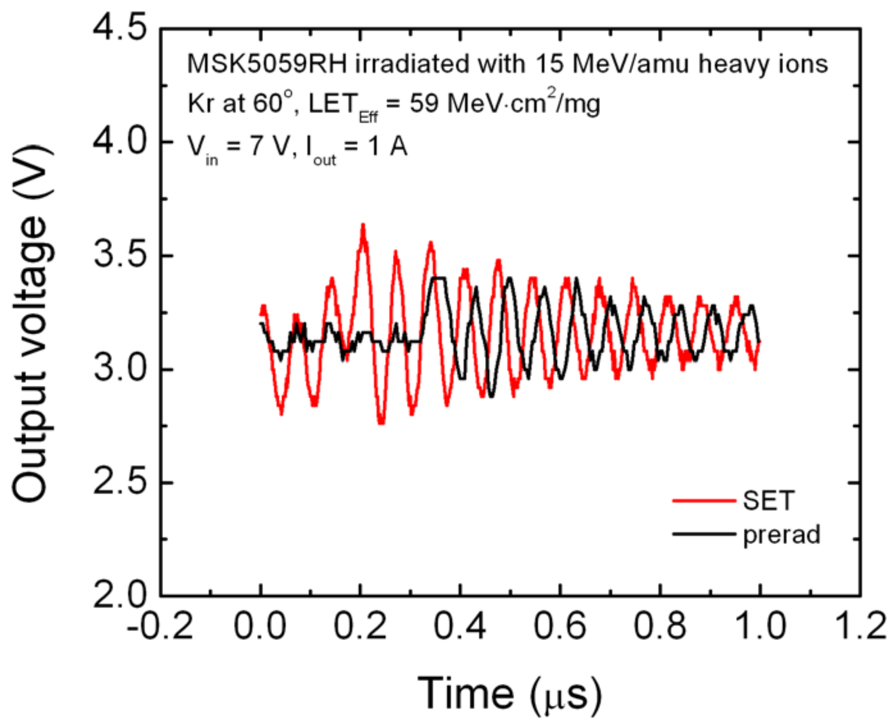

Figure 5. Output voltage vs. time for the MSK5059RH, operating with V_{in} = 7 V and I_{out} = 1 A, irradiated with Kr at 60^o with an effective LET = 59 MeV·cm^2/mg, for 15 MeV/amu tuned heavy-ions.

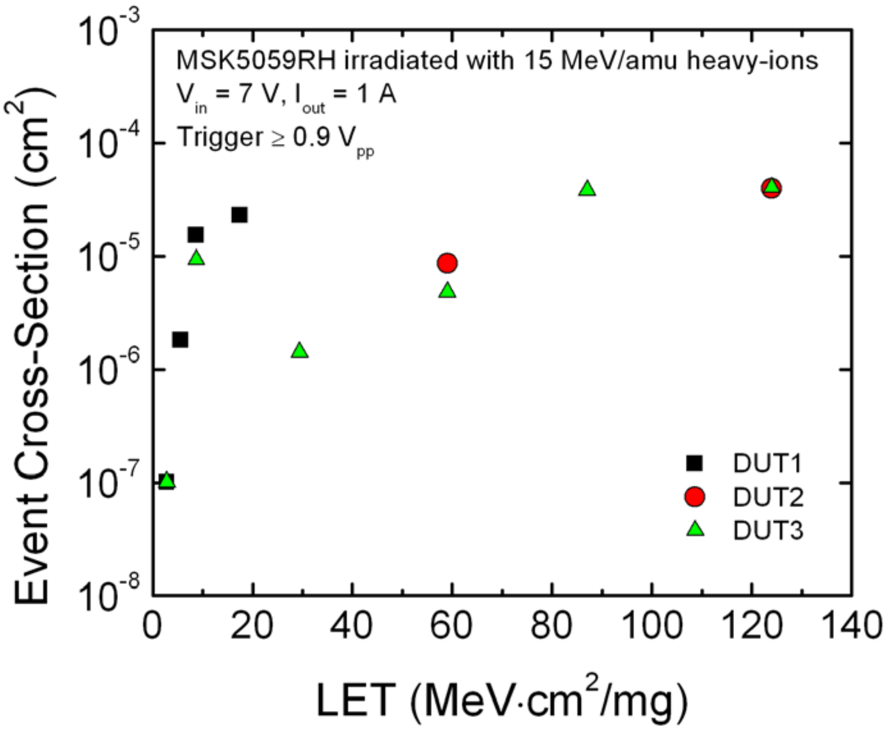

Figure 6. Event cross-section vs. LET for the MSK5059RH, operating with V_{in} = 7 V and I_{out} = 1 A, irradiated with 15 MeV/amu tuned heavy-ions, for events with magnitude ≥ 0.9 V.

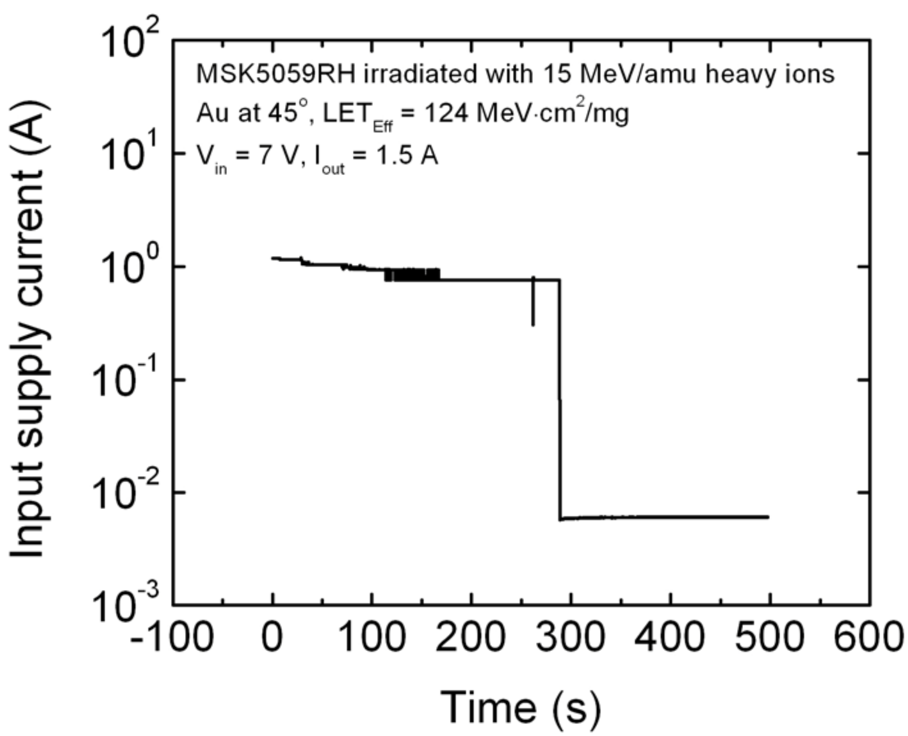

Figure 7. Input supply current vs. time for the MSK5059RH, operating with V_{in} = 7 V and I_{out} = 1.5 A, irradiated with Au at 45°, with an effective LET of 124 MeV·cm^2/mg, for 15 MeV/amu tuned heavy-ions.

VI. Conclusions

The MSK5059RH showed susceptibility to output perturbations from heavy-ions. The heavy-ion irradiation increased the output oscillation noise by ~ 0.5 V, in the worst cases. The LET threshold for these events is less than 2.8 MeV·cm^2/mg with the device operating at V_{in} = 7 V and I_{out} = 1 A. The event cross-section increases with increasing LET. However the cross-section appears nearing saturation at an effective LET of 124 MeV·cm^2/mg, where the cross-section is approximately 4×10^{-5} cm^{-2}. It may be necessary to investigate with additional tests, which will include various levels of output filtering, and other circuit layout considerations that will reduce the output oscillation and improve output stability. We believe the magnitudes of the radiation-induced fluctuations will decrease as the output oscillation is reduced.

VII. Appendix

Table III. Heavy-ion irradiation run summary.

Run #	DUT #	Vin (V)	Iout (A)	Trigger (V)	Ion	Angle (deg)	LET (MeV·cm2/mg)	Eff LET (MeV·cm2/mg)	Dose (krad(Si))	TID (krad(Si))	Flux (ions/cm2/s)	Fluence (ions/cm2)	SETs	Cross-Section (cm-2)
9	2	7	1	2.8, 3.7	Kr	0	29.4	29.4	4.7	20.1	2.70E+04	1.00E+07	0	0.00E+00
10	2	7	1	2.9, 3.5	Kr	0	29.4	29.4	2.5	22.6	2.87E+04	5.36E+06	105	1.96E-05
11	2	7	0.5	2.9, 3.5	Kr	0	29.4	29.4	4.7	27.3	2.97E+04	1.00E+07	1	1.00E-07
12	2	7	0.1	2.9, 3.5	Kr	0	29.4	29.4	4.7	32	3.10E+04	1.00E+07	0	0.00E+00
13	2	7	0.1	3.1, 3.3	Kr	0	29.4	29.4	0.65	32.65	3.08E+04	1.37E+06	162	1.18E-04
14	2	7	0.5	3.0, 3.4	Kr	0	29.4	29.4	0.24	32.89	2.90E+04	5.09E+05	74	1.45E-04
15	2	7	1.5	2.75, 3.5	Kr	0	29.4	29.4	4.7	37.59	3.00E+04	1.00E+07	0	0.00E+00
16	2	7	1.5	2.85, 3.35	Kr	0	29.4	29.4	0.8	38.39	3.05E+04	1.70E+06	90	5.29E-05
17	2	7	0.1	2.9, 3.5	Kr	60	29.4	59	9.4	47.79	3.00E+04	1.00E+07	0	0.00E+00
18	2	7	0.1	3.1, 3.3	Kr	60	29.4	59	0.36	48.15	3.05E+04	3.86E+05	73	1.89E-04
19	2	7	1	2.9, 3.5	Kr	60	29.4	59	0.95	49.1	3.11E+04	1.00E+06	99	9.90E-05
20	2	7	1	2.8, 3.7	Kr	60	29.4	59	9.5	58.6	1.07E+05	1.00E+07	86	8.60E-06
21	2	7	0.5	2.9, 3.5	Kr	60	29.4	59	9.5	68.1	1.05E+05	1.00E+07	170	1.70E-05
22	2	7	1.5	2.85, 3.35	Kr	60	29.4	59	0.77	68.87	9.95E+04	8.14E+05	68	8.35E-05
23	2	7	1.5	2.75, 3.5	Kr	60	29.4	59	9.4	78.27	1.03E+05	1.00E+07	8	8.00E-07
24	3	7	1.5	2.75, 3.5	Kr	60	29.4	59	9.5	9.5	9.75E+04	1.00E+07	24	2.40E-06
25	3	7	0.5	2.9, 3.5	Kr	60	29.4	59	9.5	19	9.80E+04	1.00E+07	110	1.10E-05
26	3	7	1	2.8, 3.7	Kr	60	29.4	59	9.5	28.5	9.96E+04	1.00E+07	48	4.80E-06
27	3	7	1	2.8, 3.7	Kr	0	29.4	29.4	4.7	33.2	1.00E+05	1.00E+07	14	1.40E-06
28	3	7	0.5	2.9, 3.5	Kr	0	29.4	29.4	4.7	37.9	9.54E+04	9.96E+06	3	3.01E-07
29	3	7	1.5	2.75, 3.5	Kr	0	29.4	29.4	4.7	42.6	9.80E+04	1.00E+07	0	0.00E+00
30	3	7	1.5	2.75, 3.5	Au	0	87.5	87.5	14	56.6	1.06E+05	1.00E+07	110	1.10E-05
31	3	7	0.5	2.9, 3.5	Au	0	87.5	87.5	8.4	65	8.70E+04	6.00E+06	193	3.22E-05

32	3	7	1	2.8, 3.7	Au	0	87.5	87.5	5.6	70.6	7.43E+04	4.00E+06	152	3.80E-05
33	3	7	0.1	2.9, 3.5	Au	0	87.5	87.5	14	84.6	7.00E+04	1.00E+07	18	1.80E-06
34	3	7	1.5	2.75, 3.5	Au	45	87.5	124	12	96.6	9.80E+04	6.00E+06	129	2.15E-05
35	3	7	0.1	2.9, 3.5	Au	45	87.5	124	29	125.6	9.10E+04	1.00E+07	11	1.10E-06
36	3	7	1	2.8, 3.7	Au	45	87.5	124	6.5	132.1	8.90E+04	3.30E+06	133	4.03E-05
37	2	7	1	2.8, 3.7	Au	45	87.5	124	5.1	83.37	8.00E+04	2.60E+06	103	3.96E-05
38	2	10	1	2.8, 3.8	Au	45	87.5	124	29	112.37	8.30E+04	1.00E+07	669	6.69E-05
39	2	10	0.5	2.9, 3.5	Au	45	87.5	124	1.4	113.77	7.58E+04	7.10E+05	57	8.03E-05
40	2	7	0.5	2.9, 3.5	Au	45	87.5	124	5.5	119.27	8.00E+04	2.80E+06	112	4.00E-05
41	2	7	1.5	2.75, 3.5	Au	45	87.5	124	16	135.27	6.00E+04	8.20E+06	a lot	#VALUE!
42	2	7	1.5		Au	45	87.5	124	8.7	143.97				#DIV/0!
43	2	7	1.5		Au	45	87.5	124	4.8	148.77				#DIV/0!
44	2	7	1		Au	45	87.5	124	20	168.77				#DIV/0!
45	3	7	1.5		Au	45	87.5	124	20	152.1				#DIV/0!
46	3	7	1.5		Au	45	87.5	124	20	172.1				#DIV/0!
47	3	7	1	2.8, 3.7	Ar	0	8.7	8.7	1.4	173.5				#DIV/0!
48	3	7	1	2.8, 3.7	Ar	0	8.7	8.7	1.4	174.9	1.40E+05	1.00E+07	73	7.30E-06
49	3	7	0.5	2.9, 3.5	Ar	0	8.7	8.7	1.4	176.3	1.10E+05	1.00E+07	57	5.70E-06
50	3	7	0.1	2.9, 3.5	Ar	0	8.7	8.7	1.4	177.7	9.60E+05	1.00E+07	3	3.00E-07
51	3	7	1.5	2.7, 3.5	Ar	0	8.7	8.7	1.4	179.1	9.60E+05	1.00E+07	0	0.00E+00
52	3	7	1.5	2.75, 3.5	Ar	0	8.7	8.7	1.4	180.5	1.00E+05	1.00E+07	10	1.00E-06
53	3	7	0.1	2.9, 3.5	Ar	0	8.7	8.7	1.4	181.9	1.10E+05	1.00E+07	5	5.00E-07
54	3	7	1	2.8, 3.7	Ar	0	8.7	8.7	1.4	183.3	9.60E+04	1.00E+07	93	9.30E-06
55	3	7	0.5	2.9, 3.5	Ar	0	8.7	8.7	1.4	184.7	1.10E+05	9.96E+06	52	5.22E-06
56	3	10	0.1	2.9, 3.5	Ar	0	8.7	8.7	1.4	186.1	1.30E+05	1.00E+07	79	7.90E-06
57	3	10	1	2.8, 3.7	Ar	0	8.7	8.7	0.39	186.49	1.20E+05	2.80E+06	92	3.29E-05
58	1	7	1	2.8, 3.7	Ar	0	8.7	8.7	1.4	1.4	1.20E+05	1.00E+07	152	1.52E-05
59	1	7	0.5	2.9, 3.5	Ar	0	8.7	8.7	1.4	2.8	1.30E+05	1.00E+07	28	2.80E-06
60	1	7	0.1	2.9, 3.5	Ar	0	8.7	8.7	1.4	4.2	1.30E+05	1.00E+07	0	0.00E+00
61	1	7	0.1	2.9, 3.5	Ar	0	8.7	8.7	1.4	5.6	1.40E+05	9.96E+06	0	0.00E+00
62	1	7	1.5	2.75, 3.5	Ar	0	8.7	8.7	1.4	7	1.30E+05	1.00E+07	32	3.20E-06
63	1	7	0.1	3.05, 3.35	Ar	0	8.7	8.7	1.4	8.4	1.30E+05	1.00E+07	136	1.36E-05
64	1	7	1	2.8, 3.7	Ar	60	8.7	17.5	1.7	10.1	1.35E+05	6.20E+06	141	2.27E-05
65	1	7	0.5	2.9, 3.5	Ar	60	8.7	17.5	2.8	12.9	1.30E+05	1.00E+07	70	7.00E-06
66	1	7	0.1	3.05, 3.35	Ar	60	8.7	17.5	2.8	15.7	1.26E+05	1.00E+07	365	3.65E-05
67	1	7	1.5	2.75, 3.5	Ar	60	8.7	17.5	2.8	18.5	1.23E+05	9.97E+06	45	4.51E-06
68	1	7	1	2.8, 3.7	Ne	60	2.8	5.6	0.89	19.39	1.24E+05	1.00E+07	18	1.80E-06
69	1	7	0.5	2.9, 3.5	Ne	60	2.8	5.6	0.89	20.28	1.23E+05	1.00E+07	11	1.10E-06
70	1	7	0.1	3.0, 3.4	Ne	60	2.8	5.6	0.9	21.18	1.27E+05	1.00E+07	34	3.40E-06
71	1	7	1.5	2.75, 3.5	Ne	60	2.8	5.6	0.9	22.08	1.29E+05	1.00E+07	0	0.00E+00
72	1	7	1.5	2.8, 3.3	Ne	60	2.8	5.6	0.15	22.23	1.22E+05	1.70E+06	116	6.82E-05

73	1	7	1	2.8, 3.7	Ne	0	2.8	2.8	0.45	22.68	1.25E+05	1.00E+07	1	1.00E-07
74	1	7	0.5	2.9, 3.5	Ne	0	2.8	2.8	0.5	23.18	1.36E+05	1.00E+07	2	2.00E-07
75	1	7	0.5	2.95, 3.45	Ne	0	2.8	2.8	0.45	23.63	1.12E+05	1.00E+07	67	6.70E-06
76	1	7	1.5	2.75, 3.4	Ne	0	2.8	2.8	0.44	24.07	1.22E+05	9.96E+06	0	0.00E+00
77	1	7	1.5	2.8, 3.3	Ne	0	2.8	2.8	0.17	24.24	1.23E+05	3.92E+06	128	3.27E-05
78	3	7	1	2.8, 3.7	Ne	0	2.8	2.8	0.44	186.93	1.29E+05	9.94E+06	1	1.01E-07
79	3	7	0.5	2.95, 3.45	Ne	0	2.8	2.8	0.44	187.37	1.36E+05	9.94E+06	53	5.33E-06
80	3	7	0.1	3, 3.4	Ne	0	2.8	2.8	0.44	187.81	1.33E+05	9.97E+06	7	7.02E-07
81	3	7	1.5	2.75, 3.4	Ne	0	2.8	2.8	0.45	188.26	1.22E+05	1.00E+07	9	9.00E-07
82	3	7	1.5	2.8, 3.35	Ne	0	2.8	2.8	0.45		1.25E+05	1.00E+07	0	0.00E+00