How radio frequency waves interact with living systems

Some observations on bioelectromagnetics by J.W. Frazer, professor of Pharmacology at the University of Texas Health Science Center at San Antonio, and J.E. Frazer.

One unstated, but important, objective of bioelectromagnetic research in both the U.S. and East bloc countries has been for many years the possibility of weapons use. Serious biological research has had scientifically unusual fits, starts, abrupt endings, and a lack of coherence for many years. Applications seemed remote, except for common microwave ovens, and the understanding of electromagnetic interaction with matter has been less than complete.

At the same time, there has been considerable public concern about biological effects that may be produced by constant, low-level radiation from the many radio frequency emitters in our environment, both at home and at the workplace.

These concerns motivated U.S. federal agencies in the 1950s to undertake serious investigation of the biological effects of microwaves, a series of efforts extending to the present. Programs have changed, participating agencies have changed, funding levels have changed precipitously. In the aggregate, U.S. federal agencies have invested more than $300 million in this study over the past 35 years.

It cannot be said that the biological effects of electromagnetic radiation are uninvestigated or that little is known about them. A considerable amount of this information is contained in the book *Biological Effects of Electromagnetic Radiation,* (edited by John Osepchuk, IEEE Press, New York). The National Telecommunications Information Agency, Department of Commerce, and the Office of Naval Research (ONR) have summaries of other recent research on the subject.

These programs have investigated the electromagnetic (EM) properties of tissue in some detail, and have defined the distribution of fields inside the body both practically and theoretically. The practical definition of field distribution uses methodology developed by Dr. A.W. Guy's group at the University of Washington; the theoretical approach uses programs developed by Dr. H. Schwann (Moore School of Engineering), Drs. Durney and Ghandi (University of Utah), and many other extremely competent individuals.

Biological responses to these EM fields have been measured by investigators, such as Dr. Saul Michaelson (University of Rochester School of Veterinary Medicine), Dr. W.R. Adey (Jerry Pettis Memorial VA Hospital, Loma Linda, California), and many others of good scientific repute. The sophistication used in measuring bioresponses has increased as the sophistication of biosciences themselves has exploded in the past 40 years.

This constant increase in theoretical sophistication, engineering practice, and particularly in the biosciences has made it necessary to constantly reevaluate the evidence for electromagnetic bioeffects, particularly at low field levels using modulated fields, and in relatively long-term experiments with a large variety of experimental animals.

Anyone who has put food in a microwave oven knows that the food can come out well cooked in a short time. If they observe the power setting/time trade-off, they notice that higher power cooks more rapidly, but the cooking may appear somewhat uneven.

We now know it is possible to manipulate "hot spots" within objects. When the wavelength of the radio frequency

field relative to the size of the object is controlled, correlated with the ratio of electric and magnetic vectors immediately around the object, surface reflections are not so likely to occur. Variations of electric/magnetic (E/H) ratio are commonly found in the "near field" or Fresnel zone of a transmitting antenna, thus area power absorption, resultant heating, and distribution of heat within the body can vary markedly.

Why does heat occur? Heat occurs primarily because water molecules (which form about 60% of humans) absorb RF energy. At frequencies less than 1 gHz, conductive ions add to energy absorption. Other cellular molecules also absorb energy, but are present in smaller quantity or in lower concentration. Herein is the source of an argument that is still pursued. Namely, "Does this relatively small proportion of total energy absorption produce bioeffects that cannot be explained simply by local heating?"

Development of the brain inactivators for small animals

During one of the programs analyzing RF bioeffects, it became necessary to know whether RF fields could cause a perturbation of the neurotransmitters known at the time. The turnover rate of these neurotransmitters was known to be very fast, one-half times of milliseconds, so that times taken for ordinary dissection and isolation procedures were simply inadequate to do quantitative comparison between animals or between specific brain areas.

A microwave brain inactivator was built, using some of the principles of field impedance matching which had been learned from previous development of a Near Field Synthesizer, a machine built to intentionally alter field impedance surrounding experimental animals. The brain inactivator in its present form can completely inactivate ($T > 85°C$) mouse, rat, or guinea pig brains in about 150 msec, allowing independent determination of neutrotransmitter contents of 1 mg portions of specific brain areas. It has also been used to determine total vascular volume of the brain after a variety of pharmacological treatments. This instrument caused an immediate increase in the accepted concentrations of neurotransmitters and phosphonucleotides occurring in the brain, concentrations which compare well with more recent determinations made with *in vivo* nuclear magnetic resonance.

After developing the instrument and measuring the distribution of power in the brain, the instrument was used to measure a few of the performance effects on animals. These showed that a high-intensity pulse could cause performance degradation paralleling a gradual fall in choline acetyl transferase activity, still decreasing at the longest time measured. This is the enzyme which resynthesizes acetylcholine, which is one of the important neurotransmitters.

So why is this important? We usually think of brain functions as a series of electrical signals, and yet we also know that there are a myriad of molecular activities that are the basis of brain functions.

Because the measurement technique uses electrodes which convert ion activities or concentrations to electrical signals, we have confused the measurement technique with the event. Underlying the changes in ionic mobilities, sodium and potassium in particular, are alterations in nerve cell membranes that allow alterations in ionic activity.

The real nerve signals are these molecular orientations. The molecular orientations at synaptic junctions, i.e., the spaces between neurons, are initiated by chemical substances called neurotransmitters, which are released from one neuron directly to a second neuron and are the basis for neural communication.

Activation of the receiving neuron causes molecular orientation shifts which allow potassium to leak out after sodium has leaked in and allows release of calcium ion, but also causes the formation of cyclic nucleotides which in turn activate phosphoproteins, which control molecular access to both RNA and DNA. The energy to reform the parent condition of the membranes is supplied by the biological coin of the realm, adenosine triphosphate, which then is reformed by a mechanism known as oxidative phosphorylation, which forms ATP at the expense of glucose.

Other types of cells in the brain form columns around active neurons. These cells transfer metabolites from the bloodstream to active neuronal cells. Thus these cells, which measure blood concentrations and control energy delivery are an important part of the neural feedback loop. The data concerning performance effects of microwave pulses was published in 1981, but doesn't seem to have excited any interest in further experimentation. We still do not know whether the fall in enzyme activity is a result of cessation of nuclear genome expression or whether some activation of degradative activity has occurred resulting in a net loss of enzyme. Gene expression results in production of proteins by coding ribosomes in the cytoplasm and initiating protein synthesis. It is possible that neuroglial damage was produced, as suggested by the data of Kholodov in the proceedings of an international conference on microwave bioeffects in Pushkino, U.S.S.R., 1980, or any of a legion of other effects.

This is a very important question, since we know that application of neurotransmitters, or conversely their pharmacological blocking, can alter the expression and coding capability of neuronal DNA. Many workers believe the pattern code of DNA distributed through several cells is the molecular basis of human memory.

There has been a gradual acceptance of the fact that single neurons may contain many different neurotransmitters—up to 100, including several polypeptides, which have distinctly different effects on postsynaptic cells and switch-

ing of protein production from DNA codes. Exactly how this type of system produces a visual, auditory, and sensory memory is, of course, still unknown. Certainly, it forms one of the highest-level targets of experiment of which we are capable.

Parallels in other systems

Since we know that production of at least one very important enzyme is altered by very short pulses of high-intensity fields, but do not know the exact mechanism, perhaps parallels can be found in other systems more amenable to experimental attack and support. For some time a comparison has been made between the molecular memory systems of the brain and that present in the immune system. Perhaps the clearest demonstration of molecular influences of RF fields is on the coordinate expression of genes on several chromosomes at once to produce antibody molecules, much of which follows a standard pattern with a given species, but which have hypervariable regions depending on the challenging antigen.

The total immune response is distributed among many cell types, apparently as a result of passage of information between cell types, so that T-cells can become NK or natural killer cells, B-cells can secrete circulating antibodies with T-cell collaboration, and macrophages can be activated as a result of T-cell secretions. This very complex system thus depends on multiple chromosome responses in single cells, and information transfer between several types of cells depending on whole sets of secretions (lymphokines, interleukins, etc.) that seem to act in a way analogous to that of neurotransmitters in the central nervous system.

The effects of hyperthermia on T-cells have already been mentioned. In experiments with high-strength HF band fields, it was found that lymphocytes were suppressed, replaced by neutrophils, then lymphocytes returned within 24 hours. After returning, the response to standard plant lectins was markedly altered, yielding an increased division response. Plant lectins are used as ways of discriminating different kinds of lymphocytes, for instance T-cells respond to a bean protein extract and B-cells respond to a pokeweed protein extract. The experiment was run at three frequencies, only one of which caused hyperthermia as measured by rectal temperature measurement in rhesus monkeys.

A more complete set of experiments was run in another laboratory, showing that response to several other lectins was also altered. The effect appeared distributed through the memory systems of several components of the immune system.

It appears, then, that moderately high-strength fields can alter components of the memory system of the immune system that may have counterparts in the central nervous system, but there is a sad lack of data at this point. Recently, experiments done in Italy have shown that moderately low-strength magnetic fields operating at 50 kHz can produce very similar effects on tritiated thymidine incorporation into lymphocyte nuclei, reinforcing the idea of a response involving synthesis of genetic material. No hyperthermia was expected or measured in those experiments. Those particular experiments are marked by the fact that more than 1,000 animals were exposed and examined, leading to very high statistical confidence levels.

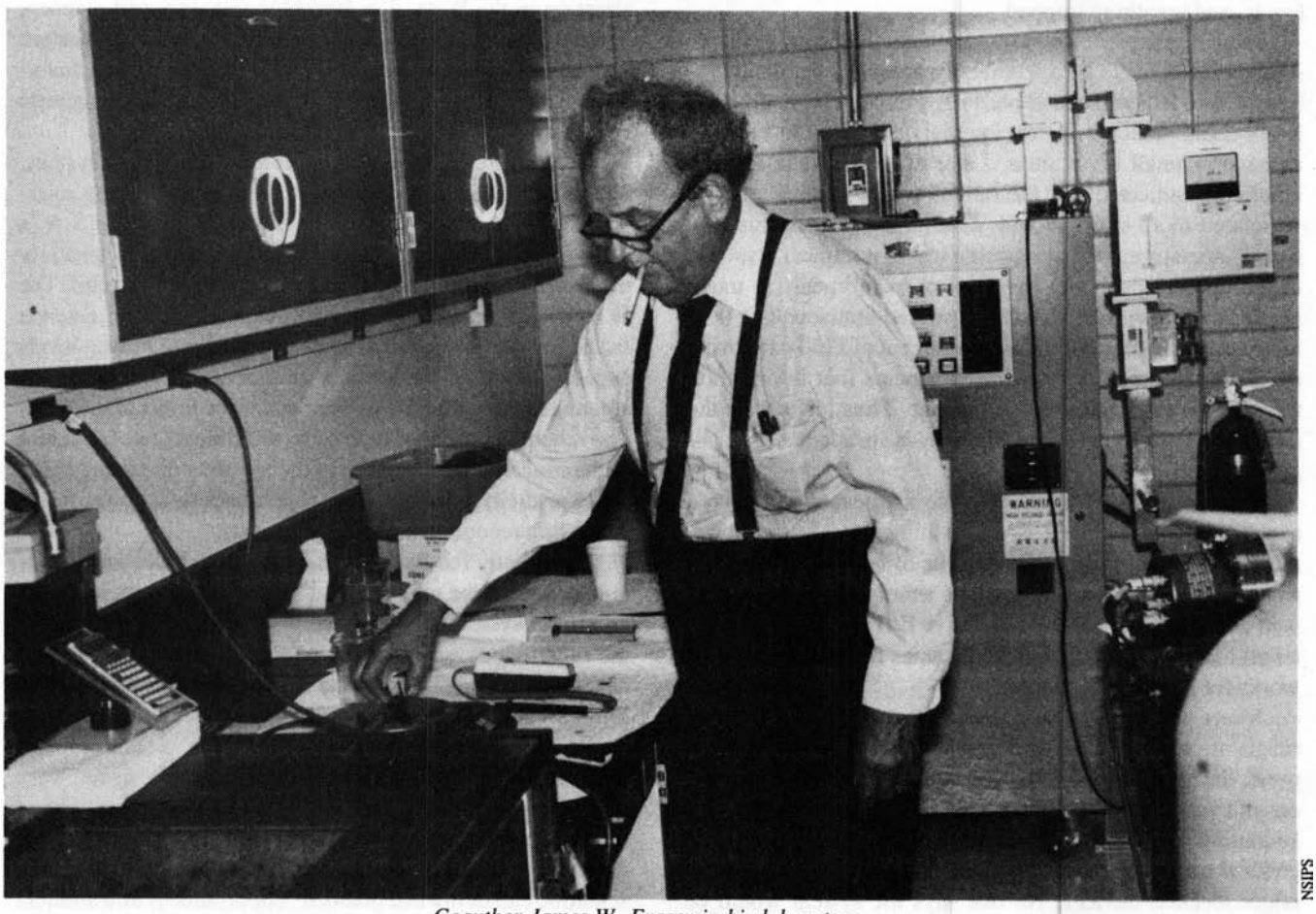
Many people, very well-qualified scientists, object to the thesis that there can be any form of direct field interaction with macromolecules in biological systems that does not involve hyperthermia. As mentioned above, this has been an argument of nearly 80 years' standing. A good deal of skepticism is warranted. Use of electric lines was followed by many complaints of ills caused by them in the early 20th century, which have largely been shown to be without basis.

The charlatans of the early 20th century foisted a legion of products on an unsophisticated public, promising all manner of health cures on the basis of mystical electrical emanations which, in may cases at least, simply did not exist. The early enthusiasm for diathermy applicators, useful as a muscle relaxant in some cases, might have gone on to fairly useful treatment of infections in the 1930s, were it not for the much greater efficacy and scientific base for the sulfa drugs and later antibiotics. As recently as 1952, however, hyperthermia induced by intentional infection with malaria was still used for treatment of neurosyphilis; some of this occurred because of undertreatment with penicillin when it was first introduced. Fortunately, the practice has largely ceased. A plethora of electrical equipment was simply not as effective as a pharmacologic approach to the treatment of human disease.

In recent years, hyperthermia has been used in the treatment of various types of cancer, so that some work with radio frequency-induced hyperthermia has appeared. This is a reincarnation of the first public use of radio frequency generators by D'Arsonval about 1900. The power generator constructed by D'Arsonval's group was used for induction therapy of tumors, then became the first power transmitter for Radio Paris. Obviously, if the treatment were remarkably successful, it wouldn't have fallen into early disuse.

Part of the problem then, as now, was lack of control of internal distribution of RF fields, consequently the hyperthermia they induce. From the research effort generated by this interest has come some appreciation of the importance of field control. Perhaps better results will be obtained in the future.

On the other hand, the dawn of molecular biology is some 30 years back, and the information now becoming available allows determination of chromosomal locations of some tumorigenic responses. Really modern work is aimed at deriving antibodies to these aberrant cells. It now seems fairly certain, however, that genetic subsets of tumorigenic cells are fairly common in single tumors which confer some sort



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Coauthor James W. Fraser in his laboratory.

of immunity to metastasizing cells, i.e., tumor cells that can utilize a variety of paths to invade surrounding issues. Often it is possible to treat a primary tumor successfully, only to have patients die from the effects of the metastasizing subpopulation of cells. A variety of antibodies, antibody-producing cells, lymphokines, or other biological agents may be necessary to control these processes. The fond dream of many workers in biological therapy is to harness the survival capabilities of these metastasizing cells to the survival of the entire organism. First things first, though. We have to find out how to control them.

The situation, then, is somewhat analogous to the introduction of antibiotics in that research efforts are directed into the "new" molecular biology of tumor cells and away from the "old" concept of hyperthermia as an adequate treatment tool for cancer.

While we now have some experience in directing internal field distribution so that better field management with visual control is becoming possible, even to the formation of internal elliptic waves, it now seems that major investigative support for such activities has vanished in favor of the investigation of fundamental properites of immunogenetics. The sobering thought is that the two approaches are not mutually exclusive, but should be done together, since we already know of direct field effects on cell fusion and local macrophage activity.

Direct effects on neural function

During the early 1970s, a microwave brain inactivator was built for purposes of measuring high turnover neurotransmitter intermediates in anatomically specific brain regions. The instrument caused an immediate reevaluation of neurotransmitter concentrations in the brain and their movement between brain regions as noted above.

Absorbed power levels below that required to thermally inactivate the brain were capable of disturbing behavior and learning patterns.

Exposure of experimental animals to an inhomogeneous field resulted in inactivation of the medulla near the foramen magnum (at the base of the skull), requiring fairly low power

levels, and breathing stopped.

From this experience, it was apparent that lethal or debilitating effects could be intentionally produced by manipulation of field E/H ratios and phasing. Frequencies and power levels could induce sufficient internal field strengths to cause damage in small brain areas. Later experiments in another laboratory indicated that the rate of power application was correlated more strongly with debilitating effects than was final temperature, indicating some sort of nonlinear response to the applied fields. In longer-term experiments at much lower power levels, it was demonstrated that adequate field modulation could produce an entrainment of EEG patterns in monkeys. In other experiments it appears that information transfer can take place in this manner. Thus, effects on the living brain can be produced when fields are adequately managed.

One can think of many possible applications of such a capability. The simplest is an instrument of warfare. Required is a set of transmitters capable of relatively long (100 msec) pulse emission at high-pulse average power (1 megawatt at least), with control of relative E/H and phasing at the target location. At different frequencies the same basic idea works for flying insect control.

Many people have long averred that the power requirements are too high, the specificity of target location is too great, the chances of appropriate interaction are too low, and on and on. The simple fact is that gyrotron emitters are becoming available together with antenna systems which could do the job, especially with several different types of target location devices. No one says the system would be simple, since each element has to have rapid, computer-controlled acquisition and control—but if all the elements were put together, it could be a most efficient system.

That type of system would also be remarkably efficient at destroying computer controls in other weapon systems, using a variety of mechanisms, many of which are already well known in conventional electronic warfare. Whether or not such a system should be built, is largely a question of its practical capability in comparison with other weapon systems. At least one system ought to be crafted so that some practical experience could be gained. We may need it.

Crafty East bloc thinking

In this respect, East bloc emphasis on accelerator design, which led to "gyrotron" developments, an admitted technological surprise to Western manufacturers, is a "can't lose" effort. The technology can be used for accelerators, nuclear pulse generation, magnetic confinement design, or simply high-power radar emitters, with power and phase coherence not easily approached with other methodologies.

Used as an optical "pump" for laser drives, another type of weapon system, which uses both optical and microwaves, becomes possible which doesn't seem to have received much attention in the West. The East bloc scientists and planners must be congratulated for some very crafty thinking. Western planners preoccupied with computer interfacing and analysis, could face nasty surprises in the vulnerability of central systems.

Given the capabilities of an orbiting microwave system, one reflects on the capabilities inherent in an orbiting solar-powered system such as the one examined by the U.S.A.'s National Academy of Sciences, a few years ago. Apparently the East bloc is preparing to place such a station in orbit. The U.S. design used a microwave beam focused on antenna farms on the ground for power generation. Power levels expected were in the vicinity of 100 milliwatt/cm^2 in the antenna farm, with little power outside the limits of the farm. The scheme was placed on hold by the United States, because of the concern about stability of the radiating platform, which could result in radiation of the general public at power levels exceeding recommended safety limits.

Apparently the East bloc has chosen to build such a system in a stepwise manner. The military capabilities of such an orbital system are worth very serious consideration. On the other hand, such a system could present isolated areas near the Arctic Circle in Russia with sufficient power to allow limited wintertime agriculture, a fact of great importance to the Russian economy. The development then, is another "can't lose" effort by Soviet scientists and planners, again, very crafty thinking.

The crafty thinking repeatedly alluded to is an indirect indictment of those who consistently downplay East bloc scientific capability and practice. The attitude is unwarranted and dangerous.

There is another side to the radio frequency problem which is not as obvious as the brute force systems alluded to above.

We have already mentioned the evidence for direct field effects on immunoreactivity and the similarity of some immunoreactivity to much more rapid events in cerebral neurones, known effects of properly modulated fields on neuronal behavior, and known effects on genome encoding systems.

We already know some information can be transferred by direct field effects, but very little research effort has been expended, with properly engineered fields, on the extent to which such information transfer might be possible. We already know that animals exposed to fairly high field strengths show signs of anxiety (maybe associated with hyperthermia), but know little else. The "clicking" sound of high-intensity pulse fields can be coded for information transfer, perhaps as an auditory code. What then of an entire population exposed to a properly designed field?

One would think the actions of modulated fields at frequencies and impedances known to affect different regions of the brain would be fairly high priority for investigation, but this appears not to be the case in the Western world. It

has been a longstanding investigation in the East bloc. Perhaps we are in for another technological surprise.

There really should be no uncertainty as to whether electromagnetic fields have predictable actions on biological systems at the present state of knowledge. The uncertainty grows from lack of appreciation of the importance of supramolecular organization of cells and tissues where forces not necessarily related to chemical bonding forces come into play.

One example of a way to analyze such forces is the polarization transfer experiments done with nuclear magnetic resonance which measures nuclear Overhauser magnetic coupling through space, not necessarily dependent on chemical bonding. This single type of measurement is adequate demonstration of coupling in molecules beyond the usual electrostatics of conventional biophysics when applied to macromolecules and whole cells or tissues. This coupling also indicates the possibility of field interactions directly on such a coupled ensemble, but even theoreticians pause at the possible implications. This level of electromagnetic field interaction remains little investigated except with the resonant spectroscopies.

We know that hyperthermia by itself can have many effects on our slow, internal chemical communication system (the endocrine system). This system includes the pituitary output and, directly or indirectly through pituitary release, also controls adrenal steroid secretion, pancreatic, thyroid, and sex hormone function, and controls the action of pituitary growth factors.

Therefore, we must understand that no conscientious scientist could aver that there are no effects of RF radiation on humans if the field strengths are sufficient to produce regional or general hyperthermia. Endocrine responses to such field applications have been measured, perhaps not as extensively as we all would wish, but enough to have formed part of the rationale for the present American National Standards Institute Recommended Safety Standard of 1 mw/cm as a tolerable level of RF field exposure for the general public.

According to EPA measurements, most environments outside the immediate vicinity of RF transmitters are far below this recommended limit.

Other effects which can be triggered by adrenal corticoid release include suppression of large parts of the immune system. We have learned to be fascinated by this type of action as a result of the AIDS problem, but have not found such suppression a significant factor at the recommended safe field levels.

The effects of frequency modulation

Dr. Adey's group has been examining modulated fields since the late 1960s. They initially found that fields modulated at frequencies near ordinary biorhythms (7-30 Hz) had dramatic effects on the release of calcium from cerebral tissues in the intact cat and in chick cerebral hemispheres. The experiments were repeated in EPA labs using very sophisticated equipment. It was found there was a "window" in field amplitudes during which the effect occurred.

This finding fueled heated debate as to the biological significance and validity of such an event at a time when the extreme sophistication of calcium's action in biological systems was still developing (as it still is) in independent scientific inquiries. Now we know that calcium is required at nearly every step, from transcribing external perturbations, to expression of genetic sequences. There are still gaps in our knowledge, but that which we know bespeaks an order of cell molecular and supramolecular organization unsuspected 20 years ago, and still eluding the grasp of all but the extremely astute.

More recent experiments have demonstrated effects on lymphocyte capping following lectin interaction, fibroblast mobilization, and protein secretion, showing that appropriate low-level modulations do indeed have actions on a very sophisticated system in isolation. The biological significance of such actions in an intact organism are still subject to some doubt. They are, however, clinically useful, as shown in Becker's work on healing of resistant bone fractures. This work, furthered at Columbia University, is commercially available.

An extension of such phenomena is the work of Zimmermann at Würzburg showing that radio frequency polarization of cells (similar to the "pearl chain" effect from the 1930s), followed by DC pulse can result in genetic fusion of cells in culture. Some of our own work indicates this type of phenomenon can also operate on bacteriophage insertion in bacteria and perhaps cells *in situ* with particular types of field applicators. It must be emphasized that these are high-intensity fields, more than 5×10^5 V/meter, much more intense than those found in any environment other than well-designed laboratory enclosures.

Research programs are extant now to study some of the biological interactions, some of them at the level of molecular systems. The old bromides about no effect on macromolecules are largely laid to rest by developments of field-focusing electrophoretic apparatus.

It is puzzling, however, that dielectric measurements of molecules is hard put to detect this interaction, though optical studies (Raman spectra and polarization studies) pick it up. Very strange. Several experiments combining field applications together with optical and resonant mode spectroscopies on whole tissues and highly selected molecular systems are required.

There are no obvious programs extant concerning weapons development. This is a very mysterious lack, perhaps relating to the prohibitions in the SALT agreements, but we suspect more related to the engineering idea of impossibility. Impossible things are potent sources of technological and political surprise.