Test Report for Heavy Ion Testing of the PE9915X Point-of-Load Switching Regulator

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I. Introduction

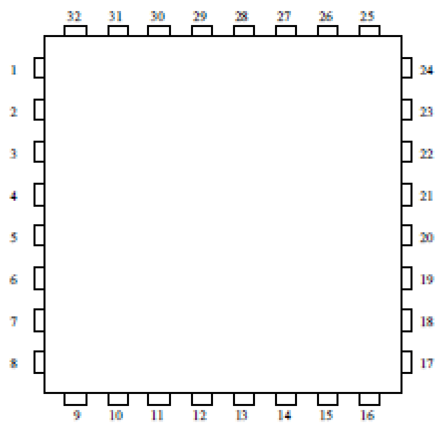
The purpose of this test is to examine the heavy-ion induced single event effects (SEE) susceptibility of the PE9915X buck switching voltage regulator from Peregrine Semiconductor. The test was performed at the Lawrence Berkeley National Laboratory facility.

II. Device Description

The PE9915X is series of point-of-load (POL) switching regulator fabricated in Peregrine's UltraCMOS™ technology, which utilizes Silicon-On-Sapphire (SOS) process. We examine the PE99151 (2 A) and the PE99155 (10 A) versions. The output voltage is adjustable down to 1 V. 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	PE99151, PE99155
Package Marking	TBD
Manufacturer	Peregrine Semiconductor
Wafer Lot Code	PE99155 - S11060-2 PE99151 - S11058-2
Quantity tested	3
Part Function	Buck switching regulator
Part Technology	SOS
Package Style	32-lead ceramic package
Test Equipment	Power supply, electronic load, digital oscilloscope, multimeter, and computer



Pin No.	Pin Name	Description
1	AGND	Band-gap ground
2	VREF	1.000V reference output, loop to EAINP Additional low pass filtering may be necessary
3	EAINP	Error Amplifier (+) input, loop to VREF
4	EAINM	Error Amplifier (-) input, load feedback
5	EAOUT	Error Amplifier output/loop to ISET
6	ISET	Current Set-point input/loop to EAOUT
7	ICOMP	Variable current compensation/resistor to VOUT
8	RSET	Resistor to set reference current
9	SYNCOb	Loop-through complement output
10	PGOOD	Power Good flag output
11	RSEL	Reference resistor selection
12, 15, 16, 17, 18, 24, 25, 29	GND	Input power/signal ground
13, 14, 26, 27, 28	VIN	Input power supply
19, 20, 21, 22, 23	OUT	PWM power output
30	SDb	Shutdown (L)/enable input
31	SYNC	Oscillator sync input or int. osc freq select
32	SScap	Soft Start timing cap input

Figure 1. Pin configuration for the PE99155.

III. Test Facility

Facility: Lawrence Berkeley National Laboratory
Cocktail: 10 MeV/nuc
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 (per run)
Ions: Shown in Table II

Table II. Heavy-ion LET and range in Si.

Ion	Initial LET in air (MeV·cm^2/mg)	Energy (MeV)	Range in Si (μm)
Xe	58.78	1232	90.0

IV. Test Methods

Figure 2 shows the schematics for a typical application circuit. A detailed schematic diagram is shown in the Appendix section. The input voltage (V_{in}) was set to 5 V. We tested two versions of the PE99155, with outputs of 2.5 V and 1 V, capable of delivering up to 10 A continuous current. We also tested a PE99151, with V_{out} = 2.5 V, and maximum load current of 2 A.

Figure 3 shows a schematic of the test setup. The cable lead length from the power supply to the input connector at the board was relatively long (approximately 7 to 10 ft), due to test facility requirements/limitations. Therefore we had to compensate for the large voltage drop across the cable for high current conditions. The long cable lead length from the electronic load to the output connector at the board also introduced issues at high currents, which limited the maximum load current to 8 A on the 2.5V 10A converter and 5A on the 1V 10A converter. The oscilloscope was connected at a Kelvin board output to monitor transients. Therefore the oscilloscope cable length was not affected by the high current conditions.

The irradiation chamber is contained in a vacuum environment. We mounted the device on a cooling plate for heat sinking. The cooling plate is attached with plastic tubes which use liquid circulation for heat dissipation. They are fed through the connector plate to a liquid nitrogen pump located outside of the chamber. We also attached thermistor to monitor the case temperature of the part. The resistance of the thermistor change in response to temperature variances. A digital multimeter measures and records the change in resistance. We used LabVIEW programs to control the power supply, electronic load, and capture transients, and monitor the temperature. Figure 4 shows a photograph of the actual test setup. The test conditions are also listed below.

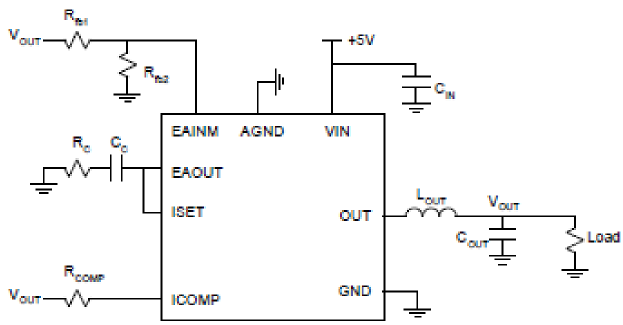


Figure 2. Application circuit diagram.

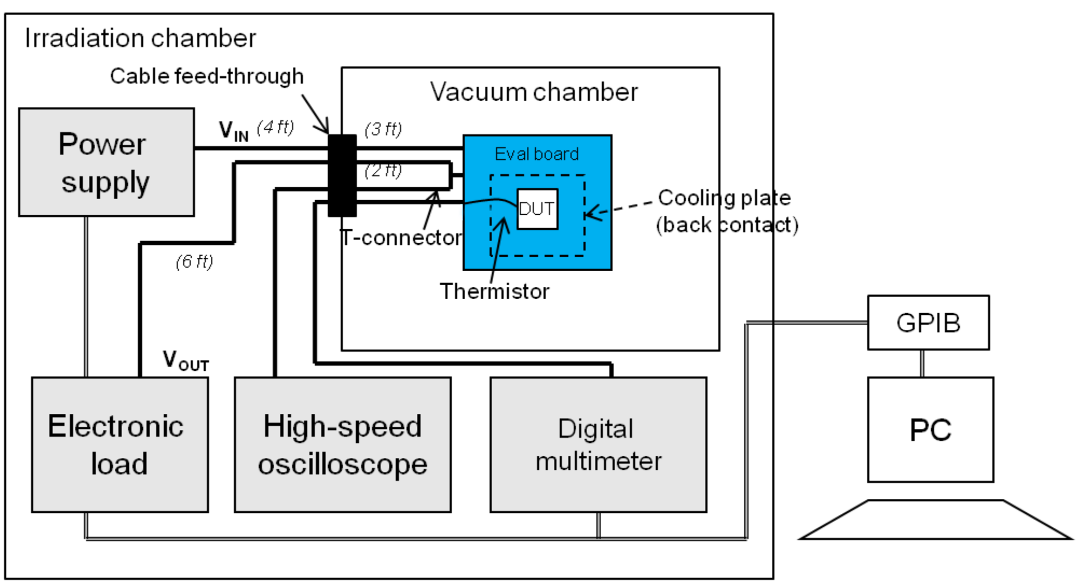


Figure 3. Block diagram of the testing setup.

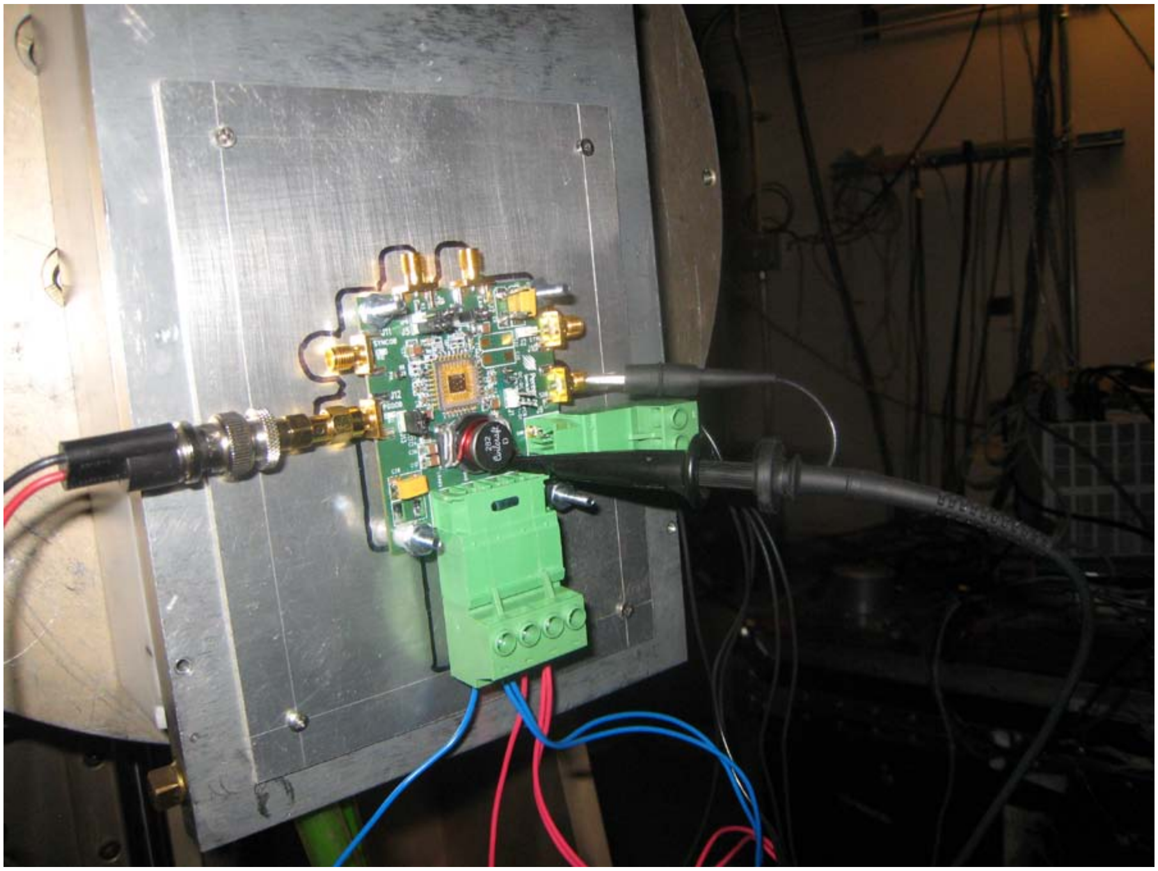


Figure 4. Photograph the PE9915X test board mounted with heat sink in the irradiation chamber.

Test Conditions

Test Temperature:	Cooling plate temperature *
Operating Frequency:	DC (Oscillation frequency internally limited ~ 500 kHz)
Power Supply:	V_{in} = 5 V
Output Load:	I_{out} = 0, 2, and 8 A for the PE99155 2.5 V device
	I_{out} = 0, 2, and 5 A for the PE99155 1 V device
	I_{out} = 0, and 1.5 A for the PE99151 2.5 V device
Angles of Incidence:	0^o (normal) and 60^o
Parameters:	1) Input supply voltage
	3) Input current (set limit to 2× pre-irradiation value)
	4) Output voltage (set limit to ± 50% of V_{out}, look for triggers at 5%, 10%, and 20%)
	5) Power Good
	6) SW (± 20% pulse width deviations)
Beam Hours:	**4**

* The actual temperature at the cooling plate is unknown. However we approximate the plate temperature to be between 5^oC and 15^oC.

V. Results

We irradiated the devices with Xe at 0^o and 60^o incident angles, for various load conditions. We observed a few incidences of a sharp peak in the output noise. The magnitudes of the peaks were approximately 0.4 to 0.6 V. However the duration was on the order of tens of nanoseconds. Figures 5 and 6 show examples of these events, for a PE99155 device at V_{out} = 1 V and I_{out} = 5 A, and a PE99151 device at V_{out} = 2.5 V and I_{out} = 1.5 A, respectively.

These events are not considered the classical example of a single event transient (SET). The irradiation magnified the output noise, resulting in the voltage spike. However the noise appeared extrinsic to the device and board circuitry. The noise resonated at approximately 20 kHz. We believe the noise originates from external equipments linked to the vacuum chamber.

The duration of the triggering spikes were less than one pulse width of the switching output and much less than the output filter time constant. The simultaneously captured SW node traces showed no perturbation. Thus these transients on the LOAD point cannot originate within the device. The triggered events coincided with the ambient EMI burst signature.

We also observed an incidence where the input current, hence the output voltage, dropped during a run with the PE99155 operating at 2.5 V output and 8 A. The input supply current dropped from the normal operation range of ~ 4.5 A to ~ 77 mA, as shown in Figure 7. The device was operational for the lower load currents ($\leq$ 5 A) after power cycling a few minutes following the run. However the device failed to regulate at the 8 A load. It is possible that the regulation failure was in part due to device overheating and/or accumulated dose. Peregrine performed parametric characterization a few days following the heavy-ion test. The results showed parametric drifts in the current control paths. The total ionizing dose is largely responsible for the parametric shifts. However it is less likely that the total dose-induced degradation caused the drop in the input supply current. The incident is more likely caused by issues arising from the high load conditions, such as device overheating. We did not observe any similar event for other operation conditions.

A summary of each irradiation run is shown in Table III in the Appendix.

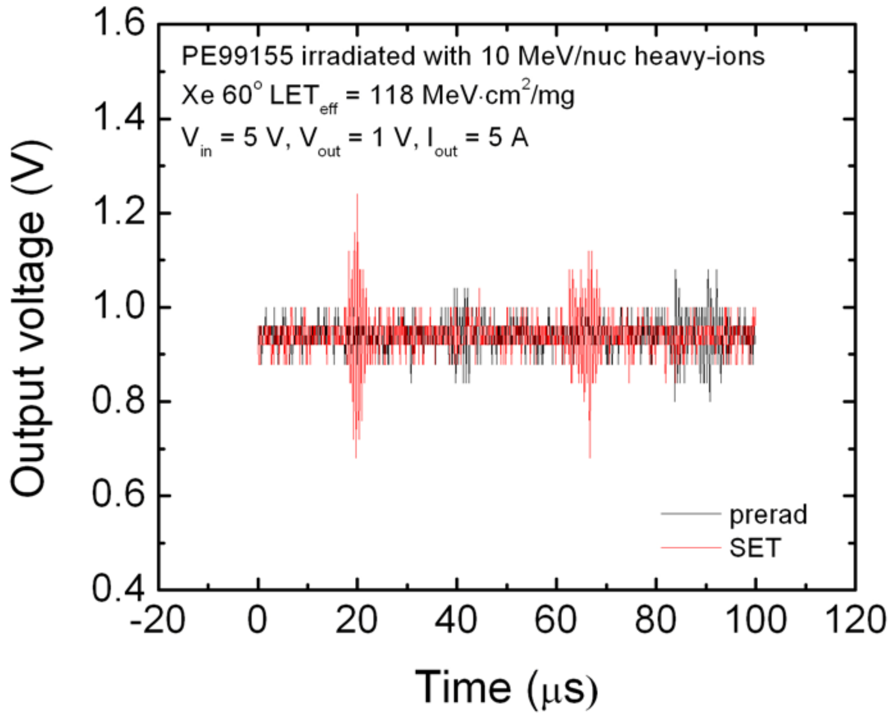


Figure 5. Output voltage vs. time for the PE99155, operating with V_{out} = 1 V and I_{out} = 5 A, irradiated with Xe at 60^o with an effective LET = 118 MeV·cm^2/mg, for 10 MeV/nuc heavy-ions.

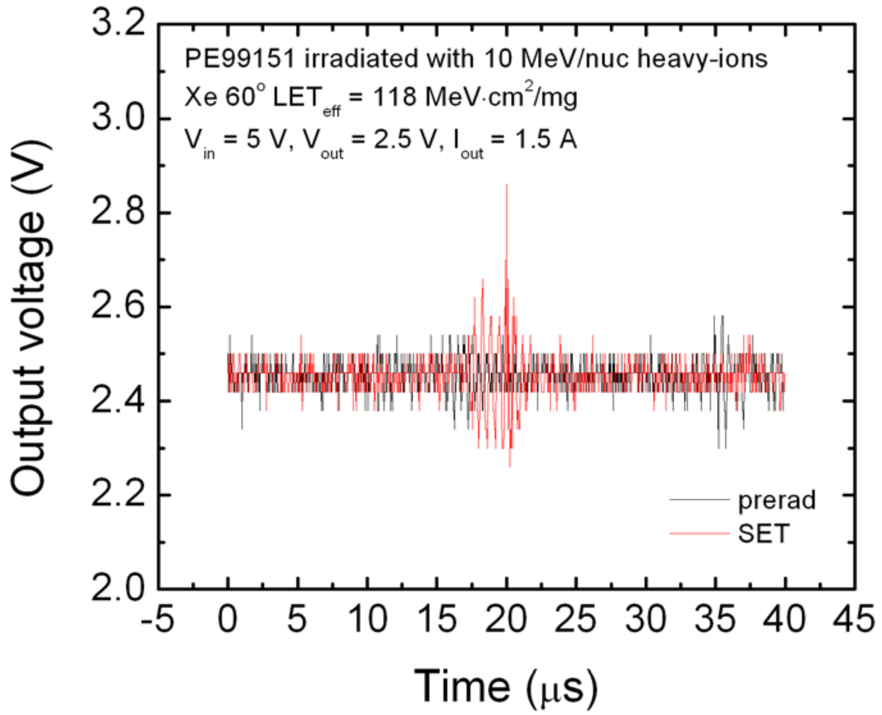


Figure 6. Output Output voltage vs. time for the PE99151, operating with V_{out} = 2.5 V and I_{out} = 1.5 A, irradiated with Xe at 60^o with an effective LET = 118 MeV·cm^2/mg, for 10 MeV/nuc heavy-ions.

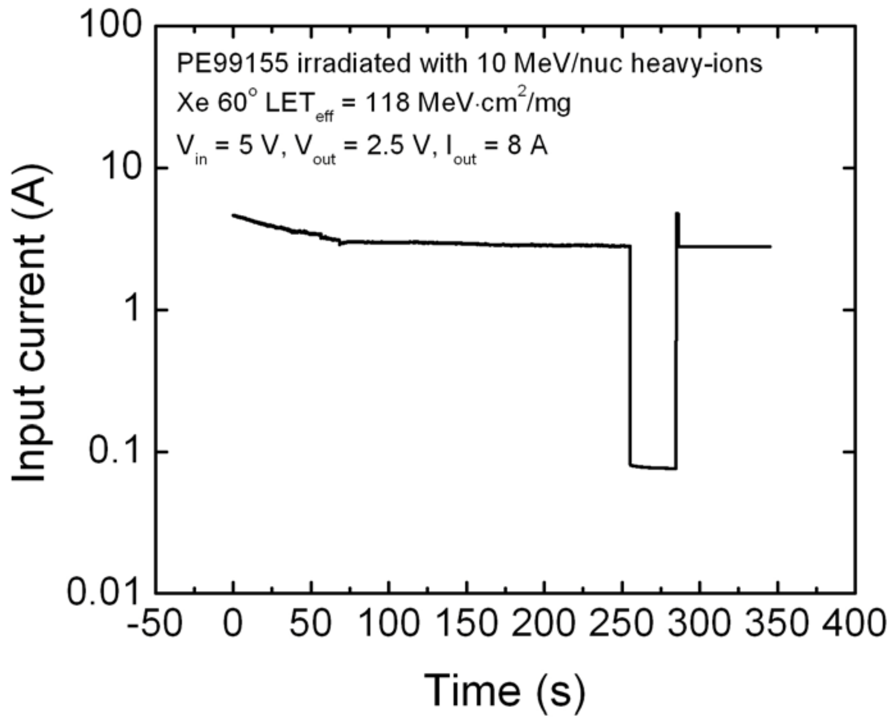


Figure 7. Input current vs. time for the PE99155, operating with V_{out} = 2.5 V and I_{out} = 8 A, irradiated with Xe at 60^o with an effective LET = 118 MeV·cm^2/mg, for 10 MeV/nuc heavy-ions.

VI. Conclusion

The PE9915X was relatively radiation hardened for the given test condition here. We observed a few events where the output voltage spiked, with magnitude of ~ 0.4 to 0.6 V and duration on the order of tens nanoseconds. We believe that these events originate from noise external to the device. The noise is further amplified by the heavy-ion irradiation and/or the ambient electrical activity associated with it.

We also observed an incidence where the input supply current fell rapidly, which caused the output regulation failure. We believe that the event is not caused by a single particle strike. It may be caused in part by device overheating, as conductive heat-sinking becomes inefficient in a vacuum environment. The long cable leads, both from the input supply and electronic load to the device output, present further problems during high current conditions. The parametric degradations from accumulated dose may have also contributed to the current drop. Additional tests in air, eliminating the heat sinking issues may verify the cause of the event.

VII. Appendix

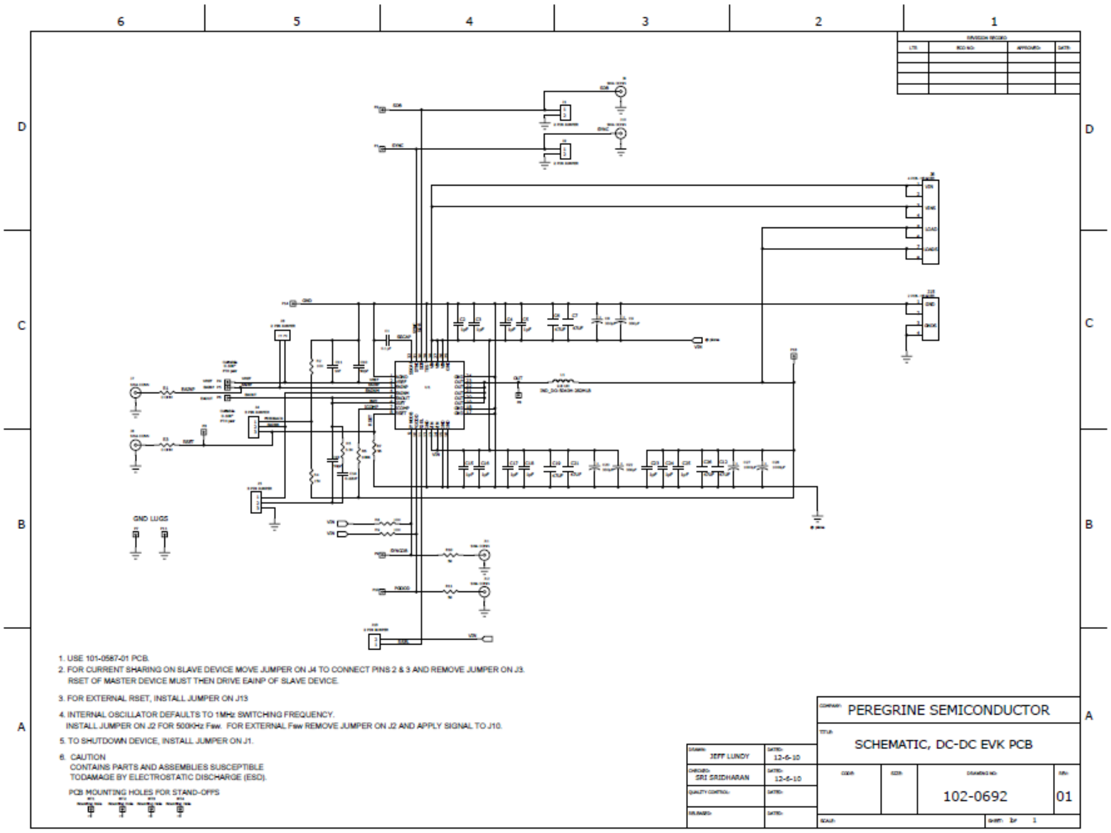


Figure 4. Detailed application circuit schematic diagram.

Table III. Irradiation summary; PE9915X irradiated with 10 MeV/nuc heavy-ions.

Run	Device S/N	Part #	Trigger	Vin	Vout	Iin	Iout	Ion	Range	LET	Angle	Eff LET	Dose	Acc Dose	Ave. Flux	Fluence	Event(s)
#	#		*mV*	*V*	*V*	*A*	*A*		*µm*	*MeV.cm2/mg*	*deg*	*MeV.cm2/mg*	*rad(Si)*	*rad(Si)*	*#/cm2/sec*	*#/cm2*	
1	1	PE99155	300	5	2.5	0.059	0	Xe	90	58.8	0	58.8	9.41E+03	9.41E+03	1.31E+04	1.00E+07	0
2	1	PE99155	300	5	2.5	1.12	2	Xe	90	58.8	0	58.8	9.41E+03	1.88E+04	1.31E+04	1.00E+07	0
3	1	PE99155	300	5	2.5	4.82	8	Xe	90	58.8	0	58.8	9.41E+03	2.82E+04	1.41E+04	1.00E+07	0
4	1	PE99155	300	5	2.5	0.067	0	Xe	90	58.8	60	118	9.41E+03	3.76E+04	1.37E+04	1.00E+07	0
5	1	PE99155	300	5	2.5	1.13	2	Xe	90	58.8	60	118	9.41E+03	4.70E+04	1.46E+04	1.00E+07	0
6	1	PE99155	300	5	2.5	4.52	8	Xe	90	58.8	60	118	2.73E+03	4.98E+04	1.46E+04	2.90E+06	I_{in} drop
7	3	PE99155	500	5	1	0.035	0	Xe	90	58.8	60	118	9.41E+03	9.41E+03	1.46E+04	1.00E+07	0
8	3	PE99155	500	5	1	0.487	2	Xe	90	58.8	60	118	9.41E+03	1.88E+04	1.44E+04	1.00E+07	1
9	3	PE99155	500	5	1	1.2	5	Xe	90	58.8	60	118	9.41E+03	2.82E+04	1.48E+04	1.00E+07	2
10	5	PE99151	300	5	2.5	0.038	0	Xe	90	58.8	60	118	9.41E+03	9.41E+03	1.41E+04	1.00E+07	0
11	5	PE99151	300	5	2.5	0.871	1.5	Xe	90	58.8	60	118	9.41E+03	1.88E+04	1.45E+04	1.00E+07	3