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LETTERS

Tagging Technologies

Ruth H. Howes ("Tagging Technologies and Reduction of Conventional Forces in Europe," January 1990) gives needed exposure to the important question of tags and seals. But she does herself and the field a disservice by concluding, "It seems unlikely that either side would agree to electronic tags that could be monitored by satellites since these tags might conceivably provide targeting data or enough information on deployment to be militarily useful."

I have carefully explained (1) that monitoring electronic tags by satellite can give important verification that the treaty-limited item (TLI) is where it is claimed to be, within tens of meters Yet for reasons both of cost and to prevent the use of this verification system as a targeting aid, such interrogation would be physically possible only with the cooperation of the operator of the TLI. The tag on the TLI would communicate not by radio but by infrared (like the remote control on your TV) to a relay box maintained by the host country. The protocol in the arms control agreement would provide for the host country, on request, to move such a box to within a few meters of the tag on the TLI, and to provide power to the relay so that the relay box itself could communicate by radio with the monitoring satellite, as well as (by infrared) with the tag on the TLI.

It is thus physically impossible for the electronic tag to provide any information about the TLI except with the explicit consent and cooperation of the operator of the TLI.

At least one well-known advocate of non-electronic tags continues to make statements like the one quoted above, although he readily concedes that electronic tags would normally be designed and used in such a way that there would be absolute protection against obtaining information other than that voluntarily revealed. He argues, however, that there is "a perception" that tags would provide targeting information — reminding me of the young man whom threw himself on the mercy of the court as an orphan, having been convicted of murdering his father and mother.

1. R.L. Garwin, "Tags and Seals for Verification," *Bulletin of The Council for Arms Control*, October 1988 (London).

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Response:

Since the enormous political changes in eastern Europe continue to propel us toward a CFE agreement, verification issues must be debated now. I am grateful to Richard Garwin and Physics and Society for encouraging this debate.

Garwin correctly points out that it is possible to devise electronic tags with read-out systems that prevent them from providing information that could be used for targeting. On the other hand, the systems used during the read-out and the electronic tags themselves are technologically fairly complex. While such devices might work well for mobile strategic nuclear weapons systems, where a few hundred weapons manned by elite troops are fielded under carefully monitored conditions usually in a limited geographic area, a CFE Treaty would involve tens of thousands of weapons deployed over an enormous geographic area and manned by all types of troops who are often less than careful in handling their weapons.

Even if the electronic tags themselves can be made rugged enough to survive field deployment, including not only the hazards of weather and rugged terrain but also the harsh chemicals used to decontaminate equipment during training with chemical weapons, supplying portable reading devices to remote posts in all weather conditions may prove difficult. In order to obtain a reading for verification, each treaty party is dependent on the technological skill of a nation being inspected and manning the reader. Each nation must provide its own satellite receiver or rely on that of its allies. Particularly in view of the recent rapid political changes in Europe, it seems unlikely to me that participants in a treaty likely to involve 23 nations would agree to such a complex and potentially expensive scenario.

Life-cycle costs of a complete satellite system consisting of 2-3 satellites with one or two ground stations and operating costs and expenses would be $150 to $200 million annually (1). Data on detailed costs vary widely, but this number can be compared to the $50 million annual budget of the On-Site Inspection Agency which verifies the INF Treaty. Included in the budget are expenses for training, equipping and fielding inspection teams, support personnel, escorts for Soviet inspectors on U.S. territory and the cost of stationing personnel at the permanent monitoring station at Votkinsk. Rule of thumb costs are $60,000 to field a ten person inspection team for two weeks in the field and $0.5 million annually per inspector stationed at a permanent monitoring station or Soviet territory.

These rough budget numbers and consideration of field conditions for verifying limitations on conventional weapons demonstrate the advantages of keeping verification technology as simple as possible. Tags like intrinsic surface fingerprints can be applied by troops in the field, will require a minimum number of on-site inspections and promise the durability needed for a long-term treaty regime. Verification technology should be subject to the KISS rule used in planning military operations: Keep It Simple Stupid.

1. Hans Günter Brauch, editor, Verification and Arms Control Implications for European Security: The Results of the Sixth International AFES-PRESS Conference, Part 1, p. 42 (AFES-PRESS, Mossbach, 1990).

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ARTICLES

Forum Award Lecture: Comparing Risks—A Hazardous Undertaking

Richard Wilson

[*Editor's note:* Richard Wilson is winner of the 1990 Forum Award for promoting public understanding of the relation of physics to society. His citation is given in the April 1990 issue. The following paper is based on his lecture at the Forum Awards session held 16 April 1990 at the Washington DC APS meeting. He is Mallinckrodt Professor of Physics at the Department of Physics and the Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138. For the award banquet, Barbara Levi, past Forum Chair and our resident poet, wrote a limerick "About Richard Wilson and Risk Assessment":

In pollution the world seems to wallow.
Dick gives us a guide we can follow.
What risk, do you think,
In water we drink?
For some, it is too much to swallow.]

Understanding problems of the environment, and particularly those associated with energy consumption, involves an understanding of numerical magnitudes. Physical scientists, physicists and chemists, develop this understanding automatically as a result of their work. Many people, including many scientists in the biological and medical fields, do not.

My involvement with explaining the risks and dangers of life to people began about earth day 20 years ago when I was asked some questions by undergraduate students. They were eager to get my help in understanding the problems of nuclear energy, and thought that I as a nuclear physicist was an ideal man to help them. It did not take long for me to realize that the problems, and even the issues of nuclear energy are very little to do with nuclear physics: the problems are of engineering, and of perception.

These studies confirmed what the industry had badly presented: that nuclear power produces fewer fatalities than most other electricity generating schemes.

Nevertheless, they are amenable to calculation and analysis.

For me a nuclear reactor had been a source of neutrons and isotopes for experiments. I had to learn about the nuclear power industry from scratch. I was, and still am, disappointed with their advertising. The public, and the technology, deserve better.

In 1970, the claim that no one in the public had been killed as a result of radiation from a licensed nuclear facility worried me. It would be incorrect if cancers produced by low levels of radiation were included according to a linear dose response relation. It was not relevant for comparison purposes, because much less electricity had been generated from nuclear power than from other sources of energy. I therefore produced, in a letter to Physics Today, my own table of deaths including those calculated but not directly observed, from producing electricity from all sources, divided by the amount of electricity produced (Table 1). Thus one can find a more relevant measure — deaths per kilowatt hour. I was helped in this undertaking by the fact that I was born and brought up in London and every November we had the notorious London fogs which not only affected visibility, and had obvious effects on those with respiratory ailments, but also in many ways made life less pleasant.

Table 1. Deaths per kilowatt hour in USA (based on 1965 figures)*

Coal mining	
black lung disease	10^{-9}
accidents	6×10^{-11}
Petroleum refining	
oil-well accidents	7×10^{-12}
Uranium mining cancers	
no breeder	1.5×10^{-11}
breeder	7×10^{-14}
Uranium processing, fuel fabrication, accidents (estimate)	
no breeder	2×10^{-11}
breeder	2×10^{-13}
Coal/gas/oil air-pollution deaths	3×10^{-9}
Radiation cancers, normal operation (0.1 mr/yr at year 2000) of reactors and processing plants	3×10^{-13}
Potential reactor accidents (1 per 30 years of WASH 740 severity by year 2000)	
direct deaths	3×10^{-11}
possible extra cancer deaths	3×10^{-11}
Gas main explosions:	3×10^{-12}
Gas poisoning:	6×10^{-12}
Dam failures (1 per 50 years as in Vaiont, Italy):	6×10^{-10}

*Reprinted from *Physics Today*, Vol. 25, p. 73 (1972).

Not everyone liked this comparison. According to one of my spies, the President of Boston Edison company told a staff meeting that I was "an intervenor type" and a pain in the neck! Presumably because I referred at that time to "the conspiracy to whitewash coal" in which the Sierra Club have for the last 15 years supported the burning of coal by the utility industry. I wish that he had put his complaint in writing. I would use it as a letter of recommendation.

This crude risk comparison stimulated others, in particular Dr. Leonard Hamilton of Brookhaven National Laboratory, who is a physician, also born in England, and unusual in that he has a clear understanding of quantitative magnitudes. These studies, done for the DOE, and other similar studies in France, UK, and Italy, confirmed what the industry had badly presented: that nuclear power produces fewer fatalities than most other electricity generating schemes.

Such studies led naturally to wondering why this point seems so hard for most members of the public to believe, understand and accept. One reason, most analysts surmise, is that when something goes wrong with nuclear energy many people are affected by one accident, as for example in the Ukraine after Chernobyl. But that is not the whole reason. Hundreds of people have died in single aircraft accidents, as for example in the Azores where two loaded passenger jets collided on the ground. No one has even suggested banning airplane travel. Hundreds of people have been killed in single failures of hydroelectric dams; yet I have heard no clarion call for emptying all reservoirs. Therefore a simple comparison of risks, even if weighted by the number of people involved in a single accident, while instructive, does not enable us to decide on public acceptance.

In 1976 I added chemical risks to my repertoire. This was in response to a request of a former Harvard student working as VP of Air Products. In 1977 Donald Kennedy, then administrator of FDA and now President of Stanford, got into trouble by proposing to ban saccharin. Table 2 shows the risks of a number of chemical additives before him at that time.

Table 2. Food and drug administration issues of 1977: Cancers/yr (my calculation)

Aflatoxin B1	3000
Saccharin	500
2,4,DAA (hair dye coupler)	
drunk	6
on hair (before measure)	1/30
on hair (in 1988)	1/1000
Vinyl Chloride plastic bottles	less than 1/100
Lead Acetate	1/100

Of these, the Environmental Defense Fund was concerned about hairdyes; both the 2,4,DAA (Clairol Hairdye coupler), and Combe, Inc's lead acetate (Grecian formula). The table shows that these give smaller calculated effects on health than saccharin. How could a good scientist even listen to EDF if he did not propose to ban saccharin?

My comparison of risks seems to have convinced some people that I was in the pay of a wicked nuclear power industry. I received several anonymous letters enclosing articles by some of the more virulent, and less quantitative opponents of nuclear power. Yet at that time I had even insisted on paying for my own coffee from the cafeteria at a power station. Although troubling, those letters and phone calls convinced me that someone was listening to and reading what I said, a conviction that I have not always had in high energy physics. So I continued.

About this time also I wrote an article, "The Daily Risks of Life," explaining how we take risks every moment of our lives, and how we might, if we so chose, express our decisions quantitatively. Of course we do not usually so choose! It took me a year to get this article published. No one wanted it. The Harvard Business Review thought that I was playing a joke on them. But Technology Review, of MIT, accepted it. Within two weeks the dam had burst. It was reprinted in the Chicago Tribune, Honolulu Advertiser, Miami Gazette, and the San Francisco Chronicle. The article included a table of risks (Table 3) which included a risk of drinking water.

When a reader asked the chief engineer of the Miami water supply what he thought of my number (calculated for the risk of chloroform in the drinking water) of the risks of drinking Miami water, he replied that the risk is small compared to the risk to Professor Wilson if he ever gets his hands on me! Regretfully, I have never met him, although if I did I would watch his hands as closely as someone in a western movie watches the hands of a gunfighter in a saloon.

Table 3. Risks which increase the chance of death by 0.000001*

Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 ltr of wine	Cirrhosis of the liver
Spending 1 hr in a coal mine	Black lung disease
Spending 3 hr in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution
Traveling 6 min by canoe	Accident
Traveling 10 mi by bicycle	Accident
Traveling 30 mi by car	Accident
Flying 1000 mi by jet	Accident
Flying 6000 mi by jet	Cancer from cosmic rad
Living 2 mos in Denver	Cancer from cosmic rad
Living 2 mos in stone or brick bldg	Cancer from nat rad
Chest x-ray taken in a good hospital	Cancer from rad
Living 2 mos with a cigarette smoker	Cancer and heart disease
Eating 40 tblspns peanut butter	Liver cancer from aflatoxin B
Drinking Miami drinking water for 1 yr	Cancer from chloroform
Drinking 30 12 oz. cans diet soda	Cancer from saccharin
Living 5 yrs at site boundary of nucl power plant in the open	Cancer from rad
Drinking 1000 24 oz. soft drinks from recently banned plastic bottles	Cancer from acrylonitrile monomer
Living 20 yrs near PVC plant	Cancer from vinyl chloride
Living 150 yrs within 20 miles of nuclear power plant	Cancer from rad
Eating 100 charcoal broiled steaks	Cancer from benzopyrene
Risk of accident by living 5 miles of nuclear reactor for 50 yrs	Cancer from rad

*1 part in 1 million

A San Francisco Chronicle reporter was told to interview me about the article by phone. He tracked me down in a Leningrad hotel. I had to explain the whole list of risks. When I got to Aflatoxin B1 in peanut butter the phone went dead. Presumably the person who was listening in on our conversation thought that we were talking in code!

A whole industry of "risk communication" has grown up over the last 10 years to discuss this question of public acceptance. While I agree with much that they say, I reject the idea that public perception of a risk is more important than the actual magnitude of the risk. The public is diverse; the perceptions can change rapidly, both in space and in time in the same way that the political background of eastern Europe has changed in the last 12 months. The risk itself stays the same. Of course we do not know the risk itself; all we know is the perception of that risk by an expert. When we state it this way, a part of the problem becomes apparent. There is an anti-scientific feeling around, as Gerald Holton discusses elsewhere in this meeting. Some people reject experts; and what they say.

I have been repeatedly misquoted by risk communication experts: by Ellen Silberoeld, by Paul Slovic, by Barry Fischoff and by Vincent Covello. Each of these has claimed that I say that everyone ought to make their decisions based solely on the magnitude of the risks. I have never said that; and I do not believe it. What I have said is that a comparison can be a useful part of the decision process. It can also help in understanding. A comparison can stimulate a person to come forward and say what concerns them. Sometimes that has been disconcerting.

I did not realize it at first, but now I am sure that there are a large number of people who do not want the public to know the truth, or at least believe that they would not understand it. They are not all industry leaders. Some are labor leaders, politicians, or environmentalists. Some are in the EPA. I have had a 10 year argument with the EPA about drinking water. We have to chlorinate our water to get rid of bacteria, otherwise we would have the same high typhoid rate as we had in the last century. The chlorine interacts with any organic matter to produce chloroform. Chloroform produces liver tumors in mice and kidney tumors in rats.

We use a lot of chlorinated solvents in domestic and industrial applications. One of them, trichloroethylene (TCE), produces liver tumors in mice. In Table 4 I show that chloroform is clearly worse than trichloroethylene. We do not have to calculate the full risk to show this, but I merely note that it takes 20 times as much weight of trichloroethylene to produce liver tumors in mice as it does chloroform. Surely therefore, chloroform is more closely regulated than trichloroethylene? No. 20 times more chloroform is allowed (by EPA standards) in drinking water, for a total difference in risk level at the standard of 400 (based on a linear dose response relationship).

Table 4. Risks of chloroform and trichloroethylene

	Chloroform	Trichloroethylene
Toxicity LD50 (mg/kg)	500	5000
Carcinogenic potency (mg/kg day)		
Rat	2.5×10^{-3} (kidney)	Not significant
Mouse	1.1×10^{-2} (liver)	7.3×10^{-4}
EPA Limit	100	5

Possible reasons are obvious. We can reduce TCE if we wish and it is the wicked industry that has to bear the cost. It is much harder to have a viable, pure water supply without chlorination. These reasons are honorable; but the EPA has been reluctant to admit them. Worse still, public health officials do not know the facts, and following only what they hear from EPA give inappropriate advice to people. There are at least three documented cases where a person has been consuming well water at twice the EPA standard and has been advised to switch to treated city water with chloroform at 1/2 the EPA standard. Stated this way, the advice sounds good. But when risks are compared we see that they were being advised to increase their risk 100 fold.

We can make a similar comparison of aflatoxin in peanut butter and accidental contamination of soil by 2,3,7,8 dibenzo-o-dioxin (or just dioxin). The two chemicals give similar numbers of tumors in rats and mice at similar absolute levels. Aflatoxin is a mutagen whereas TCDD is not. Yet the FDA only regulate dioxin in peanut butter above 20 ppb, and the center for disease control calls 1 ppb in soil "a source of concern."

These studies are simple, but time consuming. when explaining things to the press one has to know ones' facts, however trivial. That means work. They are also expensive. I counted over 130 cases where some newsman called me soon after Chernobyl. They wanted to know all of physics in an hour: all of nuclear engineering in another 1/2 hour, and all of medicine in 15 minutes more. In many cases I had to return phone calls from airports while changing planes. I calculated that I spent over $500 of my own money in so doing.

I talked to one agitated lady from Ohio. "My daughter is going to Europe for a vacation. Should she fly through that radiative cloud?" Comparisons are here of limited help. Of course you get a higher radiation exposure by flying at 30,000 feet, and Table 1 suggests that aircrews have a high occupational exposure. Moreover detailed calculation shows that, as a group, they are the highest exposed of any radiation workers (although they are not so classified). But that is not calming.

Nor do people understand the inverse square law. "The only plane that I do not want to be on is the helicopter hovering over the plant and dropping lead and sand," I said, with no effect.

"You must understand that I am talking as a mother" she persisted.

"You are not unique: there are roughly a billion of you," I replied!

Some people like what I say. I have had thanks from several secretaries of DOE. But such thanks merely get me on another unpaid hard-working advisory committee. The thanks do not affect staff further down. When I ask for my research funds in high energy physics I have been told more than once that I do not need them; I am spreading myself too thin by my work on risks. Fortunately in the last few years, it is not always that way. I have found that lawyers pay for the advice you give them, and a lawyers' rate of pay is higher than that of most physicists.

Over the last 10 years I have had the excellent help in much of this work from several collaborators. I want to particularly single out Dr. E. A. C. Crouch and Dr. Lauren Zeise. They have helped me to sharpen my understanding and ensure that the risk assessments stand up to scrutiny. This award is partially owed to them and many other collaborators. I give them my thanks.

I will now come to the worst hazard of comparing risks: boring ones friends and family. All scientists get consumed by what they are doing, and get particularly concerned by politicians and others who seem to delight in ignoring the truth. I tend to talk about it at all moments. My wife has borne all this with her usual patience for 20 years. She is after all, the daughter of a physicist and her sister married a physicist. I see her in the audience. Therefore at this time I will stop and I will bore her and you, no longer. I thank you and the APS for paying attention.

Israeli Ballistic Missile Capabilities

Steve Fetter

[This article appeared in the July 1990 issue. Unfortunately, a computer mistake rendered many in-text mathematical symbols unrecognizable. I apologize. Herein, we try again! —*Editor*]

In a class I teach on Science and National Security, I came across a good example of how to apply a knowledge of basic physics to an important public policy problem — the proliferation of ballistic missile technology. On 19 September 1988, and again on 3 April 1990, Israel launched a satellite. The example given below shows how one can calculate, from knowledge of the satellite's orbital parameters, the payload that the same rocket could deliver at a given range if it was used as a ballistic missile.

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The physics of ballistic trajectories

The first satellite was placed in an elliptical orbit with a perigee of 250 km, an apogee of 1150 km, and an inclination of 148 degrees; the perigee and apogee of the second satellite were 200 km and 1450 km. The latitude of the launch site was 32 degrees, and the satellite was launched due west over the Mediterranean Sea (1).

The velocity needed to put the satellite into orbit is given (2) by

$$v_c = \left[GM_e\left(\frac{2}{R_e} - \frac{1}{a}\right)\right]^{1/2} \qquad (1)$$

where G is the gravitational constant (6.67×10^{-20} km^{3}s^{-2}kg^{-1}), M_e is the mass of the earth (5.98×10^{24} kg), and R_e is the radius of the earth (6370 km). The semi-major axis of the satellite orbit, a, was 7070 km for the first satellite and 7210 km for the second satellite, which gives v_c=8.30 km/s and 8.36 km/s, respectively.

To get the burnout velocity of the missile, we must add to Eq. (1) the component of the earth's rotational velocity in the direction of the launch (δv_r) and an amount to compensate for the effects of air resistance and gravity on the rocket during launch (δv_a):

$$v_b = v_c + \delta v_r + \delta v_a \qquad (2)$$

$$\delta v_r = (2\pi R_e/86164)\cos(\Phi)\,|\cos(\Omega)| = 0.33 \text{ km/s} \qquad (3)$$

where Φ is the latitude, Ω is the orbital inclination, and 86164 is the number of seconds per sidereal day.

Israel's missile probably has three stages; the plume of the first stage, as recorded on film, clearly indicates that it is solid-fueled. Assuming that each stage provides the same δv or increase in missile velocity, the total mass of the rocket would be given (3) by

$$M_r = m_s\{1-f[1-\exp(-v_b/3v_e)]\}^{-3} \qquad (4)$$

where m_s is the mass of the satellite payload, f is the ratio of the total mass of each stage to the propellant mass, and v_e is the exhaust velocity of each stage. (This is the optimal solution if all stages have equal f and v_e, as I assume here.)

If the same rocket were used as a ballistic missile, the payload mass for a given burn-out velocity v would be given by

$$m_b = M_r\{1-f[1-\exp(-v/3v_e)]\}^3 \qquad (5)$$

The ratio of the ballistic-missile payload mass to the satellite payload mass is therefore given by

$$\alpha = \left\{\frac{1 - f\,[1 - \exp(-v/3\,v_e)]}{1 - f\,[1 - \exp(-v_b/3\,v_e)]}\right\}^3 \qquad (6)$$

The burnout velocity v necessary to give a ballistic missile a range of r is given (4) by

$$v = \left[\frac{GM_eR_e(1-\cos\phi)}{(R_e+h)^2\sin^2\Theta - R_e(R_e+h)\sin(\Theta-\phi)\sin\Theta}\right]^{1/2} + \delta v_a \qquad (7)$$

where h is the burnout altitude (assumed to be 250 km, the perigee of the satellite orbit) and $\phi=r/R_e$.. The maximum range (i.e., minimum-energy trajectory) is given by $\Theta=(\phi+\pi)/4$.

All that remains is to substitute values for f, v_e, δv_a into Eq. (6). For solid-fuel rockets, typical values are $f = 1.05$, $v_e = 2.5$ km/s, and $\delta v_a = 1$ km/s (5). To estimate the effect of uncertainties in these values I used the following equation

$$\sigma_\alpha^2 = \sigma_f^2\left[\frac{d\alpha}{df}\right]^2 + \sigma_{ve}^2\left[\frac{d\alpha}{dv_e}\right]^2 + \sigma_{\delta va}^2\left[\frac{d\alpha}{d\delta v_a}\right]^2 \qquad (8)$$

where σ_α, σ_f, σ_{ve}, and $\sigma_{\delta va}$ are the uncertainties in α, f, v_e, and δv_a. I assumed that $\sigma_f = 0.02$, $\sigma_{ve} = 0.2$ km/s, and $\sigma_{\delta va} = 0.2$ km/s.

The ratio of the ICBM payload mass to the satellite payload mass predicted by Eqs. (6)-(8) is shown in Fig. 1 as a function of the maximum range of the ICBM.

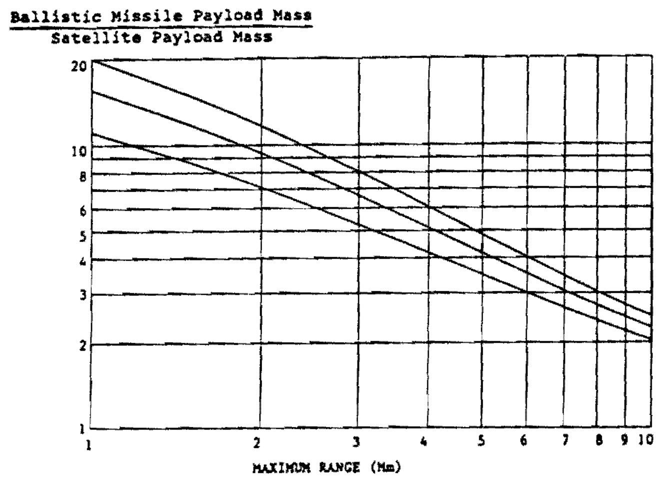

Fig. 1. The ratio of the payload mass if the rocket is used as a ballistic missile to the satellite payload mass as a function of the maximum range of the ballistic missile. The upper and lower graphs represent uncertainties around the central graph.

Israel's ballistic missile capabilities

The mass given by the Israelis was 156 kg for the first satellite and 170 kg for the second satellite; including a guidance and control package would bring the total payload mass to at least 200 kg. If this is correct (there is no way to independently verify the mass of a satellite), then Israel could loft a 3±1 tonne payload 1000 kilometers.

How much might an Israeli nuclear warhead weigh? The first US

The missile could deliver an 800 kg payload at a range of over 4000 km.

bombs, Little Boy and Fat Man, weighed 4000 and 4900 kg. There are reports that Swedish scientists had by 1958 designed a 20-kt fission bomb weighing only 600 kg, in which they had high confidence without nuclear testing (6). Israeli scientists could do at least as well, and may have designed nuclear weapons weighing as little as 100 to 200 kg. A first-generation inertial guidance system might weigh 50 kg. An Israeli nuclear ballistic missile payload, including the warhead, reentry vehicle, guidance system, and arming and fusing mechanisms, might weigh less than 400 kg (α=2), and certainly no more than 800 kg (α=4).

Assuming a satellite payload of 200 kg, the missile could therefore deliver an 800 kg payload at a range of at least 4000 km, which would put the entire Arab world (plus most of Europe, including European USSR) within its range. If payloads as light as 400 kg are available, the missile would have intercontinental range.

Of course, even if Israel possesses a suitable nuclear warhead, a reentry vehicle would still have to be developed. But if an RV *is* developed and tested, Israel will have a truly formidable ballistic missile capability.

References and notes

1. J. Diehl, "Israel launches satellite into surveillance orbit," *Washington Post*, 4 April 1990, p. A35; S. E. Gray, Lawrence Livermore National Laboratory, personal communication.
2. S. Glasstone, *Sourcebook on the Space Sciences* (van Nostrand, Princeton, 1959).
3. Although I have not been able to find a reference for this equation, it is easily derived. Note that as the number of stages becomes large, $(m_f/M_r) \approx \exp(-fv_b/v_e)$.
4. The range equation is developed in several textbooks. See, for example, R. R. Bate, D. D. Mueller, and J. E. White, *Fundamentals of Astrodynamics* (Dover, New York, 1971).
5. Glasstone, *op cit.*; also E.H. Sharkey, "The Rocket Performance Computer," RM-2300-RC (The RAND Corporation, Santa Monica, CA, 1959).
6. C. Larsson, "Build a Bomb!" *Ny Teknik*, 25 April 1985, cited in L. S. Spector, *The Undeclared Bomb* (Ballinger, Cambridge, MA, 1988).

Symposium: Health Effects of Nonionizing Radiation

The Forum sponsored a session on the health effects of nonionizing radiation at the April 1990 APS meeting in Washington, DC. Out of the four papers presented at that session, I have received two manuscripts, reprinted here. The second of these, by M. Granger Morgan, was in the form of the transparencies used to outline the talk; I believe that readers will find this outline useful. The other two papers were "Substrates of Electromagnetic Field Interactions in Biomolecular Systems," by W. Ross Adey, Veterans Administration Medical Center, and "Nonionizing Electromagnetic Radiation Activities and Issues," by Joe A. Elder, US Environmental Protection Agency.

Desiring a well-rounded view of this controversial topic, I contacted Robert K. Adair of Yale University to help provide balance to what I assumed would be a presentation of the four symposium papers. Adair agreed, and I informed the four symposium participants about the addition of this paper. Adey then declined to have his paper appear alongside Adair's. Thus, Adair's paper is printed here without the "other view" that Adey's paper might have provided. A controversial topic, indeed! I invite responses.
Editor

Interaction of Extremely-Low-Frequency Electric and Magnetic Fields with Humans

T.S. Tenforde

The interaction with living systems of electromagnetic fields in the extremely-low-frequency (ELF) range below 300 Hz will be summarized briefly in this paper. In materials with the electrical and magnetic properties of living tissues, a 60-Hz field has a long wavelength (~5000 m) and skin depth (~150 m). As a consequence, in their interactions with humans and other living organisms ELF fields behave as though they are composed of independent electric and magnetic field components. This "uncoupling" of the orthogonal electric and magnetic components of an ELF field is commonly referred to as the "quasi-static approximation," which permits the radiating properties of the field to be neglected in describing its interaction with living organisms.

The electric and magnetic components of an ELF field have several distinctly different features in their interactions with humans and other living organisms (1). First, the electrical conductivity of tissue is approximately 14 to 15 orders of magnitude greater than that of air at ELF frequencies. Consequently, the body behaves like a good electrical conductor in ELF electric fields (Figure 1A). As a result, an electrical charge is developed on the surface of a living object in an external ELF field, and the electric field penetrates into the body only to a very limited extent ($E_{in} \leq 10^{-7} E_{out}$). The significant conductivity of the body relative to air also has the important consequence that the local field in air near regions of the body with small radii of curvature (e.g., the head or the fingertips) is larger by more than an order of magnitude than the external field at a distance of several meters from the body. This phenomenon is referred to as the "field enhancement effect," and it greatly complicates the dosimetry of ELF electric fields in the proximity of the body.

In contrast, the magnetic component of an ELF field does not induce a surface charge and it penetrates the body without significant attenuation since the magnetic permeability of tissue is nearly identical to that of air (Figure 1B). As a consequence, the dosimetry of ELF magnetic fields in and near a living organism is relatively simple in comparison to the dosimetry of ELF electric fields. Another feature of ELF electric and magnetic fields that differs is the pathway of induced currents within the body. Induced electric currents in tissue flow predominantly in the direction of an external ELF electric field, whereas the electric currents induced in tissue by an external ELF magnetic field circulate in planes that are orthogonal to the direction of the applied field (Figure 2).

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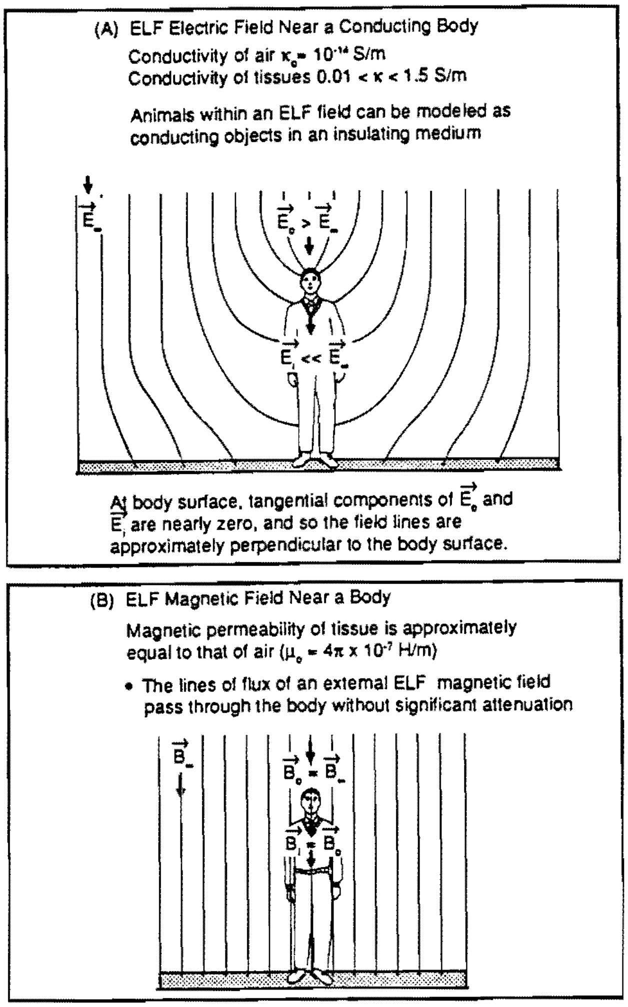

Figure 1. The electromagnetic fields near a body

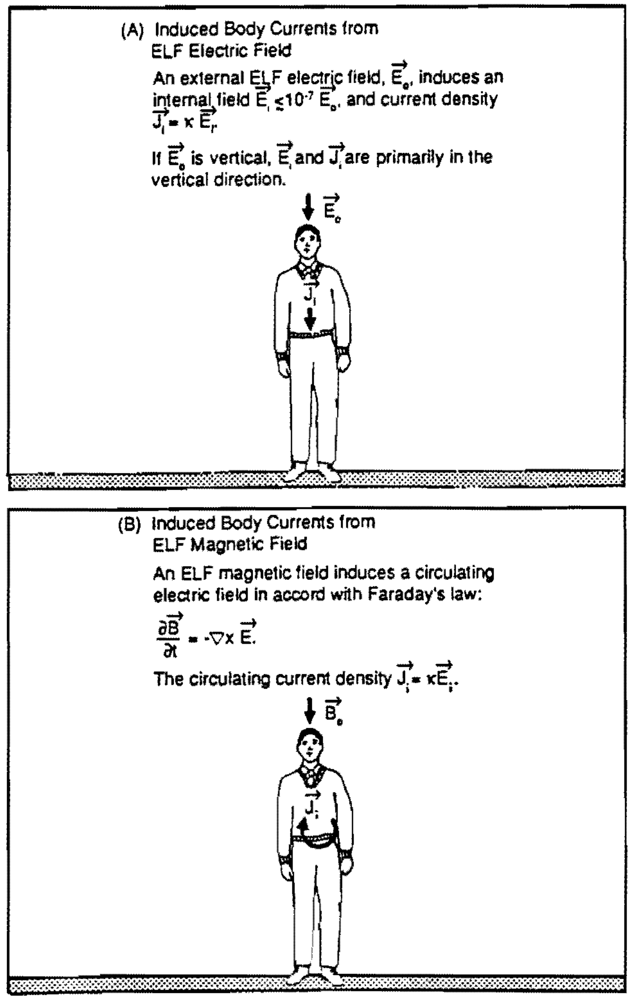

Figure 2. Induced body currents.

Another point to be made regarding the physical interactions of ELF fields applied to the body through air is that their interactions are primarily nonthermal in nature. This conclusion follows from the fact that the highest electric field level that can be induced in tissue by an externally applied ELF field in air is less than one V/m. Larger fields cannot be induced in tissue because the externally applied electric field would have to exceed the dielectric breakdown threshold of air. The maximum rate of joule heating of tissue by these weak induced fields is on the order of a nanodegree per second, which is about five orders of magnitude less than the rate of metabolic heating in humans. Because of the efficient heat conduction and convection processes in humans and other living organisms, this rate of tissue heating cannot be detected by presently available techniques.

The existence of intracellular responses to ELF field transduction is illustrated by several lines of experimental evidence.

A careful review of the published literature has demonstrated that the biological effects of ELF fields are directly correlated with the current density induced in tissue (2). A few biological effects have been observed to occur in response to induced current densities that are comparable to the naturally occurring currents that flow in the body as a result of endogenous electrical activity of excitable tissues such as the heart and brain, i.e., 0.1 to 10 mA/m^2. These effects include the visual phenomena known as electrophosphenes and magnetophosphenes, and effects on the circadian rhythm in melatonin synthesis by the pineal gland.

At higher levels of induced current density in the range of 10 to 100 mA/m^2, a variety of alterations in tissue and cellular properties have been reported to occur in response to the application of ELF fields, including beneficial effects such as the facilitation of bone fracture reunion. With induced current densities in the range of 100 to 1000 mA/m^2, thresholds for neuronal and neuromuscular effects are exceeded. Finally, at levels above 1 A/m^2 the induced currents in tissue can produce severe, and potentially fatal, respiratory and cardiac effects. Current densities of this magnitude, however, can be produced only by electrodes in direct contact with the body, and not by fields applied to the body through air.

The major challenge in ELF field research at the present time is the elucidation of mechanisms by which exposure to extremely weak ELF fields can result in reproducible biological effects. A large number of physical and electrochemical models have been proposed in which the cell membrane is viewed as playing a primary role in transducing the weak signals presented by induced ELF electrical currents in tissue. A growing body of experimental evidence suggests that electrochemical events initiated at the membrane surface by circulating pericellular currents can alter ion binding to membrane macromolecules and influence ligand-receptor interactions at the cell surface (e.g., the binding of hormones, growth factors, etc.). These field interactions at the cell surface can trigger transmembrane phenomena involving alterations in ion transport and changes in the electroconformational states of membrane proteins.

Events initiated at the inner membrane surface in response to these transmembrane signals can, in turn, influence the cytoplasmic concentrations of biologically important "second messengers" such as calcium ions and cyclic nucleotide that regulate macromolecular synthesis and control cellular growth and functional states. The molecular details of this cascade of transduction events that carry ELF field signals from the extracellular milieu into a living cell remain to be revealed by careful experimentation. However, the present state of knowledge strongly implicates the cell membrane as a site of ELF field transduction and signal amplification (1).

The existence of intracellular responses to ELF field transduction is illustrated by several lines of experimental evidence. As shown in Figure 3, it has been demonstrated that ornithine decarboxylase levels are increased in several lines of cultured cells after exposure to a 60-Hz electric field (3). This enzyme is essential for polyamine biosynthesis, and is activated by a number of chemicals that bind to receptors at the cell surface and stimulate cell proliferation. One example is the class of tumor promoters known as phorbol esters, and the results of Byus et al. (3) suggest that ELF field interactions may alter cellular biochemistry in a manner similar to these compounds. Phorbol esters have been shown to produce large elevations in ornithine decarboxylase activity via their binding to membrane-associated phosphokinase C receptors and the subsequent production of new messenger RNA specific for ornithine decarboxylase (4).

In other studies involving dipteran salivary gland cells, it has been demonstrated that exposure to either pulsed or sinusoidal electromagnetic fields leads to altered messenger RNA transcription patterns (5-7). This effect is accompanied by a significant change in the spectrum of cellular proteins synthesized by the exposed cells relative to control cells (8). A total of 248 polypeptides in the control cells were resolved by two-dimensional gel electrophoresis, while 326 were observed in cells exposed to a 72-Hz pulsed magnetic field. The polypeptides synthesized in the dipteran salivary gland cells were specific to the characteristics of the ELF field to which these cells were exposed, with various polypeptides being either enhanced in quantity or suppressed relative to those observed for unexposed cells.

Recent studies with cultured human cells have also demonstrated that an increased level of specific RNA transcripts occurs in response to ELF field exposure (9). Using the technique of dot blot hybridization, it was observed that exposure to pulsed or sinusoidal ELF fields increased the levels of RNA with specific homology for b-actin, histone H2B and c-myc DNA. As illustrated in Figure 4, the activation of protein biosynthetic pathways by ELF fields is frequency dependent (10). In addition, recent studies have demonstrated that the time course of ELF field effects on protein biosynthesis has a complex dependence on the amplitude of the applied field.

These recent experimental findings provide a useful set of clues regarding the biochemical events that occur in response to

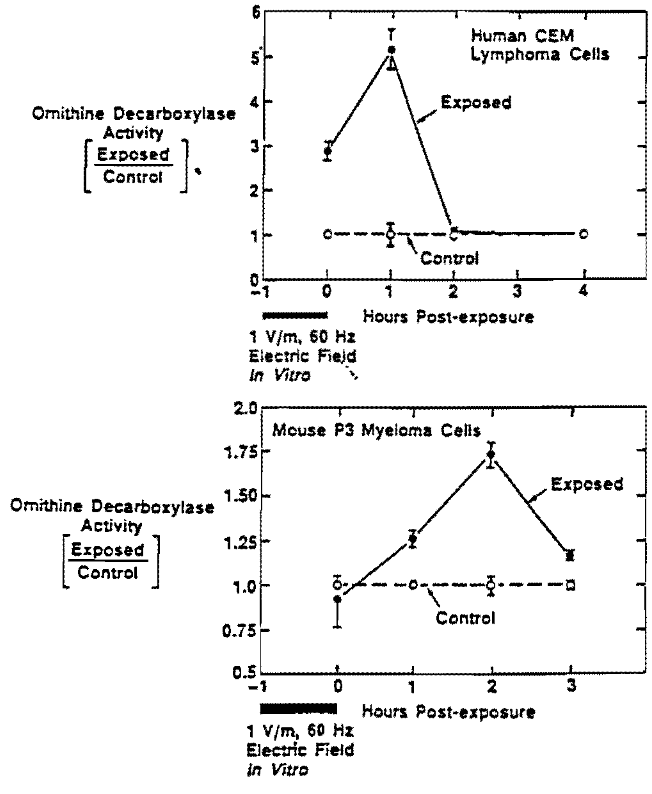

Figure 3. Changes in ornithine decarboxylase activity in cultured human and mouse cells exposed for 1 hour to a 1-V/m, 60-Hz electric field applied to the culture medium by electrodes. The increased enzyme activity was transient, and peaked 1 to 2 hours after termination of the electric field exposure. (Adapted from Figs. 1 and 2 of Ref. 3.)

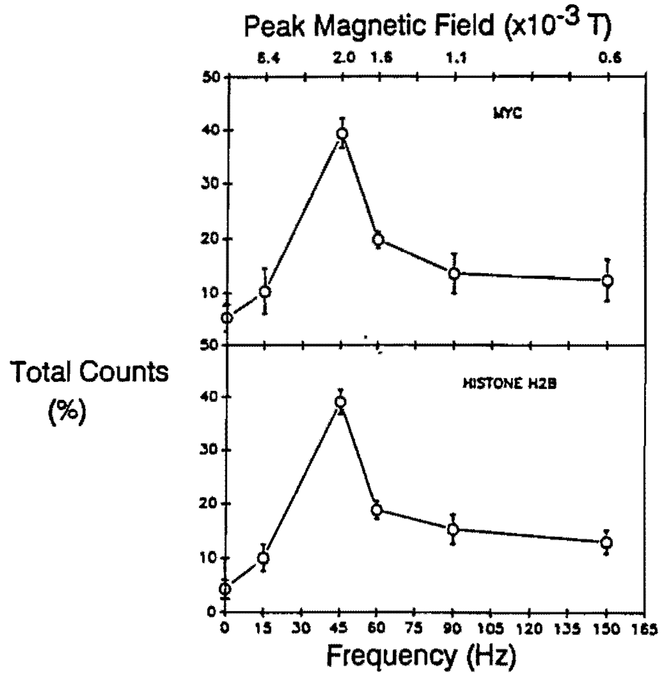

Figure 4. Effect of ELF field frequency on the quantity of RNA transcripts of myc and histone H2B genes in human HL60 cells. The peak magnetic field level was decreased as an inverse function of the field frequency in order to maintain the same value of the induced electric field and current density in the cell culture medium over the entire frequency range that was studied. The maximum stimulatory effect on transcription was observed at 45 Hz. (Adapted from Fig. 1 of Ref. 10.)

ELF field signals transmitted from the cell surface into the cytoplasm. The further elucidation of these signal transduction mechanisms constitutes a major challenge for future research on ELF field interactions with living systems.

References

1. T.S. Tenforde and W.T. Kaune, *Health Phys.* Vol. 53, pp. 585-606 (1987).
2. T.S. Tenforde, in *Extremely-Low-Frequency Electromagnetic Fields: The Question of Cancer*, pp. 291-318, edited by B.W. Wilson, R.G. Stevens, and L.E. Anderson (Battelle Press, Columbus, OH, 1990).
3. C.V. Byus, S.E. Pieper, and W.R. Adey, *Carcinogenesis* Vol. 8, pp. 1385-1394 (1987).
4. A.R. Verma, R.-C. Pong, and D. Ericksen, *Cancer Res.* Vol. 46, pp. 6149-6155 (1986).
5. R. Goodman, C.A.L. Bassett, and A.S. Henderson, *Science* Vol. 220, pp. 1283-1285 (1983).
6. R. Goodman, J. Abbot, and A.S. Henderson, *Bioelectromagnetics* Vol. 8, pp. 1-7 (1987).
7. R. Goodman and A.S. Henderson, *Bioelectromagnetics* Vol. 7, pp. 23-29 (1986).
8. R. Goodman and A.S. Henderson, *Proc. Natl. Acad. Sci. (USA)* Vol. 85, pp. 3928-3932 (1988).
9. R. Goodman, L.-X. Wei, J.-C. Xu, and A. Henderson, *Biochim. Biophys. Acta* Vol. 1009, pp. 216-220 (1990).
10. L.-X. Wei, R. Goodman, and A. Henderson, *Bioelectromagnetics* Vol. 11, in press.

60 Hz Electromagnetic Fields: Problems in risk assessment and policy response

M. Granger Morgan

I will talk about five things:

- Why this topic is so controversial.
- Insights from experience to date.
- Limits to risk analysis and the importance of public understanding and public perceptions.
- The need for utilities and public health organizations to think strategically about their policy responses.
- The need to work on what comes "after the smoking gun".

Why is this topic so controversial?

- In his classic book *The Structure of Scientific Revolutions*, Thomas Kuhn argued that science does not advance in a smooth and continuous way, but rather through a series of discontinuous "paradigm shifts".
- Over the past couple of decades we have been witnessing such a shift in scientific thinking about biological effects from electric and magnetic fields.

The conventional paradigm

ELF fields can *not* produce biological effects since:

- Joule heating and h, v are both vanishingly small
- ambient cellular fields and naturally induced currents are larger than externally imposed fields.

Counter evidence and paradigm shift

- Over the past several years evidence has mounted that indicates effects *do* occur.
- The validity of specific individual studies may be open to question, but in my mind the many positive studies in the refereed literature affirmatively resolve any question of *whether* effects exist.
- In the face of this evidence it has taken time for scientists to readjust their thinking... i.e., to "shift their paradigm".
- It remains unclear whether there are risks to public health, but as I will explain, there is a basis for concern.

Sources of evidence

- Cellular level studies.
- Whole animal studies.
- Epidemiological studies.

Evidence to date

- Clearly indicates that there are biological effects but leaves unresolved the question of whether exposure to fields presents public health risks.
- Suggests that if there is a risk, dose may not be measured by a simple time integral of field strength, i.e., that is at least in some circumstances across common exposures "more may not be worse".
- In short, we have only some pieces of what appears to be a complex puzzle. We are still struggling to put the full picture together.

The problem is *not* cover up

It is important to note that while parties with economic and other interests play roles in the public debate, interest group obfuscation is a secondary, not a prime cause of the uncertainty and scientific controversy.

Insights from experience to date

Four insights related to research:

- It is important to define "the problem" too narrowly.
- It is important to maintain a mix of cellular studies, laboratory-based animal and human studies, and human epidemiological studies.
- We need more flexible and adaptive research management with heavy emphasis on quality control.
- We need substantially expanded and more diverse sources of research support. In the United States, EPRI can not do it all alone.

Four insights related to policy:

- Risk assessment poses great challenges. Today only approximate bounding is possible.
- Public perceptions are likely to play a major not a minor role.
- Utilities and public health organizations need to think strategically about the strategies they should adopt. Incremental extrapolations from business-as-usual may not be adequate.
- It is not too soon to start working on what comes "after the smoking gun."

Problems in risk analysis

- Dose is not defined. If there are risks, the effects function may not be a monotonically increasing function of the time integral of field strength.
- This makes it very difficult to perform conventional risk analysis. Parameterized approaches lead to a combinatorial explosion.
- Attempts we have made at bounding analysis have led to bounds that are too large to be very useful.

Standards

- There is growing public pressure for standards.

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- The science does not currently support a safety based standard.
- Today the available basis for a standard is either:
  - equity or "similarity".
  - prudence.

The importance of public perception

- In the short term, public perceptions may be as or more important in controlling policy responses than the science.
- An obvious question is how effectively can one communicate the essence of this issue to lay people?
- We have a substantial study of risk perception and risk communication under way at Carnegie Mellon and would be happy to provide details to interested people.

Choosing an option to deal with exposure

- Minimum response - no action on exposure.
- Prudent avoidance - limited action on exposure.
- Dramatic response - major action on exposure.

Possible strategies beyond supporting more research

- Denial minimum
- Passive information supply.
- Active information supply.
- Limited response for new facilities.
- Reduction of non-power line field exposures.
- Major response for new facilities.
- Limited retrofit of old facilities.
- Major retrofit of old facilities.

Denial

A strategy of denial makes sense only if there is reason to believe that:

- it is virtually impossible that there are risks from field exposure, and
- the problem is likely to disappear as a public issue if it is not talked about.

In my view, *neither* of these conditions now obtain.

Passive information supply

- Do nothing to increase general public awareness of the 60 Hz fields issue but when inquiries come in, deal with them in a full and complete way.
- In addition to general information about fields, a utility or public health agency might:
- choose to develop specific information about local facilities (e.g., typical field profiles, etc.)
- offer a fields measurement service, either directly or through referral.
- Most US utilities are currently practicing the passive information supply option.

Active information supply

Utilities or public health organizations mounts a proactive program to educate lay people who live in the region and/or decision makers who control the local regulatory environment. Use:

- informational mailing to customers,
- briefings for decision makers,
- opinion/editorial pieces contributed to the press,
- speaker, exhibit and demonstration services.

Motivation: to promote an appropriate framing and understanding of the issues.

Prudent avoidance

- For the moment we do not know if fields pose a risk.
- The prudent thing to do is to try to keep people out of fields when that can be done at modest cost — but not to go off the deep end with expensive controls which may not be beneficial.
- We adopt strategies like this in our private lives all the time.
- Our adversarial risk management systems makes it harder to adopt such a strategy publicly.
- We need some careful policy work *now* on how to make prudent avoidance feasible in our society. Legislative remedies may be required but not enough work has been done to know.

We need policy-focused research

- That explores non-adversarial policy options to avoid a storm of socially unproductiveliability litigation against appliance manufacturers, utilities and others.
- Identifies ways in which companies can take responsible exposure avoidance actions now without fear of subsequent adverse legal or regulatory consequences.

Limited responses

Steps which might be taken without significantly changing the design of new facilities. Possible options include:

- Siting rules which place greater emphasis on avoiding people.
- Modifications in right-of-way land use rules.
- Somewhat wider rights-of-way.
- Limited undergrounding of T&/orD with low field designs in very high density areas.

In addition to limiting field exposure, some of these options might be attractive because of cost savings they achieve in improved public acceptance and reduced costs from litigation in siting controversies.

Reduction of non-power line field exposures

The options for building wiring and end-use devices run a range similar to those for power systems. In addition, there are labeling options and options for voluntary and mandatory design standards.

Major responses new/old

- Dramatic re-routing to avoid population.
- Exposure siting fees and/or significantly widened rights-of-way (perhaps with facility purchase).
- Major configurational changes in transmission facilities.
- Substantially expanded use of undergrounding with low field designs.
- Major changes in distribution facilities design and operational procedures in order to assure balanced operation.
- Major changes in distribution facilities to lower residual fields after balanced operation has been achieved.

What comes "after the smoking gun"?

- Fields may not pose any significant public health risks. However, the odds are growing that they do.
- There are several experiments now in the works and others planned which, if they produce positive results, will pretty persuasively demonstrate a risk.
- If that happens, there will be sudden and enormous pressure to take risk management actions — lots of them.
- The right investment today in engineering, economic and policy studies of alternatives could make the "scramble to do risk management" much more orderly and efficient if and when it becomes necessary.

Need to estimate exposure reduction "supply curves"

- How much exposure reduction can we get — for new facilities and for retrofits — as a function of different levels of investment, given different definitions of "dose"?
- Examine all elements of the electrical system right down through end-use appliances.
- Needed today because if "homework" hasn't been done and "smoking gun" occurs, a lot of stupid and inefficient things may take place.

Electrophobia: Are Biological Effects of Weak ELF Fields Impossible?

Robert K. Adair

Aberrant science

Aberrance is a natural part of science and is usually rendered harmless eventually by the winnowing and sifting of the scientific process. N-rays, mitogenetic rays, the canals of Mars, the Allison effect, polywater, and most recently, cold fusion are the more dramatic members of a larger set of egregious errors. Each of these caused, at the worst, a diversion of scientific effort that might have been better employed elsewhere.

None of these aberrations meshed sufficiently with public affairs so as to result in great public harm. But now we have science, equally aberrant, that purports to show that the very weak extremely-low-frequency (ELF) electro-magnetic fields, ubiquitous in our civilization, are carcinogenic. This electrophobia, based on bad science, certified by an inept government review conducted by non-scientists, and shouted from the mountain tops by mercenary journalists acting in their role of intellectual terrorists, is already a burden on both the substance and the morale of our society — and that burden is worsening.

As soon as the bare minimum of details concerning the cold fusion claims were released, it was clear to most physicists that the interpretation of the alleged heat production in terms of the D-D fusion reaction was in serious error. If the energy was derived from the D-D reaction, many orders of magnitude more neutrons should have been observed than were seen — indeed the neutron dose to the experimenters should have been lethal.

There is an equivalent "smoking gun" that tells physicists that the many experiments (all most equivocal) that purport to demonstrate biological effects on cells of weak ELF fields in the air around tissue, are surely wrong. As a consequence of the weak coupling of weak external ELF electric fields to cells shielded by conducting electrolyte, the electric fields induced in the cell are many orders of magnitude smaller than the Johnson-Nyquist noise fields generated by thermal fluctuations in charge densities. Similarly, the coupling of the weak electric fields to charges held by cell elements, and the coupling of weak magnetic fields to the magnetic moments of such elements, are also many orders of magnitude less than the characteristic thermal energy kT. And the electric fields at the cell induced by changing ELF magnetic fields are again many orders of magnitude smaller than the thermodynamic noise. Since any conceivable coupling of the weak ELF fields to biological material in the cell must be very, very much smaller than kT, there can be no significant biological effects of weak ELF fields.

For definiteness, in the following comments we consider specifically canonical 60 hertz ***external*** fields in air such that the maximum electric field is 300 V/m — about three times the normal field at the earth's surface — and a maximum magnetic field equal to the earth's field of 500 milligauss.

Electrical noise in biological systems

If a signal is to initiate a biological effect it must not be masked by natural noise. But living systems are noisy electrically. Aside from the Johnson-Nyquist noise from thermal fluctuations of charge density, there is noise generated by muscle excitation and activity, electrokinetic noise from the squeezing of electrolyte through tissue, and most important, the $1/f$ noise from cell membrane activity, that contribute fields as great as 0.1 V/m at frequencies below 100 hertz. We consider here the generally smaller thermal noise inasmuch as the magnitude of that noise stems from the *second law of thermodynamics* — and must, therefore, constitute an irrefutable constraint on biology.

If a piece of resistive matter, in thermal equilibrium with its surroundings, is acted upon by an electric field from an LC oscillator also in thermal equilibrium, the material will absorb energy and its temperature will increase — and the oscillator will cool. This violation of the second law is removed by requiring the material to generate noise energy to be fed back to the oscillator. To return that energy, the sample must generate a noise voltage V_{kT}, over a frequency band $\Delta\nu$, such that $V_{kT}^2 = 4RkT\Delta\nu$ where R is the resistance of the sample of material. We are often more interested in a noise field taken as $E_{kT} = V_{kT}/d$, where d is the thickness of the sample.

Since we are especially interested in the effects of 60 hertz fields, we choose a band width of 100 hertz for our signal-to-noise calculations. For biological processes which act with intrinsic time-constants less than 1/100 seconds, higher frequency fluctuations will contribute to the process and the effective noise will be larger.

Electric fields in tissues and cells

For environmental concerns, the immediate measure of possible hazard is that field in the air about the tissues. Since the tissues are conducting, a constant external electric field will induce almost no field at all in the tissues though an ELF external electric field will induce very small fields. For an external field of 300 V/m, at a frequency, $\nu = 60$ hertz, $E_i \approx 3\varepsilon_o \omega \rho_t E_o \approx 6 \times 10^{-6}$ V/m where $\rho_t \approx 2\Omega \cdot m$ is the resistivity of the electrolyte saturating the tissue. But the noise field taken for a 20 μm cube of tissue the size of a cell is ≈ 0.02 V/m, about 3000 times greater than the induced field.

If a signal is to initiate a biological effect it must not be masked by natural noise.

A typical mammalian cell in tissue can be taken as a sphere with a radius $r \approx 10$ μm, bathed in tissue electrolyte and encased in a membrane of thickness $d \approx 50$ Å, with a specific resistance of $\rho_{mem} \approx 10^6$ ohms. The field E_{mem} in the membrane will be about $E_{mem} \approx 1.5\ E_i(r/d)$. For an external field of 300 V/m, $E_{mem} \approx 2 \times 10^{-2}$ V/m. But the mean noise field across the membrane of ≈500 V/m is about 25,000 times the externally induced field.

Electric fields are also generated by changing magnetic fields. Taking a typical effective human body area as that of a circle with a radius of r=10 cm, we estimate the mean amplitude of the electric field induced by a 60 hertz oscillating magnetic field of amplitude B=500 milligauss field acting over the body, as $\bar{E}_B = (B\omega r/2) \approx 10^{-3}$ V/m. Although the noise field in the electrolyte volume the size of a cell of 0.02 V/m is only about 20 times larger, the noise of 500 V/m in the cell membrane where biological activity takes place is 500,000 times greater than the induced

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field.

To put the effects of ELF magnetic fields in context, we note that the electric field induced by walking through the earth's field is equal to the maximum electric field produced by a 40 milligauss 60 hertz field.

In summary, the strengths of the interactions of externally induced fields with electric charges and with electric and magnetic dipole moments are all many orders of magnitude less than kT.

Resonances

According to the Johnson-Nyquist formula, $E_{kT} \alpha \sqrt{\Delta v}$. Hence, if we are to find striking gains in signal-to-noise ratios in ELF actions, we must look to narrow band-pass filters such as are generated by resonances. However, the existence of such low-frequency resonances at the cellular level can be shown to be inconsistent with the properties of cells in biological media.

From equipartition, the oscillating system must have an energy kT. This energy will be equal to $m\omega^2A^2/2$ where ω is the angular frequency and A is the amplitude of oscillation. With the small ELF value of ω, and the small mass of cell elements, the required amplitude is, typically, larger than the size of the cell.

For example, the minimum amplitude of 60 hertz oscillation of a large cell part - with the mass of the membrane - is 5μm and the amplitude of a 60 hertz Calcium ion resonance (such as a cyclotron resonance) is one meter!

Moreover, if a resonance is narrow with a width Δv, it must persist for a time $\Delta t \approx 1/\Delta v$. Hence, the damping of the resonance must be small. For a narrow resonance in the ELF range, that time must be very long in terms of characteristic molecular collision or interaction times; the resonance state must have a very small probability of being interrupted if it is to be significant. We can estimate the characteristic interaction time or energy exchange time for the smallest elements in a solid as roughly $a/v \approx 10^{-11}$ sec, where a is a mean spacing of molecules and v is a velocity of a bombarding molecule of mass m where $1/2\ mv^2 \approx kT$. Then if the resonance width is 1/100 hertz, the probability of deexcitation in an interaction must be of the order of 10^{-13} where one might reasonably expect a value near one.

The experimental record

No amount of theoretical objection destroys a solid observation. But the experimental results that purport to demonstrate biological effects of weak ELF fields are as shoddy as they are voluminous. There seems to be no result that shows a rational dose-response relation. Attempts to replicate the more loudly advertised results have failed. There is no coherence of results. Indeed, the experimental pattern is very like that for extra-sensory-perception.

Generally, such science is pushed into a small corner tended by eccentrics and ignored by the main stream. Scientifically, this has happened. The quite revolutionary claims have had no effect on the center of biology; no eminent biologists are rushing into this field; no eminent biologist finds the idea sufficiently credible. Good men do not consider time spent correcting the work of their inferiors well spent. (And more research money will not buy them.)

Though it lies in a scientific dust-bin, the ties to the deepest of human fears is propelling electrophobia to the front of the public stage. I have heard that $100,000,000 is the present cost of refuting the Pons-Fleischman cold-fusion experiment. But the equally strange science of Adey, supported by Morgan's inane government report and advertised by Brodeur's terror journalism, can cost us more by a hundred-fold.

REVIEWS

Commercial Observation Satellites and International Security, edited by Michael Krepon, Peter D. Zimmerman, Leonard S. Spector, and Mary Umberger

St. Martin's Press, New York, 1990, $45.

With the launch of the French SPOT satellite in February 1986, high-resolution photographic imagery from space became available for the first time on a worldwide commercial basis. The late 1980s witnessed several other countries following suit: the US with its Landsat 4/5 satellites, the Soviet Union with the KFA-1000 satellite, and even India and Japan. Although airplane reconnaissance dramatically entered public consciousness when President Kennedy showed U-2 photos of Soviet missiles in Cuba during the famous crisis of 1962, the implications of open-market satellite imagery are just beginning to be explored.

This book offers a timely and even-handed discussion of these implications for the non-technical reader. However, the 26 contributors to this 230-page volume give it not only its strengths — a diversity of views and a wealth of expertise — but also its principle weaknesses: a somewhat incoherent and repetitious flow of arguments, and limited technical offerings widely dispersed among the chapters. Like satellite imagery itself, the book generates more questions than answers. Nevertheless, its editors admit that the study is exploratory, and seen in this light, the discussions merit our attention.

Many of the authors exhibit a healthy skepticism over the "technological miracles" of satellite imagery. We are introduced to the problems of cost, resolution, and timeliness in acquiring photographs, as well as privacy concerns on the corporate and national levels, and the question of pernicious interpretation of images.

Potential benefits of these satellites are numerous: monitoring cease-fire and arms control agreements, making surprise attacks less tractable, and aiding in disasters such as Chernobyl and the Armenian earthquake, as well as applications in meteorology, agriculture, forestry, and environmental monitoring. However, we are reminded that there may be "unsettling" consequences as well: aiding hostile countries in targeting distant military sites or in regional wars (such as Iran/Iraq), or the unwanted politicizing of national disputes by other states. Most contributors to this volume agree, however, that while such uses of satellite data could be "troublesome" and complicate crises, they rarely if ever would be militarily decisive.

Beyond this consensus, the political insights are weak, partly because the book's organization allows so little room for a discussion of satellite *capabilities.*

First, I was disturbed by the definition given for resolution: "the area on the ground that a single pixel (light sensitive picture element) sees at any given instant." This definition not only ignores the optical requirements mandated by diffraction, but also fails to say at what point atmospheric turbulence comes into play. It further assumes the reader knows that almost all modern reconnaissance satellites use digital charge-coupled devices (forming the pixels), and not photographic film. (The important exception to this is the Soviet KFA-1000 satellite, which still drops film cannisters periodically to earth.)

Second, we are given no sense of how fast satellite resolution is improving. *Today*, SPOT achieves 10-20 meter resolution, and Landsat 4/5 up to 30-meter resolution, but US "military" photo-reconnaissance is said to achieve resolution far better than 1 meter, and possibly even better than 10 cm. Just how expensive would it be to obtain this resolution commercially? And to do so must a satellite wait for a perfect spring afternoon and then swoop down temporarily into an unstable orbit? And how much area can be imaged at this resolution on a single pass?

These criticisms are not arbitrary. The book soon launches into lengthy discussions of how international politics might be affected in the future by what is frequently referred to as "high-resolution" imagery. For example, the following words of R. Jeffrey Smith are quoted by at least two authors:

> Nations that know what their enemies are doing are less likely to increase world tension through actions born out of fear. And nations that know their enemies are observing them are far less likely to threaten international peace through rash behavior. Governments are also more likely to propose and sign treaties if they believe they can verify their enemies' compliance—

Without a concrete idea of what can be seen (or might be seen in the near future), such general statements seem to be no more than platitudes.

Late in the book there is an excellent chapter on the nature of crises, but the role of satellites there seems to be an afterthought. It is argued that the vast majority of crises are not of the 13-day variety, such as the Cuban Missile crisis, but are protracted like the Iran hostage crisis, or the collapse of the Marcos regime in the Philippines, and are managed by governments using a whole host of intelligence sources. Although the failed rescue mission for the Iranian hostages had not been practiced for fear that the media would have detected and leaked the information, no case is made that a satellite photograph of such an exercise would have been decisive in such a leak. Indeed, one is hard pressed to imagine the American public being able to distinguish via a photograph one military exercise from another, especially at a resolution of 10 meters.

As an author from the developing world surmised, the excitement over increasingly available satellite imagery might be compared to early alarmist predictions involving nuclear proliferation, increases in oil prices, Star Wars, and cultural domination via broadcast-satellites. Another author argued that those nations most desiring imagery for national security, e.g., Israel and India, have every reason to develop their own satellites rather than relying on commercial sources: resolution, time-urgency, control during crises, keeping secret the locations of photographed areas, and international status. Nevertheless, a computer search of the SPOT image catalog revealed just how many different photographs have actually been commissioned for specific hot-spots in the Middle-East, Persian Gulf, and Pakistan.

Another essay gives an excellent introduction to the use of multi-spectral imagery for interpreting, locating, and even assisting with estimates of yields for underground nuclear tests, by observing disturbances on the surface such as spalled rock, tailings from the drill holes, and surface activity over the months preceding the test. A similar but less definitive discussion for non-proliferation efforts is also presented.

If one is willing to read carefully, technical details with important implications can be culled from the text. For instance, the cost for a third-party to develop, manufacture, and launch its own satellite would be around $400 million — almost two-thirds of the U.N. peacekeeping budget for 1989. However, individual Landsat images covering a 185-km square area cost only about $3600 and are thus widely affordable. There is also an excellent discussion of the built-in discriminatory practices involving countries that do not have their own ground-receiving stations, as well as intransigence by those that do, priorities given for reasons of "national security" and for more profitable requests for photographs, and pirating of raw satellite data.

Two chapters are also devoted to the role of the U.N. in a possible International Satellite Monitoring Agency (ISMA), an idea first proposed by the French in 1978. However, little insight is offered as to how decisions within such a body would be made; the discussion portrays the ISMA as a benevolent observational body, somehow shielded from conflicts-of-interest over sensitive matters of state. Between the lines one can infer that when satellite imagery achieves the resolution needed for more precise characterization of questionable activities (e.g., better than 5 meters), conflicts between members of such an organization could well become intractable.

The most concrete contribution of the book is the professional image interpretations that the Carnegie Endowment commissioned for this study. Using these examples, the book definitively refutes the much-quoted table of "resolution requirements" for detection, identification, and analysis of various structures, showing it to be overly pessimistic. According to this table, "general identification" with 10-m resolution is only possible for structures as large as ports and harbors, railroad yards, and urban areas. However, we are told that the sources from which this table is derived do not define "resolution"!

The conclusions are presented in the 19th chapter, where a new table is given showing the empirical detection and identification thresholds for bridges and roads, vehicles and missiles, military headquarters, aircraft, etc., in terms of Landsat (80 and 30 m) and SPOT (20 and 10 m) resolutions. When combined with the book's plates showing a SPOT photograph of a French missile base and a Soyuzkarta/KFA-1000 photograph of Fort Riley, Kansas — and surprisingly detailed descriptions of these fortresses by three professional image-interpreter firms — this is a key contribution. Furthermore, since digital image-enhancement techniques and collateral intelligence were not used to help interpret these photos, one begins to appreciate the broader implications of today's commercial satellite imagery.

The interested reader will find much here to stimulate further study into what is becoming a fascinating issue for the 1990s.

Dan L. Fenstermacher
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NEWS

Spring 1990 APS Meeting: Contribute a Paper to the Forum's Session!

Once again, the Forum is sponsoring a contributed paper session at the Spring meeting in Washington, DC. Physics and society concerns are surely sufficiently worthy of our professional time to warrant at least one contributed session per year. Get involved! Contribute a paper! We need to establish the continuing precedent of a contributed paper session every year, and we can do so only with your help. Specify to APS that your paper should be included with the Forum's physics and society session.

Minutes of the 16 April 1990 Meeting of the Forum Executive Committee

We met at the Ramada Renaissance Hotel, Washington DC. Members present were R. Scribner (Chair), T. Moss (Vice-Chair), H. Barschall (Secretary-Treasurer), B. Levi, K. Gottfried, S. Baldwin, V. Thomas. Members absent were D. Hafemeister, D. Schroeer, S. Brush, E. Colglazier, G. Farrar, R. Boy. Present as observers were A. Hobson, R. Howes, M. Sobel, P. Zimmerman, H. Lustig. Scribner called the meeting to order at noon.

The minutes of the 1989 meeting (*Physics and Society*, July 1989) were approved.

Programs. Moss requests six Forum sessions for next year's April meeting. Concern was expressed about poor attendance at some Forum sessions. Contributed paper sessions were also discussed. Forum members should be encouraged to contribute papers. Perhaps Congressional Fellows could be persuaded to do so.

Fellowships. All six candidates proposed by the Forum were approved by Council. The number proposed in recent years appears reasonable. A special effort should be made to include women. The appointment of a chair of the Forum Fellowship committee is urgent.

Awards Endowment. No progress was reported in getting endowments for the Szilard and Forum Awards. Many felt that the current $250 award was worse than no monetary award, but no action was taken to change the award. There is a strong possibility that the awards cannot be continued if they are not endowed.

Councillor's Report. Hafemeister submitted a written report. Under the proposed new APS Constitution the number of councillors representing divisions will be determined by the number of members in the division, except for the Forum which will have only one councillor. APS headquarters and AIP headquarters may move to the Washington area in a couple of years. The final decision on whether to move from New York will be made by the Council on April 29. AAPT will participate in the April meeting beginning next year.

BAPS changes. An APS Task Force has recommended that the Bulletin be divided into a Newsletter, similar to the AAPT Announcer, and Transactions, which will contain meeting abstracts. Some of the material currently in the Forum Newsletter may be appropriate for the new APS Newsletter.

POPA. Two studies are under consideration: Safeguarding of nuclear materials and global warming. There has also been discussion of a study of the health effects of non-ionizing radiation, but no study of this is planned.

Education. Howes is chair of the APS Education Committee. There has been discussion of the establishment of an APS Forum on Education for the purpose of enhancing educational activities without competing with AAPT activities. Alternatively the Forum on Physics and Society may wish to become more involved in education issues. In either case activities need to be closely coordinated with AAPT interests, as well as AIP activities in educational issues. Levi, who also serves on the AOS Education Committee, volunteered to report on the committee's activities in the Forum Newsletter.

Ballot Experiment. Barschall reported on the ballot experiment in which the ballots were sent by first-class mail rather than as part of the Newsletter. 830 ballots were returned compared with around 200 in previous years. The question was whether the increased participation justified the substantial expense. The Secretary was authorized to use first-class mail again.

Forum Studies. Howes reported on the Energy study. Half the manuscripts are at AIP in final form, the remaining manuscripts were still at the authors for a final revision. The book should be ready this fall. The Executive Committee authorized a reimbursement to Ball State for Howes' expenses of about $400. The Executive Committee voted to thank Ruth Howes and Tony Fainberg for their excellent work in directing this study. Levi distributed a Proposal for a Forum Study: A Syllabus for Physics Literacy. It has four parts: (1) survey relevant issues, (2) evaluate educational needs, (3) survey existing materials, (4) prepare resource materials. The Executive Committee felt that more work was needed before a decision could be reached and did not yet authorize the requested expenditure of $5000 for convening a group to work on the proposal.

Newsletter. The Executive Committee commended Art Hobson for his excellent work as editor. Hobson was reelected unanimously for another three-year term as editor.

Bylaws. Last year the proposed changes in the Forum Bylaws were approved. The next step is to get approval from the APS Committee on Constitution and Bylaws. This has not yet been initiated. Levi agreed to take care of this problem.

Treasurer's Report

Income Account:

Balance 4/1/89	$10,649
Dues	+10,325
Registration Fees	+4,746
Interest	+992
Contributions	+30
Awards	-1,864
Ballots	-1,665
POPA travel	-1,235
Energy study	-2,130
Operating expenses	-1,782
Speakers	-237
Newsletter	-8,047
Balance 4/1/90	$9,782

Award Fund:

Balance 1/1/89	$1,263
1989 Awards	-873
Transf fr income acct	+1,864
Interest	+89
Balance 11/1/89	$2,343

Following action by the Executive Committee in 1989 the expenses for the 1988 and 1989 Awards were transferred from the Award Account to the Income Account. A proposed budget is presented below. The cost of the Newsletter may be less than estimated because of the lower cost of printing charged by AIP than by the outside printer used previously.

Proposed Budget:

Awards	900
Ballots	1,700
POPA Travel	1,200
Operating Expenses	1,500
Speakers	1,500
Newsletter	9,200
	$15,000

Workshop. The possibility of scheduling a workshop on global warming was discussed.

Mass Mailing. The Treasurer will explore the cost of mailing a flyer or a copy of the Newsletter to all APS members.

Recruiting and Retaining Women

A topical AAPT/APS conference, addressing ways that physics undergraduate departments can attract and keep women, will be held at the National 4-H Council in Chevy Chase, MD, on 2-3 November 1990. For information and registration, contact Topical Conference on Recruitment and Retention of Women, AAPT Executive Office, 5112 Berwyn Road, College Park, MD 20740. Support may be available for some participants. Apply for support to: Mary H. Fehrs, Co-chair, Steering Committee, c/o AAPT Executive Office, noting your background and how support might affect your attendance. Applications from women students and faculty are especially sought.

Undergraduate Research Enhancement

A group of researchers met in May at an APS/AAPT workshop on enriching the upper-level undergraduate physics courses. Too often these courses fail to convey the excitement of active research. Thus the workshop proposed to compile a list of research-related problems that illustrate core-course concepts while applying them to topics of current interest. Such problems would be distributed widely to physics departments.

Please submit examples! Include: the intended course; description of the techniques needed to solve the problem; the problem's connection to current research; a short bibliography of supplemental reading; statement of the problem; solution; your name and affiliation. Contact Bill Cooke, University of Southern California; or Joe Reddish, University of Maryland; or Barbara Levi, Physics Today.

Stanford Fellowships in Arms Control

Stanford University's Center for International Security and Arms Control announces one-year fellowships designed to provide mid-career scientists an opportunity for study in international security, defense policy and planning, and arms control, starting Fall 1991. This program provides a year in residence. Scientists who have demonstrated technical excellence in any field of science or engineering, are welcome to apply.

Applicants should send a letter describing the proposed research, a curriculum vitae including a bibliography of publications, and three letters of recommendation (sent directly to the Center). Application deadline is February 15, 1991. Contact David Bernstein, 320 Galvez Street, Stanford CA 94305-6165.

Social Science Research Council Fellowships in Foreign Policy Studies

The Program in Foreign Policy Studies of the Social Science Research Council announces its sixth fellowship competition. Its purpose is to encourage research on US foreign policy-making processes, particularly the role of the media. This is accomplished through workshops. Activities are organized by the council-appointed interdisciplinary and international Committee on Foreign Policy Studies.

Applications, including letters of reference and language competency forms, must be received by 1 December 1990. Contact the Program in Foreign Policy Studies, Social Science Research Council, 605 Third Avenue, New York, NY 10158 (212-661-0280).

To Receive *Physics and Society!*

Physics and Society, the quarterly of the Forum on Physics and Society, a division of the American Physical Society, is distributed to members of the Forum and to physics libraries. Nonmembers may receive the newsletter upon request by writing to the editor; voluntary contributions of $10 per year are most welcome. Make checks payable to the APS/Forum.

Physics libraries may receive *Physics and Society* free upon request by writing to the editor. The Forum hopes that libraries receiving *Physics and Society* will archive it. Forum members should request that their libraries do this.

If you are an APS member it is easy to join the Forum and receive *Physics and Society*. Just complete and mail (either to the editor or directly to the APS office) the following form, or mail us a letter containing this information.

I am an APS member who wishes to join the Forum:

NAME (print) ______________________________

ADDRESS ______________________________

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