



Total Ionizing Dose Environment for the EO1 spacecraft

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1 Scope

The purpose of this document is to estimate yearly total ionizing dose (TID) levels for the EO1 spacecraft.

2 Description of the mission

The EO1 trajectory is a 703 km altitude circular orbit with a 98.7 degrees inclination. EO1 was launched in November 2000. For an 8 year mission ending in October 2008, we will consider 4 years of solar maximum activity and 4 years of solar minimum activity. For this type of orbit, both high energy trapped particles, electrons and protons, and high energy protons generated during solar events contribute to the TID environment.

3 Trapped protons

The NASA AP8 model has been used to determine the trapped proton environment. Table A1 gives the one-year spacecraft incident trapped proton fluence versus energy spectra for solar minimum and solar maximum conditions.

4 Trapped electrons

The NASA AE8 model has been used to determine the trapped electron environment. Table A2 gives the one-year spacecraft incident orbit averaged trapped electron fluence versus energy spectra for solar minimum and solar maximum conditions.

5 Solar protons

The NASA PSYCHIC model has been used to determine the solar proton environment. Table A3 gives the average one year solar proton fluence versus energy spectra for solar minimum and solar maximum conditions.

6 Total ionizing dose curve

Total dose has been calculated from the surface incident integral particle fluences as a function of aluminum shield thickness of a solid sphere. The solid sphere doses represent an upper boundary for the dose inside an actual spacecraft and are used as a top-level requirement. In cases where the amount of shielding surrounding a sensitive location is difficult to estimate, a more detailed analysis of the geometry of the spacecraft structure may be necessary to evaluate the expected dose levels. Table A4 and Figure 1 give the TID dose-depth curve for one year during solar minimum conditions. Table A5 and Figure 2 give the TID dose-depth curve for one year during solar maximum conditions. Table A6 and Figure 3 give the dose-depth curves for yearly increments up to 8 years.

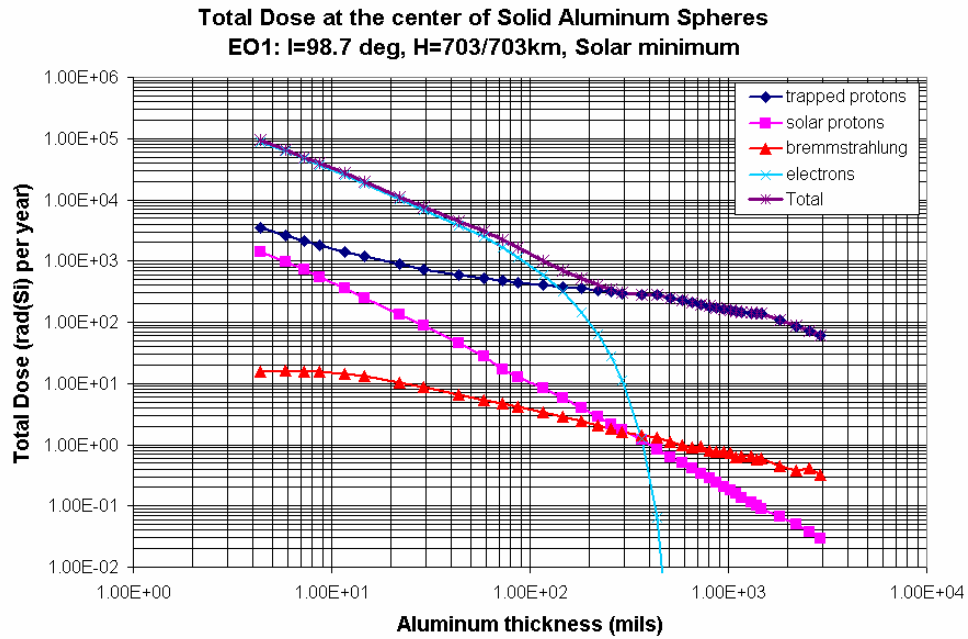


Figure 1: Total Ionizing Dose-depth curve for one year and solar minimum condition.

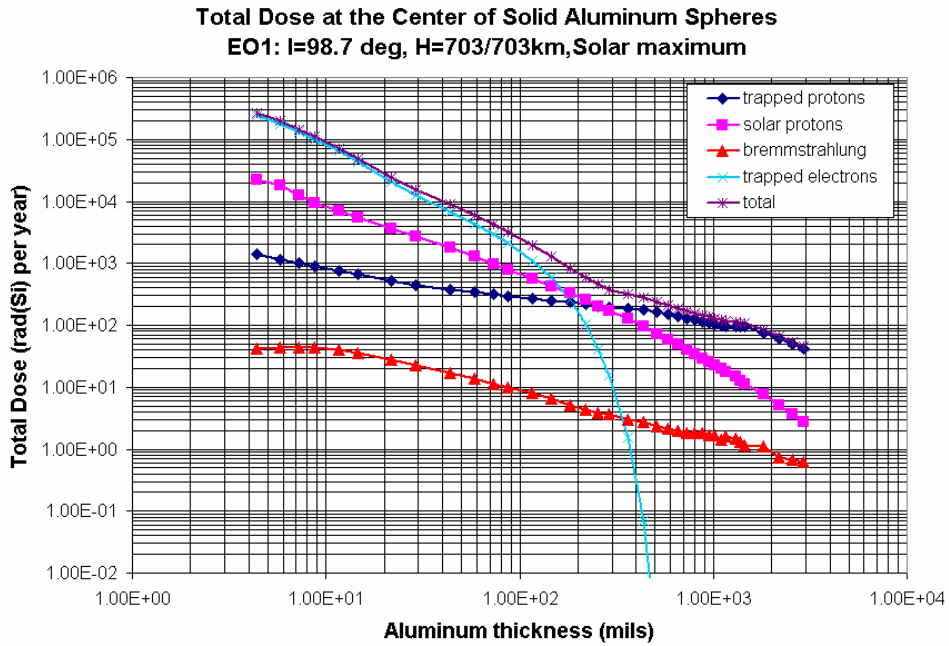


Figure 2 : Total Ionizing Dose-depth curve for one year and solar maximum condition.

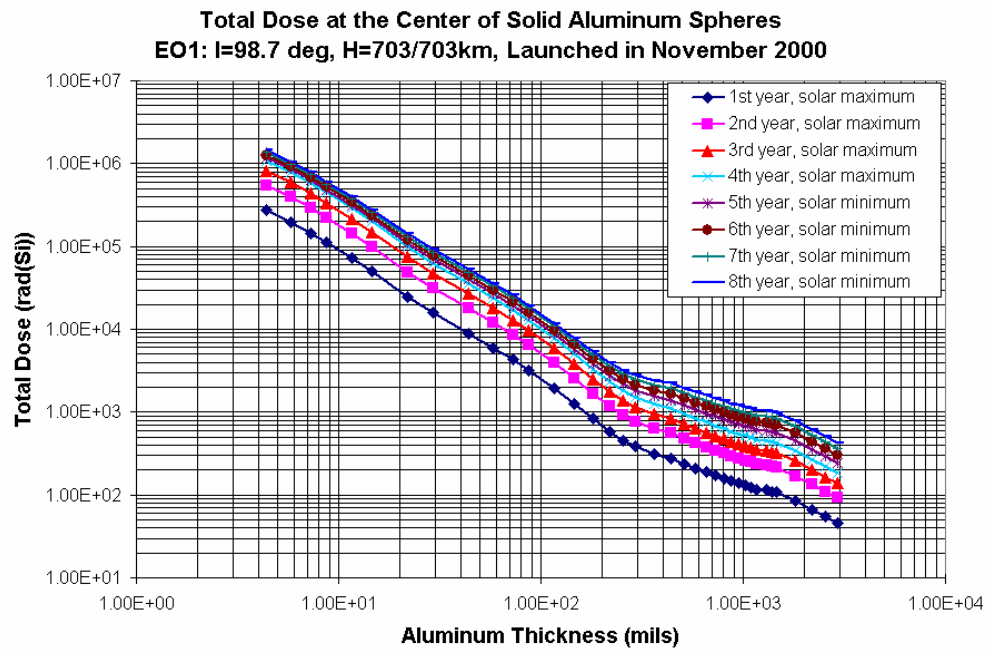


Figure 3 : Total Ionizing Dose-depth curve for yearly increments up to 8 years.

7 Appendices

Table A1: Spacecraft Incident Trapped Proton Fluences for 1 year

Energy	Fluence	
	Sol. Min.	Sol. Max.
(>MeV)	(#/cm2/yr)	(#/cm2/yr)
0.05	1.49E+11	1.54E+11
0.25	5.12E+10	4.13E+10
0.5	2.42E+10	1.48E+10
1	1.22E+10	5.92E+09
1.5	9.03E+09	4.35E+09
2	7.31E+09	3.62E+09
2.5	6.40E+09	3.32E+09
3	5.74E+09	3.10E+09
3.75	5.01E+09	2.85E+09
4.5	4.57E+09	2.70E+09
6	3.98E+09	2.49E+09
10	3.32E+09	2.17E+09
15	2.98E+09	1.99E+09
30	2.49E+09	1.67E+09
50	2.04E+09	1.38E+09
100	1.22E+09	8.59E+08
200	4.31E+08	3.14E+08
300	1.57E+08	1.13E+08
400	5.88E+07	4.17E+07

Table A2 : Spacecraft Incident Trapped Electron Fluences for 1 year

Energy	Fluence	
	Sol. Min.	Sol. Max.
(>MeV)	(#/cm ² /yr)	(#/cm ² /yr)
0.04	5.34E+12	1.35E+13
0.07	4.13E+12	1.06E+13
0.1	3.23E+12	8.37E+12
0.15	2.01E+12	5.41E+12
0.2	1.31E+12	3.56E+12
0.3	6.91E+11	1.67E+12
0.5	2.79E+11	5.26E+11
0.7	1.59E+11	2.83E+11
0.9	1.02E+11	1.80E+11
1	8.37E+10	1.47E+11
1.2	5.77E+10	1.04E+11
1.4	3.98E+10	7.38E+10
1.6	2.81E+10	5.26E+10
1.8	2.02E+10	3.76E+10
2	1.45E+10	2.68E+10
2.5	6.54E+09	1.20E+10
3	2.68E+09	4.53E+09
4	4.50E+08	5.74E+08
5.5	9.61E+06	9.72E+06

Table A3 : Spacecraft Incident Solar proton Fluences for 1 year

Energy	Fluence	
	Sol. Min.	Sol. Max.
> MeV	p/cm2/yr	p/cm2/yr
0.88	5.72E+09	6.67E+10
1.15	4.42E+09	5.45E+10
1.43	3.49E+09	4.57E+10
1.79	2.63E+09	3.76E+10
2.27	1.96E+09	3.01E+10
3.03	1.23E+09	2.18E+10
4.2	7.33E+08	1.54E+10
4.94	5.57E+08	1.17E+10
5.96	3.81E+08	9.47E+09
7.25	2.62E+08	7.61E+09
8.65	1.85E+08	6.21E+09
11.1	1.11E+08	4.59E+09
13.6	7.06E+07	3.54E+09
16.1	4.80E+07	2.82E+09
19.24	3.06E+07	2.17E+09
24.2	1.93E+07	1.56E+09
28.7	1.33E+07	1.18E+09
35.2	8.15E+06	8.17E+08
42.9	5.09E+06	5.59E+08
51	3.33E+06	3.87E+08
63.2	1.98E+06	2.37E+08
83.95	9.92E+05	1.20E+08
92.5	7.98E+05	9.35E+07
107	5.83E+05	6.39E+07
121	4.46E+05	4.52E+07
154	2.55E+05	2.30E+07
178	1.80E+05	1.55E+07
230	9.11E+04	9.15E+06
327	2.87E+04	3.32E+06

**Table A4 : Total Ionizing Dose at the Center of Aluminum spheres
for 1 year, solar minimum condition**

Al shielding thickness			dose [rad(Si)]				
g/cm ²	mm	mils	trapped protons	solar protons	bremsstrahlung	trapped electrons	total
3.00E-02	1.11E-01	4.37E+00	3.44E+03	1.41E+03	1.57E+01	8.86E+04	9.35E+04
4.00E-02	1.48E-01	5.83E+00	2.62E+03	9.78E+02	1.62E+01	6.26E+04	6.62E+04
5.00E-02	1.85E-01	7.29E+00	2.13E+03	7.36E+02	1.59E+01	4.71E+04	5.00E+04
6.00E-02	2.22E-01	8.75E+00	1.79E+03	5.52E+02	1.54E+01	3.73E+04	3.97E+04
8.00E-02	2.96E-01	1.17E+01	1.38E+03	3.54E+02	1.44E+01	2.54E+04	2.71E+04
1.00E-01	3.70E-01	1.46E+01	1.18E+03	2.48E+02	1.30E+01	1.85E+04	1.99E+04
1.50E-01	5.56E-01	2.19E+01	8.87E+02	1.34E+02	1.03E+01	1.02E+04	1.12E+04
2.00E-01	7.41E-01	2.92E+01	7.29E+02	8.82E+01	8.60E+00	6.77E+03	7.60E+03
3.00E-01	1.11E+00	4.37E+01	6.01E+02	4.54E+01	6.65E+00	3.82E+03	4.47E+03
4.00E-01	1.48E+00	5.83E+01	5.28E+02	2.83E+01	5.41E+00	2.46E+03	3.02E+03
5.00E-01	1.85E+00	7.29E+01	4.79E+02	1.69E+01	4.74E+00	1.67E+03	2.17E+03
6.00E-01	2.22E+00	8.75E+01	4.48E+02	1.26E+01	4.13E+00	1.16E+03	1.62E+03
8.00E-01	2.96E+00	1.17E+02	4.06E+02	8.25E+00	3.38E+00	5.92E+02	1.01E+03
1.00E+00	3.70E+00	1.46E+02	3.81E+02	5.72E+00	2.85E+00	3.17E+02	7.07E+02
1.25E+00	4.63E+00	1.82E+02	3.65E+02	4.04E+00	2.41E+00	1.44E+02	5.15E+02
1.50E+00	5.56E+00	2.19E+02	3.35E+02	2.89E+00	2.03E+00	6.37E+01	4.04E+02
1.75E+00	6.48E+00	2.55E+02	3.14E+02	2.18E+00	1.79E+00	2.73E+01	3.45E+02
2.00E+00	7.41E+00	2.92E+02	2.95E+02	1.72E+00	1.64E+00	1.12E+01	3.10E+02
2.50E+00	9.26E+00	3.65E+02	2.79E+02	1.19E+00	1.45E+00	1.25E+00	2.83E+02
3.00E+00	1.11E+01	4.37E+02	2.78E+02	8.34E-01	1.29E+00	6.43E-02	2.80E+02
3.50E+00	1.30E+01	5.10E+02	2.48E+02	6.26E-01	1.10E+00	3.12E-04	2.50E+02
4.00E+00	1.48E+01	5.83E+02	2.25E+02	4.98E-01	9.94E-01		2.26E+02
4.50E+00	1.67E+01	6.56E+02	2.08E+02	4.06E-01	9.05E-01		2.09E+02
5.00E+00	1.85E+01	7.29E+02	1.93E+02	3.34E-01	9.31E-01		1.94E+02
5.50E+00	2.04E+01	8.02E+02	1.81E+02	2.82E-01	7.95E-01		1.82E+02
6.00E+00	2.22E+01	8.75E+02	1.71E+02	2.38E-01	7.75E-01		1.72E+02
6.50E+00	2.41E+01	9.48E+02	1.62E+02	2.05E-01	7.54E-01		1.63E+02
7.00E+00	2.59E+01	1.02E+03	1.56E+02	1.79E-01	7.25E-01		1.57E+02
7.50E+00	2.78E+01	1.09E+03	1.50E+02	1.56E-01	6.26E-01		1.51E+02
8.00E+00	2.96E+01	1.17E+03	1.43E+02	1.36E-01	6.39E-01		1.44E+02
9.00E+00	3.33E+01	1.31E+03	1.42E+02	1.15E-01	6.46E-01		1.43E+02
9.50E+00	3.52E+01	1.39E+03	1.39E+02	1.03E-01	5.66E-01		1.40E+02
1.00E+01	3.70E+01	1.46E+03	1.37E+02	9.00E-02	5.90E-01		1.38E+02
1.25E+01	4.63E+01	1.82E+03	1.09E+02	6.71E-02	4.43E-01		1.10E+02
1.50E+01	5.56E+01	2.19E+03	8.64E+01	4.91E-02	3.79E-01		8.68E+01
1.75E+01	6.48E+01	2.55E+03	7.13E+01	3.73E-02	4.04E-01		7.17E+01
2.00E+01	7.41E+01	2.92E+03	6.00E+01	2.94E-02	3.15E-01		6.03E+01

**Table A5: Total Ionizing Dose at the Center of Aluminum spheres
for 1 year, solar maximum condition**

Al shielding thickness			dose [rad(Si)]				
g/cm ²	mm	mils	trapped protons	solar protons	bremsstrahlung	trapped electrons	total
3.00E-02	1.11E-01	4.37E+00	1.42E+03	2.24E+04	4.20E+01	2.47E+05	2.71E+05
4.00E-02	1.48E-01	5.83E+00	1.15E+03	1.80E+04	4.46E+01	1.78E+05	1.97E+05
5.00E-02	1.85E-01	7.29E+00	9.94E+02	1.23E+04	4.38E+01	1.32E+05	1.45E+05
6.00E-02	2.22E-01	8.75E+00	8.84E+02	9.43E+03	4.34E+01	1.01E+05	1.11E+05
8.00E-02	2.96E-01	1.17E+01	7.49E+02	7.05E+03	3.96E+01	6.44E+04	7.22E+04
1.00E-01	3.70E-01	1.46E+01	6.56E+02	5.54E+03	3.52E+01	4.35E+04	4.97E+04
1.50E-01	5.56E-01	2.19E+01	5.18E+02	3.66E+03	2.81E+01	2.04E+04	2.46E+04
2.00E-01	7.41E-01	2.92E+01	4.43E+02	2.74E+03	2.26E+01	1.25E+04	1.57E+04
3.00E-01	1.11E+00	4.37E+01	3.82E+02	1.78E+03	1.69E+01	6.69E+03	8.87E+03
4.00E-01	1.48E+00	5.83E+01	3.45E+02	1.31E+03	1.35E+01	4.31E+03	5.98E+03
5.00E-01	1.85E+00	7.29E+01	3.13E+02	9.69E+02	1.12E+01	2.99E+03	4.28E+03
6.00E-01	2.22E+00	8.75E+01	2.93E+02	7.90E+02	9.81E+00	2.13E+03	3.22E+03
8.00E-01	2.96E+00	1.17E+02	2.65E+02	5.78E+02	7.96E+00	1.10E+03	1.95E+03
1.00E+00	3.70E+00	1.46E+02	2.49E+02	4.33E+02	6.42E+00	5.84E+02	1.27E+03
1.25E+00	4.63E+00	1.82E+02	2.38E+02	3.31E+02	5.20E+00	2.57E+02	8.31E+02
1.50E+00	5.56E+00	2.19E+02	2.19E+02	2.57E+02	4.42E+00	1.06E+02	5.86E+02
1.75E+00	6.48E+00	2.55E+02	2.05E+02	2.06E+02	3.82E+00	4.09E+01	4.56E+02
2.00E+00	7.41E+00	2.92E+02	1.93E+02	1.70E+02	3.65E+00	1.53E+01	3.82E+02
2.50E+00	9.26E+00	3.65E+02	1.83E+02	1.27E+02	3.01E+00	1.52E+00	3.15E+02
3.00E+00	1.11E+01	4.37E+02	1.81E+02	9.49E+01	2.71E+00	6.86E-02	2.79E+02
3.50E+00	1.30E+01	5.10E+02	1.63E+02	7.25E+01	2.34E+00	6.64E-04	2.38E+02
4.00E+00	1.48E+01	5.83E+02	1.49E+02	5.86E+01	2.12E+00		2.10E+02
4.50E+00	1.67E+01	6.56E+02	1.38E+02	4.88E+01	1.98E+00		1.89E+02
5.00E+00	1.85E+01	7.29E+02	1.29E+02	4.05E+01	1.79E+00		1.71E+02
5.50E+00	2.04E+01	8.02E+02	1.22E+02	3.44E+01	1.79E+00		1.58E+02
6.00E+00	2.22E+01	8.75E+02	1.15E+02	2.93E+01	1.84E+00		1.46E+02
6.50E+00	2.41E+01	9.48E+02	1.10E+02	2.56E+01	1.70E+00		1.37E+02
7.00E+00	2.59E+01	1.02E+03	1.06E+02	2.28E+01	1.68E+00		1.30E+02
7.50E+00	2.78E+01	1.09E+03	1.02E+02	2.01E+01	1.42E+00		1.24E+02
8.00E+00	2.96E+01	1.17E+03	9.79E+01	1.74E+01	1.59E+00		1.17E+02
9.00E+00	3.33E+01	1.31E+03	9.76E+01	1.48E+01	1.46E+00		1.14E+02
9.50E+00	3.52E+01	1.39E+03	9.59E+01	1.28E+01	1.29E+00		1.10E+02
1.00E+01	3.70E+01	1.46E+03	9.51E+01	1.10E+01	1.15E+00		1.07E+02
1.25E+01	4.63E+01	1.82E+03	7.62E+01	7.73E+00	1.10E+00		8.50E+01
1.50E+01	5.56E+01	2.19E+03	6.07E+01	5.18E+00	7.45E-01		6.66E+01
1.75E+01	6.48E+01	2.55E+03	5.04E+01	3.70E+00	6.79E-01		5.48E+01
2.00E+01	7.41E+01	2.92E+03	4.26E+01	2.72E+00	6.12E-01		4.59E+01

Table A6: Dose depth for yearly increments up to 8 years

Al Shielding Thickness			Dose level in rad(Si)							
g/cm ²	mm	mils	1st year Oct-01 solmax	2nd year Oct-02 solmax	3rd year Oct-03 solmax	4th year Oct-04 solmax	5th year Oct-05 solmin	6th year Oct-06 solmin	7th year Oct-07 solmin	8th year Oct-08 solmin
3.00E-02	1.11E-01	4.37E+00	2.71E+05	5.42E+05	8.13E+05	1.08E+06	1.18E+06	1.27E+06	1.36E+06	1.46E+06
4.00E-02	1.48E-01	5.83E+00	1.97E+05	3.94E+05	5.92E+05	7.89E+05	8.55E+05	9.21E+05	9.87E+05	1.05E+06
5.00E-02	1.85E-01	7.29E+00	1.45E+05	2.91E+05	4.36E+05	5.81E+05	6.31E+05	6.81E+05	7.31E+05	7.81E+05
6.00E-02	2.22E-01	8.75E+00	1.11E+05	2.23E+05	3.34E+05	4.45E+05	4.85E+05	5.25E+05	5.64E+05	6.04E+05
8.00E-02	2.96E-01	1.17E+01	7.22E+04	1.44E+05	2.17E+05	2.89E+05	3.16E+05	3.43E+05	3.70E+05	3.98E+05
1.00E-01	3.70E-01	1.46E+01	4.97E+04	9.95E+04	1.49E+05	1.99E+05	2.19E+05	2.39E+05	2.59E+05	2.79E+05
1.50E-01	5.56E-01	2.19E+01	2.46E+04	4.92E+04	7.38E+04	9.84E+04	1.10E+05	1.21E+05	1.32E+05	1.43E+05
2.00E-01	7.41E-01	2.92E+01	1.57E+04	3.14E+04	4.71E+04	6.28E+04	7.04E+04	7.80E+04	8.56E+04	9.32E+04
3.00E-01	1.11E+00	4.37E+01	8.87E+03	1.77E+04	2.66E+04	3.55E+04	3.99E+04	4.44E+04	4.89E+04	5.34E+04
4.00E-01	1.48E+00	5.83E+01	5.98E+03	1.20E+04	1.79E+04	2.39E+04	2.69E+04	3.00E+04	3.30E+04	3.60E+04
5.00E-01	1.85E+00	7.29E+01	4.28E+03	8.57E+03	1.28E+04	1.71E+04	1.93E+04	2.15E+04	2.36E+04	2.58E+04
6.00E-01	2.22E+00	8.75E+01	3.22E+03	6.45E+03	9.67E+03	1.29E+04	1.45E+04	1.61E+04	1.78E+04	1.94E+04
8.00E-01	2.96E+00	1.17E+02	1.95E+03	3.90E+03	5.85E+03	7.80E+03	8.81E+03	9.82E+03	1.08E+04	1.18E+04
1.00E+00	3.70E+00	1.46E+02	1.27E+03	2.54E+03	3.82E+03	5.09E+03	5.80E+03	6.50E+03	7.21E+03	7.92E+03
1.25E+00	4.63E+00	1.82E+02	8.31E+02	1.66E+03	2.49E+03	3.32E+03	3.84E+03	4.36E+03	4.87E+03	5.39E+03
1.50E+00	5.56E+00	2.19E+02	5.86E+02	1.17E+03	1.76E+03	2.35E+03	2.75E+03	3.15E+03	3.56E+03	3.96E+03
1.75E+00	6.48E+00	2.55E+02	4.56E+02	9.11E+02	1.37E+03	1.82E+03	2.17E+03	2.51E+03	2.86E+03	3.20E+03
2.00E+00	7.41E+00	2.92E+02	3.82E+02	7.64E+02	1.15E+03	1.53E+03	1.84E+03	2.15E+03	2.46E+03	2.77E+03
2.50E+00	9.26E+00	3.65E+02	3.15E+02	6.29E+02	9.44E+02	1.26E+03	1.54E+03	1.82E+03	2.11E+03	2.39E+03
3.00E+00	1.11E+01	4.37E+02	2.79E+02	5.57E+02	8.36E+02	1.11E+03	1.39E+03	1.68E+03	1.96E+03	2.24E+03
3.50E+00	1.30E+01	5.10E+02	2.38E+02	4.76E+02	7.14E+02	9.51E+02	1.20E+03	1.45E+03	1.70E+03	1.95E+03
4.00E+00	1.48E+01	5.83E+02	2.10E+02	4.19E+02	6.29E+02	8.39E+02	1.07E+03	1.29E+03	1.52E+03	1.74E+03
4.50E+00	1.67E+01	6.56E+02	1.89E+02	3.78E+02	5.66E+02	7.55E+02	9.64E+02	1.17E+03	1.38E+03	1.59E+03
5.00E+00	1.85E+01	7.29E+02	1.71E+02	3.43E+02	5.14E+02	6.85E+02	8.79E+02	1.07E+03	1.27E+03	1.46E+03
5.50E+00	2.04E+01	8.02E+02	1.58E+02	3.16E+02	4.75E+02	6.33E+02	8.15E+02	9.97E+02	1.18E+03	1.36E+03
6.00E+00	2.22E+01	8.75E+02	1.46E+02	2.92E+02	4.38E+02	5.85E+02	7.57E+02	9.29E+02	1.10E+03	1.27E+03
6.50E+00	2.41E+01	9.48E+02	1.37E+02	2.75E+02	4.12E+02	5.49E+02	7.12E+02	8.75E+02	1.04E+03	1.20E+03
7.00E+00	2.59E+01	1.02E+03	1.30E+02	2.61E+02	3.91E+02	5.22E+02	6.79E+02	8.36E+02	9.93E+02	1.15E+03
7.50E+00	2.78E+01	1.09E+03	1.24E+02	2.47E+02	3.71E+02	4.94E+02	6.45E+02	7.96E+02	9.46E+02	1.10E+03
8.00E+00	2.96E+01	1.17E+03	1.17E+02	2.34E+02	3.51E+02	4.68E+02	6.11E+02	7.55E+02	8.99E+02	1.04E+03
9.00E+00	3.33E+01	1.31E+03	1.14E+02	2.28E+02	3.42E+02	4.55E+02	5.98E+02	7.41E+02	8.84E+02	1.03E+03
9.50E+00	3.52E+01	1.39E+03	1.10E+02	2.20E+02	3.30E+02	4.40E+02	5.80E+02	7.19E+02	8.59E+02	9.99E+02
1.00E+01	3.70E+01	1.46E+03	1.07E+02	2.15E+02	3.22E+02	4.29E+02	5.67E+02	7.04E+02	8.42E+02	9.80E+02
1.25E+01	4.63E+01	1.82E+03	8.50E+01	1.70E+02	2.55E+02	3.40E+02	4.50E+02	5.59E+02	6.69E+02	7.78E+02
1.50E+01	5.56E+01	2.19E+03	6.66E+01	1.33E+02	2.00E+02	2.67E+02	3.53E+02	4.40E+02	5.27E+02	6.14E+02
1.75E+01	6.48E+01	2.55E+03	5.48E+01	1.10E+02	1.64E+02	2.19E+02	2.91E+02	3.63E+02	4.34E+02	5.06E+02
2.00E+01	7.41E+01	2.92E+03	4.59E+01	9.19E+01	1.38E+02	1.84E+02	2.44E+02	3.04E+02	3.65E+02	4.25E+02