> Summary

In spring 2003, the predecessor of the FOEN – the Swiss Agency for the Environment, Forests and Landscape (SAEFL) – published a report based on more than 200 scientific studies carried out on human beings for the purpose of assessing the health risks associated with exposure to high frequency non-ionising radiation in the low dose range. The report ("Umweltmaterialien Nr. 162, BUWAL 2003 – hereinafter referred to as "UM 162") summarised and evaluated the status of knowledge as of the end of 2002.

The term "low dose range" refers to radiation intensities lying below the exposure limit values stated in the Ordinance Relating to Protection from Non-Ionising Radiation (ONIR) – or, in the case of mobile telephones, lying below the limit value for the local specific absorption rate recommended by the International Commission for Non-Ionising Radiation Protection (ICNIRP). Thermal effects that occur at higher intensities are sufficiently known and are not dealt with in the present report.

The epidemiological and experimental studies on the exposure of human beings to high frequency radiation were pursued further and updated. The first update of the status of scientific knowledge was published as "Supplement A" in spring 2004, and is now superseded by the present report. It is based on almost 150 scientific publications on the exposure of human beings to high frequency radiation that have been published in the period from the end of 2002 to September 2006. The studies conducted on human beings were collected and assessed by the ELMAR documentation centre at the Institute for Social and Preventive Medicine at the University of Basel. Please refer to the ELMAR database (which is available for public access) for further details (www.elmar.unibas.ch/index.html). In addition, this report evaluates the findings from the internationally co-ordinated research programmes, "Perform B" and "REFLEX", which focused on exposure of cells and animals (and not humans) to high frequency radiation. This section of the report was prepared by the Centre for Biomedicine at the University of Basel.

As was the case in UM 162, for each biological effect studied to date relating to exposure to high frequency radiation, on the basis of all existing studies on the respective effects the **evidence** for the existence of the effect was assessed using a differentiated scale. Classification was carried out in accordance with the system defined by the World Health Organisation (WHO) for assessing the carcinogenic properties of a given substance or agent (*http://monographs.iarc.fr*). This classification was adopted and extended to include non-carcinogenic effects. The criteria for each evidence level are:

- **Established:** An effect is regarded as established if it meets stringent scientific criteria, i.e. is replicated several times in independent investigations, if a plausible biological model exists and the effect is not in contradiction with other results.

> **Probable:** An effect is classified as probable if it has been found repeatedly and with relative consistency in independent studies. The studies concerned must be of a sufficiently high quality to exclude other factors with a large degree of certainty. No plausible causation mechanism is known.

> **Possible:** Effects are regarded as possible where they occur sporadically in the studies. However, the results are not entirely consistent and could be attributable to methodological weaknesses. The scientific evidence is corroborated by case reports. Classification as "possible" refers to the correlation between exposure and effect. It does not indicate an assessment of the probability of the occurrence of the effect.

> **Improbable:** There are no indications of an association, but multiple indications of its absence. No theoretically plausible biological model exists.

> **Not assessable:** The scientific basis is too limited for an assessment to be made. While isolated evidence exists, this is often contradictory. The methodology of the studies concerned is regarded as insufficient to permit conclusions to be drawn.

In a further step, the **relevance to health** of the above effects was classified into three groups. In order to make a clearer distinction between these categories, different designations have been used here versus those that were applied in UM 162:

> **Diseases and mortality:** The effect causes serious health problems that lead to a drastic reduction in the quality of life. It constitutes a threat to life and reduces life expectancy. This category includes all cancerous diseases, stillbirths and deformities in infants, and increased mortality.

> **Reduced well-being:** While the effect does not represent a direct threat to life, it significantly curtails the quality of life and/or well-being. This category includes non-specific health symptoms such as headaches, insomnia, mental symptoms, electromagnetic hypersensitivity and microwave hearing.

> **Physiological changes:** The effects are physiologically measurable and lie within the normal variability range of healthy individuals. Such effects do not represent a risk to health *per se*, and since they are normally not perceived, do not lead to a reduction in the quality of life. It is not known whether they represent a risk to health in the long term. This group includes fluctuations in the hormone, immune and cardiovascular systems, genotoxic effects, variability in EEG readings and changes in the perception and processing of stimuli.

For effects classified as established, probable or possible, a lower exposure threshold for their appearance was estimated on the basis of the results of available studies. To enable the results of studies on mobile telephones, stationary transmission installations and exposure in experimental settings to be compared, the different dose metrics had to be standardised. Maximum SAR_{10} was chosen as the common dose metric. This specifies the amount of radiation that is absorbed locally by the body at the point of maximum absorption (SAR_{10} = local specific absorption rate in W/kg averaged over 10 g of

body tissue). While some reports specify SAR_{10} directly, for others it had to be estimated.

Results and evaluation of studies on humans as of the end of September 2006

Table 4 contains a summary of the evaluation of the evidence pointing to health effects caused by high frequency radiation in the low dose range, taking account of the results of all available studies carried out directly with or on human beings, up to the end of September 2006.

established

There are no new effects that may be regarded as established. It is generally accepted that high frequency radiation may impair the function of technical appliances, and in the case of implanted medical devices (e.g. cardiac pacemakers), this may have consequences on health. However, many devices in use today are largely insensitive to radiation from mobile telephones. Acoustic perception (microwave hearing) was consistently identified for pulsed radiation exceeding a given energy per pulse. In the case of radar installations, this phenomenon may occur even when the exposure limit values are observed, while there are no indications that this is also the case with mobile communication equipment. It is known that the risk of accidents is higher when telephone calls are made during driving, whether a hands-free set is used or not. However, this does not result from the radiation as such, but rather from the associated distraction.

probable

It is still regarded as probable that exposure to mobile telephones leads to a change in the electric activity of the brain. In spontaneous EEG tests on subjects who were either asleep or awake, the most consistent effect observed was an increase in amplitude of the electroencephalogram alpha band. In several studies, effects were identified during the first fifteen minutes after termination of exposure. Changes in sleep phases, which were observed in a number of studies, are also regarded as probable. Exposure effects were also observed in most experiments aimed at studying the evoked brain potentials. However, earlier findings were not confirmed by two replication studies using improved methods. The effects occurred at very low radiation intensities, and may therefore not be explained by the conventional thermal model.

With respect to the occurrence of non-specific symptoms (e.g. headaches, discomfort, fatigue, dizziness and burning skin) from the use of mobile telephones, not all the new studies were able to identify a correlation, and some suffered from methodological weaknesses. In view of these findings, together with the results of earlier Scandinavian studies (cf. UM 162), it is still regarded as probable that frequent use of mobile telephones is associated with an increase in non-specific symptoms. It could not be determined, however, whether this increase is due to high frequency radiation or other factors relating to the use of mobile telephones, e.g. higher stress levels.

Tab. 4 > Summary of the evidence for high frequency radiation effects on health at low dose levels (exposure of human beings).

The figures for the effect threshold (given in mW/kg or W/kg) are only intended as a rough guide. They refer to the maximum local specific absorption rate (SAR_{10}) occurring in the body.

EVIDENCE	EFFECT			EXPOSURE SOURCE	EFFECT THRESHOLD
	Diseases and mortality	Reduced well-being	Physiological changes		
Established (consistent findings)		Interference effects on implanted medical devices		Electronic appliances (e.g. mobile telephones)	
		Microwave hearing		Radar installations	Energy< flux density per pulse >20 mJ/m²
Probable (multiple indications)		Non-specific symptoms (headaches, fatigue, problems of concentration, disquiet, burning skin, etc.)		Mobile telephones	20 mW/kg–2 W/kg
			Brain activity Sleep phases	Mobile telephones	20 mW/kg–2 W/kg
Possible (isolated indications)	Leukaemia and lymphomas			TV and radio transmitters	In the region of the installation limit value
	Brain tumours			Mobile telephones	20 mW/kg–2 W/kg
		Sleep quality		Radio transmitters	In the region of the installation limit value
			Cognitive functions, reaction times	Mobile telephones	20 mW/kg–2 W/kg
			Ability to perceive weak electromagnetic fields	Mobile telephones	20 mW/kg–2 W/kg
Improbable (multiple indications of absence of the effect)	Mortality			Mobile telephones	
	Salivary gland tumours			Mobile telephones	
Not assessable (insufficient data)	Breast cancer			Various	
	Eye tumours			Mobile telephones	
	Tumours of the testicles			Radar guns	
	Stillbirth			Diathermal appliances	
		Non-specific symptoms (insomnia, headaches, etc.)		Mobile telephone base stations	
		Mental symptoms		Various	
			Fertility	Mobile telephones	
			Hormone system	Various	
			Immune system	Various	
			Cardiovascular functions	Various	
			Hearing and balance	Mobile telephones	
			Genotoxicity	Exposure at the workplace	

possible

As before, only one study has been carried out to date that focuses on sleep-related problems suffered by persons living in the vicinity of a radio transmitter, and new evaluations have been published concerning this study. Since a correlation was observed here, it is regarded as possible – as was the case in UM 162 – that emissions from powerful short-wave radio transmitters can have an effect on the quality of sleep.

The findings relating to the influence of mobile phone exposure on cognitive functions are less uniform than they were at the end of 2002. In double-blind replication studies, the previously observed shortening of reaction times was not confirmed. The evidence for the effects of mobile phone exposure on cognitive functions has therefore been downgraded from probable to possible.

The new provocation studies on the ability to perceive weak electromagnetic fields show that even people who attribute their symptoms of reduced well-being to exposure to high frequency radiation are generally unable to perceive these fields in a test situation. No new studies have been carried out in which multiple tests were performed on the same person. Earlier studies have led to the assumption that there might be very few people who have the ability to perceive weak electromagnetic fields.

On the basis of studies published up to the end of 2002 it was regarded as possible that the risk for tumours of the haematopoietic and lymphatic systems is higher in the vicinity of powerful broadcasting stations. The two new studies do not alter this evaluation.

With respect to the risk of brain tumours in users of mobile telephones, some evaluations of the so called “Interphone” multicentric case-control study were published up to the end of 2006, but only one of these contained pooled data. In addition, findings are available from two large-scale case-control studies conducted by a Swedish research group. In view of these and earlier results it has to be generally regarded as possible that intensive long-term use of mobile telephones could lead to an increased risk of brain tumours.

improbable

There are no new findings relating to total mortality. On the basis of the results of earlier studies, a correlation with exposure to high frequency radiation in the low dose range was assessed as improbable in UM 162. Similarly, in view of the existing case-control data, a causal relationship between exposure to high frequency radiation and the risk of contracting a salivary gland tumour also appears to be improbable.

not assessable

With respect to tumours of other organs, the scientific basis is still too limited to permit the assessment of possible associations. This includes the risk of tumours of the eyes and testicles, as well as breast cancer. It is also not assessable whether exposure to high frequency radiation at the workplace can lead to genotoxic cell damage. Similarly, an assessment of the effects on blood pressure, pulse rate and heart rate variability cannot be made at this time. And as before, the scientific basis is still too limited to permit an

assessment of the evidence for effects of exposure to high frequency radiation on the hormone and immune systems, hearing, fertility, the stillbirth rate and mental health.

Findings and evaluation of Perform B and REFLEX (exposure of cells and animals) research programmes

In the past few years, two internationally co-ordinated research programmes have studied the effects of electromagnetic fields on biological systems. The projects initiated by the "Perform B" programme primarily concerned the replication of earlier studies with the aim of re-examining the various findings, while the REFLEX programme (full name: "Risk Evaluation of Potential Environmental Hazards from Low Energy Electromagnetic Field Exposure using Sensitive "in vitro" Methods") focused on studying the effects of electromagnetic fields on cells under controlled laboratory conditions.

On the basis of findings from earlier studies, the "Perform B" programme set out to study the influence of high frequency radiation on the genetic material DNA, the activity of a metabolic system enzyme and the behaviour of animals. To some extent these took the form of replication experiments that were carried out in order to independently re-examine already existing findings, while other studies were extended or improved in terms of methodology. The various studies showed that exposure to high frequency radiation did not lead to any detectable DNA damage in isolated human lymphocytes, either on their own or in combination with a mutagen (X-ray). Similarly, no evidence was found of any change in the activity of ornithine decarboxylase under varying exposure conditions. Finally, no altered learning patterns of the type that had been described earlier was detected in rats and mice exposed to high frequency radiation, nor did their anxiety behaviour and the permeability of the blood brain barrier appear to be affected in any way. Insofar as these were genuine replication experiments, the results obtained from earlier studies were thus not confirmed.

In the "REFLEX" programme the aim was to study the effects of high frequency exposure on cells under standardised, strictly controlled laboratory conditions. Here the frequency of DNA strand breaks, the occurrence of micronuclei and chromosome aberrations, influences on the cell cycle, cell differentiation and cell death, as well as the expression of genes, were measured. Tests were carried out with exposure to both high frequency and low frequency radiation, but for the purposes of this report, only the results obtained from exposure to high frequency radiation have been considered.

The occurrence of effects identified in "REFLEX" can currently be regarded as possible, but not established. This is because the findings were obtained from initial observations that have not yet been independently replicated, or because replication experiments yielded contradictory results that have not yet been satisfactorily explained. The lowest threshold for the (local) SAR at which an effect was observed is 0.3 W/kg, which is in the non-thermal range, roughly half-way between the installation limit value and the exposure limit value stipulated in the Ordinance relating to Protection from Non-Ionising Radiation Protection.

In connective tissue cells, temporary DNA strand breaks were observed and there were occurrences of micronuclei and chromosome aberrations. Here, the modulation of the signal appears to be decisive, along with the intensity and duration. DNA strand breaks are in themselves nothing out of the ordinary. They occur naturally and are corrected by repair mechanisms within the cell. At present it is not clear whether the temporary strand breaks identified as the consequence of exposure are repaired correctly, or whether they may lead to permanent changes in the genetic substance. The observation made during similar experiments with low frequency fields, namely that the frequency of strand breaks decreases again after several hours of exposure, points in favour of the former. However, the fact that micronuclei and chromosome aberrations were observed in addition to strand breaks, would appear to favour the latter, since they constitute permanent alterations of the genetic material. Should the latter case be confirmed, this would be significant, since it would mean that cellular dysfunctions would have to be expected. The question of whether the identified molecular occurrences truly lead to such dysfunctions needs to be studied more thoroughly. The end points investigated, such as cell cycle, cell differentiation and cell death were either not influenced at all by exposure to high frequency radiation, or at most only to a minor extent. The degree to which the molecular effects identified are of importance for cell functions therefore still needs to be clarified.

Other studies focused on the question whether genes are expressed more strongly or more weakly as a consequence of exposure to high frequency radiation. It is hoped that, by learning more about molecular processes in cells, we will be able to understand more clearly how an external stimulus can affect cell function. However, given the large number of genes and proteins, we are currently only in the initial stage of collecting empirical data. The most advanced hypothesis is that high frequency radiation acts as a stressor and the cell thus forms stress proteins. The studies showed that, in certain cell types, the expression of individual genes when exposed to high frequency radiation is influenced in various ways: some proteins appear to be increased, while others are reduced. Here, too, we would expect that a deregulated gene expression can influence end points such as cell cycle, cell differentiation and cell death, but this was not observed.

Conclusions:

There are still many gaps to be filled in the scientific basis for assessing the risk to human health associated with high frequency radiation in the low dose range. Experiments conducted on humans and on cell cultures indicate direct effects of high frequency radiation that cannot be explained by the thermal concept. Very few long-term studies have been carried out on human beings in their natural environment and only one study focussing on the effects on the health of people living in the vicinity of mobile telephone base stations meets the minimum scientific standards.

The following conclusions may be drawn from the present-day status of knowledge:

- No new established effects on health have been identified in the dose range below the limit level recommended by the ICNIRP, and thus below the exposure limit level specified in the ONIR.
- A number of effects associated with the exposure of human beings to radiation from mobile telephones may be regarded as probable. These are primarily effects for which the relevance to health is uncertain. They occur at a local SAR_{10} in the range from 20 mW/kg to 2 W/kg, i.e. below the level of 2 W/kg recommended by the ICNIRP. A rough estimate indicates that the radiation from stationary transmitters would have to reach an intensity that lies between Switzerland's specified installation limit value and the exposure limit value in order to produce a comparable SAR_{10}. This permits the general conclusion that effects due to exposure to mobile telephones that are classified as probable are not to be expected below Switzerland's specified installation limit values.
- Effects on human health that are classified as possible occur in association with both mobile telephones and broadcasting stations. For radiation from mobile telephones, the effect threshold is within the same range as cited above (SAR_{10} between 20 mW/kg and 2 W/kg), while for radiation from broadcasting stations it is at a field strength around Switzerland's installation limit value.
- A temporary or permanent alteration of the genetic material of certain cells is regarded as possible, as is an altered expression of genes. The lowest threshold for (local) SAR at which an effect was observed in the experiment on cells was 0.3 W/kg. The significance of these findings as far as cell functions are concerned is uncertain at this time.

Although the picture has become broader since the publication of UM 162, it has not grown clearer. Especially in the area of experimentation involving human beings, new studies have been carried out using new technologies or incorporating physiological parameters that had barely been analysed before. The number of scientifically observed effects for which it is currently not possible to assess whether they are causally related to radiation, has increased. While some of these effects are known to have the potential to cause serious harm to health, for others this is uncertain. At the same time, there has been an increase in the number of health parameters for which no association with high frequency radiation has been ascertained. Especially where experimental studies are concerned, it would be beneficial if the findings could be re-tested on larger or more sensitive populations, taking into account the often cited time delay, before new targets are envisaged or other research methods are developed. Until then, it is not possible to draw conclusions regarding long-term effects. In population studies, estimating the degree of exposure remains a major problem. It is to be hoped that the new devices which are currently being developed to measure individual exposure will help the study of long-term effects to progress.

From the scientific point of view there are no grounds for adjusting the limit values of the ICNIRP or the exposure limit values specified in the ONIR (which are based on the ICNIRP levels). However, it is still not possible to determine whether these limit values also offer sufficient protection against long-term harm. This also applies to

exposure at levels around the installation limit values specified in the ONIR, since at this level of dosage, too, there are still some indications of potential health-relevant effects. From a scientific standpoint the precautionary approach to non-ionising radiation should be maintained and research intensified.