Fraunhofer
FHR

FRAUNHOFER INSTITUTE FOR HIGH FREQUENCY PHYSICS AND RADAR TECHNIQUES FHR

RESEARCH ON THE TNO STUDY ON POTENTIAL HEALTH EFFECTS FROM A MILITARY SMART-L RADAR

- FINAL REPORT -

RESEARCH ON THE TNO STUDY ON POTENTIAL HEALTH EFFECTS FROM A MILITARY SMART-L RADAR

[redacted]

Fraunhofer Institute for High Frequency Physics and Radar Techniques, FHR
in Wachtberg, Germany.

Project number FHR: 151-101820;
Contract number: 4501837712
Project partner: The State of the Netherlands, represented by the Minister of Defence,

Content

1 Introduction

1.1 Executive Summary

The Ministry of Defence in the Netherlands has announced its intention to install a radar system to be used by the Royal Netherlands Air Force (Klu) for monitoring the airspace over the Netherlands. This radar system is also important for guiding friendly fighter aircraft. The proposed location for this long-range radar is Broekgraaf 1 in Herwijnen, municipality of West-Betuwe. Local residents participating in various public meetings have voiced concerns about the possible adverse health effects that can be incurred from exposure to this radar system. For that reason, the Ministry of Defence has commissioned a scientific study “TNO-rapport gezondheidsaspecten RF-velden voorgenomen SMART-L-radar Herwijnen” by TNO [1].

The aim of the present report “RESEARCH ON THE TNO STUDY ON POTENTIAL HEALTH EFFECTS FROM A MILITARY SMART-L RADAR” is to review and evaluate the TNO study with respect to two specific research questions addressing the validity of TNO’s approach and the obtained results with regard to the evaluation of health effects due to cumulative RF-fields.

Based on the prerequisites stated in section 1.2, it can be concluded that the methodology used by TNO for evaluation of cumulative exposure directly follows the ICNIRP-1998 Guidelines. The results have been reproduced in the present study and, except for slight differences, agree very well with the results provided in the TNO report.

It might be necessary to further study exposure to electromagnetic fields at publicly accessible locations that are closer to the SMART-L radar than the nearest dwelling, which is the location for which TNO evaluated the data.

1.2 Assumptions and Prerequisites

At the time of conducting the research of the TNO report, the Council of State in the Netherlands had accepted the ICNIRP-1998 norms [2] (as recommended by the European Council) to which emission levels of radiation in the Netherlands must comply.

The present report will solely address the review and evaluation of the TNO report with respect to the ICNIRP-1998 Guidelines. It will not comment on regulatory aspects in the Netherlands (i.e., it will assume that the ICNIRP Guidelines are the appropriate norm in the Netherlands) and also the evaluation of the ICNIRP Guidelines will not be part of this review.

It is noted that a recent update of the ICNIRP Guidelnes has been published in May 2020 [3]. However, since at the time of writing this report the update has not been established as a legal norm yet, the 1998 version [2] is taken as a reference here. Possible changes introduced by [3] will be addressed in Section 2.3.

1.3
Research Questions

The aim of the present report is to answer two specific research questions with respect to the TNO study on potential health effects from a military SMART-L radar:

1. Considering the laws and regulations in the Netherlands and the scientific debate at the time of conducting the TNO study, can the Fraunhofer Institute support the chosen methodological approach with regard to the evaluation of health effects due to cumulative RF-fields?

2. Are the obtained results in line with this approach?

These two research questions will be addressed in detail in Section 4.

1.4
Background on Fraunhofer FHR's Expertise related to the Research Questions

Fraunhofer FHR owns and operates the TIRA Tracking and Imaging Radar on its campus in Wachtberg, Germany, close to the cities Bonn and Cologne. This radar system is used for space observation and provides valuable support for space missions: space agencies from all over the world use the special capabilities of the Fraunhofer scientists and their system.

The radar is protected by a radome having a diameter of 47 meters and is therefore the largest of its kind worldwide. The building has an overall height of approximately 56 meters and accommodates an antenna with a diameter of 34 meters.

The theoretical peak power can reach 1 MW and higher, with the main beam being directed to space. However, the first side lobe of the emitter system may hit the ground (depending on elevation) and gives rise for close monitoring of electromagnetic field levels both on the campus as well as in general public areas.
In order to make sure that electromagnetic field levels are within the allowed range, various measurement campaigns as well as theoretical considerations have been undertaken in the past.

2
The ICNIRP Guidelines

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) was established in May 1992. The functions of the Commission are to investigate the hazards that may be associated with the different forms of Non-Ionizing Radiation (NIR), develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection.

A large number of reports and publications provided the scientific rationale for the ICNIRP-1998 Guidelines [2], the main objective being to establish guidelines for limiting electromagnetic fields (EMF) exposure that will provide protection against known adverse health effects.

The guidelines distinguish between "basic restrictions" (based directly on established health effects, e.g. specific energy absorption rate (SAR)) and "reference levels" (derived quantities that are easier to measure, e.g., electric field strength). It is important to note that "In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded."

The following aspects are explicitly not covered by the ICNIRP guidelines [2]:
- Product standards and techniques used to measure any of the physical quantities that characterize electric, magnetic, and electromagnetic fields.
- Interference with, or effects on, medical devices such as metallic prostheses, cardiac pacemakers and defibrillators, and cochlear implants.

"The guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to EMF. In the case of potential long-term effects of exposure, such as an increased risk of cancer, ICNIRP concluded that available data are insufficient to provide a basis for setting exposure restrictions."

As regards the current study, focusing on frequencies in the GHz range, "exposure to electromagnetic fields at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. […] At frequencies from 10 MHz to 300 GHz, heating is the major effect of absorption of electromagnetic energy, and temperature rises of more than 1-2 °C can have adverse health effects such as heat exhaustion and heat stroke." Several studies "have demonstrated that exposure for up to 30 min, under conditions in which whole-body SAR was less than 4 W/kg, caused an increase in the body core temperature of less than 1°C".

The basis for the definition of EMF limits is the following: "Available experimental evidence indicates that the exposure of resting humans for approximately 30 min to EMF producing a whole-body SAR of between 1 and 4 W/kg results in a body temperature increase of less than 1 °C. […] The threshold for irreversible effects in even the most sensitive tissues is greater than 4 W/kg under normal environmental conditions." For occupational exposure restriction, a large safety factor of 10 is applied, leading to whole-body average SAR of 0.4 W/kg. "An additional safety factor of 5 is introduced for exposure of the public, giving an average whole-body SAR limit of 0.08 W/kg." This value is also the basis for the considerations in this report.

2.1 Reference Levels for Electric Fields

In this section, only reference levels for general public exposure are summarized. Reference levels for occupational exposure are higher by a factor of $\sqrt{5}$ for the field levels, corresponding to the above mentioned safety factor of 5 between occupational and general public exposure.

In the relevant frequency range, the reference levels for electric fields are:
- 10-400 MHz: 28 V/m
- 400 MHz - 2 GHz: 1.375 $f^{1/2}$ V/m (f: frequency in MHz)
- 2-300 GHz: 61 V/m

The squares of the field strengths, E^2, are to be averaged over any 6-min period. This corresponds to averaging the power density.

The limit for peak field strengths is higher by a factor 32 (equivalent to a factor 1000 for the power density).

2.2 Cumulative Effects

In real environments, simultaneous exposure to EM fields generated by different sources at different frequencies is often the case. It is obvious, that for thermal effects in the relevant frequency range, the corresponding SAR values should be added. However, the reference levels for electric fields depend on frequency, which calls for a special procedure for handling cumulative exposure.

Let E_i be the electric field strength at frequency i and $E_{L,\,i}$ be the electric field reference level at frequency i, then the ratio $(E_i / E_{L,\,i})^2$ is the percentage to which the reference value is used by the exposure at frequency i. The square is applied because the power densities are to be added, which correspond to the square of the electric field.

For evaluation of cumulative exposure, all these percentages for the different frequencies are simply added up. The sum should then be less than or equal to 1 (equivalent to 100%), in order to ensure the total exposure complies to the basic restriction. The corresponding formula for this condition is the following:

$$\text{Total Percentage} = \sum_i \left(\frac{E_i}{E_{L,\,i}}\right)^2 \leq 1$$

2.3 A Brief Review of the 2020 Update

In May 2020, an update of the ICNIRP Guidelines has been published [3], in order to reflect advances in the relevant scientific knowledge. One difference as compared to the 1998 guidelines is a more detailed consideration of localized SAR (e.g., head, limb, etc.). The whole-body average SAR as basic restriction for general public exposure, however, remains at 0.08 W/kg.

More important differences arise in the deduction of reference levels:
- 30-400 MHz: 27.7 V/m

- 400 MHz - 2 GHz: $1.375\ f^{1/2}$ V/m (f: frequency in MHz)
- 2-300 GHz: S_{inc} = 10 W/m^2

It should be noted that above 2 GHz, the incident power density (S_{inc}) is to be measured, rather than the electric field strength. Under far-field conditions, $S_{inc} = E^2/Z_0$ (Z_0 = 377 Ohms), so the mentioned 10 W/m^2 translate to 61.4 V/m, which is more or less equivalent to the 1998 guidelines.

Finally, the time interval for averaging the quantities is set to 30 minutes (ICNIRP-1998: 6 minutes). Since in normal operation mode, the periodicity of a rotating radar is less than both values, this makes no difference for the time-average evaluation of fields.

To summarize, it appears that, although ICNIRP-2020 introduces some changes, no significant change is anticipated in the frequency range relevant in this study.

3
The TNO Report

This section summarizes the TNO Report [1] with respect to the research question, and includes the underlying basic assumptions as well as a brief review of TNO's approach of estimating exposure to EM fields generated by the SMART-L radar in Herwijnen.

3.1
Basic Assumptions

One of the central assumptions in the TNO report [1] is that the worst-case or most critical scenario occurs at the nearest dwelling, which is located at a distance of 450 m to the SMART-L radar.

Further assumptions are made with respect to the question which relevant sources need to be considered for cumulative exposure. In this context, four types of sources are identified:
- Own sources (personal WiFi routers/APs, DECT and mobile phones)
- Other communication sources (exposure level due to mobile telephony and broadcasting technologies; expected 5G infrastructure)
- SMART-L radar (PSR primary surveillance radar with either rotating or stationary antenna, MSSR secondary radar); the rotating antenna is the normal mode of operation, while during tracking mode (stationary antenna) the MSSR is switched off
- Other radar sources (KNMI weather radar, navigation radars of ships on the Waal river)

For evaluation of cumulative exposure, different scenarios are considered in the TNO report:
- Section 5.2.1: Cumulative exposure without SMART-L and own RF sources
- Section 5.2.2: Cumulative exposure without SMART-L, but with own RF sources
- Section 5.2.3: Cumulative exposure with SMART-L, but without own RF sources
- Section 5.2.4: Cumulative exposure to SMART-L (both in normal operation and in tracking mode), including own RF sources

3.2
Results

As a conclusion on cumulative exposure, the TNO report states: "As can be concluded from the above tables, the cumulative exposure of the expected external sources including the SMART-L falls within the exposure limit set in the ICNIRP Guidelines."

More quantitatively, in the worst case scenario (SMART-L radar in tracking mode, plus own RF sources) "the cumulative exposure is between 24.6 % and 30.9 % of the ICNIRP Guidelines", where the lower value corresponds to the minimum and the higher value corresponds to the maximum expected field strength. "The terms 'minimum' and 'maximum' refer to the levels of electromagnetic fields within which the actual exposure will likely occur."

4
Evaluation of the TNO Report with respect to the ICNIRP Guidelines

4.1
Review of Basic Assumptions

It is recognized that the assumption about the most critical scenario occurring at the nearest dwelling (distance of 450 m to the SMART-L radar) is absolutely adequate as long as permanent stay of people is considered.

However, it is believed that general public exposure in the sense of the ICNIRP Guidelines also covers publicly accessible areas at closer distances. It is recommended to further study at which distances the main beam of the radar reaches relevant heights above ground, e.g., 1.80 m, which of course depends on the antenna position above ground and the elevation radiation pattern of the antenna. If field strengths at these locations are expected to exceed the general public reference levels of the ICNIRP Guidelines, further steps might need to be taken, e.g., declaration to occupational exposure area or access restrictions. However, such considerations are beyond the scope of this study.

The selection of RF sources as well as the definition of different scenarios is certainly adequate. While the different scenarios are useful for general considerations and comparisons, the last scenario (section 5.2.4, including all sources), as a worst case, is enough for the evaluation of compliance with the ICNIRP Guidelines.

4.2
Review of Methodology

The methodological approach of the TNO report with regard to the evaluation of health effects due to cumulative RF fields directly corresponds to the procedure described in the ICNIRP Guidelines. More precisely, the formula in section 2.3.4 of the TNO report corresponds to equation (9) in [2] or the formula in section 2.2 of this report. Since this formula is the foundation for evaluating cumulative fields, the methodology can fully be supported.

4.3
Review of Results

As stated above, the worst-case scenario (section 5.2.4 in the TNO report, including all sources) is sufficient for the evaluation of compliance with the ICNIRP Guidelines. For this reason, only this scenario is evaluated quantitatively and compared with the results in the TNO report. As a first step, for each of the RF sources, the corresponding estimated field strengths are evaluated in the following. During this step, the following formulas are applied:

Radiated power density: $S = \frac{PG}{4\pi r^2}$ (*P*: radiated power; *G*: antenna gain; *r*: distance)

Electric field strength: $E = \sqrt{120\pi\, S}$

For a radar system, it is convenient to specify the pulse power P_P, so the above formula leads to the pulse field strength E_P. The so-called duty cycle η is the fraction of time in which the radar is transmitting power. For evaluation of thermal effects, this means that the effective power is only the fraction η of the peak power and the corresponding field strength is $E' = \sqrt{\eta} E_P$. Similarly, if the antenna rotates and illuminates the observation point only for a fraction ξ of time, the corresponding field strength is $E = \sqrt{\xi} E'$.

Following this introduction on how to calculate the field strengths, each RF source is examined quantitatively. For each source, as a starting point, assumptions, e.g., concerning transmitted power are made in the TNO report (some of these assumptions are not quantitatively stated in the TNO report but have been provided by TNO in additional material). These assumptions are summarized here, but not further investigated. Apart from that, as a worst case, only the “maximum” levels as referred to in the TNO report, are used here.

2.4 GHz WiFi
Assumptions: f = 2.4 GHz, P = 100 mW radiated isotropically (G = 0 dBi), r = 2 m
Resulting field strength: E = 0.87 V/m (same as in TNO report)
ICNIRP-1998 limit: 61 V/m
Percentage used: 1.42%

5 GHz WiFi
Assumptions: f = 5.2 GHz, P = 1 W radiated isotropically (G = 0 dBi), r = 2 m
Resulting field strength: E = 2.74 V/m (same as in TNO report)
ICNIRP-1998 limit: 61 V/m
Percentage used: 4.49%

DECT phone
Assumptions: f = 1.88 GHz, P = 250 mW, G = 2.15 dBi (dipole), r = 2 m
Resulting field strength: E = 1.75 V/m (same as in TNO report)
ICNIRP-1998 limit: 59.62 V/m
Percentage used: 2.94%

Mobile phone
Assumptions: f = 0.7 GHz, P = 200 mW radiated isotropically (G = 0 dBi), r = 42.86 cm
Resulting field strength: E = 5.72 V/m (same as in TNO report)
ICNIRP-1998 limit: 36.38 V/m
Percentage used: 15.71%

Mobile telephony and broadcasting
Assumptions: f = 0.4 GHz, E = 4.1 V/m
ICNIRP-1998 limit: 28 V/m
Percentage used: 14.64 %

5G infrastructure, prediction
Assumptions: f = 2.7 GHz, E = 3 V/m
ICNIRP-1998 limit: 61 V/m
Percentage used: 4.92 %

KNMI weather radar
Assumptions: f = 5.663 GHz, P = 500 kW, G = 18 dBi, r = 510 m,
η = 0.12%, ξ = 0.1%
Note: The TNO report states 45 dBi gain, but the calculations are done using 18 dBi (this has been taken since the elevation angle in the lowest position is slightly upwards, clarified by email communication with TNO)

Resulting field strength: E_P = 60.32 V/m, E = 0.07 V/m (TNO report: 0.06 V/m)
ICNIRP-1998 limit: 61 V/m
Percentage used: 0.11%

Navigation radar
Assumptions: f = 9.5 GHz, P = 6 kW, G = 30 dBi, r = 1910 m,
η = 1%, ξ = 1.1%
Note: The TNO report states that, as a worst case, 10 navigation radars are assumed on the same spot. This would lead to multiplying the radiated power by a factor 10. However, TNO multiplied the fields by 10, which leads to higher field levels.
Resulting field strength: E_P = 22.21 V/m, E = 0.23 V/m (TNO report: 0.7 V/m, see note above)
ICNIRP-1998 limit: 61 V/m
Percentage used: 0.38%

SMART-L MSSR (only if PSR in rotating mode)
Assumptions: f = 1.2 GHz, P = 2 kW, G = 27 dBi, r = 450 m,
η = 7%, ξ = 0.6%
Resulting field strength: E_P = 12.19 V/m, E = 0.25 V/m (same as in TNO report)
ICNIRP-1998 limit: 43.48 V/m
Percentage used: 0.57%

SMART-L PSR (rotating mode)
Assumptions: f = 1 GHz, E_P = 108.3 V/m, E' = 34.20 V/m, ξ = 2%
Note: For the PSR, data such as exact frequency, transmitted power, duty cycle, etc., are classified and therefore not available for this study. However, the resulting field strengths as mentioned above are stated in the TNO report, and it is believed that these data are representative. Additional material sent by TNO suggests that in the calculations a slightly lower value has been used, which leads to lower fields in the TNO report. Since the difference is not that big, it is considered as tolerable, and the results in this study can be considered as a worst case estimation.
Resulting field strength: E = 4.84 V/m (TNO report: 3.7 V/m, see note above)
ICNIRP-1998 limit: 47.63 V/m
Percentage used: 10.15%

SMART-L PSR (stationary/staring mode)
Assumptions: f = 1 GHz, E_P = 31.6 V/m, E' = 10.0 V/m, ξ = 100%
Note: For the PSR, data such as exact frequency, transmitted power, duty cycle, etc., are classified and therefore not available for this study. However, the resulting field strengths as mentioned above are stated in the TNO report, and it is believed that these data are representative.
Resulting field strength: E = 10.0 V/m (same as in TNO report)
ICNIRP-1998 limit: 47.63 V/m
Percentage used: 21.0%

4.4 Evaluation of Cumulative Exposure

For evaluation of cumulative exposure of the relevant RF sources, two different operational cases for the SMART-L radar are distinguished:

Case A: SMART-L in rotating mode, all other RF sources present
In this case, the MSSR and PSR (rotating mode) as well as all other mentioned sources are cumulated according to the formula in section 2.2. The resulting total percentage is

24.9% (TNO report: 24.2%). The slight difference results from rounding errors and slightly different assumptions as stated above, but can be tolerated.

Case B: SMART-L in stationary/staring mode, all other RF sources present
In this case, the MSSR is switched off and PSR (stationary/staring mode) as well as all other mentioned sources are cumulated according to the formula in section 2.2. The resulting total percentage is 30.94% (TNO report: 31.1%). The slight difference results from rounding errors and slightly different assumptions as stated above, but can be tolerated.

A graphical overview of these results is summarized in Fig. 01 below.

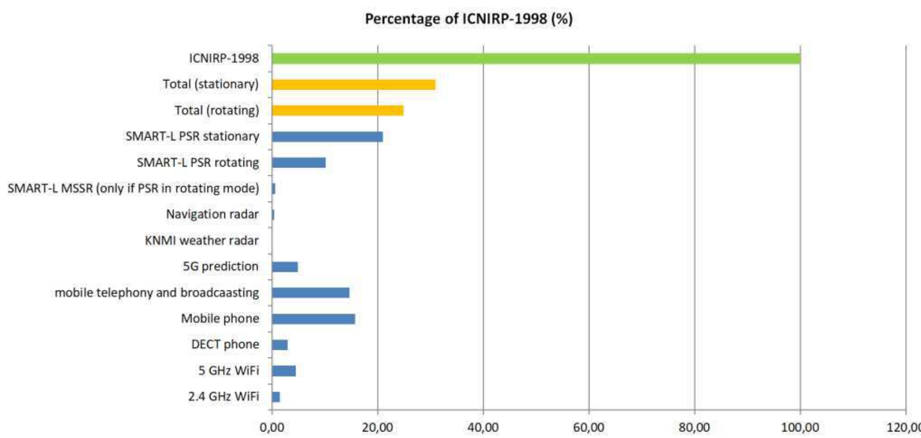

Fig. 01 Percentage of ICNIRP-1998 reference levels used by total cumulative exposure.

4.5 Note on Peak Field Strengths

As stated in section 2.1, the ICNIRP-1998 Guidelines also set limits for peak field strengths, which in comparison to the maximum allowed time averaged fields is higher by a factor 32 (equivalent to a factor 1000 for the power density). Since the expected peak field strengths are far below that threshold, compliance with ICNIRP-1998 can be stated, which is in line with the TNO report.

It should be noted that the ICNIRP-1998 Guidelines focus on thermal effects, which is the reason for the high peak limits. Potential effects on sensitive electronic or medical equipment are not covered in the ICNIRP-1998 Guidelines and are beyond the scope of this report.

5
Summary

This study presents a review of the TNO report on potential health effects by cumulative exposure to SMART-L radar emissions and other RF sources, with respect to the ICNIRP-1998 Guidelines. To concentrate on the worst case scenario, only the configuration with all relevant sources radiating is studied.

As initial assumptions, radiated powers, antenna gains, duty cycles, etc., are taken from the TNO report. A further study of these assumptions is out of the scope of this report, i.e., it is assumed that TNO has taken representative data in their research.

Based on this prerequisite, it can be concluded that the methodology used by TNO for evaluation of cumulative exposure directly follows the ICNIRP-1998 Guidelines. The results have been reproduced in the present study and, except for slight differences, agree very well with the results provided in the TNO report.

One question that might need to be addressed further is the compliance to ICNIRP-1998 at publicly accessible places at closer distance to the SMART-L than the nearest dwelling, which is the location where TNO evaluated their data. It might be necessary to mark areas as occupational exposure or to restrict access. The answer to this question is beyond the scope of this study and should be discussed on the background on currently effective regulations in the Netherlands.

Finally, as also suggested by TNO, this study recommends performing on-site measurements as soon as the SMART-L radar is in operation, in order to get more confidence about the estimated field levels.

6
References

[1] A.P.M. Zwamborn, A.P.M., Theil, A., "Evaluatie van gezondheidsaspecten doorRF-velden afkomstig van de voorgenomen SMART-L radar te Herwijnen", TNO 2020 R10094, January 2020; English translation, June 2020.
[2] [3] International Commission on Non-Ionizing Radiation Protection (ICNIRP), "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health physics* 74.4 (1998): 494-521.
[3] International Commission on Non-Ionizing Radiation Protection (ICNIRP), "Guidelines for limiting exposure to Electromagnetic Fields (100 kHz to 300 GHz)," *Health Physics* 118.5 (2020): 483-524.