Exposure Calculation Report

Raymarine Belgium BVBA
Solid state non-IMO radar,
Model: Cyclone Pro

In accordance with FCC 47 CFR Part 1.1310: 2018 and ISED Canada: Health Canada Safety Code 6:2015

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Jon Kenny	Manager (RF)	Authorised Signatory	14 May 2021

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EXECUTIVE SUMMARY
The calculation of exposure for this product was found to be compliant at a minimum distance of 20 cm (Occupational) - 50 cm (General Public) using Antenna: Model: E70628, 30 cm (Occupational) - 50 cm (General Public) using Antenna: Model: E70629 and 30 cm (Occupational) - 50 cm (General Public) using Antenna: Model: E70630 with 47 CFR Part 1.1310: 2018 and ISED Canada: Health Canada Safety Code 6:2015 assuming continuous exposure of 6 minutes or more. The calculated compliance distance is based on rotational averaged power density, assumption is made that the power is shut down when the antenna is stationary. If alternative antennas are used with greater gains or differing dimensions, the distance must be recalculated.

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Contents

1 Report Summary

1.1 Report Modification Record

Alterations and additions to this report will be issued to the holders of each copy in the form of a complete document.

Issue	Description of Change	Date of Issue
1	First Issue	14 May 2021

Table 1

1.2 Introduction

Applicant	Raymarine Belgium BVBA
Manufacturer	Raymarine Belgium BVBA
Model Number(s)	Cyclone Pro E70621 AD601YR
Hardware Version(s)	Radar Pedestal 1012140-3 with the following deviations applied: D-21-1377 D-20-1186 D-20-1264 D-21-1335 D-21-1378 D-21-1383 D-21-1407 3ft antenna: 1011615-3 4ft antenna: 1011614-3 6ft antenna: 1010556-3
Software Version(s)	V0.56.439
Specification/Issue/Date	• ISED Canada: Health Canada Safety Code 6:2015 • FCC 47 CFR Part 1.1310: 2018
Order Number Date	1310109535 20-October-2020
Related Document(s)	• RSS-102 Issue 5 Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands) • IEEE C95.3:2002 IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–300 GHz

1.3 Summary of Results

The Radar described within this report was compliant with the restrictions related to human exposure to electromagnetic fields for both general public and worker/occupational exposures at the minimum compliance distances calculated.

The calculations shown in this report were made in accordance with the procedures specified in the applied test specification(s).

1.3.1 Rotationally Averaged Compliance Boundary

Configuration	Calculated minimum compliance boundary (m) (rounded up to nearest 0.1 m)	
	Worker/Occupational	General Public
3ft Antenna: Model: E70628	0.2 m which is < Swept Volume (0.52 m)	0.5 m which is < Swept Volume (0.52 m)
4ft Antenna: Model: E70629	0.3 m which is < Swept Volume (0.67 m)	0.5 m which is < Swept Volume (0.67m)
6ft Antenna: Model: E70630	0.3 m which is < Swept Volume (0.975 m)	0.5 m which is < Swept Volume (0.975 m)

Table 2 – Rotationally Averaged Compliance Boundary Calculation Results

1.3.2 Beam Stationary Compliance Boundary

Configuration	Calculated minimum compliance boundary (m) (rounded up to nearest 0.1 m)	
	Worker/Occupational	General Public
3ft Antenna: Model: E70628	N/A	N/A
4ft Antenna: Model: E70629	N/A	N/A
6ft Antenna: Model: E70630	N/A	N/A

Table 3 – Beam Stationary Boundary Calculation Results

Assumption is made that the device does not transmit whilst stationary.

1.4 Product Information

1.4.1 Technical Description

Solid state non-IMO X-band Radar

1.4.2 Transmitter Description

The following radio access technologies and frequency bands are supported by the equipment under test.

Frequency Band (MHz)	Output Power (dBm)	Pulse Width (nS)	Pulse Repetition Frequency (Hz)	Duty Cycle (%)
9370 -9430	49.78	46	4800	0.02
9370 -9430	49.78	192	4800	0.09
9370 -9430	49.78	750	4800	0.36
9370 -9430	49.78	1020	4800	0.49
9370 -9430	49.78	1235	4800	0.59
9370 -9430	49.78	1675	4800	0.80
9370 -9430	49.78	2300	4800	1.10
9370 -9430	49.78	2710	4800	1.30
9370 -9430	49.78	3900	4800	1.87
9370 -9430	49.78	**17600**	**3600**	**6.34**
9370 -9430	49.78	23600	2400	5.66
9370 -9430	49.78	35000	1200	4.20
9370 -9430	49.78	47000	820	3.85
9370 -9430	49.78	79000	700	5.53

Table 4 – Transmitter Description

Note: Transmitter power includes upper bounds of uncertainty therefore maximum values are used in accordance with Section 2.6.

1.4.3 Antenna Description

The following antennas are supported by the equipment under test.

Antenna	Antenna length (cm)	Antenna height (cm)	Gain (dBi)	Antenna Beamwidth (Degrees)
E70628	104	6.3	25.7	1.32
E70629	134	6.3	27.7	1.99
E70630	195	6.3	29.8	2.83

Table 5 – Antenna description

Note: Antenna gain includes upper bounds of uncertainty therefore maximum values are used in accordance with Section 2.3.

2 Assessment Details

2.1 Assessment Method

The following documents provide guidance on radar RF exposure assessment.

1. FCC Guideline OET Bulletin 65
2. IEEE C95.3
3. Canada Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines
4. Australia/New Zealand AS/NZS2772-2
5. UK Defence Standard 05-74

From these documents the following assessment method is derived:

The assessment method is by calculation of the power density S in each of three antenna field regions are shown in Figure 1. the field region boundaries R_2 and R_1 are calculated in the field region boundary results.

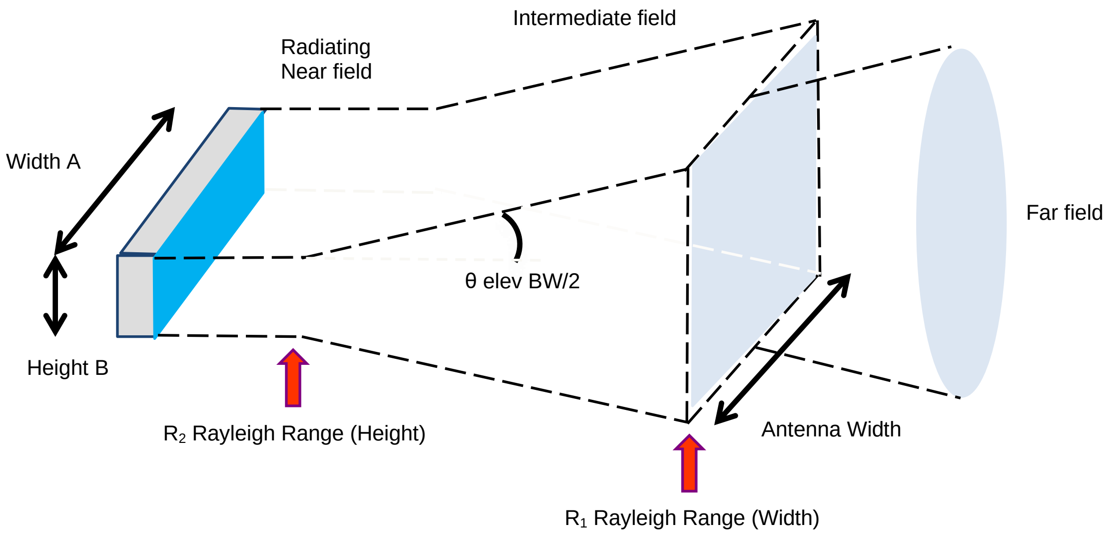

Figure 1 – Antenna Field Regions

Quantities:

The quantities used in the calculations are shown in Table 5:

Quantity	Description	Units
f	Frequency	MHz
λ	Wavelength c=fλ, c=3E8 m/s	m
G_i dB	Gain	dB
G_i	Gain $G_i=10^{(GdBi/10)}$	Ratio
t_p	Pulse width	µs
PRF	Pulse repetition frequency	Hz
$P_{o\ peak}$	Peak power into antenna	W
$P_{o\ av}$	Mean power into antenna $P_{av} = P_{Peak} * t_p * PRF$	W
A	Antenna Width - Maximum Antenna Dimension	m
B	Antenna Height - Minimum Antenna Dimension	m
$\theta_{azimuth}$	Azimuth antenna beamwidth	° Degrees
R_1	Rayleigh range distance due to antenna width A $R_1 = A^2/2\lambda$	m
R_2	Rayleigh range distance due to antenna height B $R_2 = B^2/2\lambda$	m
S	Power flux density (see equations below)	W/m^2
r	Separation distance from antenna	m

Table 6 – Quantities

Far Field:

The calculation in the far field uses the spherical model applicable under far field conditions.

$$\boldsymbol{S = \frac{Pav \times G_i}{4 \times \pi \times r^2}}$$

Intermediate Field:

No simple calculation possible but in the main beam the power density reduces as 1/distance r beyond the R_2 Rayleigh Range up to the R_1 far field boundary.
The reference power density S_{R1} at the start of the Far Field at R_1 Rayleigh Range is given by far field equation in the above paragraph. The power density within the intermediate field is therefore given by;

$$S = \frac{R_1 x S_{R1}}{r}$$

Radiating near field equation:

The maximum worst case near field power density is given by;

$$S(W/m^2) = \frac{4P_0}{Area}$$

Where: Area - Area of antenna array (A width x B height)

Rotational Averaging:

Where the antenna continuously rotates and cannot operate stationary, a rotational averaging factor can be derived to calculate the reduction in the time averaged power density. The factor calculation depends on the field region below:

Near Field:

In the radiating and intermediate near field the rotational averaging factor K depends on the antenna width A as the beam is unfocused and the resultant power density varies with distance r. The power density is multiplied by the factor K:

$$K = \frac{A}{2\pi r}$$

Far Field:

In the far field the rotational averaging factor K depends only on the antenna azimuth beamwidth θ. The power density is multiplied by the factor K:

$$K = \frac{\theta}{360}$$

Caveats:

This assessment is an estimate and if necessary, should be confirmed by measurement of the radar using suitable test instrumentation.

This assessment assumes that exposure is continuous for 6 minutes or more in accordance with the averaging time required by the exposure standards at the stated minimum compliance boundary separation distance. Exposures of less than 6 minutes at other separation distances are not addressed by this report.

The far field region boundary depends on the frequency and wavelength and also on the antenna dimension. The boundary of the far field region is calculated below to demonstrate the validity of using the spherical model.

The result is compared to the limits in Annex A to determine compliance or to calculate the required compliance distance. The calculation is based on the lowest frequency in each band as the most onerous requirement as the limits increase with frequency for frequencies above 10-50 MHz (dependent on region).

2.2 Antenna E70628 Parameters and Results:

Parameter	Value	Units	Source
Occupational Reference Level mean power SOcc	50	W/m2	
General Public Reference Level mean power SGP	10	W/m2	
Frequency f	9370	MHz	Manufacturer
Wavelength λ	0.0320171	m	c=f*λ
Power (peak) Ppeak	95	W	Manufacturer
Gain Gi	371.5	ratio	
Pulse width tp	17.6	us	Manufacturer
Pulse Repetition Frequency PRF	3600	Hz	Manufacturer
Azimuth beamwdith θ	1.32	degrees	Manufacturer
Scanning Averaging Factor K	0.00367	N/A	K = azimuth beamwidth/360 (far field)
Power (mean) Pmean	6.0192	W	PMean =PPeak*tp*PRF
Power (mean) rotationally/scanned averaged PMean rot av	0.0220905	W	PMean rot av = PMean*K
Maximum Width Dimension A	1.04	m	Manufacturer
Height dimension B	0.063	m	Manufacturer

Table 7 – Antenna E70628 Parameters

RADIATING NEAR FIELD RESULT			
The following boundaries assume radiating near field and are valid only if compliance distance < Rayleigh Range R2			
Maximum near field power density main beam Snear (beam stationary)	367.47253	W/m2	SNear = 4*PMean/A*B
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SOcc]
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SGP]
Near field power density main beam at swept volume boundary (r=A/2) (rotationally averaged)	116.97014	W/m2	S=[4*Pmean/A*B]*[1/π]
INTERMEDIATE FIELD RESULT			
The following boundaries assume intermediate near field and are valid only if compliance distance > Rayleigh Range R2 and < Raleigh Range R1			
Main Beam Compliance Boundary Occupational (beam stationary)	Less than swept volume (0.211)	m	r=R1*SR1/Socc
Main Beam Compliance Boundary General Public (beam stationary)	1.053	m	r=R1*SR1/SGP
Main Beam Compliance Boundary Occupational (rotationally averaged)	Less than swept volume (0.187)	m	r=[R1*SR1*A/2*π*Socc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	Less than swept volume (0.418)	m	r=[R1*SR1*A/2*π*SGP]^0.5
FAR FIELD RESULT			
The following boundaries assume far field and are valid only if compliance distance > Rayleigh Range R1			
Reference power density main beam (beam stationary) at R1	0.6237028	W/m2	SR1=PMean*Gi /4*π*R1^2
Reference power density main beam (rotationally averaged) at R1	0.002289	W/m2	SR1 Rot Av=PMean Rot Av*Gi /4*π*R1^2
Main Beam Compliance Boundary Occupational (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SGP]^0.5
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SGP]^0.5

Table 8 – Antenna E70628 Results

2.3 Antenna E70629 Parameters and Results:

Parameter	Value	Units	Source
Occupational Reference Level mean power SOcc	50	W/m2	
General Public Reference Level mean power SGP	10	W/m2	
Frequency f	9370	MHz	Manufacturer
Wavelength λ	0.0320171	m	c=f*λ
Power (peak) Ppeak	95	W	Manufacturer
Gain Gi	588.8	ratio	
Pulse width tp	17.6	us	Manufacturer
Pulse Repetition Frequency PRF	3600	Hz	Manufacturer
Azimuth beamwdith θ	1.99	degrees	Manufacturer
Scanning Averaging Factor K	0.00553	N/A	K = azimuth beamwidth/360 (far field)
Power (mean) Pmean	6.0192	W	PMean =PPeak*tp*PRF
Power (mean) rotationally/scanned averaged PMean rot av	0.0220905	W	PMean rot av = PMean*K
Maximum Width Dimension A	1.34	m	Manufacturer
Height dimension B	0.063	m	Manufacturer

Table 9 – Antenna E70629 Parameters

RADIATING NEAR FIELD RESULT			
The following boundaries assume radiating near field and are valid only if compliance distance < Rayleigh Range R2			
Maximum near field power density main beam Snear (beam stationary)	285.20	W/m2	SNear = 4*PMean/A*B
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SOcc]
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SGP]
Near field power density main beam at swept volume boundary (r=A/2) (rotationally averaged)	90.78	W/m2	S=[4*Pmean/A*B]*[1/π]
INTERMEDIATE FIELD RESULT			
The following boundaries assume intermediate near field and are valid only if compliance distance > Rayleigh Range R2 and < Raleigh Range R1			
Main Beam Compliance Boundary Occupational (beam stationary)	Less than swept volume (0.201)	m	r=R1*SR1/Socc
Main Beam Compliance Boundary General Public (beam stationary)	1.001	m	r=R1*SR1/SGP
Main Beam Compliance Boundary Occupational (rotationally averaged)	Less than swept volume (0.207)	m	r=[R1*SR1*A/2*π*Socc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	Less than swept volume (0.463)	m	r=[R1*SR1*A/2*π*SGP]^0.5
FAR FIELD RESULT			
The following boundaries assume far field and are valid only if compliance distance > Rayleigh Range R1			
Reference power density main beam (beam stationary) at R1	0.35867	W/m2	SR1=PMean*Gi /4*π*R12
Reference power density main beam (rotationally averaged) at R1	0.00198	W/m2	SR1 Rot Av=PMean Rot Av*Gi /4*π*R1^2
Main Beam Compliance Boundary Occupational (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SGP]^0.5
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SGP]^0.5

Table 10 – Antenna E70629 Results

2.4 Antenna E70630 Parameters and Results:

Parameter	Value	Units	Source
Occupational Reference Level mean power SOcc	50	W/m2	
General Public Reference Level mean power SGP	10	W/m2	
Frequency f	9370	MHz	Manufacturer
Wavelength λ	0.0320171	m	c=f*λ
Power (peak) Ppeak	95	W	Manufacturer
Gain Gi	891.3	ratio	
Pulse width tp	17.6	us	Manufacturer
Pulse Repetition Frequency PRF	3600	Hz	Manufacturer
Azimuth beamwdith θ	2.83	degrees	Manufacturer
Scanning Averaging Factor K	0.00786	N/A	K = azimuth beamwidth/360 (far field)
Power (mean) Pmean	6.0192	W	PMean =PPeak*tp*PRF
Power (mean) rotationally/scanned averaged PMean rot av	0.0220905	W	PMean rot av = PMean*K
Maximum Width Dimension A	1.95	m	Manufacturer
Height dimension B	0.063	m	Manufacturer

Table 11 – Antenna E70630 Parameters

RADIATING NEAR FIELD RESULT			
The following boundaries assume radiating near field and are valid only if compliance distance < Rayleigh Range R2			
Maximum near field power density main beam Snear (beam stationary)	195.99	W/m2	SNear = 4*PMean/A*B
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SOcc]
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[4*Pmean/A*B]*[A/2*π*SGP]
Near field power density main beam at swept volume boundary (r=A/2) (rotationally averaged)	62.38	W/m2	S=[4*Pmean/A*B]*[1/π]
INTERMEDIATE FIELD RESULT			
The following boundaries assume intermediate near field and are valid only if compliance distance > Rayleigh Range R2 and < Raleigh Range R1			
Main Beam Compliance Boundary Occupational (beam stationary)	Less than swept volume (0.1438)	m	r=R1*SR1/Socc
Main Beam Compliance Boundary General Public (beam stationary)	Less than swept volume (0.7189)	m	r=R1*SR1/SGP
Main Beam Compliance Boundary Occupational (rotationally averaged)	Less than swept volume (0.2112)	m	r=[R1*SR1*A/2*π*Socc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	Less than swept volume (0.4724)	m	r=[R1*SR1*A/2*π*SGP]^0.5
FAR FIELD RESULT			
The following boundaries assume far field and are valid only if compliance distance > Rayleigh Range R1			
Reference power density main beam (beam stationary) at R1	0.35867	W/m2	SR1=PMean*Gi /4*π*R12
Reference power density main beam (rotationally averaged) at R1	0.00198	W/m2	SR1 Rot Av=PMean Rot Av*Gi /4*π*R1^2
Main Beam Compliance Boundary Occupational (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (beam stationary)	N/A	m	r=[PMean*Gi /4*π*SGP]^0.5
Main Beam Compliance Boundary Occupational (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SOcc]^0.5
Main Beam Compliance Boundary General Public (rotationally averaged)	N/A	m	r=[PMean rot av*Gi /4*π*SGP]^0.5

Table 11 – Antenna E70630 Results

2.5 Field Region Boundary Results

The field region boundary calculation result is shown in Table 6:

Field Region Boundaries (Ref: FCC Guideline OET Bulletin 65, IEEE C95.3 Annex B, Technical Guide for Interpretation and Compliance Assessment of Health Canada's Radiofrequency Exposure Guidelines 7.1, UK Defence Standard 05-74)			
Antenna Configuration	Radiating Near Field Boundary R_2	Intermediate Near Field R_2 to R_1	Far Field Boundary R_1
	$B^2/2\lambda$ (m)	$B^2/2\lambda$ to $A^2/2\lambda$ (m)	$A^2/2\lambda$ (m)
E70628 @ 9370MHz	< 0.062	0.062 – 16.9	> 16.9
E70629 @ 9370MHz	< 0.062	0.062 – 28.0	> 28.0
E70629 @ 9370MHz	< 0.062	0.062 – 59.4	> 59.4

Table 12 –Field Region Boundaries

The appropriate calculation has been applied to each of the three regions as described in the assessment method section therefore the calculation result is considered valid.

2.6 Uncertainty

The basic computation formulas presented in section **Error! Reference source not found.** are c onservative formulas for the estimation of RF field strength or power density.

No uncertainty estimations are required when using these formulas but there is clear guidance on where and when these formulas are applicable. For the estimate of S, E or H to be conservative, the transmitter power P and antenna gain G_i values shall be the upper bounds of uncertainty therefore maximum values are used.

The spherical formula is valid under far field conditions which are established in section 2.5.

ANNEX A

REGIONAL REQUIREMENTS

Frequency Range (MHz)	Power Density (W/m^2)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)
10 - 20	10	61.4	0.163
20 - 48	44.72/f^0.5	129.8/f^0.25	0.3444/f^0.25
48 - 100	6.455	49.33	0.1309
100 - 6000	0.6455*f^0.5	15.60*f^0.25	0.04138*f^0.25
6000 - 150000	50	137	0.364

Table A.1 – Health Canada Safety Code 6 Worker/Occupational Limits

Frequency Range (MHz)	Power Density (W/m^2)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)
10 - 20	2	27.46	0.0728
20 - 48	8.944/f^0.5	58.07/f^0.25	0.1540/f^0.25
48 - 300	1.291	22.06	0.05852
300 - 6000	0.02619*f^0.6834	3.142*f^0.3417	0.008335*f^0.3417
6000 - 15000	10	61.4	0.163

Table A.2 – Health Canada Safety Code 6 General Public Limits

Frequency Range (MHz)	Power Density (mW/cm^2) Note 1	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)
0 - 0.3	-	-	-
0.3 - 3	100	614	1.63
3 - 30	900/f^2	1842/f	4.89/f
30 - 300	1	61.4	0.163
300 - 1500	f/300	-	-
1500 - 100000	5	-	-

Table A.1 – CFR 47 Pt1.1310 Worker/Occupational Limits

Frequency Range (MHz)	Power Density (mW/cm^2) Note 1	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)
0 - 0.3	-	-	-
0.3 - 3	100	614	1.63
3 - 30	180/f^2	824/f	2.19/f
30 - 300	0.2	27.5	0.073
300 - 1500	f/1500	-	-
1500 - 100000	1	-	-

Table A.2 – CFR 47 Pt1.1310 General Public Limits

Note 1: The calculations and limits presented in this report for power density are in units of W/m^2. The conversion factor is; 1 mW/cm^2 = 10 W/m^2.