Typical RF SafeStop™ car stopping demonstration

The following calculation provides an assessment of a typical RF SafeStop demonstration against the requirement of the "Control of Electromagnetic Field at work regulations 2016".

System performance parameters

Magnetron power:	2.5MW
Antenna gain:	23.4dBi
System EIRP:	87.4dBW
Duty cycle:	0.1%
Pulse width:	1 to 3µs
Frequency:	1.345GHz

Assumptions

1) Any RF exposure is at the level of the peak RF power density associated with the RF transmitted beam, no account has been made for the RF spot size.

2) Full body surface area coverage is assumed.

3) Total energy absorption is taking place within the biological tissue (i.e. no RF reflection from the human body).

RF electric field action level

The RF electric field action level (AL) stated in the "Control of Electromagnetic Field at work regulations 2016" is for a continuous wave (CW) source rather than a pulsed source, at the operating frequency of the RF SafeStop system there is no AL limit for pulsed sources. Adhering to the CW source AL limit as an absolute peak RF field level would render the RF SafeStop completely ineffective against all target vehicles!

It is not a legal requirement to adhere to the specified AL for RF electric field provided the appropriate exposure limit values (ELVs) are not exceeded. During a typical RF SafeStop demonstration e2v personnel will be exposed to RF field levels greater than the 110Vm^{-1} AL specified in the "Control of Electromagnetic Field at work regulations 2016". The following sections provide evidence to show how e2v will adhere to the appropriate ELVs during a typical car stopping demonstration.

Exclusion zone based on sensory effects

For the sensory effects exposure limit value (ELV) one is concerned with the energy associated with a single high power RF pulse. For these calculations we have assumed the localised specific energy absorption (SA) level over the entire average human male.

$$SA = PD \times PW \times \frac{BA}{BM}$$

The RF field strength associated with a given power density in free space is

$$V_{RF} = \sqrt{PD \times 377}$$

Assuming the antenna is an isotropic radiator the RF power density decays as the square of the distance from the antenna and is given by the following relationship

$$PD = \frac{EIRP}{4\pi \times R^2}$$

Where

SA = Specific energy absorption
PD = Power density
PW = Pulse width
BA = Average body surface area of an adult male ($1.9m^2$)
BM = Average mass of an adult male (70kg)
V_{RF} = Root mean square of the RF field strength
EIRP = Equivalent isotropic radiated power of the microwave source
R = Range from microwave source

For each system pulse width the range at which the sensory effects ELV of $10mJkg^{-1}$ will be exceeded is given in the following table

Pulse width	Power density associated with pulse	RF field strength	Range (personnel exclusion distance)
1µs	$368.4kWm^{-2}$	$11785Vm^{-1}$	10.9m
2µs	$184.2kWm^{-2}$	$8334Vm^{-1}$	15.4m
3µs	$122.8kWm^{-2}$	$6804Vm^{-1}$	18.9m

Based on these calculations an exclusion zone 20m in front of the RF Safestop will be enforced, when the system is transmitting no personnel are allowed within this exclusion zone.

A typical demonstration involves driving the target vehicle towards the RF SafeStop, whilst it's transmitting, along a predefine course that directs the target out of the RF beam at either 20m or 25m from the RF SafeStop system. At these distances the specific energy absorption levels associated with each RF pulse width selection are given in the following table and are all below the occupational limit level of $10mJkg^{-1}$.

Pulse width	SA at 20m	SA at 25m
1µs	$3.0mJkg^{-1}$	$1.9mJkg^{-1}$
2µs	$5.9mJkg^{-1}$	$3.8mJkg^{-1}$
3µs	$8.9mJkg^{-1}$	$5.7mJkg^{-1}$

Energy absorption associated with a target demonstration run

For the specific absorption rate (SAR) ELV one must consider the cumulative absorption over any six minute period since the RF SafeStop is not operated continuously.

The standard car stopping test run involves driving the target vehicle at 25mph towards the RF SafeStop along the antenna RF boresight. RF transmission commences when the vehicle is at 100m from the RFSS system and is terminated either when the vehicle stops or exits the main RF beam at either 20m or 25m from the RF SafeStop system. If the vehicle is stopped or effected the RF transmission may continue for up to 5 seconds whilst the confirmation of the success is relayed to the RF SafeStop operator.

The RF specific absorption over a period of time is given by

$$A_{RF} = \frac{EIRP \times D}{4\pi \times R^2} \times \frac{BA}{BM} \times Time$$

Where

A_{RF} = RF absorption
D = RF SafeStop duty cycle
Time = Exposure relative to a six minute period

For the calculation of total RF absorption by the target driver during a single run the distance travelled by the target is subdivided into 5m intervals, at each interval the time is calculated from the vehicle speed and the absorption from the closest distance to the RF SafeStop system at the end of the 5m interval. For the following example it is assumed the target is stopped at the 20m exit point and hence sits at this distance for a 5 seconds confirmation time.

Distance from RF SafeStop system	Time interval	RF absorption over time interval
100	0	0
95	0.447	0.00016
90	0.447	0.00018
85	0.447	0.00020
80	0.447	0.00023
75	0.447	0.00026
70	0.447	0.00030
65	0.447	0.00035
60	0.447	0.00041
55	0.447	0.00049
50	0.447	0.00059
45	0.447	0.00073
40	0.447	0.00092
35	0.447	0.00120
30	0.447	0.00164
25	0.447	0.00236
20	5	0.04121

Total	11.705s	$0.0513Wkg^{-1}$

For each demonstration run the target vehicle driver will be subjected to a SAR level of $0.0513Wkg^{-1}$ compared to the occupational limit level of $0.4Wkg^{-1}$. The specific absorption rate (SAR) ELV is averaged over a six minute period and as the RF SafeStop system is not used as a continuous transmitter it's acceptable for the target vehicle driver to accumulate a SAR level over multiple demonstrations provided the ELV is not exceeded. Thus any individual driver can perform up to seven demonstartion runs in any six minute period and still remain within the occupational SAR ELV limit.

Notes

Although in the typical test scenario RF ground bounce will be present the effect on power density will be configuration dependent and will yield both reduction and enhance of the power density level over the distance travelled by the target vehicle. As a consequence the formula for an isotropic radiator has been used for all power density calculations, this is the approach adopted by the licensing authority when determining the general public and equipment safety distances.

RF field measurements within an unoccupied vehicle can yield localised points of RF field enhancement as a result of multiple signal reflections. However in all the above calculations the assumption is that total RF energy absorption is taking place when the signal is incident upon the human tissue (no signal reflection) and hence the RF field enhancement measured within an unoccupied vehicle will not be present. If any RF field enhancement is measured within the target vehicle when occupied would suggest that full RF absorption by the driver is not taking place and the above calculations are over estimating the driver’s exposure.